Universitat Autònoma de Barcelona

Shape modified radial artery adipo-facio cutaneous perforator flap- An observational anatomical vascular analysis & prospective randomized control clinical study

Ehtaih Sham. M

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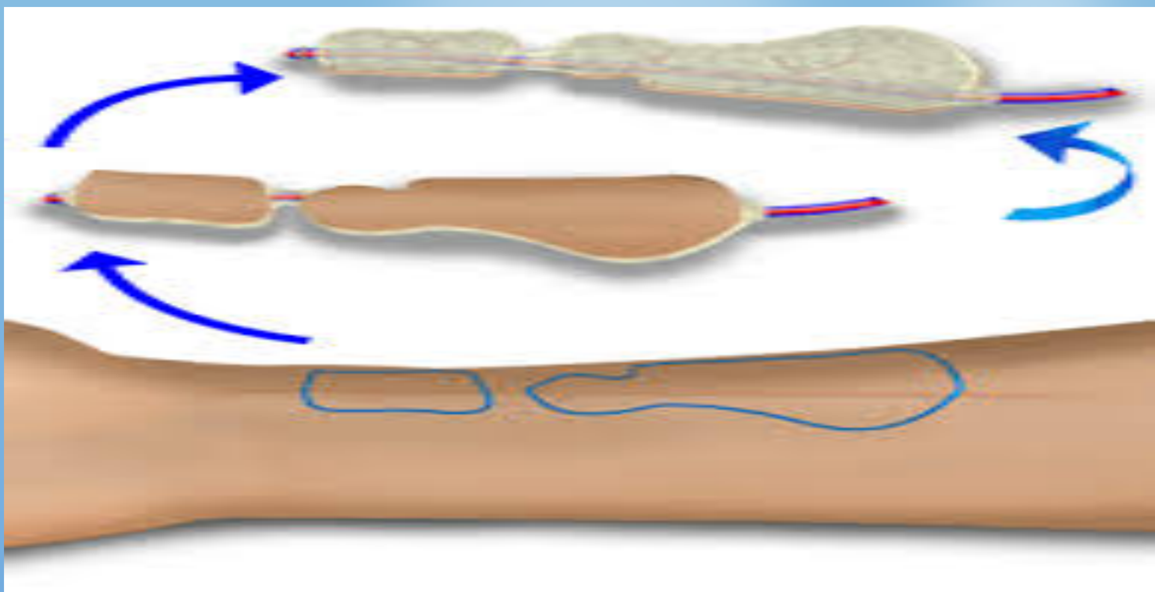

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Director

Prof. Jaume Masía Ayala

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Barcelona, Spain. 2019.

Certificate of Director

This is to certify that this dissertation entitled "**Shape modified radial artery adipo-facio cutaneous perforator flap-An observational anatomical vascular analysis & prospective randomized control clinical study"** is a bonafide PhD research work done by Mr. Ehtaih Sham. M, under the guidance of Prof. Jaume Masià Ayala, Director, Department of Plastic & Reconstructive Surgery, Hospital de la Santa Creu i Sant Pau, Universidad Autonoma de Barcelona.

Barcelona, September 2019.

Signature of Director.

CERTIFICATE TUTOR AND SUPERVISOR

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Barcelona, September 2019.

Signature of Tutor and supervisor.

Creativity is thinking up new things.

Innovation is doing new things.

Theodore Levitt.

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I would like to thank all my teachers and residents, who were and continue to be my real teachers, thank you for giving me the opportunity to learn.

To all my colleagues for letting me take the time away from them to work on this project. This work would not have been possible without the continuous support, help and guidance of my dear friend and a great colleague ***Dr. Thaygraj. J. Reddy****, Thank you for being there. My sincere gratitude and heartfelt thanks to my mentor* ***Prof. Jaume Masià Ayala****, whose constant support, Timely guidance and encouragement made this work to be accomplished. My sincere thanks and gratitude to all those who were directly or indirectly involved in completion of this work.*

Dedication

To my beloved father,

To my dearest wife Dr. Nishat.S,

To My two sweethearts, Rayyan & Arhaan,

For their endless support, encouragement, patience & understanding of my work. With their love, whole-hearted support & cheerful nature, they have always been able to give me new energy. They deserve the greatest thanks & highest respect, for they who have sacrificed the most.

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1

Resume of the study

1.1. Background: Radial forearm free flap with all its present day modifications is the workhorse of soft tissue reconstruction in head and neck. Although there are several advantages, it requires the sacrifice of a major artery of forearm. There are several modifications of harvesting a forearm flap based on perforator principles. A clear understanding of vascular anatomy of individual perforators relative to its vascular territory and flow characteristics is essential for both flap harvest and design. The purpose of this study was to demonstrate and determine the location, size and vascular territory of radial artery cutaneous perforators and further application of this knowledge of distal and proximal cutaneous perforators in achieving reliable shape modifications of radial forearm free flap in reconstruction of head and neck defects.

1.2. Materials and Methods:

Anatomical/Cadaveric study

12 fresh human cadavers and 24 cadaveric forearms were dissected to determine the total number, location, size and vascular territory of radial artery adipo-facio cutaneous perforator. The cutaneous territory of distally dominant perforators was analyzed using methylene blue injections and three-dimensional computed tomographic angiogram to determine the vascular network.

Clinical Study

15 patients with various head and neck defects following oncological resections were reconstructed with shape modified adipo-fascio cutaneous free forearm flap. All these patients were prospectively followed for donor site healing, motor and sensory nerve deficit. Function and quality of life questioner was used for donor site assessment.

1.3. Results

In the 12 fresh human cadavers and 24 forearm specimens, a total of 222 perforators were dissected for an average of 18.5 radial artery perforators per forearm. Of the total 222 perforators dissected 118 were smaller than 0.5mm in diameter (53.15%) these were not clinically significant. 104 perforators were greater than 0.5mm in diameter (46.84%) these were clinically significant. Of the 222 radial artery perforators dissected, 127 perforators (57.20%) were radially distributed and 95 perforators (42.79%) had ulnar distribution. A total of 90 perforators (40.54%) were identified on distal side (radial styloid) and 132 perforators (59.45%) were identified on proximal side (lateral epicondyle). Mean number of perforators on radial side was 10.6 and 7.9 on ulnar side, a comparison of both using student t paired test gives a P value of 0.006, which was statistically significant. Comparison of mean number of perforators on the distal side was 7.5 and proximal side was 11.0, Student Paired t test gives a P value of 0.003, which was statistically significant. Comparison of mean diameter of perforators between the distal side (1.11) and proximal side (0.86), side using Student Paired t test gives a P value of 0.01 which was statistically significant. A chi square test was done to compare mean diameter of perforators on distal side, which were more than 1mm (80%) and less than 1mm (20%) and on proximal side more than 1mm (35.6%) and less than 1mm (64.4%). Chi square value of 42.406 was obtained, degree of freedom value was 1 and P value of <0.001 was achieved which was found to be highly significant. Methylene blue injections into the proximal part of radial artery demonstrated clusters both in proximal and distal forearm and also cutaneous territory of flap. Three-dimensional computed tomographic angiography reveals a network of linking vessels found to communicate between adjacent perforators and running parallel to radial artery.

Large network of linking vessels could be found between fascia and dermis, which also explains the ability to harvest forearm flap at the supra-fascial level. A total of 15 patients were reconstructed with shape modified radial forearm flap following oncologic resections. Wound healing in all 15 patients was good, with scar assessment fairing better than traditional radial forearm flap. There was no sensory or motor nerve deficit. Although pedicle length was comparatively shorter in shape modified radial forearm flap, there was no problem in anastomosing to neck vessels.

1.4. Statistical Analysis:

Statistical Package for Social Sciences [SPSS] for Windows, Version 22.0. Released in 2013.Armonk, NY: IBM Corp. was used to perform statistical analyses.

Descriptive Statistics:

Descriptive analysis of all the explanatory and Outcome parameters was done using frequency and proportions for categorical variables, whereas in Mean and SD for continuous variables.

Inferential Statistics:

Independent Student t Test was used to compare the mean Flap Dimensions (in Sq.cm), Pedicle Length (in cm), Duration of Follow-up, Scar assessment & Quality of Life [QoL] scores between 2 groups.

Chi Square Test was used to compare the presence of Sensory and Motor deficit between 02 groups.

The level of significance [P-Value] was set at $P<0.05$.

1.5. Conclusion:

Increase in knowledge of vascular territory of radial artery cutaneous perforators with regards to numbers, size, location, and cutaneous territory can lead to expanded use of radial forearm flap based on either distal or proximal perforator alone, without sacrificing the radial artery. Shape modified technique for harvesting radial forearm flap allows primary closure of donor site. Donor site is better healed and shows a predicted pattern, which is functionally and aesthetically good.

2

Summary of papers

The first publication is a detailed anatomical review on vascular analysis of radial artery perforators and is the basis for second study, which emphasizes and analyzes its clinical applications as well as its implications in head and neck reconstructive surgery. The first review is the basis to justify the research detailed in the second publication, whose objective is to demonstrate the possibility of shape modified adipo fascio-cutaneous radial forearm free flap in head and neck reconstruction.

2.1. First paper

Vascular Analysis of Radial Artery Perforator Flaps

Sham E, Masia JA, Reddy TJ. Vascular analysis of radial artery perforator flaps. Ann Maxillofac Surg 2018; 8: 66-72.

Background: Radial forearm free flap with all its present day modifications is the workhorse of soft tissue reconstruction in head and neck. Although there are several advantages, it requires the sacrifice of a major artery of forearm. There are several modifications of harvesting a forearm flap based on perforator principles. A clear understanding of vascular anatomy of individual perforators relative to its vascular territory and flow characteristics is essential for both flap harvest and design. The purpose of this cadaveric observational anatomical study was to determine the location, size and vascular territory of the radial artery cutaneous perforators.

Materials and Methods: 12 fresh human cadavers and 24 cadaveric forearms were dissected to determine the total number, location, size and vascular territory of radial artery adipo-fascio cutaneous perforator. The cutaneous territory of distally dominant perforators was analyzed using methylene blue injections and three-dimensional computed tomographic angiogram.

Results: In the 12 fresh human cadavers and 24 forearm specimens, a total of 222 perforators were dissected for an average of 18.5 radial artery perforators per forearm. Of the total 222 perforators dissected 118 were smaller than 0.5mm in diameter (53.15%) these were not clinically significant. 104 perforators were greater than 0.5mm in diameter (46.84%) these were clinically significant. Of the 222 radial artery perforators dissected, 127 perforators (57.20%) were radially distributed

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Conclusion: Increase in knowledge of vascular territory of radial artery perforators with regards to numbers, size, location, and cutaneous territory can lead to expanded use of radial forearm flap based on either distal or proximal perforator alone, without sacrificing the radial artery.

2.2. Second Paper

Adipo Fascio Cutaneous Perforator Based Shape Modified Radial Forearm Flap: Vascular Analysis of Perforators and Its Clinical Applications in Head and Neck Reconstruction. Sham, E., Masia, J.A. and Reddy, T.J. (2018) International Journal of Otolaryngology and Head & Neck Surgery, 7, 268-286.

Resume of the study and Background: Radial forearm free flap with all its present day modifications is the workhorse of soft tissue reconstruction. All though there are several advantages, it requires sacrifice of a major artery of forearm. Several modifications are described in harvesting a forearm flap. In order to achieve a reliable, safe flap harvest and design one must have a very clear understanding of radial artery perforators, relative to its distribution, territory and flow. The purpose of this study is to determine the location, size and vascular territory of the radial artery cutaneous perforators and to demonstrate application of shape modification of radial forearm free flap based on its distal and proximal perforators in various head and neck defects.

Materials and Methods: Anatomical Study: 12 fresh human cadavers and 24 cadaveric forearms were dissected to determine the number, location, size and vascular territory of radial artery perforator. The cutaneous territory of distally dominant perforators was analyzed using methylene blue injections and three-dimensional computed tomographic angiogram to determine the vascular network. Clinical Study: 15 patients with various head neck defects following oncological resections were reconstructed with shape modified adipo-fascio cutaneous free forearm flap. All these patients were prospectively followed for donor site healing, motor and sensory nerve deficit, function and quality of life questioner for donor site assessment.

Results: 12 fresh human cadavers and 24 cadaveric forearms were dissected, and a total of 222 perforators were dissected for an average of 18.5 perforators per forearm. 118 were smaller than 0.5 mm in diameter (53.15%) and were not clinically significant. 104 perforators were greater than 0.5 mm in diameter (46.84%) and were clinically significant. 127 perforators (57.20%) were radially distributed and 95 perforators (42.79%) had ulnar distribution. 90 perforators (40.54%) were identified on distal side (Radial styloid) and 132 perforators (59.45%) were identified on proximal side (Lateral epicondyle). Mean number of perforators, on radial side was 10.6 & 7.9 on ulnar side; comparison of both using student t paired test gives a P value of 0.006, which is significant. Comparison of mean number of perforators on the distal side was 7.5 and proximal side was 11.0; Student Paired t test gives a P value of 0.003, which was statistically significant. Comparison of mean diameter of perforators on Distal side (1.11) and Proximal side (0.86), side using Student Paired t test gives a P value of 0.01 which was statistically significant. A chi square test was done to compare mean diameter of perforators on distal side, which was more than 1 mm (80%) and less than 1 mm (20%) and on proximal side more than 1 mm (35.6%) and less than 1 mm (64.4%). Chi square value of 42.406 was obtained, degree of freedom value was 1 and P value of <0.001 was achieved which was found to be highly significant. Methylene blue injections demonstrated clusters both in proximal and distal forearm and also marked the cutaneous territory of flap. Three-dimensional computed tomographic angiography reveals a network of linking vessels found to communicate between adjacent perforators and running parallel to radial artery. A total of 15 patients were reconstructed with shape modified radial forearm flap following oncologic resections. Wound healing in all 15 patients was good, with scar assessment faring better than traditional radial forearm flap. There was no sensory or motor nerve deficit. Although pedicle length was comparatively shorter in shape-modified flap, there was no problem in anastomosing to neck vessels.

Conclusion: Increase in knowledge of vascular territory of radial artery perforators with regards to numbers, size, location, and cutaneous territory can lead to expanded use of radial forearm flap based on either distal or proximal perforator alone. Shape modified technique for harvesting radial forearm flap allows primary closure of donor site. Donor site is better healed and shows a predicted pattern, which is functionally and aesthetically good.

3

Abbreviations

DSA	**Digital subtraction angiography**
CT	**Computed tomography**
MRI	**Magnetic resonance imaging**
RFFFT	**Traditional radial forearm free flap**
SRFFF	**Shape modified radial forearm free flap**
DP	**Distal perforator**
PP	**Proximal perforator**
PL	**Pedicle length**
SC	**Scar Score**
QOLS	**Quality of life questioner**
Sq. Cm	**Square centimeter**

4

Introduction

Increased knowledge of vascular anatomy has inevitably led to innovations in flap design and its use in clinical arena. The evolution of random pattern flaps to facio-cutaneous flaps to myocutaneous flaps and finally to the perforator flaps has followed a linear progression, largely because of pioneering vascular anatomical studies. The information derived from such kind of work has fuelled an evolution in flap designs and its clinical applications.

The ultimate goal of reconstruction is to match optimal tissue replacement with minimum donor site expenditure while maintaining function. Perforator flaps meet these goals and are the result of over 30yrs of evolution in flap refinement and design.

4.1. History of Microsurgery

Parre in 1552[1] described the first vascular ligature and in 1759 Hallowell[2] repaired a wound in the brachial artery by thrusting a pin through the margins of the wound and tying a thread around it. In 1820, Jones[3] studied the healing process in vascular injuries in animals and stressed the importance of neo-intima, which had regenerated at the suture site. Jassinowski[4] reported the first successful end-to-end anastomosis of the carotid artery in sheep in 1889. At the end of nineteenth century, Murphy[5] in 1897 published the first experimental and clinical work on the suturing of human blood vessels. In 1902, Alex Carrel[6] reported end-to-end vascular anastomosis by hand with a three-stay suture technique, which has been a fundamental technique of vascular surgery till now. The discovery of anticoagulant substance by McLean[7] in 1916 gave vascular surgeons a method of preventing thrombosis at the inner surface of the suture site. In 1918, Howell & Holt[8] named this substance “Heparin” and the final purification of heparin by

Charles & Scott[9] in 1933 made it safe to prescribe this substance to patients. It was one of the revolutions in development of vascular surgery. The introduction of operating microscope, a pioneering work by Nylen[10] in 1921 opened the doors to micro-vascular surgery. Nevertheless, until the beginning of the 1960's, the safe and reliable suturing of blood vessels smaller than 2mm in diameter was still impossible. With further technical improvements of the operating microscope and refinements of suturing materials and needles, Jacobson & Suarez[11] in 1960 were able to unify small vessels with a diameter of only 1mm. Within a few years, a number of publications appeared demonstrating the tremendous possibilities, which were opened by the technique of micro-vascular anastomosis in clinical practice, such as, first replantation of fingers by Kleinert & Kasdan[12] in 1963 and amputated arms by Malt & McKhann[13] in 1964. Krizek & coworkers did experimental research, on composite free tissue transfer. Antia & Buch[14] published the first clinical case. In 1971 the same year, Black & coworkers[15] did a palatal reconstruction using jejunal flap. In 1972 McLean & Buncke[16] covered a scalp defect with an omentum flap. Also in 1972 McGregor & Jackson[17] introduced the groin flap, which was subsequently used for various reconstructive procedures, until it was replaced by other flaps, particularly the radial forearm flap, having vascular pedicles suitable for micro-vascular surgery. With the development of numerous reliable proven flaps so far, today the choice of appropriate donor site seems to be more difficult than the reconstruction itself.

4.2. Development & Indications of radial forearm free flap.

In 1978, a fascio-cutaneous free flap from the volar aspect of the forearm and pedicled on the radial artery was first used in China. This so-called "Chinese flap" was originally described by Yang et al[18] in 1981 and Song et al[19] in 1982, both groups had already performed more than 100 successful free flap transfers. European surgeons, who visited their colleagues in China, later popularized this technique. In 1981, Muhlbauer[20] was the first to describe the advantages of radial forearm free flap in European literature. Very soon, many authors favored this flap for reconstruction in head and neck defects and for intraoral lining. Soutar & coworkers[21] reported on different indications of radial forearm flap in reconstruction of oral cavity and hand. Cheng[22] used this flap for tongue reconstruction. Hatako et al[23] & Chen et al[24] favored this flap for coverage of hard and soft palate defects and thus proposed this flap for rehabilitation of cleft lip and palate patients. Apart from reliable closure of oro-antral fistulas, they were able to resurface the alveolar ridge and build a vestibule for reliable fitting of dentures. Radial forearm flap was also used as a tubed flap to re-establish the ability of phonation or deglutition by inserting it in defects of hypopharynx, trachea, or esophagus. By including a bony segment of the radius, an osteo-cutaneous flap can be raised which was proposed for mandibular reconstruction by Muhlbauer[20], Soutar[21] & Stock[25]. Boorman[26] describes rich vascular plexus permit two or more isolated skin paddles suitable for closure of defects of oral cavity. Niranjan & Watson[27] described a technique for cheek reconstruction using the tendon of palmaris longus muscle.

Sadove in 1991[28] & Takada 1987[29] have performed lip reconstructions by incorporating a segment of brachioradialis muscle into the radial forearm flap, which then was re-innervated by a branch of facial nerve and sutured to the end of resected orbicularis muscle. Vascularized facial flaps from forearm have been placed in oral cavity to facilitate re-epithelialization and thus to achieve a mucosal surface. Wolf et al 1996[30] have demonstrated that the appearance radial forearm donor site can be improved by linear closure of forearm skin. Urken et al 1990[31] have facilitated sensory recovery of radial forearm flap by anastomosing a branch of ante brachial cutaneous nerve to a sensory nerve at the recipient site.

Apart from these many indications in head and neck area, the radial forearm flap with all its current modifications is a workhorse flap in traumatology of extremities and also may be used in many other reconstructive procedures.

4.3. Surgical Anatomy.

The skin of the volar (anterior) surface of the forearm is usually thin and pliable, especially the distal half. It is however unfortunately a hair-bearing skin, especially on the proximal and lateral sides of the forearm; consequently one might have hair growth in the oral cavity following reconstruction with a radial/ulnar flap. The subcutaneous fat is thin, especially over the distal third of the forearm. However overweight patients and even some normal individuals may have a disproportionate amount of fat in this distal area.

In the subcutaneous tissues lie the venous tributaries from the main superficial venous drainage system of the forearm, i.e. the cephalic and basilic veins, which lie deep to the fatty layer (Figure 1). The cephalic vein is the most commonly used single vein for venous drainage of RFFFs. It is a large, fairly thick- walled vein and is found in a relatively constant location deep beneath the subcutaneous fat. Unfortunately, due to its size and superficial position, it is also very often used for intravenous lines, which may cause fibrosis and/or thrombosis of the vessel. It drains the anterolateral forearm and is formed mainly by the confluence of superficial veins on the dorsal aspect of the hand. From there the vein, or its tributaries, traverses the lateral "snuffbox" area to lie over the lateral side of the distal forearm. It gradually courses more medially towards the mid-lateral cubital fossa. The lateral ante brachial nerve accompanies it. The superficial branch of the radial nerve lies in close proximity to the vein in the distal third of the lateral forearm and over the "snuffbox" area up to the lateral aspect of the dorsum of the hand[32].

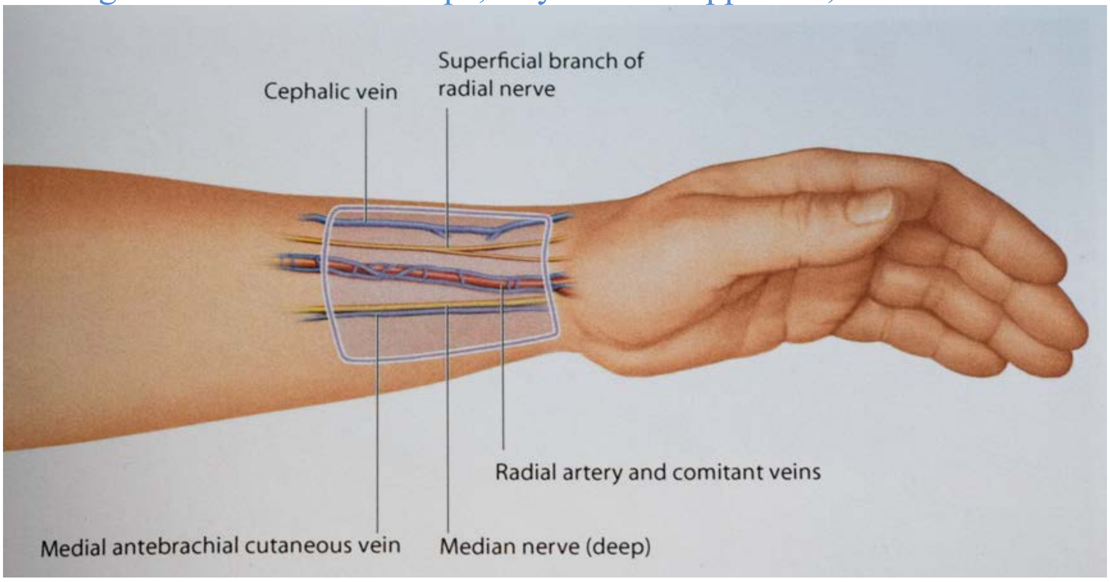
The basilic vein runs towards the lateral cubital fossa along the medial side of the forearm and is located deep beneath the subcutaneous fat.

The median (ante brachial) vein of the forearm lies between the cephalic and basilic veins. Occasionally it may be large and a better drainage system to use for a flap. It is usually thin-walled and is situated more superficially in the subcutaneous fat than the cephalic, basilic veins[32, 33].

A great variety of venous interconnections may be encountered in the cubital fossa. The median cubital vein (vena mediana cubiti) runs obliquely from lateral to medial to connect the cephalic and basilic systems. There is often an important connection between the superficial veins and the deep brachial venous system in the cubital fossa; this is usually between the brachial venae comitantes and the median cubital vein or the cephalic vein.

The forearm and cubital fossa are invested by deep fascia; in the cubital fossa it is strengthened by the bicipital aponeurosis. The perforating vein connecting the superficial and deep venous systems lies lateral to the bicipital aponeurosis with the brachial vessels lying immediately deep to it.

Figure 1. Volar surface of left forearm demonstrating cephalic and basilic venous systems, the median antebrachial vein of the forearm and the associated nerves. Source: Klaus-Dietrich Wolff and Frank Holzle. Raising of Micro-vascular flaps; a systematic approach, second addition.



The superficial nerves accompany the superficial veins. The lateral ante brachial nerve is the termination of the musculocutaneous nerve, which, after supplying the flexors of the upper arm, pierces the deep fascia just proximal to the cubital fossa. The anterior branch of the ante brachial nerve then accompanies the cephalic vein distally and supplies sensation to the anterolateral forearm, (which is also the main area of a distal RFFF). The posterior branch supplies sensation to the postero- lateral forearm.

The medial ante brachial nerve runs with the basilic vein; they pierce the deep fascia in the medial part of the mid-upper arm. It has an anterior branch supplying Sensation to the anteromedial forearm and a posterior branch supplying to the posteromedial forearm.

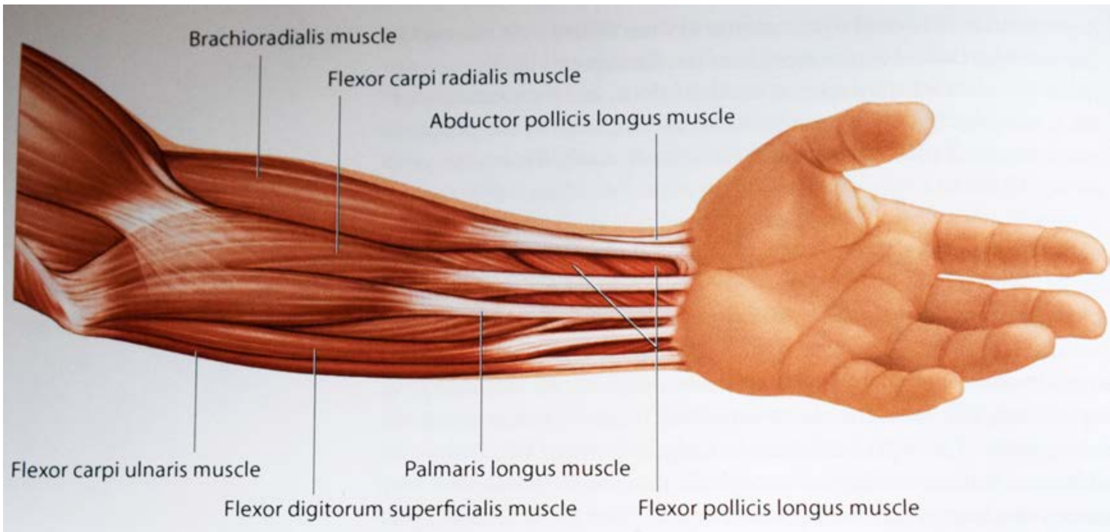
Deeper nerves include the median, ulnar nerves. These are usually not at risk when elevating the flap. The median nerve lies between the flexor carpi radialis and Palmaris longus tendons. The palmar cutaneous branch of the median nerve arises just above the flexor retinaculum at the wrist and becomes cutaneous between the tendons of Palmaris longus and flexor carpi radialis. Elevation of a very distal skin flap may injure the latter branch and cause sensory loss of the proximal mid- palm. (Figure 1)

Where the radial artery enters the forearm it lies superficial to the supinator, pronator teres and flexor digitorum superficialis (FDS) muscles in the proxi- mal third of the forearm, and superficial to the flexor pollicis longus (FPL) and pronator quadratus muscles in the distal third.

The radial artery runs in the lateral inter- muscular septum, which separates the flexor and extensor compartments of the forearm. Medially are the flexor carpi radialis (FCR) and the other forearm flexor muscles. Laterally is the extensor compartment.

The key muscle when elevating a RFFF is the brachioradialis muscle and its tendon. The muscle overlies the anterolateral side of the artery. The radial nerve of the extensor compartment supplies it, even though it is an elbow flexor. This bulky muscle belly lies anterior to, and covers the radial artery in the proximal half of the forearm. In the distal forearm the muscle becomes a flat tendon. It is important to know that the tendon commonly covers the artery either partially or completely. The significance of this will become apparent during flap elevation and protection of the perforators. At the wrist the radial artery lies between the brachioradialis and flexi carpi radialis tendons. The Palmaris longus tendon can be sacrificed without causing a functional deficit. It is absent in 13% of individuals. Its tendon and muscle can be incorporated in a forearm flap for various reconstructive possibilities and it may therefore be an extremely valuable adjunct in complex reconstructions.

Figure 2. Volar view of left forearm demonstrating biceps brachii, brachioradialis, flexor carpi radialis, palmaris longus, flexor carpi ulnaris, flexor digitorum longus, flexor pollicis longus. Source: Klaus-Dietrich Wolff and Frank Holzle. Raising of Micro-vascular flaps; a systematic approach, second addition.

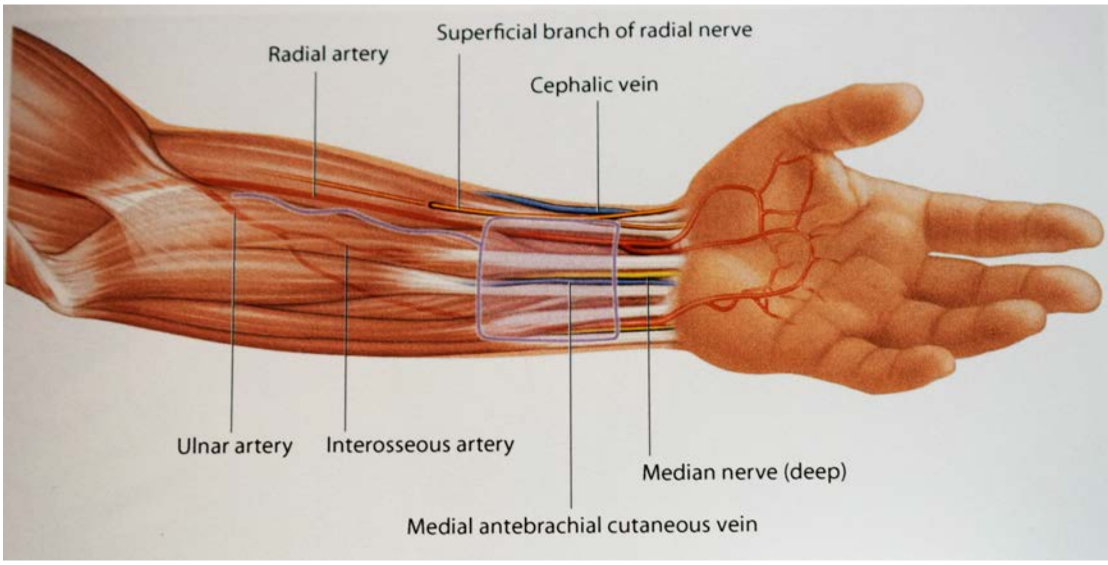


The brachial artery bifurcates into ulnar and radial arteries. The radial artery starts in the medial cubital fossa, 1cm distal to the elbow crease, just medial to the biceps tendon. It then courses down the forearm in the lateral intramuscular septum, which separates the flexor and extensor compartments of the forearm to the (palpable) radial pulse, just medial to the tip of the styloid process of the radius.

Branches in the forearm include the radial recurrent artery close to its origin; and distally, the palmar carpal branch, the superficial palmar branch and the continuation of the artery, the dorsal carpal branch. Along its course in the forearm it gives off muscular branches[34].

A variable number (average 12) of septo- cutaneous perforators exit the artery to supply the overlying fascia and skin. The greatest number of perforators is found in the distally third of the forearm, approximately 12 - 20cm from the origin of the radial artery. A major perforator is located 0 - 2cm proximal to the radial styloid Process and a cluster of perforators are located in the distal 1/5 of the forearm with another cluster in the proximal forearm. Periosteal blood supply to the distal radius is via branches to the deep flexor pollicis longus and pronator quadratus muscles; perforators also pass through the lateral intermuscular septum from the radial artery to the periosteum[35].

Figure 3. Volar view of left forearm demonstrating course of radial artery relative to brachioradialis, pronator teres and flexor carpi radialis muscles. Source: Klaus-Dietrich Wolff and Frank Holzle. Raising of Micro-vascular flaps; a systematic approach, second addition.



According to a clinical study of Kerawala[36] 2003, the mean arterial back flow pressure of the distal stump of the radial artery is 40 mmHg in average. Thus the vascular supply to the hand is normally maintained, & ischemia of the hand after raising the radial flap, vascular anomalies is described extremely seldom.

4.4. Advantages and Disadvantages.

The radial forearm flap is a thin, pliable & mostly hairless fascio-cutaneous flap, having a great value for reconstruction in head & neck region, especially in oral cavity. High caliber of vessels & long vascular pedicle as well as the variability in flap perfusion (ortho & retrograde flow, venous drainage via the superficial or deep systems) facilitates to perform a reliable anastomosis. Flap elevation is possible simultaneous to tumor resection. Besides these advantages, some disadvantages of concern are the donor site of the forearm flap. Harvesting the flap always leads to complete interruption of radial artery; perfusion of hand must be maintained by ulnar artery and the remaining anterior and posterior interosseous vessels. An anatomic investigation of 750 cadavers by McCormak & Colleagues[37], the radial and ulnar arteries were found to be always present and the dominant vessel for hand perfusion was regularly found to be the ulnar artery, which terminates into superficial palmar arch. Despite this the blood supply of thumb and Index can totally depend on the radial artery.

A considerable disadvantage is the appearance of the donor site, which is located in an esthetically exposed region. A number of publications can be found reporting on donor site complications, the frequency of which could be between 30-50%, mostly caused by poor transplant bed for split thickness skin graft.[38, 39, 40]

Knott & colleagues[41] 2016 have described short-term donor site morbidity of radial forearm flap with tendon exposure at 14%. To reduce donor site morbidity different techniques have been developed to achieve direct wound closure, such as VY Plastik[42], the transposition flap[43], use of tissue expanders[44], pre-lamination of forearm fascia[45], and the more recent techniques of shape modification based on perforator principles[46].

Apart from these problems concerning the healing of donor site, other complications like edema formation, reduced strength and extension of hand[47], reduced or loss of sensation due to injury to the superficial branches of the radial nerve and cold intolerance are reported[48].

Following harvest of an osteo-cutaneous forearm flap, the arm has to be immobilized for about 6 weeks but nevertheless fractures are common[49], unless the donor arm is primarily stabilized by rigid fixation. Therefore and because of other flaps available providing much more bone material, the osteo-cutaneous forearm flap cannot be considered a method of first choice for mandible reconstruction. There is also a tendency of edema formation in the flap, probably because of change in perfusion from “flow through” to a “terminal flow” pattern. This edema can sometimes cause functional restrictions especially in oral cavity. Gilat et al[50] 2013, have reported development of sleep apnea following use of radial forearm flap in tongue reconstruction. Nevertheless the radial forearm free flap both conventional and with all its present day modifications still remains a work horse in head and neck reconstruction especially in developing countries.

4.5. Preoperative management.

Allen’s test has to be performed to assess the adequacy of circulation of hand especially the thumb through the ulnar artery alone. It is preferable to carry flap raising from the non-dominant hand (usually left hand). Use of tourniquet is preferable but not mandatory, because with consequent hemostasis the operating field can be kept dry even in perfused hand.

4.6. Patient positioning.

In order to use the volar aspect of whole forearm, the arm is brought in an abducted & supine position. Disinfection of entire arm from fingertips to axilla is necessary.

4.7. Flap design & Method.

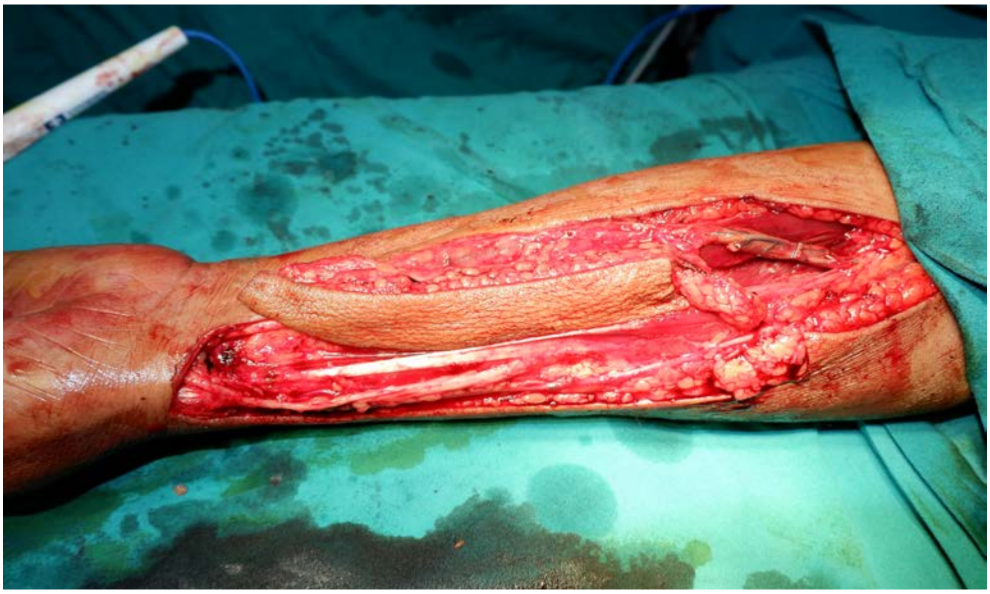
The distal flap border is place within 1cm proximal to wrist crease. The ulnar margin of the flap is outlined over flexor carpi ulnaris. The radial margin of the flap can be outlined over brachio-radialis muscle or can be extended more laterally to include the cephalic vein (traditional radial forearm design). Drainage through the deep vein commitantes is reliable and sufficient. Proximal extension of flap depends on the size of flap required to create islands. To expose the proximal pedicle a wave like incision is preferred to reduce postoperative scar shrinkage.

4.7.1. Ulnar skin incision

Skin over the ulnar border is incised through the subcutaneous fat until the forearm fascia is reached. The fascia, which is tight and dense, is bluntly undermined above the flexor carpi ulnaris tendon. The paratenon, which envelops the tendon, is left untouched.

4.7.2. Distal skin Incision with subfascial dissection

Incision at the distal margin is made through the skin and fascia. The flap contains skin, subcutaneous tissue and fascia; further dissection under the fascia is done over the tendons of flexor digitorum and palmaris longus. Paratenons are preserved.



4.7.3. Exposure of flexor carpi radialis tendon

The tendon of flexor carpi radialis is reached and isolated from forearm fascia distally.

4.7.4. Identification of radial vessels and superficial radial nerve at distal flap margin.

The radial artery can be palpated running into the septum between flexor carpi radialis and brachioradialis muscle. The septum is opened and a short segment of radial vessels is exposed, before ligating the artery and accompanying vena commitantes, the superficial branch of radial nerve is identified and preserved.

4.7.5. Ligation of radial vessels at distal flap border and Radial skin incision.

The radial artery is divided at the distal border of the flap. Always look for the pulsation of the distal stump of divided radial artery in a perfused arm, caused by intact circulation through the palmar vessel arch.

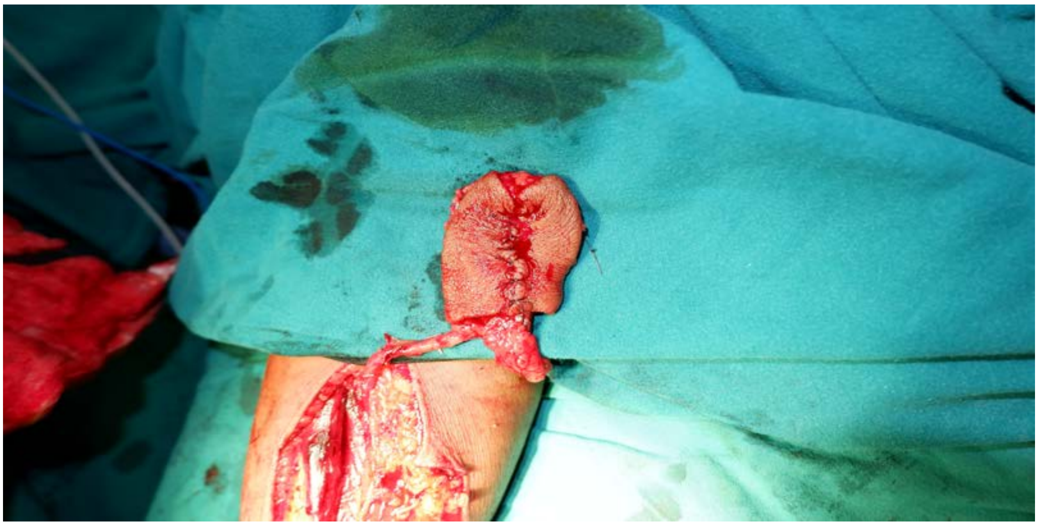
Skin incision is made 1cm radial to the artery till the forearm fascia. Superficial branches of radial nerve are identified & preserved. If the cephalic vein is included in flap design then the skin incision is extended over the dorsal aspect of the forearm.

4.7.6. Dissecting the pedicle along brachioradialis muscle with proximal exposure of vascular pedicle.

Maintaining a safe distance from radial artery the fascia is incised and tendon of brachioradialis exposed and retracted laterally. Radial artery within the intermuscular septum is separated from the brachioradialis muscle. The artery is carefully elevated together with the flap and remains firmly attached to the forearm fascia. Small branches to the radial bone and muscles are haemo-clipped or cauterized. The deep dissection plain of flap is above the flexor pollicis brevis muscle.

Undersurface of the flap is built by the forearm fascia, with the vascular bundle securely attached to the fascia by the intermuscular septum. In the distal third of forearm where the radial artery is not covered by muscle belly, the septum contains highest number of cutaneous perforators.

Outlining the flap over the distal third of forearm has the advantage of obtaining a long vascular pedicle. A wave like skin incision is made over the proximal segment to expose the vascular pedicle. Superficial veins can be carefully traced proximally by careful subcutaneous dissection and can be excluded in flap design.



The forearm fascia is incised between the bellies of brachio radialis and flexor carpi radialis. The vascular pedicle is traced proximally to achieve a comfortable pedicle length for anastomosis. At the end of flap raising, residual connections between the flap and flexor carpi radialis tendon are transected at the flap hilum and the vascular pedicle is completely freed from the donor site.

Flap can be shape modified after isolating islands on single or multiple perforators.

4.7.7. Primary closure of donor site.

4.7.8.To remember

- To avoid wrong dissection plane, incise the fascia until the underlying muscle becomes visible.
- Do not dissect deep to the flexor carpi ulnaris muscle, to avoid injury to the ulnar artery.
- Do not remove para-tenon.
- Be careful during distal third dissection of flap to avoid injury to superficial branch of radial nerve.
- Retraction of brachio radialis muscle is essential to avoid injury to vascular pedicle during dissection.
- Choose the appropriate superficial vein for venous drainage to avoid flap congestion.
- Muscle bellies for better uptake of skin graft can over sewn over flexor carpi radialis tendon.

5

Hypothesis of the study

5.1. I would like to probe that the radial forearm flap can be more versatile and we can increase the clinical indications in head and neck reconstruction if it is planned as shape modified radial adipo-fascial cutaneous perforator flap.

A study which details the precise location and vascular territory of the radial artery perforators therefore becomes all the more necessary, which would in turn facilitate operative planning to allow safer shape modifications in flap harvest. A very well described territorial outline of the consistently located, clinically significant cutaneous perforators would therefore form the basis for shape modifications in radial forearm flap harvest. This study precisely localizes the vascular territory of cutaneous perforators and also facilitates in demonstrating the usefulness & reliability of various shape modifications that are now possible in a radial forearm free flap, for functional reconstruction of head and neck defects with minimum donor site morbidity.

6

Objectives of this study

6.1. First Objective

To demonstrate in cadaver dissection specimens that the perforators are constant and also the morphology of the vessels.

1. Number of perforators.
2. Orientation of perforators.
    a. Radial distribution.
    b. Ulnar distribution.
3. Size of perforators.
4. Cutaneous territory of perforators.

6.2. Second objective

Demonstrate the reliability of this new approach and also the versatility of the design based on perforators. To evaluate for:

1. Donor site healing.
2. Scar evaluation through subjective scores.
3. Motor function/deficit evaluation for wrist extension & flexion.
4. Sensory evaluation with fine touch and pin prick method.
4. Quality of life assessment for objective scores.

7

Justification

The radial forearme flap was considered the workhorse for small and midium size defects. This flap provides a long vascular pedicle, sensitive nerves, nice pliable skin and subcutaneous tissue and also you can add tendons and a piece of bone. The anatomy is very constant and easy to dissect.

In the last 15 years this flap has been replaced by the ALT (Antero-lateral thigh flap) because the donor site defect is less visible and most of the times it's possible to do a direct closure. But if you analise the quality of the tissue pliability, the radial forearm flap is still much better.

This is the reason we try to review and to assess further possibilites of re-designing the radial forearm flap and to expand its clinical indications.

7.1. In the last forty years there have been multiple modifications in order to optimize the design of radial forearm free flap and to reduce its donor site complications.

Following original description of radial forearm free flap in 1978 by **Yang & Yuzhi** at Shenyang military hospital this transplant got the Nick name ‘Chinese flap’ and became the standard transplant for many indications[18]. This flap was later popularized by **song et al**.[19]

Muhlbauer et al (1982) were the first to report this flap outside China[20].

Stock & Contributor raised an innervated flap in 1981 and in 1983[25].

Biemer & Stock[20] utilized an osteo-cutaneous pedicled transplant for thumb reconstruction.

Lovie (1984) reported an ulnar artery based forearm flap, which was an alternative to avoid vascular complication at the donor site. Based on the ulnar artery distal to the common interosseous branch and may include muscles, flexor carpi ulnaris, pollicis longus tendon and ulnar bone. The donor site is virtually hairless & easily closed.[51]

Soutar (1986) based on 60 clinical cases proposed forearm flap for reconstruction of oral cavity, offering a thin, pliable and predominantly hairless skin to replace oral mucosa. Furthermore the vascular anatomy of the flap simplifies the technical aspects of free tissue transfer. Thereafter the flap became the most utilized in head and neck reconstruction[21]

Timmons (1986) following his anatomical description, this versatile flap has found numerous applications in plastic and reconstructive surgery.[48]

Partecke et al (1986) described a fat fascia transplant in 2 patients resulting in a cosmetic appealing scar line[38].

Liang et al (1994) In a series of 15 patients, proposed to triangulate the volar donor defect of the radial forearm free flap and close it with a triangular shaped full thickness skin graft, harvested adjacent to the donor site. The flap is designed on the distal aspect of the volar forearm[39].

To improve the donor site morbidity, **Webster & Robinson** (1995) & S. **C. Chang et al** (1996) in a series of 400 free forearm flap reconstructions described a suprafascial forearm flap, but there were no differences demonstrable concerning the sensory outcome.[40, 52]

Wolf & Colleagues (1995) described a prefabricated facial Split thickness flap in 5 patients in tumors involving floor of mouth and tongue. The Split thickness skin graft was inserted onto the forearm fascia, 2 weeks before the scheduled flap raising[30].

Rath & Contributors (1997) widened the technical varieties by introducing a prelaminated Facio-mucosal flap. 5 distal radial forearm flaps and 1 fibula flap were prelaminated. Prelamination was performed by fixing small, full thickness mucosa pieces onto the fascia and covering the mucosa with an alloplastic sheet as large as the future flap. The six pre-laminated free flaps were harvested after 8-10 weeks.[45]

Hamdy El-Khatib (1997) reported an anatomic study in eleven fresh and fixed cadavers, designing a island adipofascial flap based on distal five to eight septocutaneous perforators of radial artery and their vena comitantes. The advantage being preservation of radial artey.[53]

Daping yang & colleagues (2003) Investigated 10 fresh cadavers and dissected 24 forearms in order to identify cutaneous perforators of radial artery adjacent to superficial branch of the radial nerve and lateral ante-brachial cutaneous nerve. The authors proposed a reversed forearm island flap supplied by the septo-cutaneous perforators of the radial artery[32].

Cesare Tiengo (2004) Investigated 8 fresh human cadaveric forearms for anatomical vascular basis of the forearm fascio- subcutaneous flap fed by distal perforators of the fascia. This type of flap was proposed in hand reconstructive surgery, to avoid the disadvantages caused by axial pattern reverse radial forearm fascio-cutaneous flap based on ligation and rotation of radial artery. The authors proposed based on their findings that perforator arteries and epifascial branches are smaller in distal forearm, so that during surgical dissection the distance from radial styloid should be taken into account[33].

Jeng-Yee lin (2006) present their modification of harvesting a forearm flap based on a large septo-cutaneous branch of radial artery in the proximal forearm without sacrificing the radial artery itself. A total of 14 free proximal radial forearm flaps were used in head and neck reconstruction in 12 patients. The authors concluded that proximal radial forearm flap could be used successfully in head and neck reconstruction with the advantage of moving the donor site to the proximal forearm for better scar concealment and possible preservation of the radial trunk[54].

Cesare Tiengo & colleagues (2007) investigated the anatomical vascular basis of proximal radial artery perforator flap and its clinical application in reconstructive surgery. 16 un-embalmed cadaveric forearms were studied for number, diameter, site, interval of origin, and course of collateral. The authors concluded that PRAP flap is a good reconstructive option[55].

Mark Schaverien (2008) conducted a study involving 12 fresh human cadavers and 24 radial forearm flaps harvested from these cadavers to elucidate the role of deep fascia in perfusion of radial forearm flap. The authors concluded that inclusion of deep fascia during flap harvest does not contribute to flap perfusion or vascularity[34].

Mateev, Musa A (2009) To overcome the donor site morbidity associated with the traditional radial forearm free flap described a shape modified radial artery perforator flap. The authors analyzed the outcome in 112 cases of reconstruction with the shape modified method with regard to cause of injury, recipient site and whether the flap was free or pedicled, flap size, number of components that were divided by perforators, flap survival and quality of outcome, donor site morbidity including development of scars and dorsal hand numbness. The authors concluded this modification as a propeller flap, which also resembles flap in flap method[46].

Michel Saint-Cyr et al (2010) conducted an anatomical study in 26 fresh human cadaveric forearms to study and determine the location, orientation, external diameter and vascular territory of radial artery cutaneous perforators. Because of radial artery's superficial location in the distal forearm, Doppler examination may not be useful for locating the perforators. The authors concluded that there are two main clusters of clinically significant perforators and increased knowledge of size, location and cutaneous territory of radial artery perforators can lead to expanded use of radial artery forearm flap based on these cutaneous perforators alone, without sacrificing the main radial artery[56].

L. Giordano (2012) in a series of 43 patients, divided in two groups (new group=23 patients, old group=20 patients) described a modified skin closure technique, developed to reduce skin tension and subsequent improvement in cosmetic outcome. The authors used a modification of standard triangular full thickness skin graft technique to close the forearm donor site [21].

Raphael Ciuman and Philipp Dost (2012) Described the Forearm Flap – Indications, Appropriate Selection, Complications and Functional Outcome. The authors concluded that Micro vascular surgery often presents the only possibility to reach satisfactory functional, and cosmetic outcomes and to achieve acceptable quality of life for reconstruction in the head and neck. Due to distinct characteristics, the forearm flap is one of the most used transplants for reconstruction in the head and neck and a widely used transplant for other indications as well. Correct planning and elevation presupposed the flap success rates average at least 90% with no relevant limitations in strength, motion and hemodynamics in the forearm or hand and non-disturbing sensory and cosmetic outcome at the donor site[35].

Wael Hussein Mahmoud (2015) in a series of 20 patients with post burn and post traumatic soft tissue defects of hand, conducted a prospective double blind controlled clinical trial to evaluate and compare radial forearm free flap versus radial adipo facial perforator based flap for reconstruction. Patients were placed in two groups: Group A (Chinese flap), Group B (Perforator flap). Evaluation of operative time, length of hospital stay, incidence of complications, donor site morbidity and patient satisfaction[58].

8

Material and Methods

8.1. Design of study

This thesis consists of two papers:

1. Observational anatomical study.
2. Prospective randomized controlled clinical study.

8.1.1. Design of First publication.

Methodology:

12 fresh human cadavers and 24 cadaveric forearms were dissected. All radial artery adipo-facio cutaneous perforators were analyzed for:

1. Number of perforators.
2. Orientation of perforators.
   a. Radial distribution.
   b. Ulnar distribution.
3. Size of perforators.
4. Cutaneous territory.

The upper extremity at the level of elbow and the brachial artery was cannulated and perfused with warmed saline. This was continued until the backflow was clear. Subsequently the artery was injected with 20cc of microfil red and the arm was stored in refrigerator at 0^0 C for 24hrs. A total of 24 flaps were dissected to access the size, numbers, and location of radial artery perforators. Two flaps were used for vascular injection studies using methylene blue and lead oxide.

An incision is made on the palmar aspect of forearm, extending from wrist crease to elbow. All perforators originating from radial artery are identified and dissected. Parameters include; orientation of perforators, whether they arise on the radial side/lateral or on the ulnar side/medial,

distance from radial styloid for distal perforators and from the lateral epicondyle for the proximal perforators, external diameter (Artery) using calipers, cutaneous cluster pattern with methylene blue injections.
In order to determine the vascular cutaneous territory of a distally based radial artery perforator flap, two forearm flaps were dissected based on distal most dominant perforator found proximal to the radial styloid. The artery was cannulated and injected with methylene blue dye to examine the territory of cutaneous staining. Injection of contrast material (Lead oxide) was then injected and the specimen subjected to three-dimensional CT Scan with volume rendering function in order to access the vascular territory and identify linking vessels communicating with adjacent perforators.

8.1.2. Design of Second publication

Methodology:

15 patients who underwent oncological resections were reconstructed with shape modified adipo-fascio cutaneous radial forearm free flap. All 15 patients were prospectively evaluated for,

1. Donor site healing.
2. Scar evaluation through subjective scores.
3. Motor function/deficit evaluation for wrist extension and flexion.
4. Sensory evaluation with fine touch and pin prick method.
5. Quality of life assessment for objective scores.

Radial artery course is marked with the help of Doppler. Skin pinch test is done to mark the dimensions of skin paddle. Approximately 2 cm of skin width in distal forearm and 3 cm of skin width in proximal forearm can be harvested and closed primarily. This may slightly vary depending on the fat content in subcutaneous plain. Flap is harvested unto the origin of radial artery. Skin Island is marked and divided after visualizing the perforators to the skin. Suturing of these individual skin paddles together is done to give this flap the desired dimensions required to reconstruct the defect. After the harvest with its desired dimension and achieving the required pedicle length, donor site is closed primarily without the need for a skin graft.

8.1.3. Place where the study/thesis was carried out

Patients visiting Department of Surgical Oncology, Plastic, Maxillofacial & Reconstructive services at Vydehi Institute of Medical sciences and Research center, Bangalore, India, for reconstruction of various head and neck defects following oncologic resections.

8.1.4. Inclusion and Exclusion criteria.

Cadaveric study

Inclusion criteria:

12 fresh human cadavers with normal radial artery anatomy were included in study.

Exclusion criteria:

1) Cadavers more than one month old.

2) Anomalies of radial artery.

Clinical study:

15 patients who underwent oncological resections were reconstructed with shape modified adipo-fascio cutaneous radial forearm free flap. All patients were prospectively evaluated for

1. Donor site healing.

2. Scar evaluation through subjective scores.

3. Motor function/deficit evaluation for wrist extension and flexion.

4. Sensory evaluation with fine touch and pin prick method.

5. Quality of life assessment for objective scores.

Inclusion criteria:

1.Small to moderate defects requiring thin pliable flap for reconstruction.

Exclusion criteria:

1. Patients with systemic complications, who are not fit enough for a micro-vascular procedure.

9

Protocol of study

Following a detailed cadaveric evaluation of distribution of radial artery perforators and their cutaneous territory as explained in first publication. A prospective randomized clinical study with reconstruction of head and neck defects following oncological reconstructions was carried out in 15 patients with shape modified adipo- facio cutaneous radial artery perforator flap.

Operative procedure:

After marking the course of radial artery with a hand held Doppler is done. Pinching test of skin is done to mark the skin paddle. Approximately 2cm of skin at distal forearm and 3 cm at proximal forearm can be closed by primary method and also depends on the fat content in the subcutaneous layer. Final markings of the flap to be harvested and number of skin paddles required to reconstruct the primary defect are accomplished. Flap is harvested unto the origin of radial artery. Skin and subcutaneous tissue is divided after direct visualization of clinically significant perforators that are given to the skin and after careful evaluation of their cutaneous territory. Suturing of the desired skin paddles together to get the required flap dimensions is accomplished. Donor site is closed primarily with simple interrupted sutures with drain in situ.

Postoperative care

It is imperative that the vascularity of the hand be confirmed after releasing the tourniquet. The circulation to the thumb must be assessed to ensure once again that the collateral circulation through the ulnar artery provides sufficient vascularity. In the modified method there is no splint required, but the perfusion of upper limb/donor site is monitored for next 24 hrs with pulse-oximeter or just visual impression. A dressing is given which is removed after 2 days. And the wound inspected. If drain is placed it is removed, and the wound kept open. Patient can mobilize his hand after 48 hrs. Once the pain and edema is settled. If the suturing done is thought to be too tight then it has to be released immediately to avoid compression syndrome.

All patients were prospectively followed up in out patient after discharge from hospital and are also communicated by phone or via email.

A retrospective review of surgery done for all these patients is performed.

The donor site is inspected for appearance, itching, pigmentation, tenderness and hypertrophy or keloid. Patients and observer scar assessment score is used for subjective scoring. To avoid bias we will use three scores one each from patient, nurse and doctor (not involved in the study group).

Observer Scar Assessment Scale

	normal skin	1	2	3	4	5	6	7	8	9	10	*worst scar imaginable*
Vascularization		o	o	o	o	o	o	o	o	o	o	
Pigmentation		o	o	o	o	o	o	o	o	o	o	Hypo ☐ Mix ☐ Hyper ☐
Thickness		o	o	o	o	o	o	o	o	o	o	
Relief		o	o	o	o	o	o	o	o	o	o	
Pliability		o	o	o	o	o	o	o	o	o	o	

---+

Total score Observer Scar Scale:

Patient Scar Assessment Scale

No, no complaints	1	2	3	4	5	6	7	8	9	10	*Yes, worst imaginable*
Is the scar painful ?	o	o	o	o	o	o	o	o	o	o	
Is the scar itching?	o	o	o	o	o	o	o	o	o	o	
No, as normal skin	1	2	3	4	5	6	7	8	9	10	*Yes, very different*
Is the color of the scar different?	o	o	o	o	o	o	o	o	o	o	
Is the scar more stiff ?	o	o	o	o	o	o	o	o	o	o	
Is the thickness of the scar different?	o	o	o	o	o	o	o	o	o	o	
Is the scar irregular?	o	o	o	o	o	o	o	o	o	o	

---+

Total score Patient Scar Scale:

Motor evaluation is done, especially for wrist extension and flexion. If patients have difficulty with power grip then measurements are made for finger flexion and extension with goniometer.

Sensory evaluation is done with fine touch and pinprick method.

Photos are taken with standardized methods using a Digital SLR Camera.

Patient recipient site is also examined for functional outcome, mouth opening and tongue movement. Photos of the recipient site are taken for further evaluation.

Patient will be asked a quality of life questionnaire, which will give objective score.

Question no	average	Average	Good	Very good	Excellent	Total score (Out of 25)
	1	2	3	4	5	
Are you satisfied by this scar						
Are you in need of change of the clothing style because of scar						
Has your daily manual work or duties influenced by the donor site						
Are you in need of applying special medication for donor site						
Is there a problem in wearing ornaments or watch after surgery on affected side						

Statistical Analysis of Study

Statistical Package for Social Sciences [SPSS] for Windows, Version 22.0. Released in 2013.Armonk, NY: IBM Corp. was used to perform statistical analyses.

Descriptive Statistics:

Descriptive analysis of all the explanatory and Outcome parameters was done using frequency and proportions for categorical variables, whereas in Mean & SD for continuous variables.

Inferential Statistics:

Independent Student t Test was used to compare the mean Flap Dimensions (in Sq.cm), Pedicle Length (in cm), Duration of Follow-up, Scar assessment & Quality of Life [QoL] scores between 2 groups.

Chi Square Test was used to compare the presence of Sensory and Motor deficit between 02 groups.

The level of significance [P-Value] was set at $P<0.05$.

10

Results

10.1. First Publication:

This cadaveric study on radial forearm perforators discusses reliability of distal and proximal perforators based on size, numbers and location. It also discusses on clinical implications of perforator based shape modifications in radial forearm free flap. The results of this study are shown in results section.

10.2. Second Publication:

This article discusses on ability of shape modified adipo fascio cutaneous radial forearm free flap in reconstruction of head and neck defects. It also emphasizes on better scar healing and function as compared with traditional radial forearm free flap. The results are analyzed in result section.

Publications

10.1.1. First Article:

Vascular Analysis of Radial Artery Perforator Flaps.

Sham E, Masia JA, Reddy TJ. Vascular analysis of radial artery perforator flaps. Ann Maxillofac Surg 2018; 8: 66-72.

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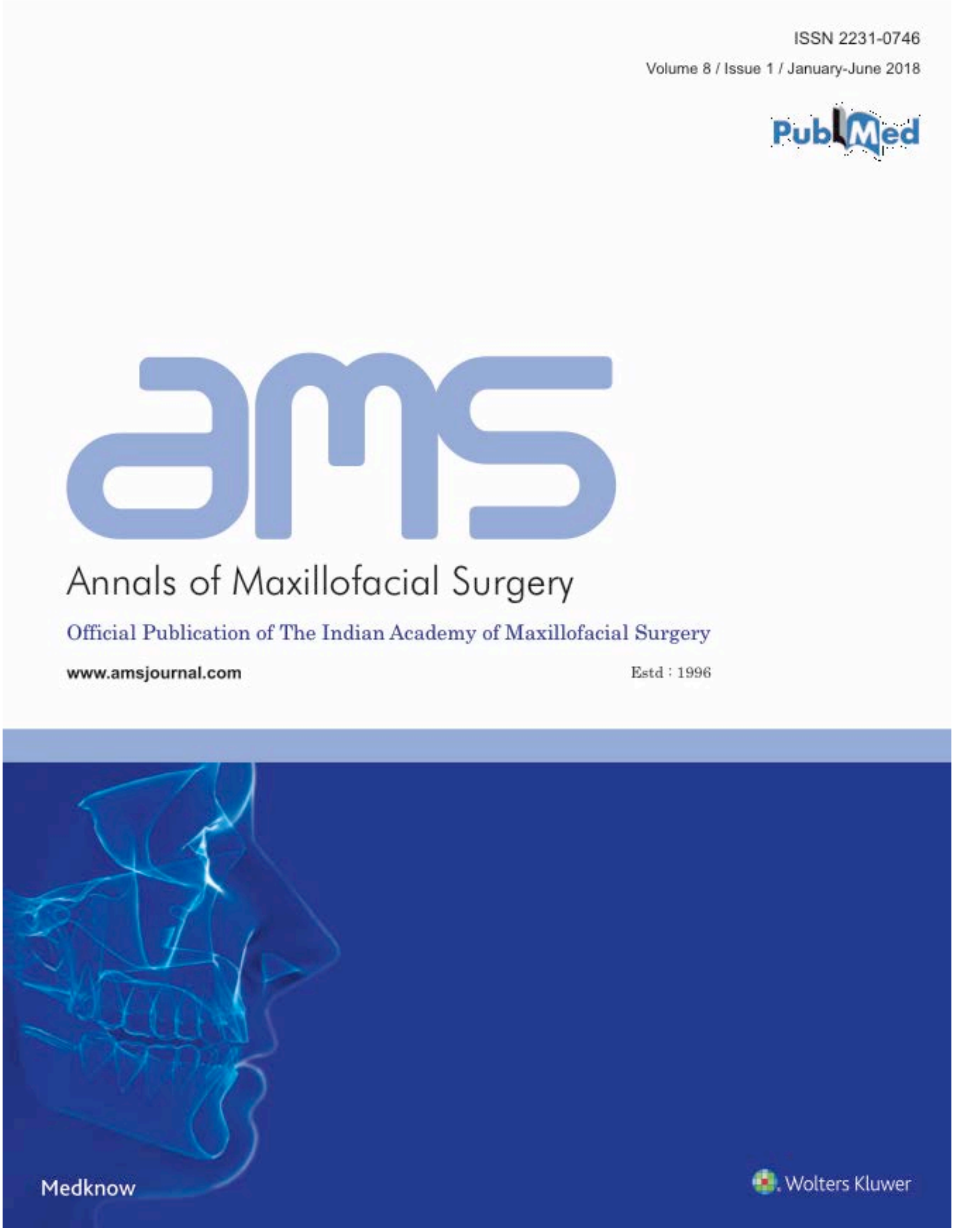
Quartile of surgery category: Q 4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Original Article - Evaluative Study

Vascular Analysis of Radial Artery Perforator Flaps

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Abstract

Background: Radial forearm free flap with all its present day modifications is the workhorse of soft tissue reconstruction in head & neck. Although there are several advantages, it requires the sacrifice of a major artery of forearm. There are several modifications of harvesting a forearm flap based on perforator principles. A clear understanding of vascular anatomy of individual perforators relative to its vascular territory & flow characteristics is essential for both flap harvest & design. The purpose of this cadaveric observational anatomical study was to determine the location, size & vascular territory of the radial artery cutaneous perforators. **Materials and Methods:** 12 fresh human cadavers & 24 cadaveric forearms were dissected to determine the total number, location, size & vascular territory of radial artery adipo-fascio cutaneous perforator. The cutaneous territory of distally dominant perforators was analyzed using methylene blue injections & three-dimensional computed tomographic angiogram. **Results:** In the 12 fresh human cadavers & 24 forearm specimens, a total of 222 perforators were dissected for an average of 18.5 radial artery perforators per forearm. Of the total 222 perforators dissected 118 were smaller than 0.5mm in diameter (53.15%) these were not clinically significant. 104 perforators were greater than 0.5mm in diameter (46.84%) these were clinically significant. Of the 222 radial artery perforators dissected, 127 perforators (57.20%) were radially distributed & 95 perforators (42.79%) had ulnar distribution. A total of 90 perforators (40.54%) were identified on distal side (Radial styloid) & 132 perforators (59.45%) were identified on proximal side (Lateral epicondyle). Mean number of perforators on radial side was 10.6 & 7.9 on ulnar side, a comparison of both using student t paired test gives a P value of 0.006, which was statistically significant. Comparison of mean number of perforators on the distal side was 7.5 & proximal side was 11.0, Student Paired t test gives a P value of 0.003, which was statistically significant. Comparison of mean Diameter of perforators between the Distal side (1.11) & Proximal side (0.86) using Student Paired t test gives a P value of 0.01 which was statistically significant. A chi square test was done to compare mean diameter of perforators on distal side, which were more than 1mm (80%) & less than 1mm (20%) & on proximal side more than 1mm (35.6%) & less than 1mm (64.4%). Chi square value of 42.406 was obtained, degree of freedom value was 1& P value of <0.001 was achieved which was found to be highly significant. Methylene blue injections into the proximal part of radial artery demonstrated clusters both in proximal & distal forearm & also cutaneous territory of flap. Three- dimensional computed tomographic angiography reveals a network of linking vessels found to communicate between adjacent perforators & running parallel to radial artery. Large network of linking vessels could be found between fascia & dermis, which also explains the ability to harvest forearm flap at the supra-fascial level. **Conclusion:** Increase in knowledge of vascular territory of radial artery perforators with regards to numbers, size, location, and cutaneous territory can lead to expanded use of radial forearm flap based on either distal or proximal perforator alone, without sacrificing the radial artery.

Keywords: Anatomy, angio computed tomographic, perforator flap, radial artery, reconstruction, vascularization

Introduction

Increased knowledge of vascular anatomy has inevitably led to innovations in flap design and its use in clinical arena. The evolution of random pattern flaps to fasciocutaneous flaps to myocutaneous flaps and finally to the perforator flaps has followed a linear progression, largely because of pioneering vascular anatomical studies. The information derived from such kind of work has fuelled an evolution in flap designs and its clinical applications.

Since the original description of radial forearm flap in 1978 by Yang and Yuzhi[1] and Timmons anatomical description in 1986, this versatile flap has found numerous applications in plastic and reconstructive surgery.[2] Its value in head-and-neck

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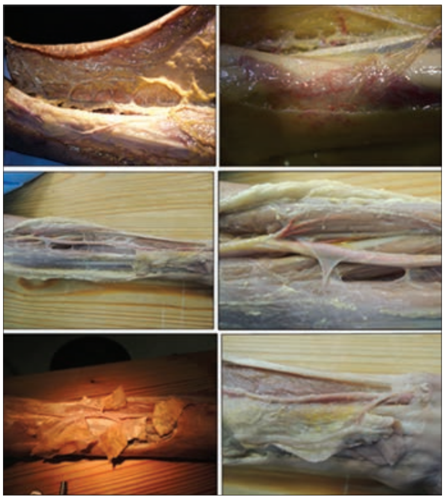


Figure 1: Radial artery perforators to skin

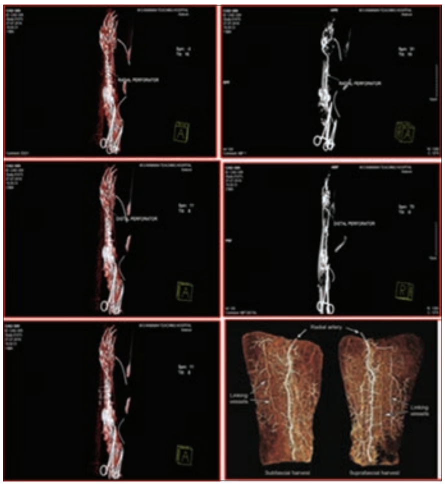
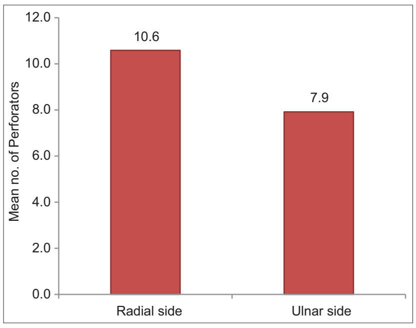


Figure 3: Angiography of radial artery perforators

Figure 2: Distal and proximal perforators

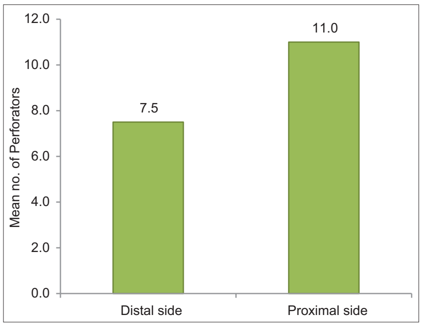


Bar Chart 1: Comparison of mean number of perforators between radial and ulnar side

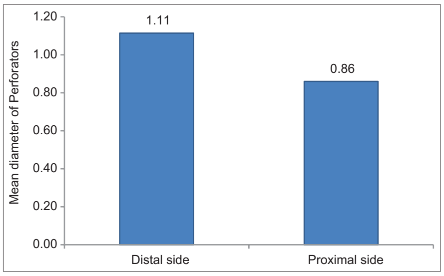
reconstruction and upper and lower extremity reconstruction is well documented. Nevertheless, its application as both retrograde flow-pedicled island flap and free flap has resulted in two major drawbacks:

1. Donor site morbidity
2. Sacrifice of the radial artery.

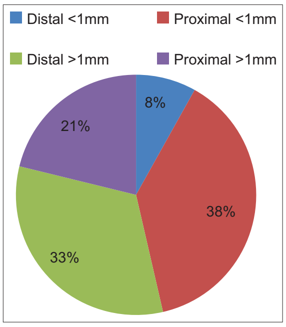
A study detailing the location and vascular territory of the radial artery perforators, therefore, becomes necessary to facilitate operative planning in perforator-based flap harvest. A well-described territorial outline of the consistently located, clinically significant perforators forms the basis for this observational anatomical study.



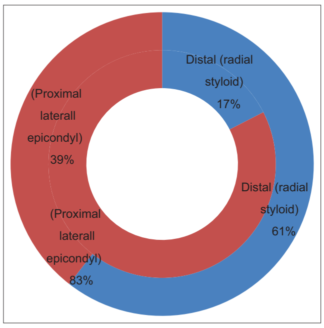
Bar Chart 2: Comparison of mean number of perforators between the distal and proximal side



Bar Chart 3: Comparison of mean diameters of perforators between the distal and proximal side



Bar Chart 4: Pictorial presentation of Chi-square test



Bar Chart 5: Component chart

Materials and Methods

Objectives

Observational anatomical study

To determine the location, size, and vascular territory of the radial artery adipo-fasciocutaneous perforators involving 12 fresh human cadavers and 24 cadaveric forearms.

Need for the study: Anatomical studies defining the perforator vessel anatomy and distribution have been done before. However, there are very few studies defining the location of perforator clusters or the cutaneous territory along the radial artery axis. A well-defined territorial outline of the consistently located, clinically significant perforators would be useful for operative decision-making of shape-modified adipo-fasciocutaneous radial artery perforator flap.

Inclusion criteria

Twelve fresh human cadavers with normal radial artery anatomy were included in study.

Exclusion criteria

1. Cadavers >1-month-old
2. Anomalies of radial artery.

Methodology

Anatomical study

Twelve fresh human cadavers and 24 cadaveric forearms were dissected. All radial artery adipo-fasciocutaneous perforators were analyzed for:

1. Number of perforators
2. Orientation of perforators
   a. Radial distribution
   b. Ulnar distribution.
3. Size of perforators
4. Cutaneous territory.

The upper extremity at the level of the elbow and the brachial artery was cannulated and perfused with warm saline. This was continued until the backflow was clear. Subsequently, the artery was injected with 20 cc of Microfil red and the arm was stored in refrigerator at 0°C for 24 h. A total of 24 flaps were dissected to access the size, numbers, and location of the radial artery perforators. Two flaps were used for vascular injection studies using methylene blue and lead oxide.

An incision is made on the palmar aspect of the forearm, extending from wrist crease to elbow. All perforators originating from the radial artery are identified and dissected. Parameters include orientation of perforators, whether they arise on the radial side/lateral or on the ulnar side/medial, distance from radial styloid for distal perforators and from the lateral epicondyle for the proximal perforators, external diameter (artery) using digital vernier caliper with an accuracy of ±0.03 mm, and cutaneous cluster pattern with methylene blue injections.

To determine the vascular cutaneous territory of a distally based radial artery perforator flap, two forearm flaps were dissected based on distal most dominant perforator found proximal to the radial styloid. The artery was cannulated and injected with methylene blue dye to examine the territory of cutaneous staining. Contrast material (lead oxide) was then injected and the specimen was subjected to three-dimensional CT scan with volume rendering function in order to access the vascular territory and identify linking vessels communicating with adjacent perforators.

The results were statistically analyzed with Student *t*-paired test and Chi-square test (Software: SPSS 17-Chicago Inc., SPSS version 22, IBM. Corp).

Results

In the 12 fresh human cadavers and 24 forearm specimens, a total of 222 perforators were dissected for an average of 18.5 radial artery perforators per forearm [Table 1]. Of the total 222 perforators dissected, 118 were smaller than 0.5 mm in diameter (53.15%), these were not clinically significant. A total of 104 perforators were >0.5 mm in diameter (46.84%), these were clinically significant [Figure 1].

Of the 222 radial artery perforators dissected, 127 perforators (57.20%) were radially distributed and 95 perforators (42.79%) had ulnar distribution [Table 1]. A total of 90 perforators (40.54%) were identified on the distal side (radial styloid) and 132 perforators (59.45%) were identified on the proximal side (lateral epicondyle) [Table 1]. The mean number of perforators on radial side was 10.6 and 7.9 on ulnar side, a comparison of both using Student *t*-paired test gives a $P = 0.006$, which was statistically significant [Table 2] [Bar Chart 1]. Comparison of mean number of perforators on the distal side was 7.5 and proximal side was 11.0, Student paired *t*-test gives a $P = 0.003$, which was statistically significant [Table 3] [Bar Chart 2]. Comparison of mean diameter of perforators between the distal side (1.11) and proximal side (0.86), side using Student paired *t*-test gives a $P = 0.01$ which was statistically significant [Tables 4-6 and Bar Chart 3].Chi-square test was done to compare the mean diameter of perforators on the distal side, which were >1 mm (80%) and <1 mm (20%) and on the proximal side >1 mm (35.6%) and <1 mm (64.4%). Chi-square value of 42.406 was obtained, degree of freedom value was 1 and $P < 0.001$ was achieved which was found to be highly statistically significant [Table 7] [Bar Charts 4 and 5].

In almost all the dissected anatomical specimens, at least one clinically significant perforator was found within 2 cm proximal to radial styloid [Figure 2]. Methylene blue injections into the proximal part of radial artery demonstrated clusters

Table 1: Master chart

Cadavers	Number of perforators	Radial side	Ulnar side	Distal side	Proximal side
1	19	10	9	8	11
2	21	12	9	11	10
3	20	11	9	7	13
4	18	11	7	7	11
5	12	10	2	7	5
6	18	10	8	7	11
7	20	13	7	6	14
8	16	9	7	5	11
9	19	10	9	10	9
10	20	11	9	7	13
11	21	9	12	9	12
12	18	11	7	6	12
Total	222	127	95	90	132

Table 2: Comparison of mean number of perforators between the radial and ulnar side-using Student paired *t*-test

Sides	*n*	Mean	SD	SEM	Mean difference	95% CI of the difference		*t*	*P*
						Lower	Upper		
Radial side	12	10.6	1.2	0.3	2.7	0.9	4.4	3.370	0.006*
Ulnar side	12	7.9	2.4	0.7					

SD=Standard deviation; SEM=Standard error of mean; CI=Confidence interval; 0.01* *P* value is significant

Table 3: Comparison of mean number of perforators between the distal and proximal side-using Student paired *t*-test

Sides	*n*	Mean	SD	SEM	Mean difference	95% CI of the difference		*t*	*P*
						Lower	Upper		
Distal side	12	7.5	1.7	0.5	−3.5	−5.6	−1.4	−3.718	0.003*
Proximal side	12	11.0	2.3	0.7					

SD=Standard deviation; SEM=Standard error of mean; CI=Confidence interval; 0.01* *P* value is significant both in the proximal and distal forearm and also revealed a large flap cutaneous territory [Figure 2].

Three-dimensional computed tomographic angiography [Figure 3] reveals a network of linking vessels found to communicate between adjacent perforators and running parallel to the radial artery. Large network of linking vessels could be found between fascia and dermis, which also explains the ability to harvest forearm flap at the suprafascial level.

Discussion

Head-and-neck oncologists often seem to confront the difficult task of balancing cancer cure with preservation of function, cosmesis, and quality of life when deciding patients best treatment protocols. Reconstruction in its true sense represents a big challenge for the reconstructive surgeon.[3,4]

Since the original description of radial forearm flap in 1978 by Yang and Yuzhi, this versatile flap has found itself numerous applications in plastic and reconstructive surgery.[1,5] However, its application as both retrograde flow pedicled island flap and free flap has resulted in two major drawbacks, drawing great attention among the reconstructive Surgeons:[2,6,7]

1. Donor-site morbidity in terms of esthetics, cold intolerance, slight–to-moderate functional deficit
2. Sacrificing a major artery of the forearm.

Several modifications and innovations in terms of donor-site closure, flap-harvesting techniques, and preservation of radial artery have been proposed and practiced.[8-12] Increased knowledge of vascular anatomy has played a definitive role in increasing our ability to understand and use perforator-based flaps for various clinical Applications.[13,14]

As we gradually shift toward perforator-based flap reconstructions, knowledge of individual perforators should supersede that of source artery.[15] Many surgeons have reported the use of perforator flaps from the forearm with ease, success, and good functional outcome.[16-18] However, it is difficult to clinically establish the exact location of dominant radial artery perforator with a handheld Doppler because of superficial course of the radial artery.[19] To establish the basis for perforator flaps, an anatomical study to determine the exact location and vascular territory become all the more essential. In our present study, we have investigated the location, size and vascular pattern, and territory of the radial artery in 12 fresh human cadavers involving 24 forearm specimens. We have demonstrated a total of 222 perforators with an average of 18.5 perforators per forearm. Perforators <0.5 mm were not considered as clinically suitable for anastomosis. Our study confirms a strong relation between the number and diameter of perforators.[19-21] Distal side demonstrates less number of perforators but a large caliber perforator is consistently present within 2 cm of radial styloid in all of the 12 cadavers, this finding is found to be consistent with the previous anatomical studies on the radial artery.[16] Michel Saint-Cyr *et al*. conducted an anatomical study in 26 fresh human cadaveric forearms to study and determine the location, orientation, external diameter, and vascular territory of radial artery cutaneous perforators. The authors concluded that there are two main clusters of clinically significant perforators and increased knowledge of size, location, and cutaneous territory of the radial artery perforators can lead to expanded use of radial artery forearm flap based on these cutaneous perforators alone, without sacrificing the main radial artery.[19]

In both distal and proximal forearms, perforators arising from the main vessel have both radial and ulnar distribution.[19] These anatomical characteristics suggest an element of safety when harvesting flaps based on either distal or proximal perforator.[19] Our study demonstrates clusters of perforators in both proximal and distal aspect of the forearm.[14,19]

Clinical use of perforator-based radial artery free flap may have limited applications, but nevertheless, cases have been reported in the literature.[22] The vascular anatomy of the fascia and subcutaneous tissue of the distally based flaps have been well described.[17] The blood supply to the fasciocutaneous flap is found to originate from 5 to 10 septocutaneous perforators arising from the radial artery in the anatomical snuffbox.[16]

Table 4: Mean diameter of perforators

	Distal (radial styloid)	Proximal (lateral epicondyle)
1	1.23	0.54
2	1.01	1.00
3	1.23	0.64
4	0.92	0.63
5	1.20	0.83
6	1.17	0.92
7	0.98	1.20
8	0.87	1.00
9	1.11	0.94
10	1.20	0.68
11	1.23	0.83
12	1.22	1.11

Table 5: Comparison of mean diameter of perforators between the distal and proximal side-using Student paired *t*-test

Sides	*n*	Mean	SD	SEM	Mean difference	95% CI of the difference		*t*	*P*
						Lower	Upper		
Distal	12	1.11	0.13	0.04	0.25	0.08	0.43	3.132	0.01*
Proximal	12	0.86	0.21	0.06					

SD=Standard deviation; SEM=Standard error of mean; CI=Confidence interval; 0.01* *P* value is significant

Table 6: Mean number and diameter on both sides

Sides	Mean	Sides	Mean
Radial side	10.6	Distal side	7.5
Ulnar side	7.9	Proximal side	11.0

Table 7: Chi-Square test

	Distal (radial styloid) (%)	(proximal lateral epicondyle) (%)	χ^2	df	*P*
<1 mm	18 (20)	85 (64.4)	42.406	1	<0.001
>1 mm	72 (80)	47 (35.6)			

Anatomical and clinical investigation of the radial forearm adipo-fascial flap based on distal perforators has been well described by Hamdy El-Khatib**,** who reported an anatomic study in 11 fresh and fixed cadavers, designing an island adipofascial flap based on distal five to eight septocutaneous perforators of the radial artery and their vena comitantes, great advantage being preservation of the radial artery.[14] Three-dimensional computed tomographic angiography in our study has shown a comparable vascular territory with linking vessels found to communicate between adjacent perforators and running parallel to the radial artery.[19] Perforators travel to dermis and form a network of linking vessels found between fascia and dermis. This finding is consistent as reported by previous similar studies.[14,16] Mark Schaverien and Saint-Cyr conducted a study involving 12 fresh human cadavers and 24 radial forearm flaps harvested from these cadavers to elucidate the role of deep fascia in perfusion of radial forearm flap. The authors concluded that inclusion of deep fascia during flap harvest does not contribute to flap perfusion or vascularity.[17] Although there are several anatomical study reports on vascular anatomy of the radial artery, our study demonstrates the cutaneous territory and location of clusters in detail. The results obtained from our study are clinically important in planning the exact dimension of the flap based on distal third perforators of the radial artery. Perhaps, the most significant finding in this study is the location of cutaneous perforators. Knowledge of these perforators can greatly facilitate the reconstructive surgeon in safe flap harvest and design.[23] Both distal and proximal perforators can be used in the designing of potential flaps for various reconstructive needs.[16] Three-dimensional computed tomographic angiogram confirms that suprafacial dissection does not compromise blood supply of the radial forearm pedicle perforator flap.[7,10] The supply to the skin is ensured by means of multiple perforators originating from the radial and ulnar sides of the radial artery, traveling to the skin and communicating with each other in the subcutaneous tissue plane by multiple linking vessels. Each perforator has its own vascular territory, called a perforasome. These perforasomes are linked to one another by both direct and indirect linking vessels, which themselves are linked by communicating branches. These numerous branches confer further protection from ischemia and vascular injury and explain the survival of single dominant perforator-based flaps.[19] Linking vessels allow communication with adjacent perforasomes and follow a direction that is parallel to the direction of perforator flow. Therefore, perforator flap skin paddles should be parallel to the linking vessel orientation, which makes it possible to harvest large flaps based on single dominant perforator.[12,19]

Conclusion

Each perforator holds a unique vascular territory. Vascular supply chain among perforators is highly complex and both direct and indirect linking vessels play a major role in maintaining flap perfusion. Our study demonstrates a consistent course of the radial artery with clusters originating on both distal and proximal ends, with each end becoming a pivot point for a pedicled flap rotation. Each perforator has the potential to become either a free or a pedicled flap depending on the size. In addition, preservation of the radial artery and ability of suprafacial harvest further lessens the morbidity burden. This phenomenon allows a myriad of perforator flap designs that can be tailored to match reconstructive defects. Present day reconstructive surgeons have more options and alternatives in replacing like with like. Local flap alternatives become more plentiful and flap design is limited only by the availability of clinically relevant perforators close to the defect. Freestyle perforator flaps are present day reality, based on the size and length of their respective source arteries and veins.

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Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Yang G, Chen B, Gao Y, Liu X, Li J, Jiang S. Forearm free skin flap transplantation. Nat l Med J China 1981;61:139-41.
2. Timmons MJ, Missotten FE, Poole MD, Davies DM. Complications of radial forearm flap donor sites. Br J Plast Surg 1986;39:176-8.
3. Mühlbauer W, Herndl E, Stock W. The forearm flap. Plast Reconstr Surg 1982;70:336-44.
4. Soutar DS, McGregor IA. The radial forearm flap in intraoral reconstruction: The experience of 60 consecutive cases. Plast Reconstr Surg 1986;78:1-8.
5. Song R, Gao Y, Song Y, Yu Y, Song Y. The forearm flap. Clin Plast Surg 1982;9:21-6.
6. Lovie MJ, Duncan GM, Glasson DW. The ulnar artery forearm flap. Br J Plast Surg 1984;37:486-92.
7. Chang SC, Miller G, Halbert CF, Yang KH, Chao WC, Wei FC, *et al.* Limiting donor site morbidity by suprafascial dissection of the radial forearm flap. Microsurgery 1996;17:136-40.
8. Partecke BD, Buck-Gramcko D, Pachucki A. Use of a fascia flap of the forearm in soft tissue defects of the extremities. Handchir Mikrochir Plast Chir 1986;18:353-5.
9. Liang MD, Swartz WM, Jones NF. Local full-thickness skin-graft coverage for the radial forearm flap donor site. Plast Reconstr Surg 1994;93:621-5.
10. Webster HR, Robinson DW. The radial forearm flap without fascia and other refinements. Eur J Plast Surg 1995;18:11-3.
11. Wolf KD, Ervens J, Hoffmeister B. Improvement of radial forearm donor site by prefabrication of facial split thickness skin grafts. Plast Reconstr Surg 1995;98:358-61.

12. Hussein Mahmoud W. Radial forearm flap versus radial adipofascial perforator based flap for reconstruction of hand soft tissue defects. Donnish J Med Med Sci 2015;2:19-25.
13. Rath T, Millesi W, Millesi-Schobel G, Lang S, Glaser C, Todoroff B, *et al.* Mucosal prelaminated flaps for physiological reconstruction of intraoral defects after tumour resection. Br J Plast Surg 1997;50:303-7.
14. el-Khatib H, Zeidan M. Island adipofascial flap based on distal perforators of the radial artery: An anatomic and clinical investigation. Plast Reconstr Surg 1997;100:1762-6.
15. Yang D, Morris SF, Tang M, Geddes CR. Reversed forearm island flap supplied by the septocutaneous perforator of the radial artery: Anatomical basis and clinical applications. Plast Reconstr Surg 2003;112:1012-6.
16. Tiengo C, Macchi V, Porzionato A, Bassetto F, Mazzoleni F, De Caro R, *et al.* Anatomical study of perforator arteries in the distally based radial forearm fasciosubcutaneous flap. Clin Anat 2004;17:636-42.
17. Schaverien M, Saint-Cyr M. Suprafascial compared with subfascial harvest of the radial forearm flap: An anatomic study. J Hand Surg Am 2008;33:97-101.
18. Mateev MA, Ogawa R, Trunov L, Moldobaeva N, Hyakusoku H. Shape-modified radial artery perforator flap method: Analysis of 112 cases. Plast Reconstr Surg 2009;123:1533-43.
19. Saint-Cyr M, Mujadzic M, Wong C, Hatef D, Lajoie AS, Rohrich RJ, *et al.* The radial artery pedicle perforator flap: Vascular analysis and clinical implications. Plast Reconstr Surg 2010;125:1469-78.
20. Lin JY, Cheng MH, Wei FC, Song D, Huang WC. Proximal forearm flap based on a septocutaneous vessel from the radial artery. Plast Reconstr Surg 2006;117:955-60.
21. Tiengo C, Macchi V, Porzionato A, Stecco C, Parenti A, Bassetto F, *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.
22. Raphael Ciuman and Phillip Dost. The Forearm Free Flap- Indications, Appropriate Selection, Complications & Functional Outcomes; 2012. Available from: http://www.intechopen.com. [Last accessed on 2012 May 05].
23. Giordano L, Bondi S, Ferrario F, Fabiano B, Bussi M. Radial forearm free flap surgery: A modified skin-closure technique improving donor-site aesthetic appearance. Acta Otorhinolaryngol Ital 2012;32:158-63.

10.2.1. Second Article:

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Adipo Fascio Cutaneous Perforator Based, Shape Modified Radial Forearm Flap: Vascular Analysis of Perforators & Its Clinical Applications in Head & Neck Reconstruction

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Abstract

Resume of the study & Background: Radial forearm free flap with all its present day modifications is the workhorse of soft tissue reconstruction. Although there are several advantages, it requires sacrifice of a major artery of forearm. Several modifications are described in harvesting a forearm flap. In order to achieve a reliable, safe flap harvest & design one must have a very clear understanding of radial artery perforators, relative to its distribution, territory & flow. The purpose of this study is to determine the location, size & vascular territory of the radial artery cutaneous perforators & to demonstrate application of shape modification of radial forearm free flap based on its distal & proximal perforators in various head & neck defects. **Materials & Methods:** Anatomical Study: 12 fresh human cadavers & 24 cadaveric forearms were dissected to determine the number, location, size & vascular territory of radial artery perforator. The cutaneous territory of distally dominant perforators was analyzed using methylene blue injections & three-dimensional computed tomographic angiogram to determine the vascular network. Clinical Study: 15 patients with various head neck defects following oncological resections were reconstructed with shape modified adipo-fascio cutaneous free forearm flap. All these patients were prospectively followed for donor site healing, motor & sensory nerve deficit, function & quality of life questioner for donor site assessment. **Results:** 12 fresh human cadavers & 24 cadaveric forearms were dissected, and a total of 222 perforators were dissected for an average of 18.5 perforators per forearm. 118 were smaller than 0.5 mm in diameter (53.15%) & were not clinically significant. 104 perforators were greater than 0.5 mm in diameter (46.84%) & were clinically significant. 127 perforators (57.20%) were radially distributed & 95 perforators (42.79%) had ulnar distribution. 90 perforators (40.54%) were identified on distal side (Radial styloid) & 132 perforators (59.45%) were identified on proximal side (Lateral epicondyle). Mean number of perforators, on radial side was 10.6 & 7.9 on ulnar side; comparison of both using student t paired test gives a P value of 0.006, which is significant. Comparison of mean number of perforators on the distal side was 7.5 & proximal side was 11.0; Student Paired t test gives a P value of 0.003, which was statistically significant. Comparison of mean diameter of perforators on Distal side (1.11) & Proximal side (0.86), side using Student Paired t test gives a P value of 0.01 which was statistically significant. A chi square test was done to compare mean diameter of perforators on distal side, which was more than 1 mm (80%) & less than 1 mm (20%) & on proximal side more than 1 mm (35.6%) & less than 1 mm (64.4%). Chi square value of 42.406 was obtained, degree of freedom value was 1 & P value of <0.001 was achieved which was found to be highly significant. Methylene blue injections demonstrated clusters both in proximal & distal forearm & also marked the cutaneous territory of flap. Three-dimensional computed tomographic angiography reveals a network of linking vessels found to communicate between adjacent perforators & running parallel to radial artery. A total of 15 patients were reconstructed with shape modified radial forearm flap following oncologic resections. Wound healing in all 15 patients was good, with scar assessment faring better than traditional radial forearm flap. There was no sensory or motor nerve deficit. Although pedicle length was comparatively shorter in shape-modified flap, there was no problem in anastomosing to neck vessels. **Conclusion:** Increase in knowledge of vascular territory of radial artery perforators with regards to numbers, size, location, & cutaneous territory can lead to expanded use of radial forearm flap based on either distal or proximal perforator alone. Shape modified technique for harvesting radial forearm flap allows primary closure of donor site. Donor site is better healed and shows a predicted pattern, which is functionally and aesthetically good.

Keywords

Vascular Anatomy, Angio Computed Tomography, Perforator Flap, Radial Artery, Reconstruction, Vascularization

1. Introduction

Knowledge of vascular anatomy has inevitably led to innovations in flap design & use in clinical arena. The evolution of random pattern flaps to facio-cutaneous flaps to myocutaneous flaps & finally to the perforator flaps has followed a linear progression, largely because of pioneering vascular anatomical studies. The information derived from such kind of work has fuelled an evolution in flap designs & its clinical applications.

The ultimate goal of reconstruction is to match optimal tissue replacement with minimum donor site morbidity while maintaining function. Perforator flaps meet these goals & are the result of over 30 yrs of evolution in flap refinement & design.

Since the original description of radial forearm flap in 1978 by Yang & Yuzhi [1] & Timmons anatomical description in 1986, this versatile flap has found numerous applications in plastic & reconstructive surgery [2]. Its value in head & neck reconstruction & upper & lower extremity reconstruction is well documented. Nevertheless, its application as both retrograde flow pedicled island flap & free flap has resulted in two major draw backs:

1) Donor site morbidity.

2) Sacrifice of radial artery.

A study detailing the location & vascular territory of the radial artery perforators therefore becomes necessary to facilitate operative planning & to allow safer flap harvest. A well described territorial outline of the consistently located, clinically significant perforators would be useful for operative decision making & forms the basis for shape modified radial forearm harvest.

2. Materials & Methods

Anatomical Study: To determine the location, size & vascular territory of radial artery adipo-facio cutaneous perforators involving 12 fresh human cadavers & 24 cadaveric forearms.

Need for the study: Anatomical studies defining the perforator vessel anatomy & distribution have been done before. However there are very few studies defining the location of perforator clusters or the cutaneous territory along the radial artery axis. A well defined territorial outline of the consistently located, clinically significant perforators would be useful for operative decision making of shape modified adipo-facio cutaneous radial artery perforator flap.

Inclusion criteria:

12 fresh human cadavers with normal radial artery anatomy were included in study.

Exclusion criteria:

1) Cadavers more than one month old.

2) Anomalies of radial artery.

Clinical study:

15 patients who underwent oncological resections were reconstructed with shape modified adipo-fascio cutaneous radial forearm free flap. All 15 patients were prospectively evaluated for donor site healing, scar, motor & sensory function & quality of life assessment.

Inclusion criteria:

1) Small to moderate defects requiring thin pliable flap for reconstruction.

Exclusion criteria:

1) Patients with systemic complications, who are not fit enough for a microvascular procedure.

2) Large defects.

3. Methodology

Anatomical study: 12 fresh human cadavers & 24 cadaveric forearms were dissected. All radial artery adipo-facio cutaneous perforators were analyzed for:

1) Number of perforators.

2) Orientation of perforators.

a) Radial distribution.

b) Ulnar distribution.

3) Size of perforators.

4) Cutaneous territory.

Upper extremity at the level of elbow & the brachial artery was cannulated & perfused with warm saline. This was continued until the backflow was clear. Subsequently the artery was injected with 20 cc of microfil red & the arm was stored in refrigerator at 0˚C for 24 hrs. A total of 24 flaps were dissected to access the size, numbers, & location of radial artery perforators. Two flaps were used for vascular injection studies using methylene blue & lead oxide. An incision is made on the palmar aspect of forearm, extending from wrist crease to elbow. All perforators originating from radial artery are identified & dissected. Parameters include; orientation of perforators, whether they arise on the radial side/lateral or on the ulnar side/medial, distance from radial styloid for distal perforators & from the lateral epicondyle for the proximal perforators, external diameter (Artery) using calipers, cutaneous cluster pattern with methylene blue injections.

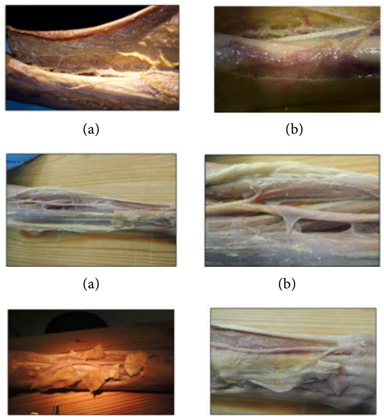
In order to determine the vascular cutaneous territory of a distally based radial artery perforator flap, two forearm flaps were dissected based on distal most dominant perforator near the radial styloid. The artery was cannulated & injected with methylene blue dye to examine the territory of cutaneous staining. Injection of contrast material (Lead oxide) was then injected & the specimen subjected to three-dimensional CT Scan with volume rendering function in order to access the vascular territory & identify linking vessels communicating with adjacent perforators. The results were statistical analyzed with student T paired test & Chi-Square test (Software: SPSS 17-Chicago Inc., SPSS version 22, IBM. Corp.).

Clinical operative procedure:

Radial artery course is marked with the help of Doppler. Skin pinch test is done to mark the dimensions of skin paddle. Approximately 2 cm of skin width in distal forearm and 3 cm of skin width in proximal forearm can be harvested & closed primarily. This may slightly vary depending on the fat content in subcutaneous plain. Flap is harvested unto the origin of radial artery. Skin Island is marked and divided after visualizing the perforators to the skin. Suturing of these individual skin paddles together is done to give this flap the desired dimensions required to reconstruct the defect. After the harvest with its desired dimension and achieving the required pedicle length, donor site is closed primarily without the need for a skin graft.

4. Results

12 fresh human cadavers & 24 forearm specimens, a total of 222 perforators were dissected for an average of 18.5 radial artery perforators per forearm (Table 1). Of the total 222 perforators dissected 118 were smaller than 0.5 mm in diameter (53.15%) these were not clinically significant. 104 perforators were greater than 0.5 mm in diameter (46.84%) these were clinically significant (Figure 1).



(a) (b)

(a) (b)

(a) (b)

Figure 1. Radial artery perforators to skin.

Table 1. Master chart.

Cadavers	No of perforators	Radial side	Ulnar side	Distal side	Proximal side
1	19	10	9	8	11
2	21	12	9	11	10
3	20	11	9	7	13
4	18	11	7	7	11
5	12	10	2	7	5
6	18	10	8	7	11
7	20	13	7	6	14
8	16	9	7	5	11
9	19	10	9	10	9
10	20	11	9	7	13
11	21	9	12	9	12
12	18	11	7	6	12
	Total = 222	Total = 127	Total = 95	Total = 90	Total = 132

Of the 222 radial artery perforators dissected, 127 perforators (57.20%) were radially distributed & 95 perforators (42.79%) had ulnar distribution (Table 1). A total of 90 perforators (40.54%) were identified on distal side (Radial styloid) & 132 perforators (59.45%) were identified on proximal side (Lateral epicondyle) (Table 1). Mean number of perforators on radial side was 10.6 & 7.9 on ulnar side, a comparison of both using student t paired test gives a P value of 0.006, which was statistically significant (Table 2) (Figure 2). Comparison of mean number of perforators on the distal side was 7.5 & proximal side was 11.0, Student Paired t test gives a P value of 0.003, which was statistically significant (Table 3) (Figure 3). Comparison of mean Diameter of perforators between the Distal side (1.11) & Proximal side (0.86), side using Student Paired t test gives a P value of 0.01 which was statistically significant (Tables 4-6) (Figure 4).

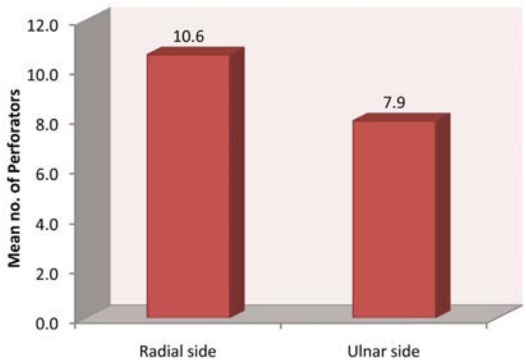


Figure 2. Comparison of mean number of perforators between radial and ulnar side.

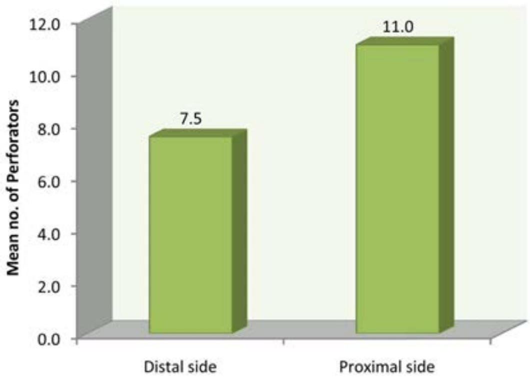


Figure 3. Comparison of mean number of perforators between the distal and proximal side.

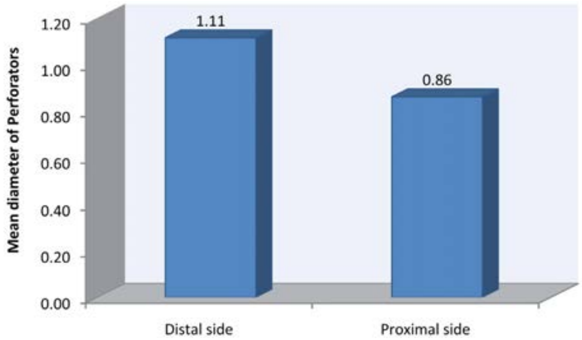


Figure 4. Comparison of mean diameters of perforators between the distal and proximal side.

Table 2. Comparison of mean number of perforators between the radial & ulnar side-using student paired t test.

Sides	N	Mean	SD	S.E.M	Mean Diff	95% CI of the Diff		t	P-Value
						Lower	Upper		
Radial side	12	10.6	1.2	0.3	2.7	0.9	4.4	3.370	0.006*
Ulnar side	12	7.9	2.4	0.7					

Table 3. Comparison of mean number of perforators between the distal & proximal side-using student paired t test.

Sides	N	Mean	SD	S.E.M	Mean Diff	95% CI of the Diff		t	P-Value
						Lower	Upper		
Distal side	12	7.5	1.7	0.5	−3.5	−5.6	−1.4	−3.718	0.003*
Proximal side	12	11.0	2.3	0.7					

Table 4. Mean diameter of perforators.

	Distal (Radial Styloid)	Proximal (Lateral Epicondyle)
1	1.23	0.54
2	1.01	1.00
3	1.23	0.64
4	0.92	0.63
5	1.20	0.83
6	1.17	0.92
7	0.98	1.20
8	0.87	1.00
9	1.11	0.94
10	1.20	0.68
11	1.23	0.83
12	1.22	1.11

Table 5. Comparison of mean diameter of perforators between the distal & proximal side-using student paired t test.

Sides	N	Mean	SD	S.E.M	Mean Diff	95% CI of the Diff		t	P-Value
						Lower	Upper		
Distal	12	1.11	0.13	0.04	0.25	0.08	0.43	3.132	0.01*
Proximal	12	0.86	0.21	0.06					

Table 6. Mean number & diameter on both sides.

Sides	Mean	Sides	Mean	Mean
Radial side	10.6	Distal side	7.5	1.11
Ulnar side	7.9	Proximal side	11.0	0.86

A chi square test was done to compare mean diameter of perforators on distal side, which were more than 1 mm (80%) & less than 1mm (20%) & on proximal side more than 1 mm (35.6%) & less than 1 mm (64.4%). Chi square value of 42.406 was obtained, degree of freedom value was 1 & P value of <0.001 was achieved which was found to be highly significant (Table 7) (Figure 5 and Figure 6). In almost all the dissected anatomical specimens at least one clinically significant perforator was found within 2cm proximal to radial styloid (Figure 7). Methylene blue injections into the proximal part of radial artery demonstrated clusters both in proximal & distal forearm & also reveal a large flap cutaneous territory (Figure 7). Three-dimensional computed tomographic angiography (Figure 8) reveals a network of linking vessels found to communicate between adjacent perforators & running parallel to radial artery. Large network of linking vessels could be found between fascia & dermis, which also explains the ability to harvest forearm flap at the supra-fascial level.

In its clinical application 15 patients were reconstructed following oncological resections. The youngest being 31 yrs old & oldest being 72 yrs of age (Figures 9-13). Total follow up period following reconstructions ranged between 6 - 12 months. 13 patients were treated for head & neck squamous cellcarcinoma & one patient for basal cell carcinoma (Figure 10) & one patient for oral sub-mucous fibrosis (Figure 13). Time taken for donor site healing was approximately 2 weeks, following which suture removal was done. In all 15 patients there was no sensory disturbance over the first web space on dorsum of hand & motor function was good (Figure 14). Pedicle length though shorter, in all cases we managed to get a length of 8 cm to 10 cm, which was sufficient enough for anatomizing to neck vessels. Scar assessment fared better (Figure 14). We developed a quality of life assessment score (total points 25) in which shape modified radial forearm flap showed better quality 23 (Score Table 8).

5. Discussion

Head & Neck oncologists are often seem to confront with the difficult task of

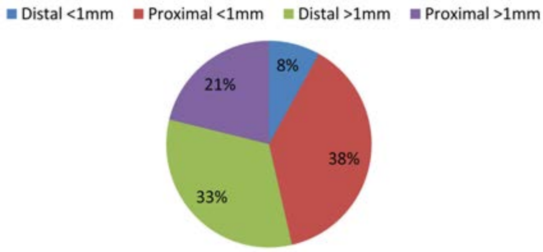


Figure 5. Pictorial presentation of chi square test.

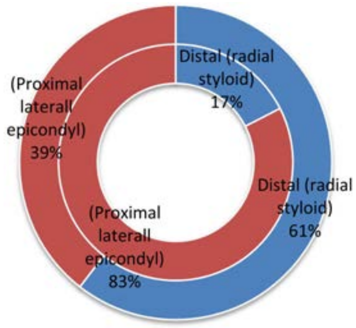


Figure 6. Component chart.

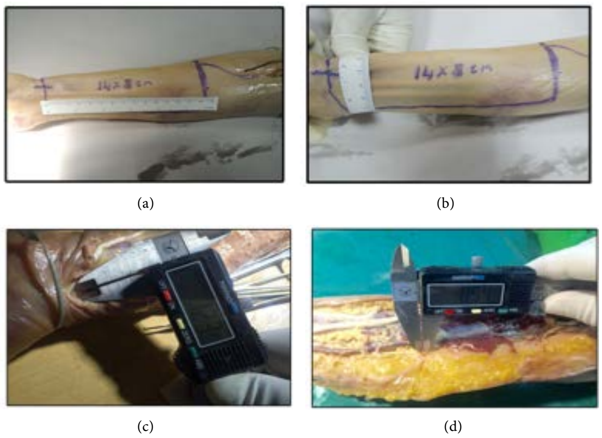
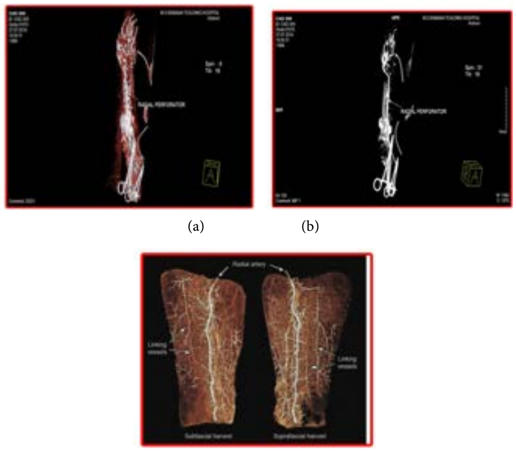


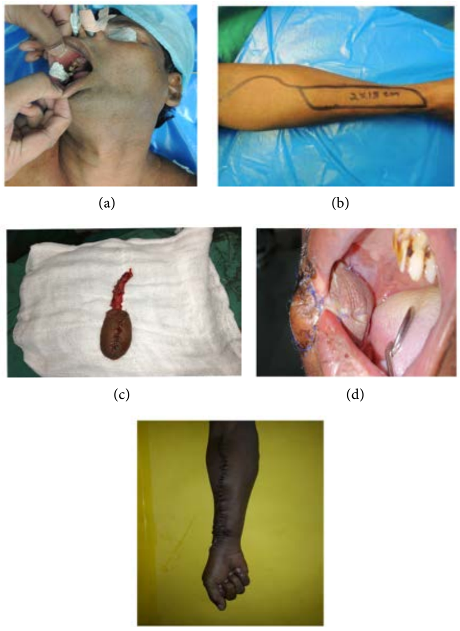
Figure 7. Cutaneous territory & distal & proximal perforators from radial artery. (a) Cutaneous territory of radial artery distal; (b) Perforators and maximum flap dimensions; (c) Distal perforator; (d) Procimal perforator.



(a) (b)

(c)

Figure 8. CT angiography of radial artery perforators.



(a) (b)

(c) (d)

(e)

Figure 9. Case 1.

Figure 10. Case 2.

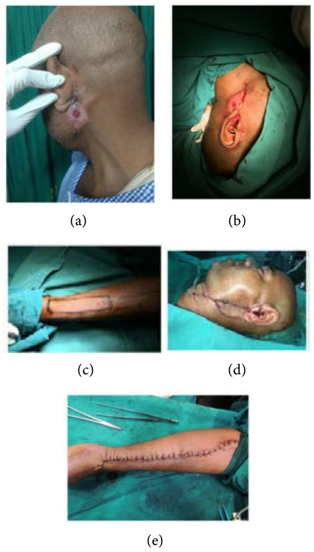


Figure 11. Case 3.

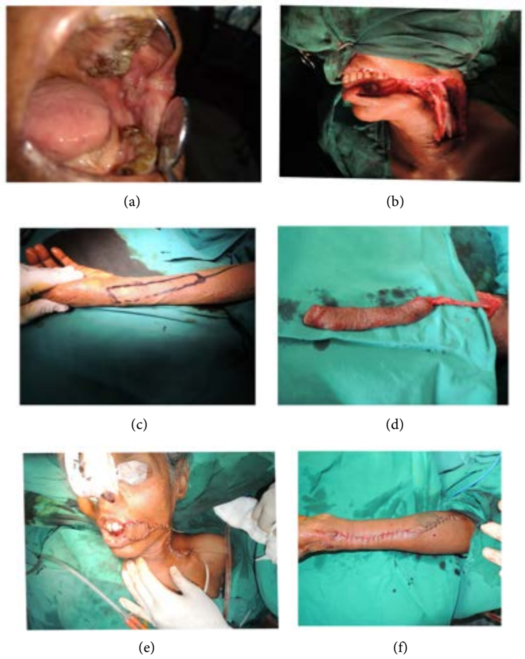


Figure 12. Case 4.

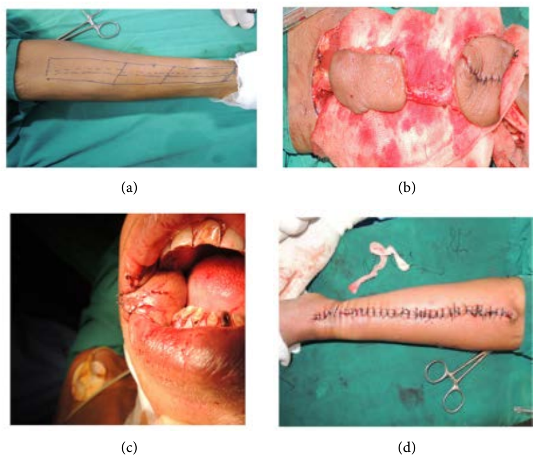


Figure 13. Case 5.

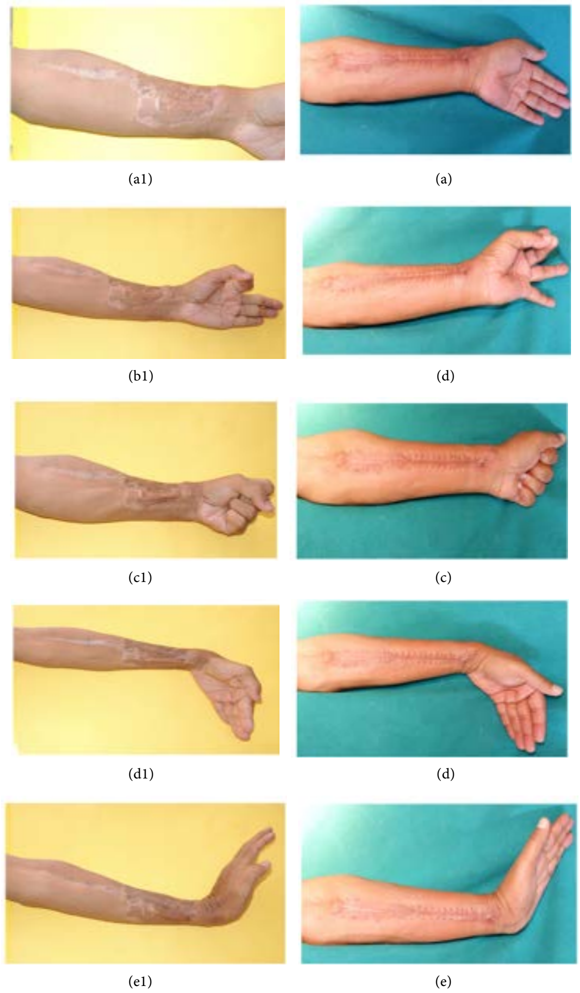


Figure 14. Donar site comparison of traditional radial forearm vs shaped modified radial forearm flap.

Table 7. Chi-Square table.

	Distal (radial styloid)	Proximal (lateral epicondyle)	X^2	df	P value
<1 mm	18 (20%)	85 (64.4%)	42.406	1	<0.001
>1 mm	72 (80%)	47 (35.6%)			

Table 8. Quality of life questioner.

Question no	Below average	Average	Good	Very good	Excellent	Total score (Out of 25)
	1	2	3	4	5	
Are you satisfied by this scar						
Are you in need of change of the clothing style because of scar						
Has your daily manual work or duties influenced by the donor site						
Are you in need of applying special medication for donor site						
Is there problem to wear the ornaments or watch after operation on affected side						

balancing cancer cure with preservation of function, cosmesis, & quality of life when deciding best treatment protocols. Reconstruction in its true sense represents a big challenge for the reconstructive surgeon [3] [4].

Since the original description of radial forearm flap in 1978 by Yang & Yuzhi, this versatile flap has found itself numerous applications in plastic & reconstructive surgery [1] [2]. However its application as both retrograde flow pedicled island flap & free flap has resulted in two major drawbacks drawing great attention among the reconstructive community [4] [5] [6].

1) Donor site morbidity in terms of esthetics, cold intolerance, slight to moderate functional deficit.

2) Sacrificing a major artery of forearm.

Several modifications & innovations in terms of donor site closure, flap-harvesting techniques, and preservation of radial artery have been proposed & practiced [7] [8] [9] [10] [11]. Increased knowledge of vascular anatomy has played a definitive role in increasing our ability to understand & use perforator-based flaps for various clinical applications [12] [13].

As we gradually shift towards perforator based flap reconstructions, knowledge of individual perforators should supersede that of source artery [14]. Many surgeons have reported use of perforator flaps from forearm with ease, success, & good functional outcome [15] [16] [17] [18]. However it is difficult to clinically establish the exact location of dominant radial artery perforator with a hand held Doppler because of superficial course of radial artery [19] [20]. In order to establish the basis for perforator flaps an anatomical study to determine the exact location & vascular territory becomes all the more essential. In our present study we have investigated the location, size & vascular pattern & territory of radial artery in 12 fresh human cadavers involving 24 forearm specimens (**Figure 1** & **Figure 7**). We have demonstrated a total of 222 perforators with an average of 18.5 perforators per forearm. Perforators smaller than 0.5 mm were not considered as clinically suitable. Our study confirms a strong relation between the number & diameter of perforators [16] [17] [20]. Distal side demonstrates less number of perforators but a large caliber perforator is consistently present within 2 cm of radial styloid in all of the 12 cadavers (**Figure 7**), this finding is found to be consistent with the previous anatomical studies on radial artery [15]. Michel Saint-Cyr *et al.* conducted an anatomical study in 26 fresh human cadaveric forearms to study & determine the location, orientation, external diameter & vascular territory of radial artery cutaneous perforators. The authors concluded that there are two main clusters of clinically significant perforators & increased knowledge of size, location & cutaneous territory of radial artery perforators can lead to expanded use of radial artery forearm flap based on these cutaneous perforators alone, without sacrificing the main radial artery [20].

In both distal & proximal forearms, perforators arising from the main vessel have both radial & ulnar distribution [20] (**Figure 1** and **Figure 7**). These anatomical characteristics suggest an element of safety when harvesting flaps based on either distal or proximal perforator [20]. Our study demonstrates clusters of perforators in both proximal & distal aspect of forearm [13] [14] [20].

Clinical use of perforator based radial artery free flap may have limited applications but nevertheless cases have been reported in literature [21]. The vascular anatomy of the fascia & subcutaneous tissue of the distally based flaps have been well described [18]. The blood supply to the fascio-cutaneous flap is found to originate from 5 to 10 septo-cutaneous perforators arising from radial artery in the anatomical snuffbox [14] [15]. Anatomical & clinical investigation of the radial forearm adipo-fascial flap based on distal perforators has been well described by Hamdy El-Khatib, who reported an anatomic study in eleven fresh & fixed cadavers, designing an island adipofascial flap based on distal five to eight septo-cutaneous perforators of radial artery & their vena commitantes, great advantage being preservation of radial artery [13]. Three-dimensional computed tomographic angiography in our study has shown a comparable vascular territory with linking vessels found to communicate between adjacent perforators & running parallel to radial artery [20] (**Figure 8**). Perforators travel to dermis & form a network of linking vessels found between fascia & dermis. This finding is consistent as reported by previous similar studies [13] [15]. Mark Schaverien conducted a study involving 12 fresh human cadavers & 24 radial forearm flaps harvested from these cadavers to elucidate the role of deep fascia in perfusion of radial forearm flap. The authors concluded that inclusion of deep fascia during flap harvest does not contribute to flap perfusion or vascularity [18]. Although there are several anatomical study reports on vascular anatomy of radial artery, our study demonstrates the cutaneous territory & location of clusters in detail. The results obtained from our study are clinically important in planning the exact dimension of the flap based on distal third perforators of radial artery. Perhaps the most significant finding in this study is the location of cutaneous perforators. Knowledge of these perforators can greatly facilitate the reconstructive surgeon in safe flap harvest & design [21] [22]. Both distal & proximal perforators can be used in designing of potential flaps for various reconstructive needs

[15]. Three-dimensional computed tomographic angiogram confirms that suprafacial dissection does not compromise blood supply of the radial forearm pedicle perforator flap [9] [11] (**Figure 8**). The supply to the skin is ensured by means of multiple perforators originating from the radial & ulnar sides of the radial artery, travelling to the skin & communicating with each other in the subcutaneous tissue plane by multiple linking vessels. Each perforator has its own vascular territory, called a perforasome, which carries a multidirectional flow pattern that is highly variable & complex. These perforasomes are linked to one another by both direct & indirect linking vessels, which themselves are linked by communicating branches. These numerous branches confer further protection form ischemia & vascular injury & explains the survival of single dominant perforator based flaps [20].

Linking vessels allow communication with adjacent perforasomes & follow a direction that is parallel to the direction of perforator flow. Therefore, perforator flap skin paddles should be parallel to the linking vessel orientation, which makes it possible to harvest large flaps based on single dominant perforator [20] [23]. If the radial forearm flap donor-site defect could be repaired primarily, then hand rehabilitation could be initiated earlier and the overall complication rate would be lower, compared with the traditional technique using a split-thickness skin graft to close the defect (**Figure 14**). This has led many surgeons to search for alternate methods of harvesting this flap allowing primary closure of the donor site. These include procedures incorporating tissue expanders or rotation flaps. Mateev *et al.* suggested a novel way of harvesting radial forearm flaps, which was termed "Shape modified method". The series being reported for scalp reconstruction [19]. No such reports are available for reconstruction of head and neck defects even though the methods appear to be elegant and avoids the use of skin grafts. The major advantage of this technique is its ability to reconstruct donor defects primarily in a one-stage operation, with better aesthetic contours of the forearm. In comparison with traditional methods such as split thickness skin grafting, the overall complication rate is minimized because hand motion can be allowed earlier, with the flexor tendons sliding beneath the flap. Soutar *et al.* reported 28% of problems in extension of wrist with traditional method [5]; we have no such reports in modified groups because of primary closure in the later group. Studies by Fenton *et al.* reports specifically the aesthetic problems in traditional method of radial forearm flap [24]. None of our patients had any sensory nerve disturbance associated with radial nerve branch. (Dorsum of thumb and first web space) (**Figure 14**). Our shape modified radial forearm flap has fared much better when compared to other methods of direct closure of donor sites. Ching-Hua *et al.* used ulnar based bilobed flaps but found the final defect has a lengthy and unsightly scar [24] [25]. Elliot *et al.* used V-Y advancement for primary closure but could only harvest 4 × 4 cm flaps and Berge *et al.* used tissue expanded skin but found difficult and used two stages for primary-Closure [26] [27]. We had problems with our method, which included reduction in pedicle length whenever the size of flap is increased. Maximum pedicle length we could harvest was 10 cm. Another probable problem mentioned in literature is the compression of the forearm due to tight closure. We did not have this complication in any of our 15 patients.

6. Conclusion

Each perforator holds a unique vascular territory. Vascular supply chain among perforators is highly complex & both direct & indirect linking vessels play a major role in maintaining flap perfusion. Our study demonstrates a consistent course of radial artery with clusters originating on both distal & proximal ends, with each end becoming a pivot point for a pedicled flap rotation. Each perforator has the potential to become either a free or a pedicled flap depending on the size. In addition preservation of radial artery & ability of supra-facial harvest further lessens the morbidity burden. This phenomenon allows a myriad of perforator flap designs that can be tailored to match reconstructive defects. Present day reconstructive surgeon has more options & alternatives in replacing like with like. Local flap alternatives become more plentiful & flap design is limited only by the availability of clinically relevant perforators close to the defect. Free style perforator flap alternatives are limited by the size & length of their respective source arteries & veins.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Yang, G., Chen, B., Gao, Y., Liu, X., Li, J., Jiang, S. and He, S. (1981) Forearm Free Skin Flap Transplantation. *National Medical Journal of China*, **61**, 139-141.

[2] Timmons, M.J., Missotten, F.E.M., Poole, M.D. and Davies, D.M. (1986) Complications of Radial Forearm Flap Donor Sites. *British Journal of Plastic Surgery*, **39**, 176-178. https://doi.org/10.1016/0007-1226(86)90078-0

[3] Mühlbauer, W., Herndl, E. and Stock, W. (1982) The Forearm Flap. *Plastic and Reconstructive Surgery*, **70**, 336-342. https://doi.org/10.1097/00006534-198209000-00007

[4] Soutar, D.S. and McGregor, I.A. (1986) The Radial Forearm Flap in Intra-Oral Reconstruction. The Experience of 60 Consecutive Cases. *Plastic and Reconstructive Surgery*, **78**, 1-8. https://doi.org/10.1097/00006534-198607000-00001

[5] Song, R., Gao, Y., Song, Y., Yu, Y. and Song, Y. (1982) The Forearm Flap. *Clinics in Plastic Surgery*, **9**, 21-26.

[6] Lovie, M.J., Duncan, G.M. and Glasson, D.W. (1984) The Ulnar Artery Forearm Flap. *British Journal of Plastic Surgery*, **37**, 486-492. https://doi.org/10.1016/0007-1226(84)90136-X

[7] Chang, S.C., Miller, G., Halbert, C.F., Yang, K.H., Chao, W.C. and Wei, F.C. (1996) Limiting Donor Site Morbidity by Suprafacial Dissection of the Radial Fore Arm Flap. *Microsurgery*, **17**, 136-140. https://doi.org/10.1002/(SICI)1098-2752(1996)17:3<136::AID-MICR7>3.0.CO;2-K

[8] Partecke, B.D., Buck-Gramcko, D. and Pachnucki, A. (1986) Use of a Fascia Flap of the Forearm in Soft Tissue Defects of the Extremities. (*German*) *Handchir Mikrochir Plast Chir*, **18**, 353-355.

[9] Liang, M.D., Swartz, W.M. and Jone, N.F. (1994) Local Full Thickness Skin Graft Coverage for Radial Forearm Flap Donor Site. *Plastic and Reconstructive Surgery*, **93**, 621-625. https://doi.org/10.1097/00006534-199493030-00032

[10] Webster, H.R. and Robinson, D.W. (1995) The Radial Forearm Flap without Fascia & Other Refinements. *European Journal of Plastic Surgery*, **18**, 11-13. https://doi.org/10.1007/BF00183691

[11] Wolf, K.D., Ervens, J. and Hoffmeister, B. (1995) Improvement of Radial Forearm Donor Site by Prefabrication of Facial Split Thickness Skin Grafts. *Plastic and Reconstructive Surgery*, **98**, 358-361. https://doi.org/10.1097/00006534-199608000-00025

[12] Mahmoud, W.H. (2015) Radial Forearm Flap versus Radial Adipofascial Perforator Based Flap for Reconstruction of Hand Soft Tissue Defects. *Donnish Journal of Medicine & Medical Sciences*, **2**, 19-25.

[13] Rath, T., Millesi, W., Millesi-Schobel, G., Lang, S., Glaser, C. and Todoroff, B. (1997) Mucosal Prelaminated Flaps for Physiological Reconstruction of Intra Oral Defects after Resection. *British Journal of Plastic Surgery*, **50**, 303-307. https://doi.org/10.1016/S0007-1226(97)90537-3

[14] El-Khatib, H. and Zeidan, M. (1997) Island Adipofascial Flap Based on Distal Perforators of the Radial Artery: An Anatomic & Clinical Investigation. *Plastic and Reconstructive Surgery*, **100**, 1762-1766. https://doi.org/10.1097/00006534-199712000-00018

[15] Yang, D.P., Moris, S.F., Tang, M.L. and Geddes, C.R. (2003) Reversed Forearm Island Flap Supplied by the Septocutaneous Perforator of the Radial Artery: Anatomical Basis & Clinical Applications. *Plastic and Reconstructive Surgery*, **112**, 1012. https://doi.org/10.1097/01.PRS.0000076192.14536.90

[16] Tiengo, C., Macchi, V., Porzionato, A., Stecco, C., Parenti, A., Bassetto, F. and De Caro, R. (2004) Anatomical Study of Perforator Arteries in the Distally Based Radial Forearm Fasciosubcutaneous Flap. *Clinical Anatomy*, **17**, 636-642. https://doi.org/10.1002/ca.20009

[17] Schaverien, M. and Saint-Cyr, M. (2008) Suprafacial Compared with Subfacial Harvest of the Radial Forearm Flap: An Anatomic Study. *Journal of Hand Surgery*, **33A**, 97-101.

[18] Mateev, M.A., *et al*. (2009) Shape Modified Radial Artery Perforator Flap Method. Analysis of 112 Cases. *Plastic & Reconstructive Surgery*, **123**, 1533-1543.

[19] Saint-Cyr, M. (2010) The Radial Artery Pedicled Perforator. *Plastic and Reconstructive Surgery*, **125**, 1469-2010.

[20] Lin, J.-Y., Cheng, M.-H., Wei, F.C., Song, D. and Huang, W.-C. (2006) Proximal Forearm Flap Based on a Septocutaneous Vessel Form the Radial Artery. *Plastic & Reconstructive Surgery*, **117**, 955-960.

[21] Tiengo, C., Macchi, V., Porzionato, A., Stecco, C., Parenti, A., Bassetto, F. and De Caro, R. (2007) The Proximal Radial Artery Perforator Flap (PRAP-Flap): An Anatomical Study for Its Use in Elbow Reconstruction. *Surgical and Radiologic Anatomy*, **29**, 245-251. https://doi.org/10.1007/s00276-007-0203-7

[22] Ciuman, R. and Dost, P. (2012) The Fore Arm Free Flap-Indications, Appropriate Selection, Complications & Functional Outcomes. http://www.intechopen.com

[23] Giordano, L., Bondi, S., Ferrario, F., Fabiano, B. and Bussi, M. (2012) Radial Forearm Free Flap Surgery: A Modified Skin Closure Technique Improving Donor Site Aesthetic Appearance. *Acta Otorhinolaryngologica Italica*, **32**, 158-163.

[24] Fenton, O.M. and Roberts, J.O. (1985) Improving the Donor Site of the Radial Forearm Flap. *British Journal of Plastic Surgery*, **38**, 504.
https://doi.org/10.1016/0007-1226(85)90009-8

[25] Hsieh, C.-H. and Kuo, Y.-R. (2004) Primary Closure of Radial Forearm Flap Donor Defects with a Bilobed Flap Based on the Fasciocutaneous Perforator of the Ulnar Artery. *Plastic and Reconstructive Surgery*, **113**, 1355-1360.
https://doi.org/10.1097/01.PRS.0000112742.51430.A7

[26] Bardsley, A.F., Soutar, D.S., Elliot, D., *et al*. (1990) Reducing Morbidity in the Radial Forearm Flap Donor Site. *Plastic and Reconstructive Surgery*, **86**, 287-292.
https://doi.org/10.1097/00006534-199008000-00014

[27] Bergé, S.J. and Wiese, K.G. (2001) Tissue Expansion Using Osmotically Active Hydrogel Systems for Direct Closure of the Donor Defect of the Radial Forearm Flap. *Plastic and Reconstructive Surgery*, **108**, 1-5.
https://doi.org/10.1097/00006534-200107000-00001

11

Comparing

Group I

Shape modified radial forearm free flap harvest

With

Group II

Traditional radial forearm free flap harvest

(Statistical analysis of data)

Statistical Analysis:

Statistical Package for Social Sciences [SPSS] for Windows, Version 22.0. Released in 2013.Armonk, NY: IBM Corp. was used to perform statistical analyses.

Descriptive Statistics:

Descriptive analysis of all the explanatory and Outcome parameters was done using frequency and proportions for categorical variables, whereas in Mean and SD for continuous variables.

Inferential Statistics:

Independent Student t Test was used to compare the mean Flap Dimensions (in Sq.cm), Pedicle Length (in cm), Duration of Follow-up, Scar assessment and Quality of Life [QoL] scores between 2 groups.

Chi Square Test was used to compare the presence of Sensory and Motor deficit between 02 groups.

The level of significance [P-Value] was set at $P<0.05$.

11.1.

Distribution of Socio-demographic characteristics among study subjects						
		Group 1 (n=15)		Group 2 (n=15)		
Variables	Group	Mean	SD	Mean	SD	P-Value
Age	Mean & SD	50.6	12.5	49.9	8.4	0.85[a]
	Range	31 - 72		39 - 65		
		n	%	n	%	
Gender	Males	10	66.7%	8	53.3%	0.46[b]
	Females	5	33.3%	7	46.7%	

Note: a. Mann Whitney U Test.
b. Chi Square test.
Group 1 - Shape Modified Radial Forearm Flap,
Group 2 - Traditional Radial Forearm Flap

11.2.

Comparison of mean Flap Dimensions (in Sq.cm) and Pedicle Length (in cm) between 2 groups using Independent Student t Test							
Variable	Group	N	Mean	SD	Mean Diff	t	P-Value
Flap	Group 1	15	29.00	5.89	-7.20	-3.103	0.004*
	Group 2	15	36.20	6.78			
Pedicle Length	Group 1	15	10.00	0.76	-3.73	-11.297	<0.001*
	Group 2	15	13.73	1.03			

* Statistically Significant.

11.3.

Comparison of mean Follow-up duration (in months) between 02 groups using Independent Student t Test						
		Group 1 (n=15)		Group 2 (n=15)		
Variables	Group	Mean	SD	Mean	SD	P-Value
Follow-up	Mean & SD	9.6	2.7	9.8	2.8	0.85
	Range	6 - 12		6 - 12		

11.4.

Comparison of presence of Sensory and Motor deficit between 02 groups using Chi Square Test							
		Group 1		Group 2			
Variable	Category	n	%	n	%	χ^2 Value	P-Value
Sensory deficit	Yes	0	0.0%	15	100.0%	30.000	<0.001*
	No	15	100.0%	0	0.0%		
Motor deficit	Yes	1	6.7%	13	86.7%	19.286	<0.001*
	No	14	93.3%	2	13.3%		

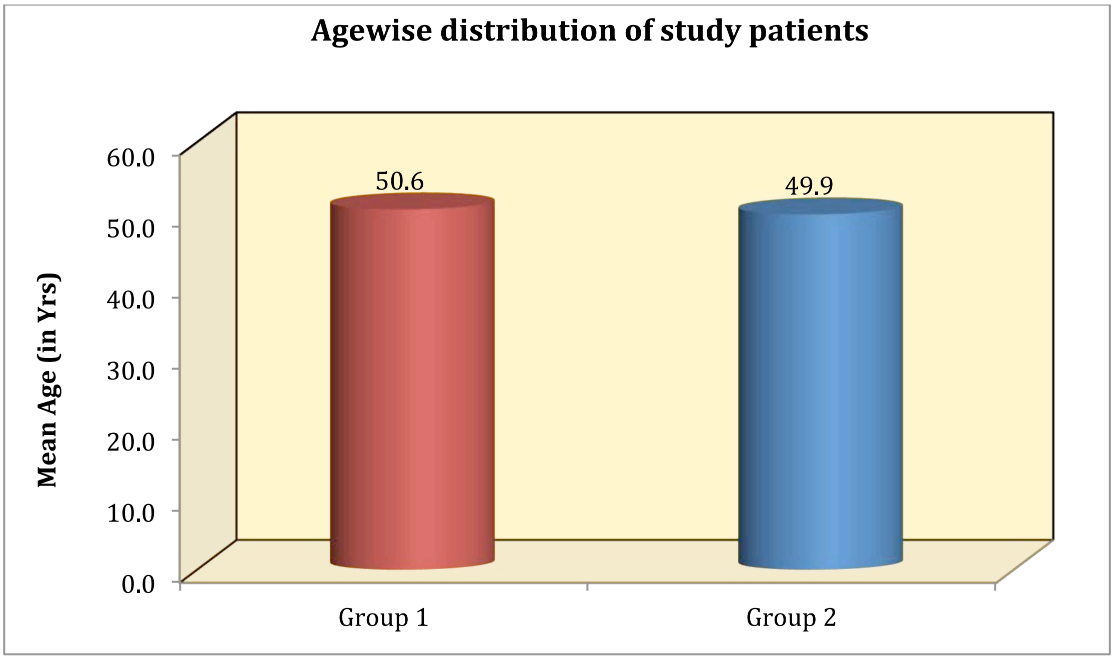
*Statistically Significant.

11.5.

Comparison of mean Scar assessment & Quality of Life [QoL] scores between 2 groups using Independent Student t Test							
Variable	Group	N	Mean	SD	Mean Diff	t	P-Value
Scar Score	Group 1	15	8.67	0.49	3.40	14.068	<0.001*
	Group 2	15	5.27	0.80			
QoL Score	Group 1	15	23.40	0.99	9.60	15.179	<0.001*
	Group 2	15	13.80	2.24			

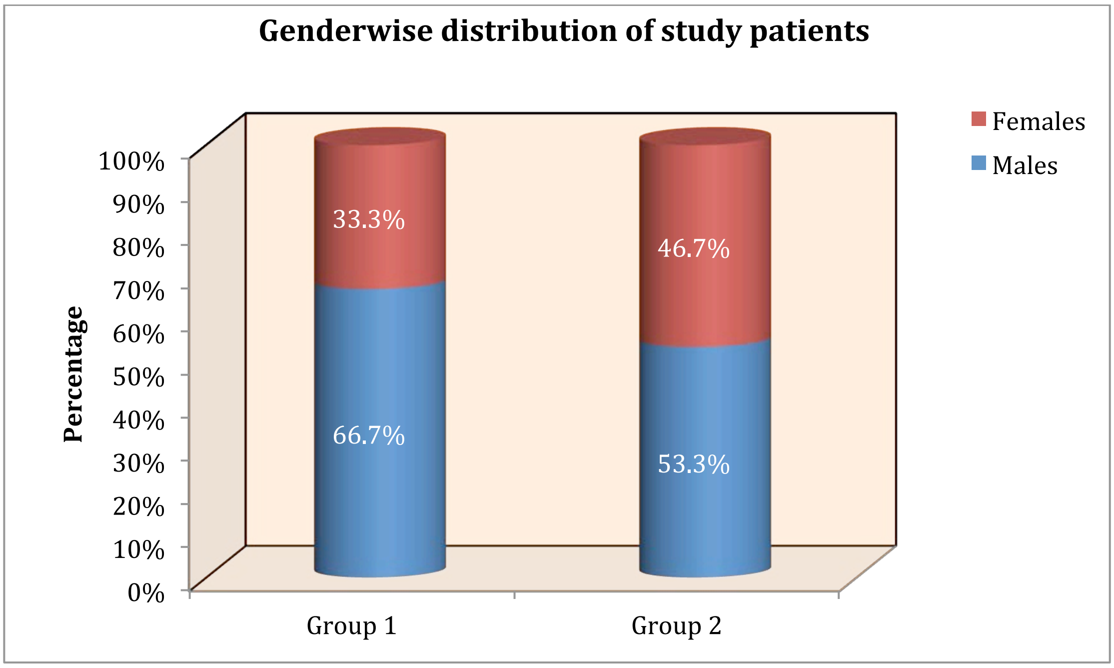
*Statistically Significant.

11.6.



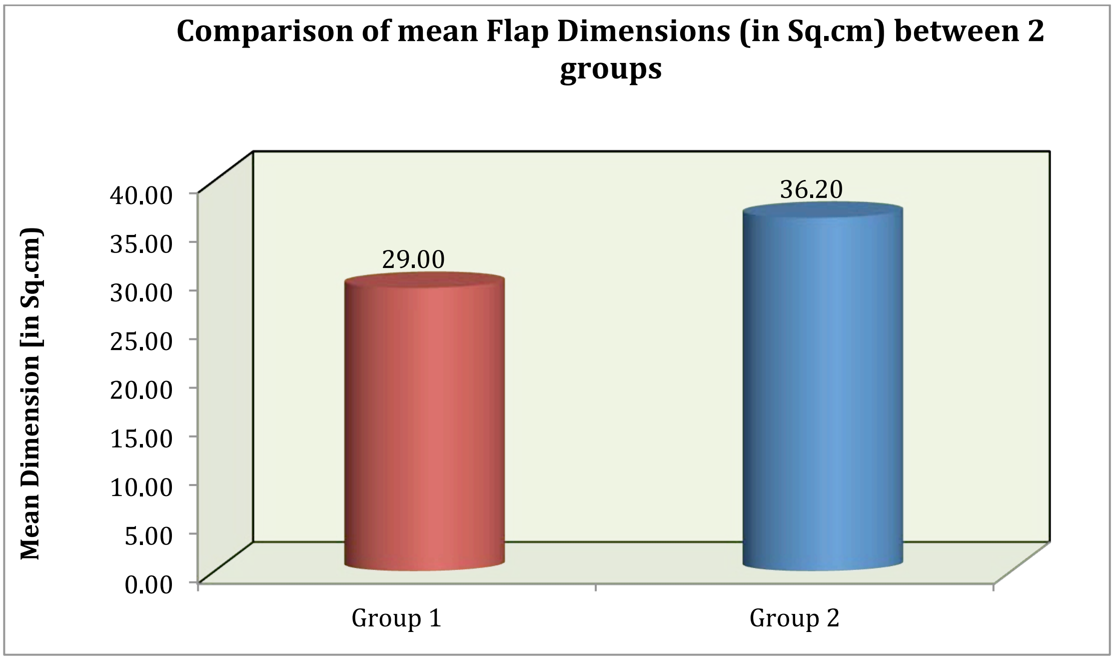
Agewise distribution of study patients
Mean Age (in Yrs)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
50.6
49.9
Group 1
Group 2

11.7.

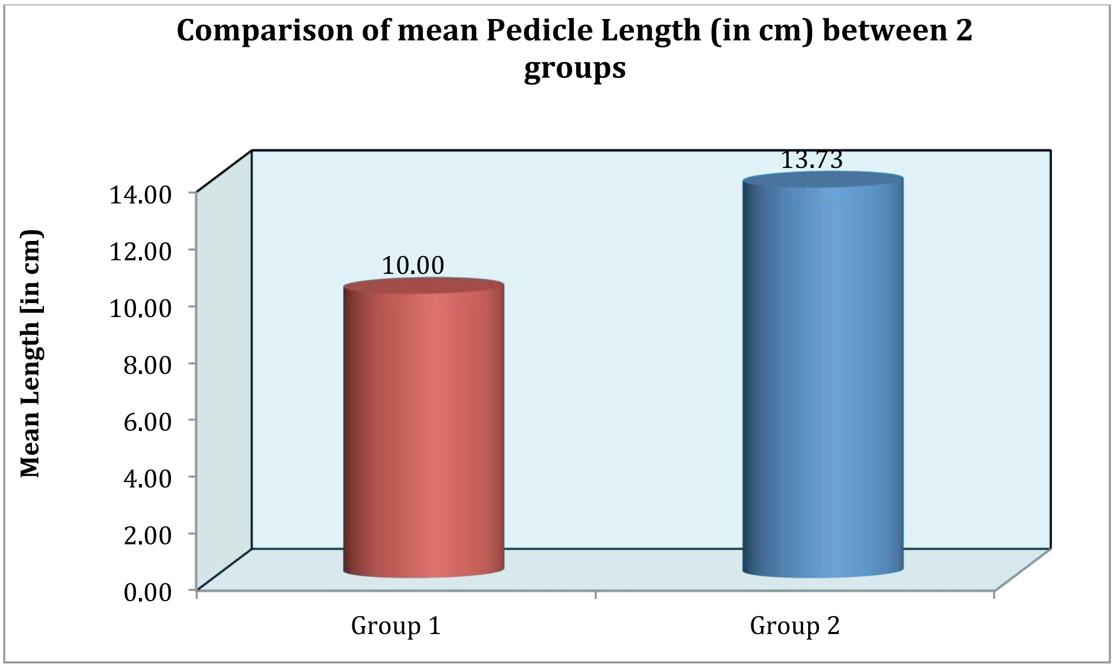


Genderwise distribution of study patients
Percentage
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
33.3%
66.7%
46.7%
53.3%
Group 1
Group 2
Females
Males

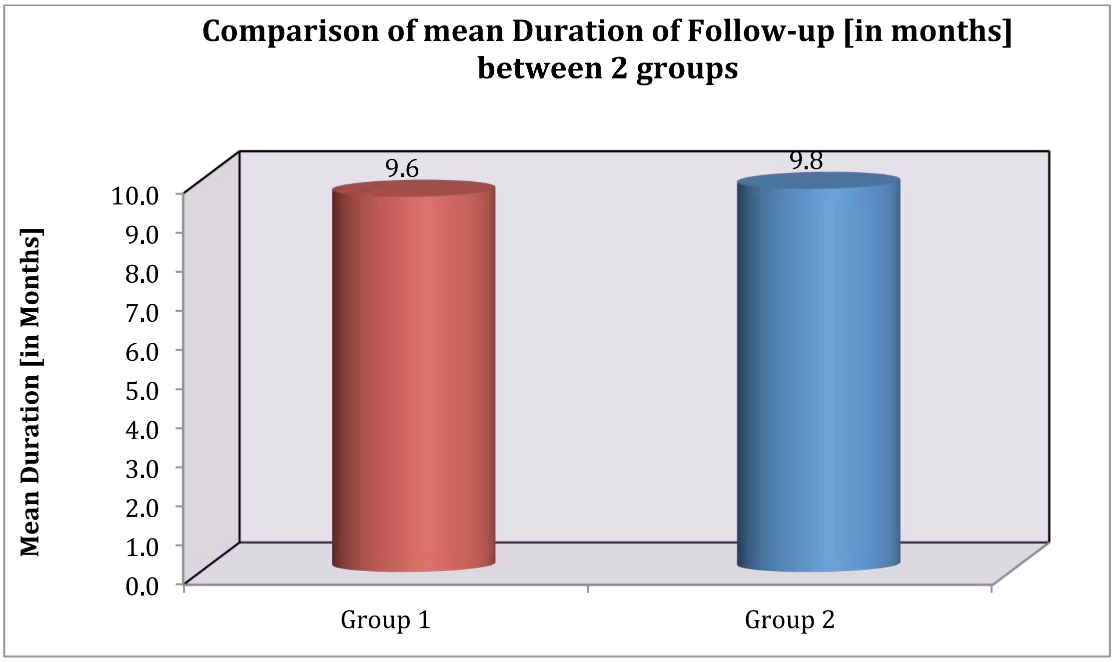
11.8.


Comparison of mean Flap Dimensions (in Sq.cm) between 2 groups
Mean Dimension [in Sq.cm)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
29.00
36.20
Group 1
Group 2

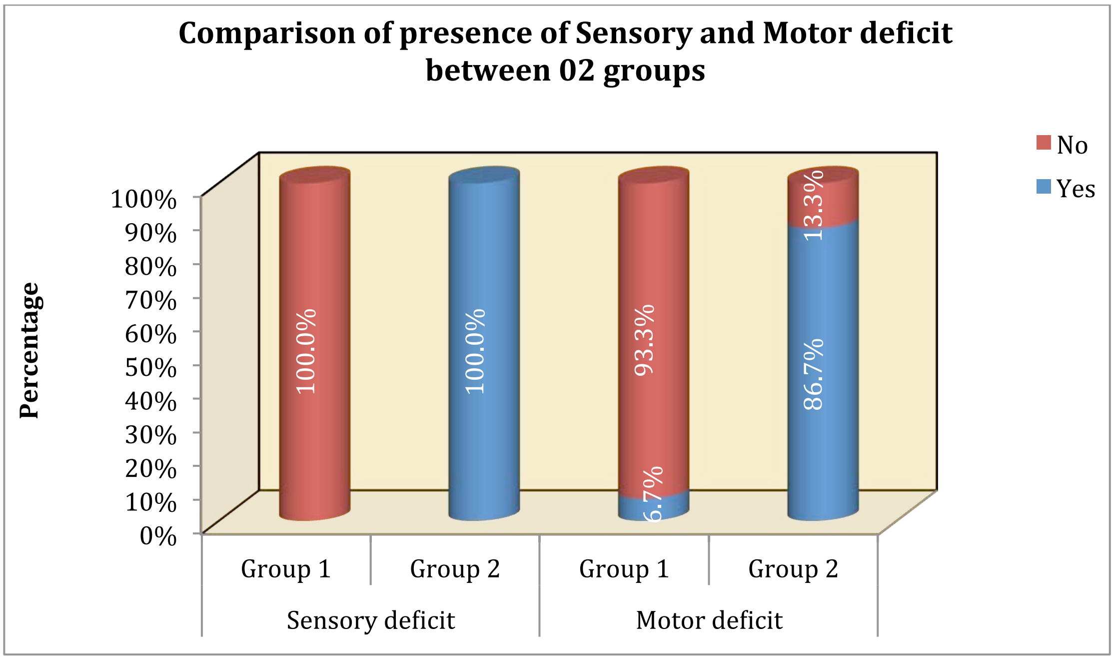
11.9.


Comparison of mean Pedicle Length (in cm) between 2 groups
Mean Length [in cm)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
10.00
13.73
Group 1
Group 2

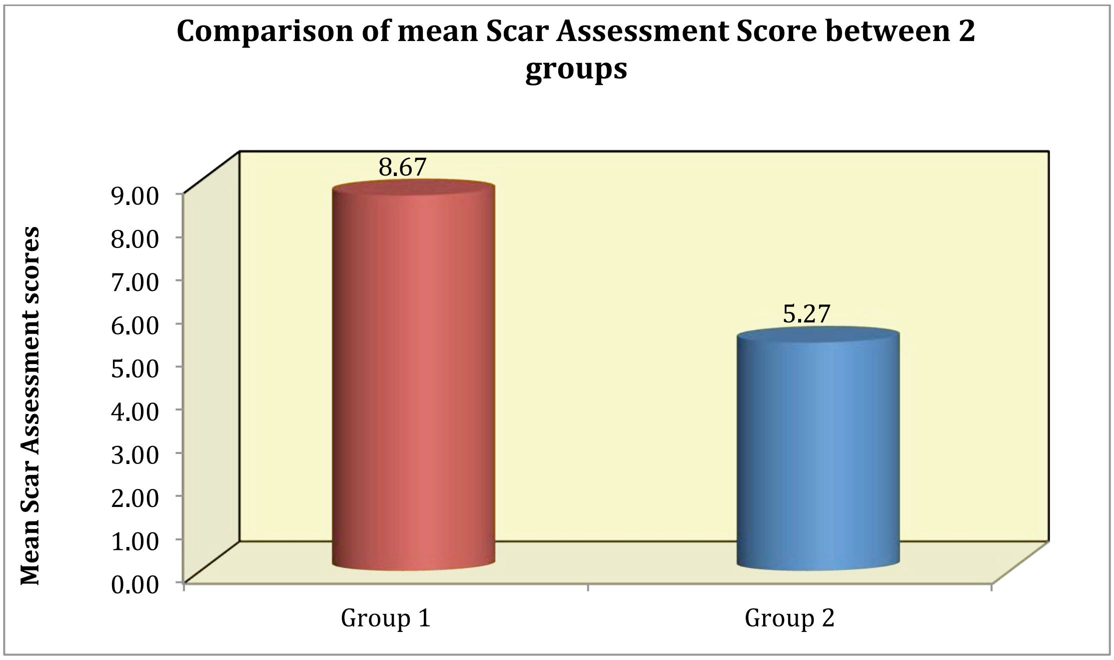
11.10.


Comparison of mean Duration of Follow-up [in months] between 2 groups
Mean Duration [in Months]
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
9.6
9.8
Group 1
Group 2

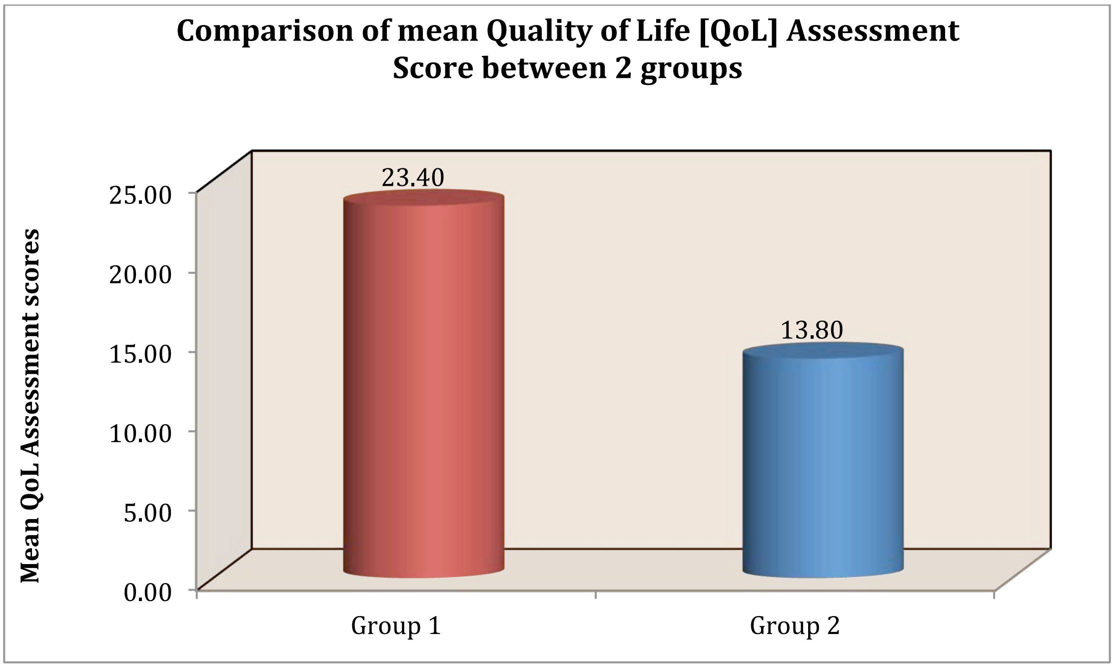
11.11.


Comparison of presence of Sensory and Motor deficit between 02 groups
Percentage
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
100.0%
100.0%
93.3%
6.7%
13.3%
86.7%
No
Yes
Group 1
Group 2
Group 1
Group 2
Sensory deficit
Motor deficit

11.12.


Comparison of mean Scar Assessment Score between 2 groups
Mean Scar Assessment scores
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
8.67
5.27
Group 1
Group 2

11.13.


Comparison of mean Quality of Life [QoL] Assessment Score between 2 groups
Mean QoL Assessment scores
25.00
20.00
15.00
10.00
5.00
0.00
23.40
13.80
Group 1
Group 2

12

Discussion and Clinical implications

Head and Neck oncologists are often seem to confront with the difficult task of balancing cancer cure with preservation of function, cosmesis, and quality of life when deciding patients best treatment protocols. Reconstruction in its true sense represents a big challenge for the reconstructive surgeon[20, 21].

Since the original description of radial forearm flap in 1978 by Yang & Yuzhi, this versatile flap has found itself numerous applications in plastic and reconstructive surgery[18, 19]. However its application as both retrograde flow pedicled island flap and free flap has resulted in two major drawbacks drawing great attention among the reconstructive community.[51, 48, 52]

1. Donor site morbidity in terms of esthetics, cold intolerance, slight to moderate functional deficit.

2. Sacrificing a major artery of forearm.

Several modifications and innovations in terms of donor site closure, flap-harvesting techniques, and preservation of radial artery have been proposed and practiced[38, 39, 40, 30, 58]. Increased knowledge of vascular anatomy has played a definitive role in increasing our ability to understand and use perforator-based flaps for various clinical applications. [45, 53]

As we gradually shift towards perforator based flap reconstructions, knowledge of individual perforators should supersede that of source artery[32]. Many surgeons have reported use of perforator flaps from forearm with ease, success, and good functional outcome[33, 34, 46]. However it is difficult to clinically establish the exact location of dominant radial artery perforator with a hand held Doppler because of superficial course of radial artery[56]. In order to establish the basis for perforator flaps an anatomical study to determine the exact location and vascular territory becomes all the more essential. In our cadaveric study we have investigated the location, size and vascular pattern and territory of radial artery perforators in 12 fresh human cadavers involving 24 forearm specimens. We have demonstrated a total of 222 perforators with an average of 18.5 perforators per forearm. Perforators smaller than 0.5mm were not considered as clinically suitable. Our cadaveric study confirms a strong relation between the number and diameter of perforators.[54, 55, 56] Distal side demonstrates less number of perforators but a large caliber perforator is consistently present within 2cm of radial styloid in all of the 12 cadavers, this finding is found to be consistent with the previous anatomical studies on radial artery[33]. Michel Saint-Cyr et al conducted an anatomical study in 26 fresh human cadaveric forearms to study and determine the location, orientation, external diameter and vascular territory of radial artery cutaneous perforators. The authors concluded that there are two main clusters of clinically significant perforators and increased knowledge of size, location and cutaneous territory of radial artery perforators can lead to expanded use of radial artery forearm flap based on these cutaneous perforators alone, without sacrificing the main radial artery[56].

In both distal and proximal forearms, perforators arising from the main vessel have both radial and ulnar distribution[56]. These anatomical characteristics suggest an element of safety when harvesting flaps based on either distal or proximal perforator[56]. Our cadaveric study demonstrates clusters of perforators in both proximal and distal aspect of forearm[53, 56].

Clinical use of perforator based radial artery free flap may have limited applications but nevertheless cases have been reported in literature[35]. The vascular anatomy of the fascia and subcutaneous tissue of the distally based flaps have been well described[34]. The blood supply to the fascio-cutaneous flap is found to originate from 5 to 10 septo-cutaneous perforators arising from radial artery in the anatomical snuffbox[33]. Anatomical and clinical investigation of the radial forearm adipo-fascial flap based on distal perforators has been well described by Hamdy El-Khatib, who reported an anatomic study in eleven fresh and fixed cadavers, designing a island adipofascial flap based on distal five to eight septo-cutaneous perforators of radial artery and their vena commitantes, great advantage being preservation of radial artery[53]. Three-dimensional computed tomographic angiography in our study has shown a comparable vascular territory with linking vessels found to communicate between adjacent perforators and running parallel to radial artery[56]. Perforators travel to dermis and form a network of linking vessels found between fascia and dermis. This finding is consistent as reported by previous similar studies[53, 33]. Mark Schaverien conducted a study involving 12 fresh human cadavers and 24 radial forearm flaps harvested from these cadavers to elucidate the role of deep fascia in perfusion of radial forearm flap. The authors concluded that inclusion of deep fascia during flap harvest does not contribute to flap perfusion or vascularity[34]. Although there are several anatomical study reports on vascular anatomy of radial artery, our study demonstrates the cutaneous territory and location of clusters in detail. The results obtained from our cadaveric study are clinically important in planning the exact dimension of the flap based on distal third perforators of radial artery. Perhaps the most significant finding in this study is the location of cutaneous perforators. Knowledge of these perforators can greatly facilitate the reconstructive surgeon in safe flap harvest and design[57]. Both distal and proximal perforators can be used in designing of potential flaps for various reconstructive needs[33]. Three-dimensional computed tomographic angiogram confirms that suprafacial dissection does not compromise blood supply of the radial forearm pedicle perforator flap[40, 52]. The supply to the skin is ensured by means of multiple perforators originating from the radial and ulnar sides of the radial artery, travelling to the skin and communicating with each other in the subcutaneous tissue plane by multiple linking vessels. Each perforator has its own vascular territory, called a perforasome, which carries a multidirectional flow pattern that is highly variable and complex. These perforasomes are linked to one another by both direct and indirect linking vessels, which themselves are linked by communicating branches. These numerous branches confer further protection form ischemia and vascular injury and explains the survival of single dominant perforator based flaps[56].

Linking vessels allow communication with adjacent perforasomes and follow a direction that is parallel to the direction of perforator flow. Therefore, perforator flap skin paddles should be parallel to the linking vessel orientation, which makes it possible to harvest large flaps based on single dominant perforator[56, 58]. If the radial forearm flap donor-site defect could be repaired primarily, then hand rehabilitation could be initiated earlier and the overall complication rate would be lower, compared with the traditional technique using a split-thickness skin graft to close the defect. This has led many surgeons to search for alternate methods of harvesting this flap allowing primary closure of the donor site. These include procedures incorporating tissue expanders or rotation flaps. Mateev et al. suggested a novel way of harvesting radial forearm flaps, which was termed “Shape modified method”. The series being reported for scalp reconstruction[46]. No such reports are available for reconstruction of head and neck defects, even though this new method appears to be elegant and avoids the use of skin grafts. The major advantage of this technique is its ability to reconstruct donor defects primarily in a one-stage operation, with better aesthetic contours of the forearm. In comparison with traditional methods such as split thickness skin grafting, the overall complication rate is minimized because hand motion can be allowed earlier, with the flexor tendons sliding beneath the flap. Soutar et al. reported 28% of problems in extension of wrist with traditional radial forearm flap harvest method[21]; we have no such reports in our shape modified radial forearm study group because of primary closure. Studies by Fenton et al report specifically the aesthetic problems in traditional method of radial forearm flap[59]. None of our patients in shape modified radial forearm flap group had any sensory nerve disturbance associated with injury to radial nerve branch (Dorsum of thumb and first web space). In our study, shape modified radial forearm flap has faired much better when compared to other methods of direct closure of donor sites. This was further confirmed by a quality of life questionnaire for assessment of donor site morbidity in harvest patients, which included 5 questions pertaining to day-to-day life activity. After analyzing the questionnaire we found that shape modified radial forearm harvest group had higher scores as compared with traditional radial forearm flap harvest. This further strengthens the results of better donor site healing in shape modified radial forearm group. Another problem that we found in the traditional radial forearm flap group is the associated skin graft donor site problem like itching and hypertrophic scar formation. This was observed in many of our patients who were reconstructed with traditional radial forearm free flap; this can be avoided by harvesting the flap based on radial artery perforators and incorporating shape modifications for defect reconstruction.

Ching-Hua et al used ulnar based bilobed flaps but found the final defect has a lengthy and unsightly scar[59, 60]. Elliot et al used V-Y advancement for primary closure but could only harvest 4 × 4 cm flaps and Berge et al used tissue expanded skin but found difficult and used two stages for primary-Closure[43, 42]. We had problems with our shape modified radial forearm group, which included reduction in pedicle length whenever the size of flap is increased. Maximum pedicle length we could harvest was 10 cm. Another probable problem mentioned in literature is the compression of the forearm due to tight closure. We did not have this complication in any of our 15 patients. Venous congestion is a common problem of perforator flaps, however in our shape modified series where the flaps were divided into two or three components we did not experience venous congestion[46]. Perforator flaps are not only advantageous because they minimize donor site morbidity and are versatile because of their thinness, they can also be used both as free flap and as a pedicled flap with a perforator serving as an axis of rotation that can be employed to reconstruct three dimensional defects. We can consider small components in our flap that are divided on individual perforators as small perforator flaps. One of the greatest advantage of our shape modified flap method, is that it effectively utilizes the flap area because its narrow shape can be modified to cover many differently shaped defects. The use of long and narrow flap results in low skin tension after donor site is closed primarily; this eliminates complications like complex regional pain syndrome[46]. Our shape modified radial forearm flaps can be considered as made to order flaps, despite the fact that flap shape at the donor site is almost exactly the same between different patients[46]. One possible disadvantage relates to the sacrifice of radial artery, however various studies in literature have shown ulnar artery to provide forearm and hand with an adequate postoperative blood supply[36, 37]. Thus we speculate that radial artery sacrifice may not result in any serious deleterious short or long term out-comes[37]. In summary our shape modified radial artery perforator flap cannot be used for every single head & neck defect, but it appears that it can be used for wide range of surgical indications (small to moderate defects) and it is useful and safe for reconstruction in both young and advanced aged patients[46].

13

Conclusion

Our study demonstrates a consistent course of radial artery with clusters originating on both distal and proximal ends, with each end becoming a pivot point for a pedicled flap rotation. Each perforator has the potential to become either a free or a pedicled flap depending on the size. In addition preservation of radial artery and ability of supra-facial harvest further lessens the morbidity burden. This phenomenon allows a myriad of perforator flap designs that can be tailored to match reconstructive defects. Present day reconstructive surgeon has more options and alternatives in replacing like with like. Local flap alternatives become more plentiful and flap design is limited only by the availability of clinically relevant perforators close to the defect. Free style perforator flap alternatives are limited by the size and length of their respective source arteries and veins. To overcome donor site morbidity of traditional radial forearm flap and to improve the utility of narrowly shaped flap, we have developed a shape modified radial artery perforator flap method. Through this we have successfully been able to reconstruct various three-dimensional head and neck defects with complete survival of our flaps.

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Bibliography

1. Pare A (1552) cited by Dale WA (1974). The beginning of vascular surgery. Surgery 76:849-866.

2. Hallowell (1759) Cited by Eastcott HHG (1969) Arterial surgery. JB Lippincott, Philadelphia, P 235.

3. Jones (1820) Cited by Callow AD (1978) Historical development of vascular surgery. In: Sawyer & Kaplitt (eds) Vascular grafts ACC, New York, PP 5-22.

4. Jassinowski A (1889) Die Arteriennhat: Eine experimentelle studie. Inaug Diss Dorpat.

5. Murphy JB (1897) Resection of arteries & veins injured in continuity end to end suture: Experimental & Clinical research. Med Rec 51:73.

6. Carrel A (1902) La technique des anastomoses vascularies et la transplantation des visceres. Lyon Med 98:859-864.

7. McLean J (1916) The thromboplastic action of cephaline. Am J Physiol 41:250-257.

8. Howell WH, Holt E (1918) two new factors in blood coagulation-heparin & pro-antithrombin. Am J Physiol 47:328-341.

9. Charles AF, Scott DA (1933) Studies on heparin I. The preparation of heparin. J Biol Chem 102:425-429.

10. Nylen CO (1954) The microscope in aural surgery, its first use & later development. Acta Otolaryngol Suppl 116: 226-240.

11. Jacobson JH, Suarez El (1960) Microsurgery in anastomosis of small vessels. Surg Forum 11: 243-245.

12. Kleinert HE, Kasdan ML (1965) Anastomosis of digital vessels. J Ky Med Assoc 63: 106-108.

13. Malt RA, McKhann CF (1964) Replantation of severed arms. JAMA 189: 114-120.

14. Anita NH, Buch VI (1971) Transfer of an abdominal dermo-fat graft by direct anastomosis of blood vessels. Br J Plast Surg 24(1): 15-19.

15. Black PW, Bevin AG, Arnold PG (1971) One stage palate reconstruction with a free neo-vascularized jejunal graft. Plast Reconstr Surg 47 (4): 316-320.

16. McLean DH, Buncke HJ Jr (1972) Auto transplant of omentum to a large scalp defect, with microsurgical revascularization. Plast Reconstr Surg 49(3): 268-274.

17. McGregor IA, Morgan G (1973) Axial & random pattern flaps. Br J Plast Surg 26(3): 202-213.

18. Yang G, Chen B, Gao Y, Liu X, Li J, Jiang S & He S. (1981). Forearm free skin flap transplantation. Natl Med J China, 61:139-141. ISSN: 0376-2491.

19. Song R, Gao Y, Song Y, Yu Y, Song Y. (1982). The forearm flap. Clin Plast Surg 1982; 9:21-26.

20. Mühlbauer W, Herndl E & Stock W. (1982). The forearm flap. Plast Reconstr Surg, 70(3), pp.336-342. ISSN: 0032-1052.

21. Soutar DS & McGregor IA. (1986). The radial forearm flap in intra-oral reconstruction. The experience of 60 consecutive cases. Plast Reconstr Surg, 78(1), pp-1-8.

22. Cheng BS (1983) Free forearm flap transplantation in repair & reconstruction of tongue defects. Zhonghua Kou Qiang Ke Za Zhi 18(1): 39-41.

23. Hatoko M, Harashina T, Inoue T, Tanaka I, Imai K (1990) Reconstruction of palate with radial forearm flap; a report of 3 cases. Br J Plast Surg 43(3): 350-354.

24. Chen HC, Ganos DL, Coessens BC, Kyutoko S, Noordhoff MS (1992) Free forearm flap for closure of difficult oronasal fistulas in cleft palate patients. Plast Reconstr Surg 90(5): 757-762.

25. Stock W, Stock M (1983) Der osteokutane Unterarmlappen. Handchirurgie 15:49.

26. Boorman JG, Green MF (1986) A split Chinese forearm flap for simultaneous oral lining & skin cover. Br J Plast Surg 39(2): 179-182.

27. Niranjan NS, Watson DP (1990) Reconstruction of cheek using a "suspended" radial forearm free flap. Br J Plast Surg 43(3): 365-366.

28. Sadove RC, Luce EA, McGrath PC (1991) Reconstruction of lower lip & chin with the composite radial forearm-palmaris longus free flap. Plast Reconstr Surg 88(2): 209-214.

29. Takada K, Sugata T, Yoshiga K, Miyamoto Y (1987) Total upper lip reconstruction using a free radial forearm flap incorporating the brachioradialis muscle. Report of a case. J Oral Maxillofac Surg 45(11) 959-962.

30. Wolf KD, Ervens J & Hoffmeister B. (1995). Improvement of radial forearm donor site by prefabrication of facial Split thickness skin grafts. Plast Reconstr Surg, 98(2), pp.358-361.

31. Urken ML, Weinberg H, Vickery C, Biller HF (1990) The neurofasciocutaneous radial forearm flap in head & neck reconstruction: A preliminary report. Laryngoscope 100(2 pt. 1): 161-173.

32. Daping Yang, M.D. Steven F Moris, Maolin Tang, Christopher R. Geddes. (2003). Reversed forearm Island flap supplied by the septocutaneous perforator of the radial artery: Anatomical basis & clinical applications. Plastic. Reconstr. Surg.112: 1012, 2003.

33. Cesare Tiengo, Veronica Macchi, Andrea Porzionato, Carla Stecco, Anna Parenti, Franco Bassetto, Raffaele De Caro (2004). Anatomical Study of Perforator Arteries in the Distally Based Radial Forearm Fasciosubcutaneous Flap. Clin. Anat. 17: 636–642, 2004.

34. Mark Schaverien, MD, Michel Saint-Cyr, MD. (2008). Suprafacial compared with subfacial harvest of the radial forearm flap: An Anatomic Study. J Hand Surg 2008; 33 A: 97-101.

35. Raphael Ciuman & Phillip Dost (2012). The fore arm free flap-Indications, appropriate selection, complications & functional outcomes. www.intechopen.com. May 2012.

36. Kerawala CJ, Martin IC (2003) Palmar arch backflow following radial forearm free flap harvest. Br J Oral Maxillofac Surg 41(3): 157-160.

37. McCormack LJ, Cauldwell EW, Anson BJ (1953) Brachial & antebrachial arterial patterns; a study of 750 extremities. Surg Gynecol Obstet 96(1): 43-54.

38. Partecke BD, Buck-Gramcko D & Pachnucki A. (1986). Use of a fascia flap of the forearm in soft tissue defects of the extremities. (German). Handchir Mikrochir Plast Chir, 18(6), pp. 353-355. ISSN: 0722-1819.

39. Liang MD, Swartz WM, Jone NF. (1994). Local full thickness skin graft coverage for radial forearm flap donor site. Plast Reconstr Surg, 93, pp.- 621-625.

40. Webster HR & Robinson DW. (1995). The radial forearm flap without fascia & other refinements. Eur J Plast Surg, 18, pp-11-13.

41. Knott PD, Seth R, Waters HH, Revenaugh PC, Alam D, Scharpf J, Meltzer NE, Fritz MA (2016) Short term donor site morbidity: A comparison of the anterolateral thigh flap & radial forearm fasciocutaneous free flaps. Head Neck 38(Suppl 1) E945-E948.

42. Elliot D, Bardsley AF, Batchelor AG, Soutar DS (1988) Direct closure of radial forearm flap donor defect. Br J Plast Surg 41(4): 358-360.

43. Bardsley AF, Soutar DS, Elliot D, Batchelor AG (1990) reducing morbidity in radial forearm flap donor site. Plast Reconstr Surg 86(2): 287-292; Discussion 293-294.

44. Masser MR (1990) The pre-expanded radial free flap. Plast Reconstr Surg 86(2): 295-301.

45. Rath T, Millesi W, Millesi-Schobel G, Lang S, Glaser C, Todoroff B. (1997). Mucosal prelaminated flaps for physiological reconstruction of intra oral defects after resection. Br J Plast Surg, 50(5), 303-307.

46. Mateev, Musa A et al. (2009). Shape modified radial artery perforator flap method. Analysis of 112 cases. Plastic & reconstructive surgery, vol123 issue-5, pp-1533-1543.

47. Hekner DD, Abbink JH, Vans ES, Rossenberg A, Koole R, Van Cann EM (2013) Donor site morbidity of the radial forearm free flap VS ulnar forearm free flap. Plast Reconstr Surg 132(2): 387-393.

48. Timmons MJ, Missotten FEM, Poole MD & Davies DM. (1986). Complications of radial forearm flap donor sites. Br J Plast Surg, 39(2), pp. 176-178. ISSN: 0007-1226.

49. Villaret DB, Futran NA (2003) the indications & outcomes in the use of osteocutaneous radial forearm free flap. Head Neck 25(6): 475-481.

50. Gilat H, Shpitzer T, Guttman D, Soudry E, Feinmesser R, Bachar G (2013) Obstructive sleep apnea after radial forearm free flap reconstruction of the oral tongue. Lyrngoscope 123(12): 3223-3226.

51. Lovie MJ, Duncan GM & Glasson DW. (1984). The ulnar artery forearm flap. Br J Plast Surg, 37(4), pp. 486-492. ISSN: 0007-1226.

52. Chang SC, Miller, G, Halbert CF, Yang KH, Chao WC & Wei FC. (1996). Limiting donor site morbidity by suprafacial dissection of the radial fore arm flap. Microsurgery, 17(3), pp-136-140.

53. Hamdy El-Khatib, M.D., Mohamed Zeidan, M.S (1997). Island adipofascial flap based on distal perforators of the radial artery: An anatomic & clinical investigation. Plast. Reconstr. Surg. 100: 1762-1766.

54. Lin, Jeng-Yee MD, Cheng, Ming-Huei MD, Wei, Fu Chan MD, Song, Dennis MD, Huang, Wei-Chao MD (2006). Proximal forearm flap based on a septocutaneous vessel form the radial artery. Plastic & Reconstructive Surgery, March 2006, vol-117-issue 3: PP 955-960.

55. Cesare Tiengo, Veronica Macchi, Andrea Porzionato, Carla Stecco, Anna Parenti, Franco Bassetto, Raffaele De Caro (2007). The proximal radial artery perforator flap (PRAP-flap): An anatomical study for its use in elbow reconstruction. Surg Radiol Anat (2007) 29:245-251.

56. Michel Saint- Cyr. (2010). The radial artery pedicled perforator. Plast. Reconstr. Surg. 125: pp-1469-2010.

57.L. Giordano, S. Bondi, F. Ferrario, B. Fabiano, M. Bussi. (2012). Radial forearm free flap surgery: A modified skin closure technique improving donor site aesthetic appearance. Acta Otorhinolaryngol ital., 32, p- 158-163.

58. Wael Hussien Mahmoud. (2015). Radial forearm flap versus radial adipofascial perforator based flap for reconstruction of hand soft tissue defects. Donnish journal of medicine & medical sciences. Vol 2(3), pp-19-25.

59. Fenton, O.M. and Roberts, J.O. (1985) Improving the Donor Site of the Radial Forearm Flap. British Journal of Plastic Surgery, 38, 504. https://doi.org/10.1016/0007-1226(85)90009-8.

60.Hsieh, CH and Kuo, Y. -R. (2004) Primary Closure of Radial Forearm Flap Donor Defects with a Bilobed Flap Based on the Fasciocutaneous Perforator of the Ulnar Artery. Plastic & reconstructive surgery, 113, 1355-1360.

15

Annexures.

Annexure 15.1. Ethical committee clearance certificate.

Vydehi Institutional Ethics Committee (VIEC)
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VIEC/2017/APP/049 **EC Reg No: ECR/747/Inst/KA/2015**

Date: 14.03.2017

To,

Dr. M E Sham,
Professor,
Dept. of Maxillofacial Surgery,
VIDS & RC,
Whitefield, Bangalore.

Dear Dr. M E Sham,

The Vydehi Institutional Ethics Committee has reviewed and discussed your project proposal application to conduct the Clinical trial/ research project entitled **"SHAPE MODIFIED RADIAL ARTERY ADIPO-FACIO CUTANEOUS PERFORATOR FLAP- AN OBSERVATIONAL ANATOMICAL VASCULAR ANALYSIS & PROSPECTIVE RANDOMIZED CONTROL CLINICAL STUDY"** On 09.03.2017

The following documents were reviewed

Study Protocol (including protocol amendments)

Data Collection Form

The following members of the Ethics Committee were present at the meeting held on 11.03.2016

Dr. Subramani S A
Dr. Prathibha Nadig
Dr. G Prabhakar
Dr. Shankarappa C
Dr. Fiaz Ahmed Sattar
Dr. Jagadeesh N
Mr. Nelson John
Mrs. Suseela N S
Mr. Murahari S

Vydehi Institutional Ethics Committee (VIEC)

Vydehi Institute of Medical Sciences & Research Centre

82, E.P.I.P. Area, Whitefield, Bangalore-560 066. Ph.: 080-28413381, Extn:289, Email: viec@gmail.com

The Ethics Committee has reviewed the study and the study was:

- [x] Approved - YES
- [ ] Conditional Approval subjected to approval of Study from DCGI
- [ ] Conditionally Approved
- [ ] Modifications Requested (details listed separately)
- [ ] Not Approved

The Vydehi Institutional Ethics Committee/Independent Ethics Committee expects to be informed about the progress of the study; any SAE's occurring in the course of the study, any changes in the protocol and patient information/informed consent and asks to be provided a copy of the final report.

Yours Sincerely,

Member Secretary, Ethics Committee

MEMBER SECRETARY
VYDEHI INSTITUTIONAL
ETHICS COMMITTEE (VIEC)
VIMS & RC, BANGALORE

Annexure 15.2. Paper presentation at World society Of Reconstructive Microsurgery (WSRM 2017) at Seoul, Korea.


WSRM2017-321

WSRM 2017
9th CONGRESS OF WORLD SOCIETY FOR RECONSTRUCTIVE MICROSURGERY

Certificate of Attendance

Be it known that:

Ehtaih sham Mohamed

Has attended

9th Congress of World Society for Reconstructive Microsurgery

June 14 ~ 17, 2017

Seoul, Korea

Myong Chul Park, M.D., Ph.D
Chairman, Organizing Committee of WSRM 2017

Annexure 15.3. Burden of Head and neck Cancer in India.

India Sees 5.5 Lakh Head And Neck Cancer Cases Every Year: Experts.

Indo-Asian News Service, October 20, 2016