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Efficacy of the Free-Style, Perforator-Plus Flap in the Reconstruction of the Soft Tissue Defects at the Lower Leg and Ankle Regions

MOHAMED T. YOUNIS, M.D.*; GAMAL EL HABAA, M.D.*; SHERIF A. ELGAZZAR, M.D.**; AL-BASHEER F.M. ANANY, M.Sc.*** and A.M. ABDELMOFEED, M.D.*

Plastic & Reconstructive Surgery Unit, General Surgery Department, Faculty of Medicine, Benha University, General Surgery Department**, Faculty of Medicine, Benha University and Department of Plastic & Reconstructive Surgery***, Nasser Institute Egypt*

ABSTRACT

Background: Reconstruction of the lower leg and ankle soft tissue defects is not that the convenient task, due to the unique anatomy and its variation.

Aim of Study: Evaluation efficacy of the Free-Style, Perforator-Plus flap concepts in the reconstruction of the soft tissue defects at lower two-thirds leg, tendo-Achilles and ankle regions.

Method: A Prospective (Case Series) Study, was carried on 20 consecutive patients, which performed at the Plastic and Reconstructive Surgery Unit of General Surgery Department of Benha University Hospitals, and Department of Plastic and Reconstructive Surgery at Nasser Institute for Research and Treatment in the period from June 2020 to June 2021.

Results: 20, consecutive, exclusively males, patients, aged from 3 to 57 years old (Mean 28±12 SD years), had a “Free-Style, Perforator-Plus Flap” reconstructive surgery, to cover defects presented at lower Leg two-thirds (75% of cases), Tendo-Achilles (10%) and Ankle (15%) regions. Flap complications were encountered in 4 cases (20%): 2 cases (10%) had distal congestion, the other 2 cases had distal ischemia, which one of them developed full-thickness distal loss. The final recipient outcome “Defect Coverage” was achieved in all cases (100%).

Conclusion: The Free-Style, Perforator-Plus Flap is reliable with relative efficiency, versatile, and has a modest rate of failure and need for secondary surgery. It capable to reconstruct small to relatively large, complex defects (exposed bone or hardware and chronic osteomyelitis) in the distal Leg two-thirds, Tendo-Achilles, and Ankle regions.

Key Words: *Free-style – Perforator-plus – Perforator flaps – Pedicled flaps – Fasciocutaneous flaps – Lower leg reconstruction.*

INTRODUCTION

Reconstruction of the lower leg and ankle soft tissue defects is not that the convenient task, mostly, due to the inherent anatomy: The decreased bulk of the soft tissues and the subcutaneous bony aspect **[1]**. Vascularity is also an important aspect on the level of the main vessels, and indeed on the level of the perforators, which have variant numbers, sites, lengths, and diameters, even in the same person on the opposite sides **[2,3]**.

No one coat is suitable for all various sizes. Almost every method of coverage is reliable when it is performed in the selected patients with indicated defects by the expertise-hands. The Free flap is nearly the only solution for the large complex defects in a patient with average medical fitness and healthy vessels **[4]**. The Cross-leg flap is the last resort for limb salvage when a Free flap is not suitable or contraindicated **[5]**. The Reverse Sural Artery Flaps are useful in patients with co-morbidities, such as Diabetes Mellitus or Peripheral Vascular Diseases **[6]**. Traditional muscle flaps remain a superior option, obviously, in avulsion injuries, degloving wounds, ischemic regions, where no longer local perforators present, or in the deep defects **[7]**. Even Negative Pressure Wound Therapy, with or without skin grafting, reduce the need for flap coverage **[8]**.

Perforator flaps are another available option; they are suitable and reliable for small- and medium-sized defects; replace like with like and preserve the muscles, main vessels, and nerves **[9]**.

Since the perforator flap was introduced by Koshima and Soeda **[10]** in 1989, and thanks to “Angiosomes” **[11]** and “Perforasome **[12]** concepts, and however, the paucity of the distal lower leg and ankle soft tissue bulk, there are many prescribed perforators flaps in the literature to cover this unique anatomical area, mostly, they are different names or modification for the same flaps **[13]**.

And although the vascular anatomy may vary among individuals and between opposite sides of the same person, the basic “vascular blueprint” is similar **[14]**.

Here, the "Free-Style" perforator flaps concept [15,16] aroused with general principles more than rigidly fixed steps in the flap approach and designing. With the premise that one adjacent anatomic cutaneous perforator territory can be safely captured radially in any direction [14]. In a retrograde manner, one can analyze the defect, detecting the nearby perforator/s by the Hand-Held Doppler (non-invasive, non-expensive, easy, and widely available), designing a provisional flap according to the perforator site and the defect dimensions. This design could be altered, if needed, according to the findings of the exploratory incision that sharing one margin with the defect and another backup flap that may be used in case of finding the perforator being unsuitable [17].

By adding the "Perforator-Plus" flaps concept [18] to the Free-Style perforator flaps concept, and when the expertise and/or special facilities are not found, it could be safeguarding any conventional fasciocutaneous flap to be a perforator flap by making sure that there is a perforator at its base. This increases the flap potential vascularity and so its size, making the flap more reliable and safe. With no need for perforator skeletonization, avoiding the hazards of the perforator and delicate venae comitantes injury. That reduces the risk of ischemia, venous congestion, and necrosis, which may complicate the flap. With more another advantage of the skin/adipofascial bridge securing another route for flap's venous drainage [19,20].

Aim of the study:

Evaluation of the Free-Style, Perforator-Plus Flap efficacy in the reconstruction of the soft tissue defects at the lower two-thirds leg, tendo-Achilles and ankle regions.

PATIENTS AND METHODS

A Prospective (Case Series) Study, performed at the Plastic and Reconstructive Surgery Unit, of the General Surgery Department, of Benha University Hospitals, and Department of Plastic and Reconstructive Surgery at Nasser Institute for Research and Treatment in the period from June 2020 to June 2021.

The study was carried on 20 consecutive Patients presented with lower two-thirds Leg, Tendo-Achilles and Ankle regions soft tissue defects, checked at Outpatient Clinic and Emergency Unit, that could be covered by a perforator-based pedicled flap, using Free-Style and Perforator-Plus concepts.

Inclusion criteria: Patient with soft tissue defect that required coverage with a skin flap. Defects post (Traumatic, Chronic wounds, Unstable scar excision or Contracture release), due to exposure of bone, hardware, tendons or neurovascular tissues, at the lower leg two thirds, Tendo-Achilles and Ankle regions.

Exclusion criteria: Patient with a degloved injury around the defect, extensive complex injury, or scaring with no available sufficient donor-tissues. No available nearby perforators were detected by the Hand-Held Doppler. Patients with Peripheral Vascular Diseases, Venous Insufficiency or Uncontrolled Diabetes.

Study procedure:

Pre-operative:

1- *Full History and Examination:* Focusing on the history of vascular diseases (including venous stasis), diabetes, smoking, and previous limb or vascular injuries and surgeries. Aiming the lower limb examination, including the vascular exam and the wound assessment.

2- *Investigations:* CBC, Liver and Kidney function tests and Coagulation Profile. HbA1c, Bone X-Ray, Chest X-Ray, ECG, or Vascular Duplex (according to the case).

3- *Fitness for surgery:* Evaluated by the anaesthesia team.

4- *In Cause of Acute Trauma:* ATLS Survey applied 1st, then wound was cleansed and debrided. Negative Pressure Wound Therapy was applied if there was a delay in coverage, otherwise daily dressing with a chemical debridement agent was used. The limb was elevated and temporarily fixed with a splint. Drugs: Antibiotic Prophylaxis, Anti-tetanus (if indicated), Anti-Edematous, Analgesics, Fluids were given.

5- *Consent:* Written informed consent about the procedure and any complications including post-operative flap loss and donor-site morbidity was obtained.

Surgical technique:

Anaesthesia: General or Regional (Spinal ± Epidural). Position: Supine, Lateral, or Prone according to the defect site. Wound Assessment: For the defect potential dimensions, base, and exposed Structures.

Flap Design: Perforator/s adjacent to the defect and next dominant one were detected by a Hand-Held Doppler.

8MHz (loud, pulsatile, and high-pitched sound) and marked. Perforators that enclosed in the scar or granulation tissue were avoided. By using a template for the defect, a potential flap/s was designed and marked (in a reverse manner) as vertically/obliquely oriented, based on the marked perforator. The flap design was slightly larger than the defect (1-2cm to the length and 0.5-1cm to the width), for avoiding flap inset under tension and to accommodate post-operative oedema. Transgressing onto the tibial subcutaneous border was avoided.

Exploration: (Under a tourniquet and use of a loupe 3.5x magnification). Initially, a relatively generous (for safety and easier assessment) exploratory incision was made at one of the flap lateral margins adjacent to the perforator, then it was deepened to the subfascial plane. This incision was common with a defect margin on one side and a backup flap margin on the other side. Perforator was identified and assessed by a direct visualization; for its pulsation (most reliable indicator), calibre, and its venae comitantes. No need for more dissection or skeletonization as long as that the flap was transposed/rotated comfortably without tension to cover the defect. The perforators were irrigated intermittently with 2% lidocaine to prevent the vascular spasm of the perforators and also keeping them moist.

Re-evaluation: Defect edges were refreshed and undermined, in addition to the wound bed debridement and curettage. The real size of the defect was then measured. The designed flap dimensions and the arc of rotation were re-evaluated and modified based on the perforator location (if needed).

Flap Elevation: Post defect dimensions re-evaluation, Flap skin was incised proximally and laterally leaving the base intact with skin or adipofascial bridge. The flap was harvested in a subfascial plan (allowed easier flap elevation, a relatively avascular plane and, more importantly, safeguarded the suprafascial plexus). During flap elevation, it is important to suture the fascia to the skin, to prevent their shearing from each other.

Flap Rest and Hemostasis: After Tourniquet release, flap perfusion (colour, capillary refill, and bleeding) was evaluated. Meticulous hemostasis was done and the flap rested insitu (native position) for 10-15min (this allows reperfusion and relief of vasospasm).

Flap In-setting: Flap was transferred to cover the defect, in-setted and approximated to defect edges with no tension, no excessive twisting, or kinking of the flap vascular pedicle. Limitation of movement was managed to a certain degree by Back-cuts, Burrow triangles or cutting skin leaving an adipofascial bridge only. "Dog's Ear" if was presented, it was left for correction later.

Delaying: If the flap was with query perfusion (especially the large one), the flap was delayed insitu for 1 week before transfer to cover the defect.

Drain: Was applied under the flap.

Donor-site: Defect size was decreased by quilting stitches and covered with STSG from the ipsilateral thigh, then fixed to the wound bed by staples and tie-over dressing.

Dressing: A light bulky soft dressing with a window for flap monitoring was applied.

Post-operative and follow-up:

Flap Monitoring: No special flap monitoring was needed; just a clinical observation for the flap colour, consistency, temperature, capillary refill, pinprick scratching test (if any doubt was there). Flap Monitoring was initiated by the time the patient arrived in his room (ensuring the positioning and instructions for the patient), again at the night of Post-Op, then twice per day for 5-7 days. Position: Limb elevation with no compression on the flap or the pedicle. Drugs: Antibiotics, IV Fluids, Anti-Edematous and Analgesics were given and DVT Prophylactic Enoxaparin 40IU according to the case. Dressing: Flap Dressing was changed on the 2^{nd} or 3^{rd} day; mobilization of the patient was recommended then after. STSG Dressing was changed on the 5^{th} day, and then every day till the patient was discharged. Follow-up: At OPC Twice in the 1^{st} week, then once at the end of the 2^{nd} week for the removal of staples and stitches.

Ethical consideration:

Approval was obtained from the ethical committee in the Faculty of Medicine, Benha University, and from the patients incorporated in the study with written consent.

Statistical analysis:

The study data were collected from the images (using ImageJ 1.50e software) and patients' documents, then tabulated, analyzed, and summarized using ®Microsoft ®Excel 2013 (15.0.4420.1017) and finally were processed by ®jASP 0.12.2 (statistical-package software), to be presented descriptively, as texts, tables and graphs.

RESULTS

Presentation: 20, consecutive, exclusively males, patients, aged from 3 to 57 years old (Mean 28±12 SD years), had a flap reconstructive surgery, using "Free-Style, Perforator-Plus Flap" concepts, to cover defects presented at lower Leg two-thirds (75% of cases), Tendo-Achilles (10%) and Ankle (15%) regions. The onset of the presentation was acute in 25% of cases, 10% subacute, and 65% were chronic. The main aetiology of presentations was RTA (65%), followed by firearm injury (20%). One patient only was diabetic controlled on insulin. More details about demographic and presentations are shown in Table (1).

Table (1): Patient presentation and co-morbidity.

No.	Age	Presentation		Cause	(Side) Site	Orientation	Smoking	Vascular Status
		Soft Tissue	Ortho					
1	34	Ch.wound	Free	RTA	(Lt) leg	Anteromedial	Nil	Free
2	15	Chronic Ulcerated Hemangioma	Free	Hemangioma	(Rt) Distal-leg	Anteromedial	Nil	Free
3	25	Acute Traumatic Soft Tissue loss	Comminuted Fracture Tibia (Exposed) and Fibula & Tubed Ex. Fix (Gustilo IIIB)	Firearm	(Lt) Mid-Leg	Anterior	Nil	Query
4	3	Chronic Unstable Scar (Constricting)	Inward Angulated Malunion Tibial Fracture	RTA	(Lt) Mid-leg	Anteromedial	Nil	Free
5	40	Chronic Wound & Unstable Scar	Unstable oblique Fracture Tibia and Fibula & Tubed Ex. Fix	RTA	(Rt) Mid-leg	Anteromedial	Nil	Free
6	27	Chronic Unstable Scar	Fracture Tibia & Tubed Ex. Fix	Firearm	(Rt) Mid-leg	Anteromedial	Smoker	Free
7	28	Acute Traumatic Soft Tissue loss	Comminuted Fracture Tibia (Exposed) & Segment Bone Loss (Gustilo IIIB)	RTA	(Lt) Mid-leg	Anteromedial	Smoker	Disturbed + Diabetic
8	24	Chronic Unstable Scar	Fracture Tibia & Tubed Ex. Fix	Firearm	(Rt) Mid-leg	Anterolateral	Smoker	Free
9	28	Chronic Sinus & Unstable Scar	Chronic osteomyelitis Sinus Tibia (Localized/Stage3/TypeBL)* & Unstable Fracture Tibia & Tubed Ex. Fix	Firearm	(Rt) Mid-leg	Anteromedial	Smoker	Disturbed
10	26	Acute Traumatic Soft Tissue loss	Achilles Tendon Injury (segment loss)	RTA	(Rt) Achilles	Posterior	Nil	Free
11	21	Chronic Wound and Sinus & Unstable Scar (Since 2ys)	Chronic osteomyelitis Sinus Talus (Superficial/Stage2/Type A)* & Old Fracture Hx	RTA	(Rt) Ankle	Anteromedial	Nil	Disturbed
12	22	Subacute Soft Tissue Loss	Fracture Tibia & Exposed Plate and Screws Fix	RTA	(Lt) Distal-Leg	Anterior	Nil	Free
13	15	Subacute Soft Tissue Loss	Healed Fracture Tibia & Exposed Tibia Post Hardware (Plate and screws Fix) Removal	RTA	(Lt) Mid-leg	Anteromedial	Nil	Free
14	25	Acute Traumatic Soft Tissue loss	Achilles Tendon Injury (Musclo-Tendoneous)	RTA	(Rt) Achilles	Posterior	Nil	Free
15	42	Chronic Wound and Sinus & Unstable Scar	Chronic osteomyelitis Sinus Tibia (Localized/stage3/TypeBL)* & Comminuted Fracture Tibia and Fibula + Infected IMN	RTA	(Lt) Mid-leg	Anteromedial	Smoker	Query
16	32	Chronic Wound & Unstable Scar (Since 2ys)	Old Fracture Tibia Hx	RTA	(Rt) Ankle	Medial	Nil	Query
17	17	Chronic Sinus & Unstable Scar	Chronic osteomyelitis Sinus Tibia (Superficial/Stage2/TypeA)*	Infection	(Lt) Distal-Leg	Anterior	Nil	Free
18	26	Chronic Wound & Unstable Scar	Exposed Necrotic Tibial Bone & Comminuted Fracture Tibia and Fibula & Ilizarov Fix	RTA	(Rt) Distal-Leg	Medial	Nil	Free
19	46	Chronic Wound and Sinus & Unstable Scar	Chronic osteomyelitis Sinus Tibia (Superficial/Stage2/TypeA)* & Exposed Necrotic Cortical Bone	Infection	(Rt) Distal-Leg	Medial	Stopped	Free
20	57	Acute Traumatic Soft Tissue loss	Exposed Tibia + Malleoli Fracture (Gustilo IIIB)	RTA	(Lt) Ankle	Medial	Stopped	Free

*Cierny-Mader classification.

Pre-op defect management: Separate surgical debridement stage was needed in 3 cases (15%). While chemical debridement with glycerin magnesia only was used in 6 patients (30%). Negative Pressure Wound Therapy (NPWT/VAC) was used in 2 patients (10%) post debridement.

Flaps characteristics: Flap Contiguity (destination) was local in 75% of cases, 10% regional (Cases No.16, 20) and distant in the 3 cases (15%) of the Cross-leg flaps. All flaps were based distally, except one that based proximally (Case No.15). Flap Composition was fasciocutaneous in all cases, except one was Myo-cutaneous (Case No.19). Flap Construction (Type of Pedicle/Bridge) was also fasciocutaneous in all cases, except 2 cases (Cases No.4, 6) that were adipofascial. 2 flaps only (Cases No. 10, 20) that needed Flap Conditioning (Preparation) in the form of flap delay for 1 week. Details about flap Conformation and Transfer Method are shown in Table (2).

Perforator system: Posterior Tibial Artery (PTA) perforator system was used in (70% of cases) with pivot point from medial malleolus tip range from 9 to 20cm (Mean 12±2.9 SD cm), Peroneal Artery (PA) perforator system was used (20%) with a pivot point from lateral malleolus tip range from 6 to 14cm (Mean 11±3.6 SD cm), and Anterior Tibial Artery (ATA) perforator system was used in 2 cases only (10%) with a pivot point from lateral malleolus tip 13 and 17cm. Perforators were detected either by the doppler only (25% of cases) or by the doppler and direct perforator visualization post exploration (75%). Flap Rotation was ranged from 25º to 160º (Mean 85±44 SD º), and 50% had an angle of rotation ≥ of 90º. More details are presented in Table (2).

Flap and defect dimensions: Final defect sizes were ranged from 15 to 125 cm^2 (Mean 49±27 SD cm^2). "Designed" Flap sizes were ranged from 40 to 175 cm^2 (Mean 93±41 SD cm^2), while "Elevated" flap sizes were ranged from 35 to 155 cm^2 (Mean 82±36 SD cm^2). "Final" flap sizes were ranged from 35 to 145 cm^2 (Mean 74±32 SD cm^2). Total flap "Wastage-Size" (elevated flap and final defect size difference) were ranged from 14 to 65% of the elevated flap (Mean 40±18.5 SD %), Fig. (1).

Lengths ratio: Flap to Leg Length ratio were ranged from 21 to 54 % (Mean 42±8 SD %). Flap length to "Narrowest flap width" ratio varied from 2:1 to 6:1, while narrowest width to widest width ratio was ranged from 38 to 100% (Mean 61±14 SD %). More details about Dimensions, Sizes and Ratios are shown in Table (3).

Operations: Ratio between Flap elevation time and total operation time range from 1:2.5 (40%) to 1:11 (9%) (Median 29%, Mean 26±10 SD %). More details are shown in Table (4).

Complications and outcome: Are shown in details in Tables (4,5,6).

Table (2): Flap transfer and perforator system.

No.	Flap Conformation (form/shape)	Transfer Method	Rotation Angle Degree	Pivot Point Distance* (cm)	Perforator System	Perforator Detection
1	Round Rectangle	Transposition	60	10	PTA	Doppler
2	Round Rectangle	Transposition	60	12	PTA	Doppler and Exploration
3	Elliptical	Transposition	65	10	PTA	Doppler and Exploration
4	Racket Shaped	Rotation	90	10	PA	Doppler and Exploration
5	Round Rectangle	Transposition	40	14	PTA	Doppler and Exploration
6	Elliptical	Transposition	60	17	ATA	Doppler and Exploration
7	Round Rectangle	Cross-Leg	45	12	PTA	Doppler and Exploration
8	Round Rectangle	Transposition	55	14	PA	Doppler
9	Round Rectangle	Cross-Leg	40	13	PTA	Doppler and Exploration
10	Round Rectangle	Rotation	160	6	PA	Doppler and Exploration
11	Flask Shaped	Cross-Leg	115	13	PTA	Doppler and Exploration
12	Round Rectangle	Rotation	110	9	PTA	Doppler
13	Round Rectangle	Transposition	25	10	PTA	Doppler and Exploration
14	Elliptical	Rotation	100	13	PA	Doppler and Exploration
15	Racket Shaped	Rotation	90	20	PTA	Doppler and Exploration
16	Flask Shaped	Interpolation	160	12	PTA	Doppler and Exploration
17	Round Rectangle	Transposition	25	13	ATA	Doppler
18	Round Rectangle	Rotation	90	9	PTA	Doppler
19	Round Rectangle	Rotation	150	14	PTA	Doppler and Exploration
20	Flask Shaped	Interpolation	150	10	PTA	Doppler and Exploration

* Vertical length from the Pivot Point (the line that parallels to flap base) to the tip of malleolus (Lateral Malleolus for PA and ATA, Medial Malleolus for PTA).

Table (3): Dimensions, sizes, and ratios.

No.	Leg Length*	Final Defect Widest Dimensions HxV** (Size)	Designed Flap Widest Dimensions HxV (Size)	Elevated Flap Size (Final Size)	Total Wastage-Size cm2 (%`)***	Flap Base (Narrowest) Width	Flap/Leg Lengths Ratio %`	Flap Length/ Narrowest Width Ratio	Flap Narrowest/ Widest Widths Ratio %
1	40	7x11 (65)	10x19 (165)	150 (145 after trimming)	85 (57)	6	48	3:1`	60
2	39	5x10 (40)	6x11 (60)	55 (50 after trimming)	15 (27)	6	28	2:1`	100
3	35	3x9 (25)	5x15 (60)	55 (50 after trimming)	30 (55)	3	43	5:1	60
4	27	10x4 (30)	5x13 (40)	35 (no trimming)	5 (14)	3	48	4:1`	60
5	37	6x10 (50)	9x16 (125)	110 (no trimming)	60 (55)	5	43	3:1`	56
6	35	7x5 (30)	6x15 (55)	50 (45 after trimming)	20 (40)	3	43	5:1	50
7	40	6x16 (85)	9x18(115)	100 (90 pedicle separation)	15 (15)	6	45	3:1	67
8	39	6x9 (50)	8x16 (100)	85 (80 after trimming)	35 (41)	4	41	4:1	50
9	40	7x14 (80)	9x18 (120)	105 (85 pedicle separation)	25 (24)	6	45	3:1	67
10	36	7x13 (75)	8x18 (110)	100 (no trimming)	25 (25)	3	50	6:1	38
11	40	11x13 (125)	15x20 (175)	155 (135 pedicle separation)	30 (19)	6	50	3:1`	40
12	35	7x8 (50)	8x16 (90)	75 (no trimming)	25 (33)	6	46	2.5:1	75
13	37	5x10 (40)	6x15 (80)	75 (70 after trimming)	35 (47)	4	41	4:1`	67
14	36	9x5 (35)	6x14 (60)	50 (no trimming)	15 (30)	4	39	3.5:1`	67
15	38	12x6 (60)	7x15(80)	70 (no trimming)	10 (14)	5	39	3:1	71
16	37	7x8 (45)	10x20 (150)	130 (50 pedicle separation)	85 (65)	5	54	4:1	50
17	38	3x6 (15)	5x8 (40)	35 (no trimming)	20 (57)	4	21	2:1	80
18	39	4x4 (15)	5x10 (45)	40 (no trimming)	25 (63)	3	26	3:1`	60
19	40	6x7 (35)	8x16 (110)	95 (no trimming)	60 (63)	5	40	3:1`	63
20	40	5x6 (25)	6x18 (80)	70 (60 after debridement)	45 (64)	3	45	6:1	50

* Length From Tibial Plateau/Fibular Head Tip to Medial/Lateral Malleolar Tip, **Horizontal x Vertical, *** Difference between The Elevated Flap and Final Defect Sizes, (`Approximated).

Table (4): Time details.

No.	Delay before flap elevation (Day)	Op. No	Total Operation/s Time per case (min)	Flap Elevation Time (min)	Flap/Total Op. Time Ratio (%`)	Hospital-Stay (Days)	Healing (Days)	Follow-up (Weeks)
1	1	1	90	30	1:3 (33)	4	28	4
2	1	1	180	30	1:6 (17)	5	42	24
3	15	2	210	60	1:3.5 (29)	21	28	4
4	1	1	105	30	1:3.5 (29)	7	42	4
5	1	1	240	45	1:5` (19)	7	21	4
6	1	1	75	30	1:2.5 (40)	7	21	4
7	15 (ICU)	2	330	30	1:11 (9)	40	42	24
8	1	1	120	45	1:3` (38)	7	21	4
9	1	2	300	30	1:10 (10)	26	35	4
10	2	2	360	60	1:6 (17)	16	35	8
11	1	2	300	60	1:5 (20)	29	42	24
12	0 (Daycase)	1	120	45	1:3` (38)	0	28	10
13	10	2	120	30	1:4 (25)	15	21	4
14	11 (ICU)	1	150	45	1:3` (30)	15	28	8
15	21	3	210	30	1:7 (14)	31	56	6
16	1	2	210	60	1:3.5 (29)	7	42	16
17	1	1	90	30	1:3 (33)	5	21	12
18	0 (Daycase)	1	90	30	1:3 (33)	0	21	4
19	0 (Daycase)	1	180	60	1:3 (33)	0	35	8
20	17	3	180	30	1:6 (17)	30	28	16

Table (5): Complications.

No.	Flap Complications	Donor-Site Complications	Recipient Complications	Infection	Intervention for complications
1	Nil	Nil	Nil	Nil	Nil
2	- Inferior Edge (1cm Width) and Distal 2cm Congestion and Superficial Loss	Nil	- Wound Dehiscence Distally	Nil	Nil (Dressing Only)
3	Nil	Nil	Nil	Klebsiella	Nil
4	- Inferior Edge (1cm Width) and Distal 2cm Congestion and Superficial Loss	Nil	Nil	Nil	Nil (Dressing Only)
5	Nil	Nil	Nil	Nil	Nil
6	Nil	Nil	Nil	Nil	Nil
7	Nil	- Graft Partial Loss (From Friction and Infection)	Nil	- Klebsiella, Pseudomonas	Skin Grafting (During Flap Separation)
8	Nil	Nil	Nil	Nil	Nil
9	Nil	Nil	Nil	Pseudomonas	Nil
10	Nil	Nil	- Wound Dehiscence Distally	Nil	Re-Approximation (OPC - Under LA)
11	Nil	Nil	- Wound Dehiscence Distally	Pseudomonas	Nil (Dressing Only)
12	Nil	Nil	Nil	Nil	Nil
13	Nil	Nil	Nil	Nil	Nil
14	Nil	Nil	Nil	Nil	Nil
15	- Distal 3cm (<20%) Ischemia, Superficial Distal 3cm Loss	Nil	Nil	Klebsiella (MDR)	Debridement and Skin Grafting
16	Nil	- Graft Partial Loss (Infection)	Nil	Pseudomonas	Nil (Dressing Only)
17	Nil	Nil	Nil	Nil	Nil
18	Nil	Nil	Nil	Nil	Nil
19	Nil	- Graft Partial Loss (Hematoma)	- Exudate Discharge (2 weeks)	Nil	Nil (Dressing Only)
20	- Distal 4cm (<20%) Ischemia and Loss during delay Period	Nil	Nil	Nil	Debridement and flap transfer
%	- 80% without complications	85%	80%	- 30% infection incidence	- 20% (actually 5%) need intervention

Table (6): Outcome.

No.	Flap Outcome (Survival)	Flap Aesthetic	Donor-Site Outcome	Recipient Outcome (Defect Coverage)
1	Satisfied-Good	Satisfied-Good	Satisfied-Good (STSG)	Satisfied-Good
2	Satisfied-Fairly	Satisfied-Good	Satisfied-Good (STSG)	Satisfied-Fairly
3	Satisfied-Good	Satisfied-Good	Satisfied-Good (STSG)	Satisfied-Good
4	Satisfied-Fairly	Satisfied-Good	Satisfied-Good (Partial 1ry Closure + STSG)	Satisfied-Fairly
5	Satisfied-Good	Satisfied-Good	Satisfied-Good (STSG)	Satisfied-Good
6	Satisfied-Good	Satisfied-Good	Satisfied-Good (Partial 1ry Closure + STSG)	Satisfied-Good
7	Satisfied-Good	Satisfied-Good	Satisfied-Fairly (STSG), Heterogeneous Appearance, HTS	Satisfied-Good
8	Satisfied-Good	Satisfied-Good	Satisfied-Good (STSG)	Satisfied-Good
9	Satisfied-Good	Satisfied-Good	Satisfied-Good (STSG)	Satisfied-Good
10	Satisfied-Good	Satisfied-Good	Satisfied-Good (STSG)	Satisfied-Fairly
11	Satisfied-Good	Satisfied-Good	Satisfied-Good (STSG)	Satisfied-Good
12	Satisfied-Good	Satisfied-Good	Satisfied-Good (STSG)	Satisfied-Good
13	Satisfied-Good	Satisfied-Good	Satisfied-Good (Partial 1ry Closure + STSG)	Satisfied-Good
14	Satisfied-Good	Satisfied-Good	Satisfied-Good (Partial 1ry Closure + STSG)	Satisfied-Good
15	Satisfied-Fairly	Satisfied-Good	Satisfied-Fairly (STSG), Heterogeneous Appearance, HTS	Satisfied-Fairly
16	Satisfied-Good	Satisfied-Fairly {Bridge (Separated) Bulky (Debulked)}	Unsatisfied (Poor) (STSG), Heterogeneous Appearance, HTS	Satisfied-Good
17	Satisfied-Good	Satisfied-Good	Satisfied-Good (STSG)	Satisfied-Good
18	Satisfied-Good	Satisfied-Good	Satisfied-Good (STSG)	Satisfied-Good
19	Satisfied-Good	Satisfied-Fairly (Bulky)	Satisfied-Good (STSG)	Satisfied-Good
20	Unsatisfied (Poor)	Satisfied-Fairly {Bridge (Separated)}	Satisfied-Good (STSG)	Satisfied-Good
%	80% Satisfied-Good	85% Satisfied-Good	85% Satisfied-Good	100% successful coverage

*Satisfied-Good=Good and Smooth outcome.
Satisfied-Fairly=Fair outcome after difficulties.
**HTS=Hypertrophic Scar.

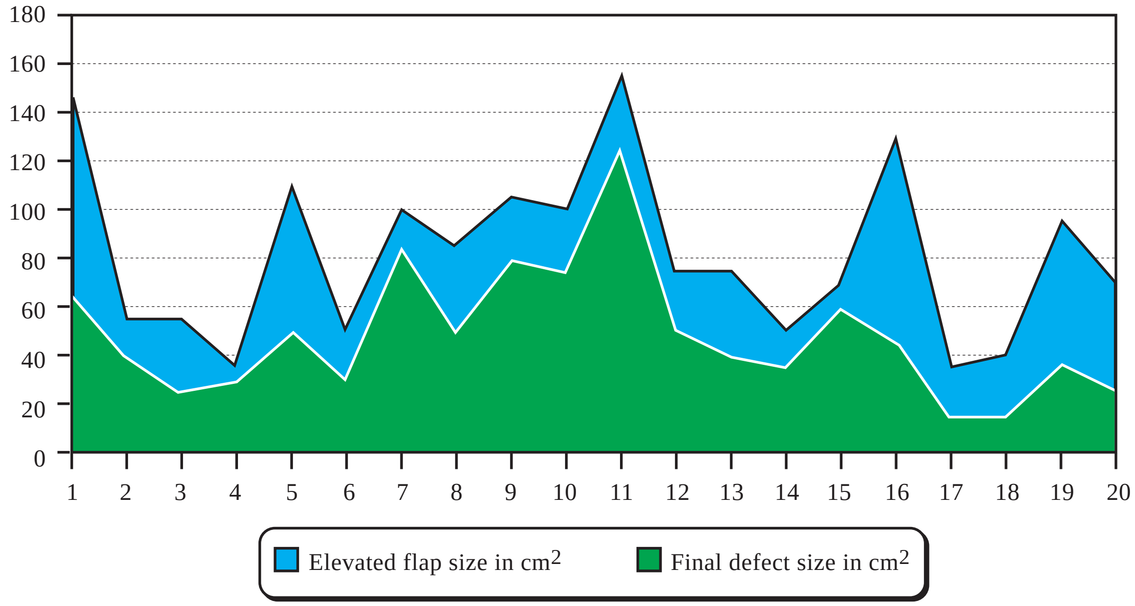

Fig. (1): Flap wastage-size.

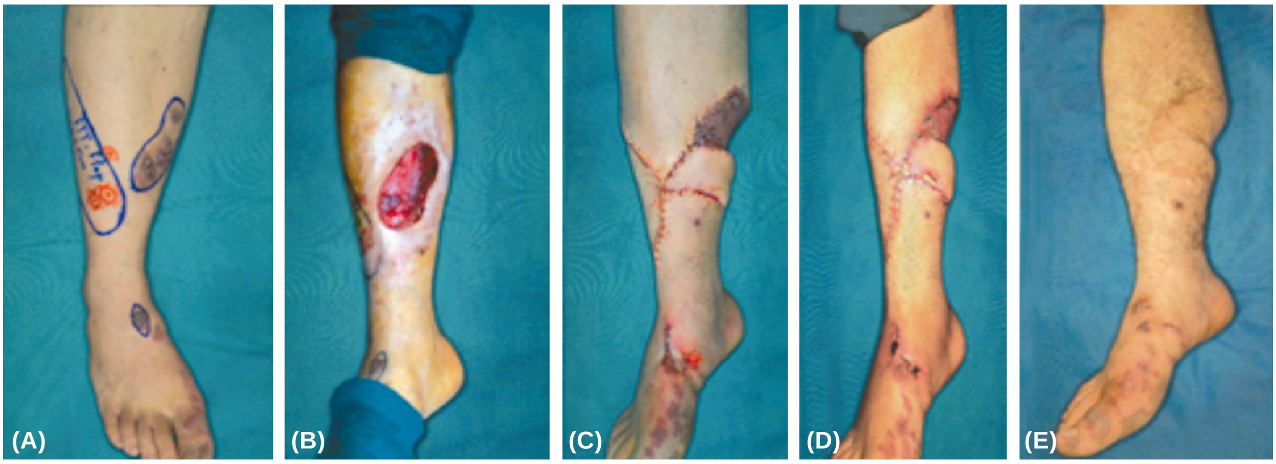

Fig. (2): Hemangioma case; (A) Hemangioma and flap design, (B) Defect post-excision, (C) Post-op defect and donor coverage, (D) Flap distal superficial loss, (E) Late follow-up showing complete healing and coverage.

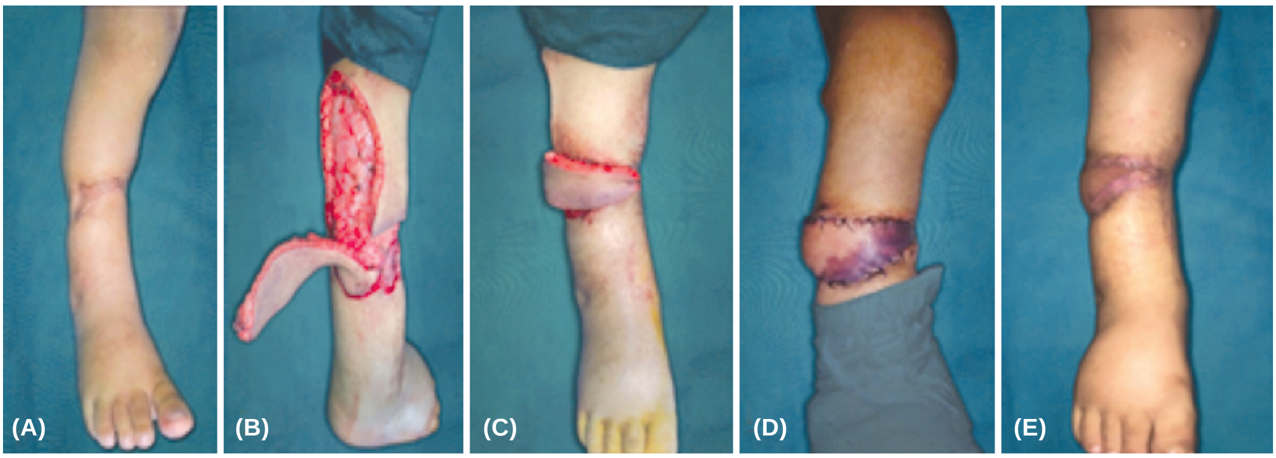

Fig. (3): Young boy case; (A) Contracted scar and leg deviation, (B) Intra-op flap elevation (Adipofascial bridge), (C) Flap transfer showing purple discolouration distally, (D) Early follow-up showing flap distal congestion, (E) Late follow-up showing complete healing and coverage.

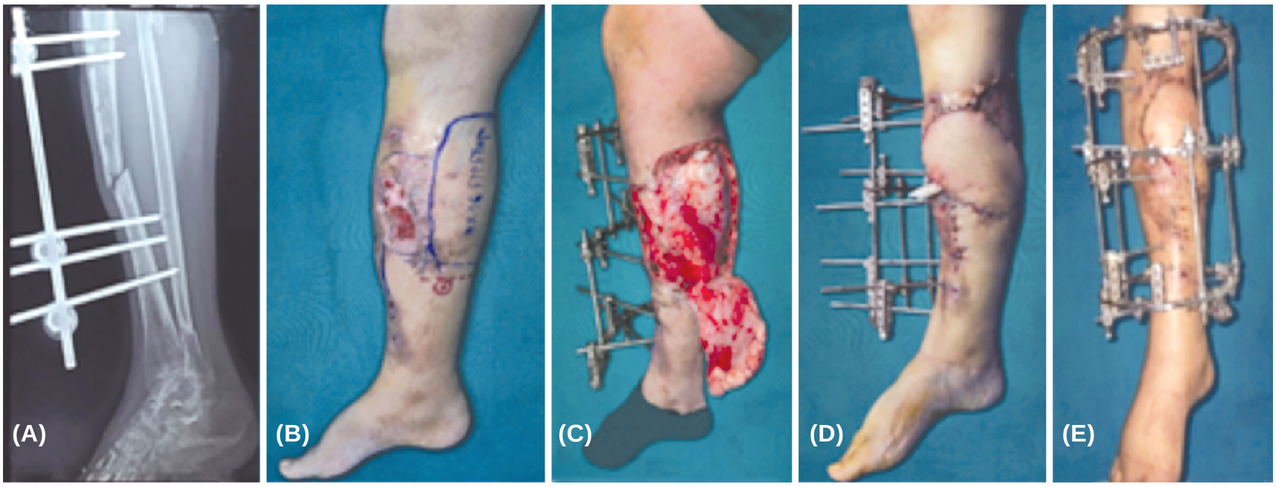

Fig. (4): Case No. 5; (A) X-ray showing tibial, fibula fracture and Ex. Fix, (B) Chronic wound, unstable scar and flap design post Ex. Fix removal, (C) Intra-op defect post-excision, flap elevation (Subfascial) and half-illizarov fixation, (D) Post-op defect and donor coverage, (E) Late follow-up showing good healing and contour of flap.

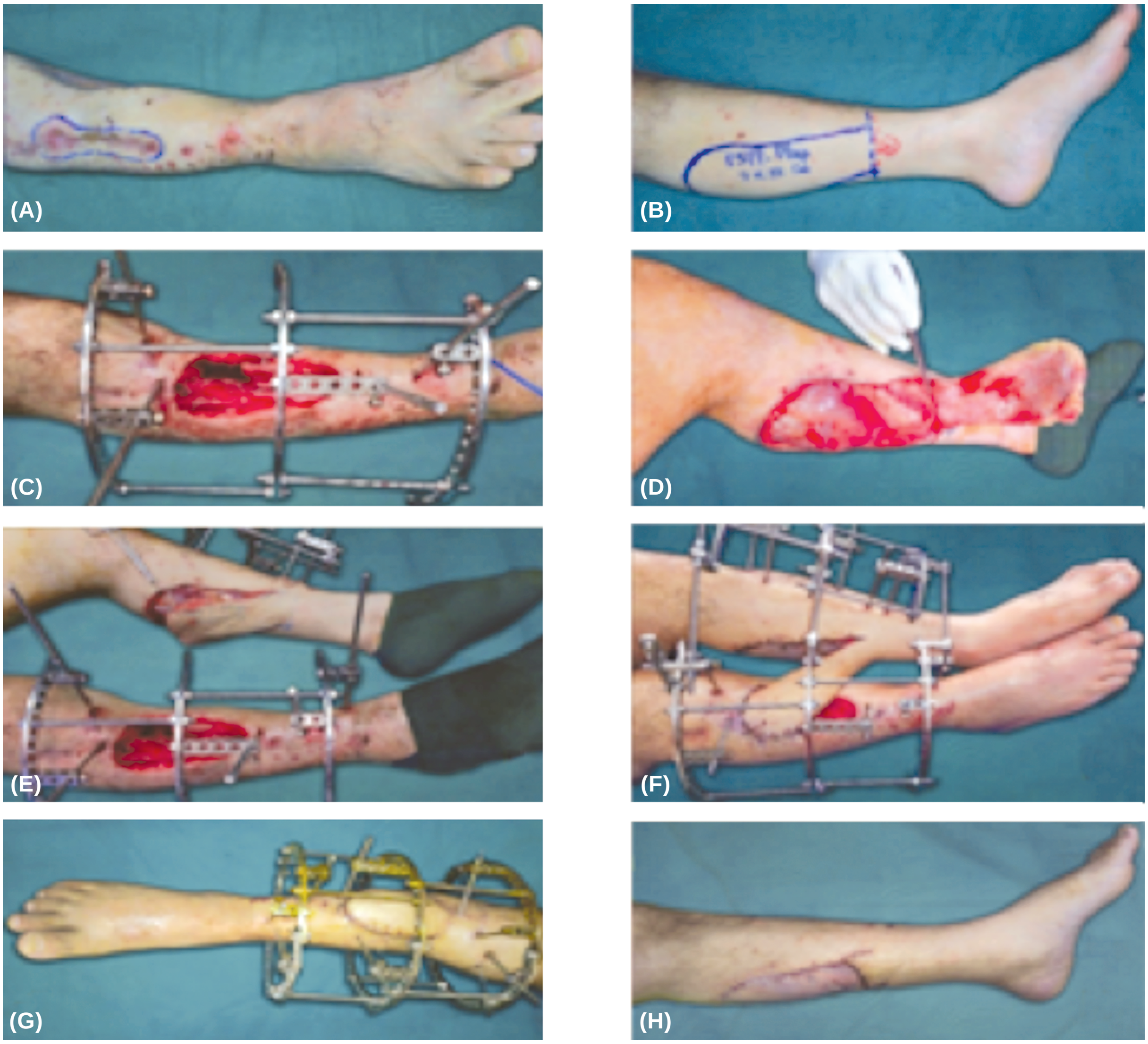

Fig. (5): Cross-leg Case No. 9; (A) Wound and unhealthy surrounding tissues, (B) Flap design in the contralateral leg, (C) Intra-op defect post-excision, bone debridement (segment loss) and half ilizarov fixation, (D) Intra-op flap elevation with forceps pointing to perforator, (E) Intra-op stage before flap insetting and fixation of both legs, (F) Early follow-up showing flap insetting and nice healing, (G) and (H) Late follow-up showing nice contour and healing for flap and donor site (also showing complete ilizarov for fixation and lengthening).

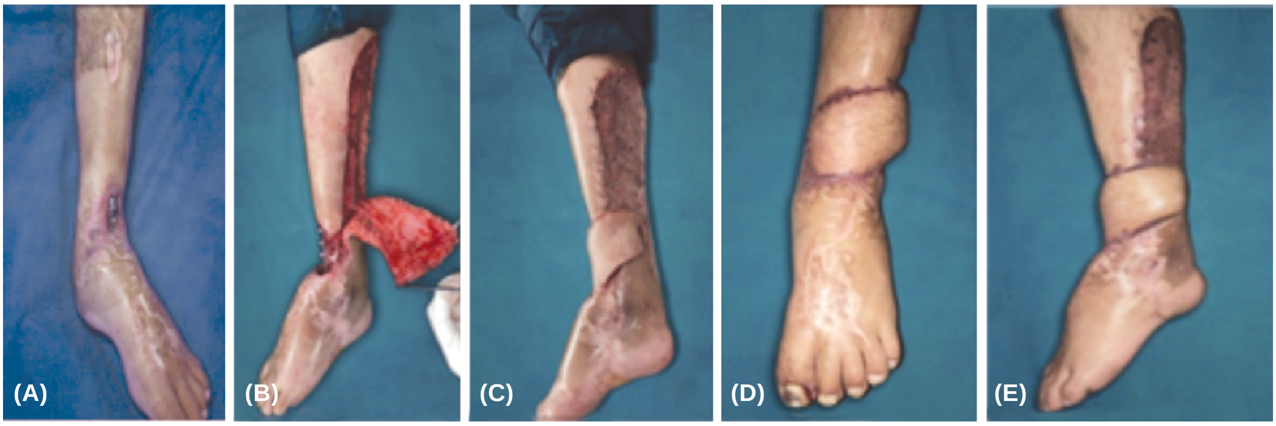

Fig. (6): Exposed hardware Case; (A) Exposed plate and screws, (B) Flap elevation, (C) Post-op flap transfer and donor STSG, (D) and (E) Late follow-up.

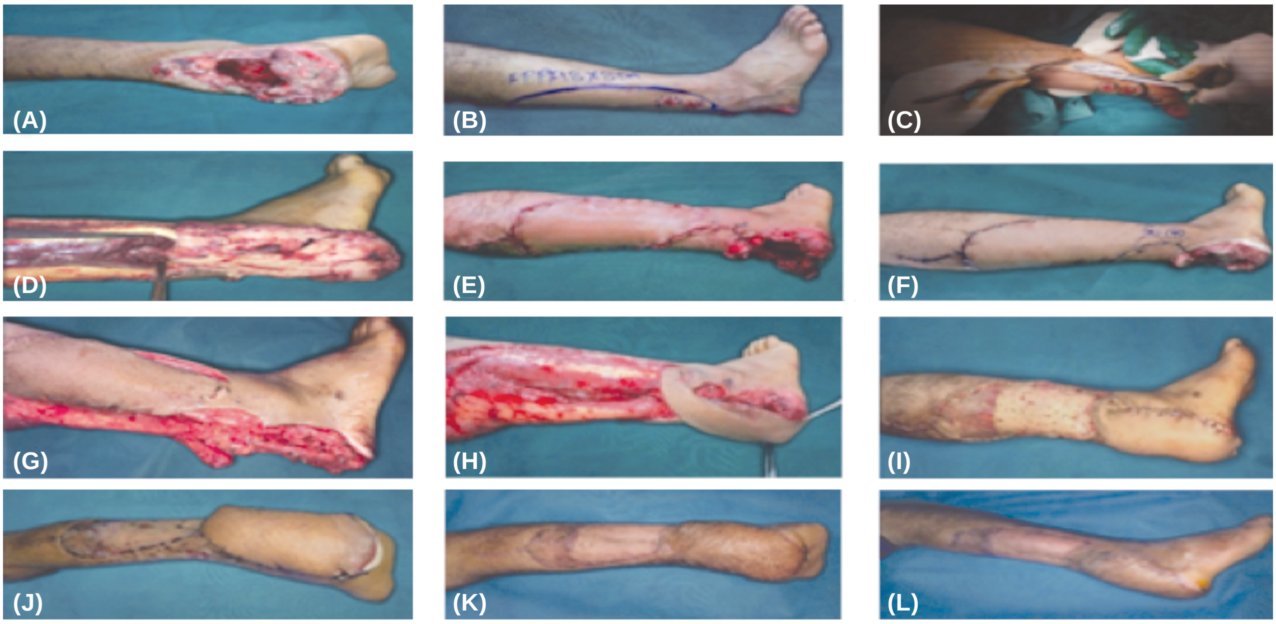

Fig. (7): Achilles Case No. 10; (A) Defect, (B) Perforator mapping and flap design, (C) Perforator exploration, (D) Forceps pointing to perforator, (E) Intra-op and (F) Late flap delay, (G) Achilles reconstruction with tendon fascia lata, (H) Flap rotation, (I) Flap transfer and donor site STSG, (J) Flap wound dehiscence distally, (K) Late follow-up showing complete nice healing and contouring for flap and donor site with no dog-ear deformity, (L) Side view.

Fig. (8): Case No. 16; (A) Medial ankle defect and flap design, (B) Intra-op flap elevation and defect post excision, (C) Post-op defect coverage and donor site STSG, (D) Donor site partial graft loss, (E) Post-op of falp separation and debulking, (F) Late follow-up post complete healing showing the fair accepted appearance of the donor site and flap.

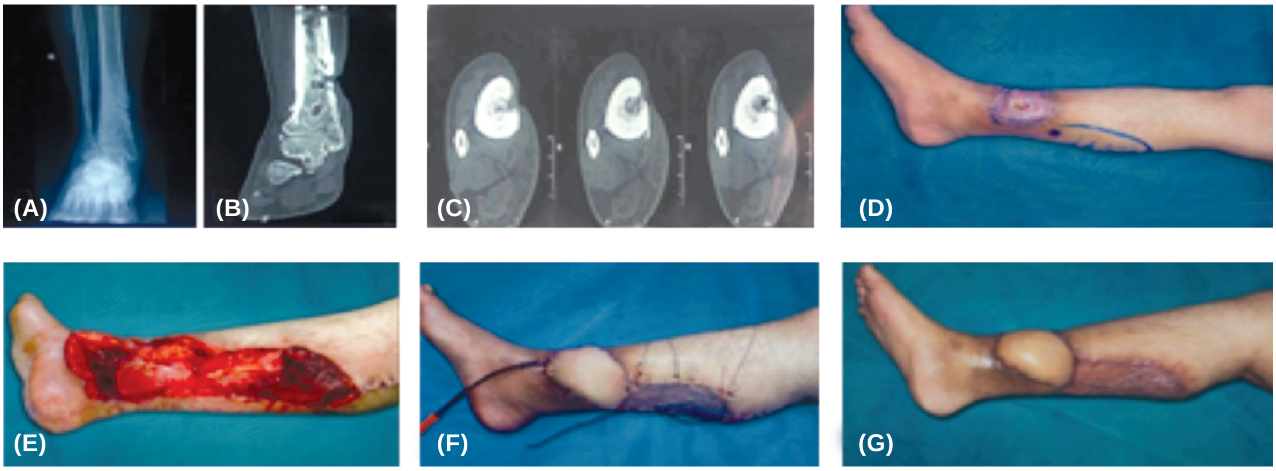

Fig. (9): Myo-cutaneous Case; (A) X-ray, (B) Axial CT, (C) Coronal CT showing superficial osteomyelitis, sinus and bone erosion, (D) Defect and flap design, (E) Myo-cutaneous flap elevation (part from the medial gastrocnemius muscle), (F) Post-op defect coverage and donor site STSG, (G) Donor site showing partial loss, (H) Late follow-up showing complete healing with donor site homogeneity and relatively bulky flap.

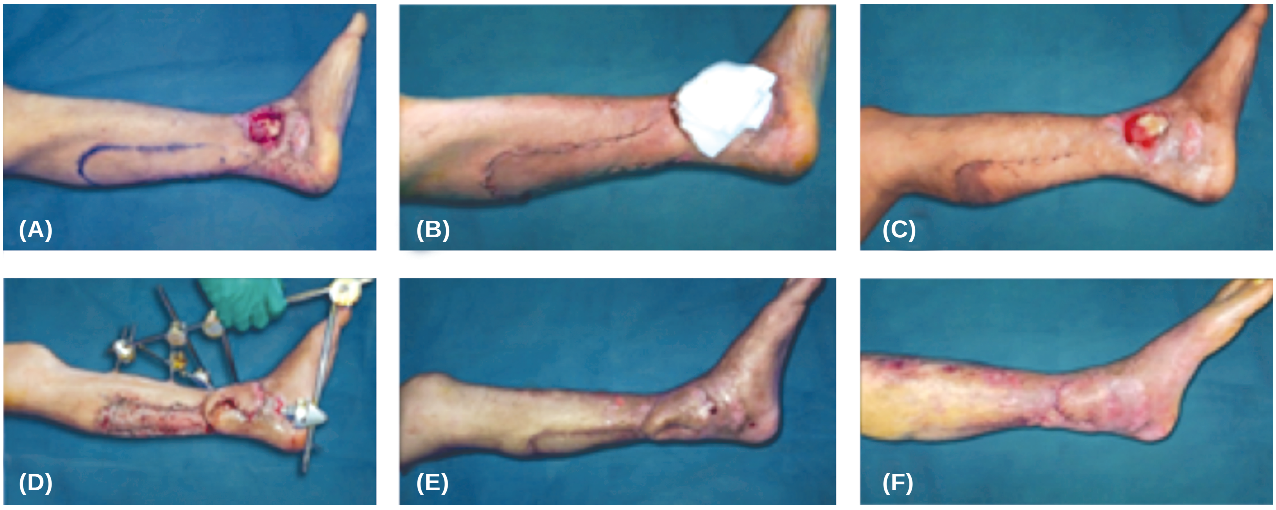

Fig. (10): Distal loss Case; (A) Perforators mapping and defect, (B) Flap design, post-op flap delay, (C) Distal flap ischemia and dark discolouration, (D) Post-op flap transfer, defect coverage and donor site STSG, (E) Post delta-frame fix removal and pre- flap separation, (F) Late follow-up showing coverage of the defect with good flap contouring.

DISCUSSION

Challenging conditions usually have multiple solutions, with no single standard method. And so, the lower leg region (including Achilles tendon and Ankle) has multiple management methods, every method has its advantages, disadvantages, and, consequently, its indications that arrange the superiority of one method over another. In reality, rather than the technique, the anatomical nature of this area is the cause of more reconstruction challenges. This nature also increases the reconstruction needs even with a small defect.

Flap reconstruction in this region is often hindered by perforator variability and venous congestion, especially with distally-based and pure perforator islands flaps. To overcome these challenges, we used the Free-Style, Perforator-Plus Flaps principles to reconstruct difficult complex defects, in 20 male patients.

According to the venosomes concept, **[21,22]** in the leg, there are 4 possible routes for integument venous drainage to the deep system: The valved superficial saphenous systems, perforator venae comitantes, venae comitantes, and the avalvular oscillating veins that interconnect them. Consequently, Perforator-Plus flaps enjoy more advantage with those possible 4 routes for drainage, when being proximally-based. Even, when being distally-based, when the saphenous venous systems are rendered unfavourable due to the retrograde valves, there would be a chance to pass these valves via the avalvular oscillating veins. The islanded pure perforator flaps, on the other hand, especially the propeller flaps, have only one possible route for venous drainage: Through the perforator venae comitantes.

Since the perforator flap depends exclusively on the perforating artery for arterial input and its vena comitans for venous output, the flap is at risk of vascular compromise if the pedicle twists, kinks, or is injured [23].

To solve this, the Perforator-Plus flap was 1st introduced by Mehrotra et al., [24] and came with key concepts to ensure that there is a perforator at the flap base that provides the main blood supply and ensuring the flap reliability and greater dimensions. Keeping the flap's base intact (skin or adipofascial bridge) as long as it reaches to defect without difficulty, not only protects the perforator from damage (during dissection), kinking, or twisting but also provides backup venous drainage (via the subcutaneous venous system and valveless oscillating veins) and potential random blood supply via the subdermal plexus's indirect linking-vessels. The presence of the perforator and the greater dimensions aid in more reach of the flap and flap base narrowing if needed.

In Perforator flaps, the significance of retaining the skin bridge at the base is still debated. Cavadas in 1997 [25] noticed that the pedicle can be elevated safely 2.0-2.5cm wide if the perforating vessel at the flap's base has been detected. In contrast, Mešić et al., [26] in their human-experimental study (patients subjected to elective abdominoplasty), noticed that converting a perforator flap with a skin bridge into an islanded perforator flap enhance the peripheral tissue perfusion: This was most likely owing to the “blood steal” from the perforator by the skin bridge. However, one of the major limitations of the study by Mešić et al., was that perfusion of the flaps was only measured at the time of surgery, with no comparison of final flap survival, leading to a lack of validity.

Zhuang et al., [23] in a rat-experimental study found no significant difference in flap necrosis between the islanded perforator and Perforator-Plus flaps, and both are equivalent in blood perfusion. Except for the 1st day, when perfusion of the islanded perforator flap was significantly greater than that of the Perforator-Plus flap.

Recently, Fang et al., [20] proved the importance of the intact bridge (in a rat-experimental study) and showed that there is no significant difference in perfusion pattern (immediately post-surgery time point) or ultimate flap survival between the islanded perforator and Perforator-Plus flaps. Indicating that the skin base at the Perforator-Plus flap's pedicle is not the 1ry pathway for arterial supply and venous drainage and that the perforating vascular pedicle takes the primary role for the flap vascularity if the perforator at the pedicle remains intact with no kinking or twisting. Gascoigne et al., [27] on the other hand, proved that hyperperfusion doesn't increase the islanded perforator flaps vascularity but open the arterio-venous shunts when pressure is increased.

Results analysis:

Presentation analysis: Overall, trauma and post-trauma sequelae were the most common aetiologies (85%). The vascular status was disturbed, in 3 cases, due to previous extensive trauma that left no sufficient healthy tissues (for locoregional flaps) or vessels (for the Free flap), these cases were managed by Cross-leg Flaps.

Ortho Status also contributed to the complexity of the reconstruction, it was free in only 2 cases (10%), Gustilo IIIB open fracture was encountered in 15% of cases, Chronic Osteomyelitis had affected 25% of cases, and 55% of cases (n=11/20) had a history of an old fracture. Overall, 40% of cases had an orthopaedic intervention concomitant with plastic surgery reconstruction.

Anaesthesia and patient position analysis: General anaesthesia was used only 7 times (22.5% from 31 operations) and the Prone position was used only in the 2 cases of the Tendo-Achilles injury; this facilitated the procedure and decreased the anaesthesia risk and cost.

Flap/reconstruction analysis: Flaps were designed with an intact skin bridge, and only in 2 cases, the skin was broken leaving only the adipofascial bridge, which allowed more reach of the flap without tension.

The designed flap widest-dimensions and real-size varied according to flap configuration. Elevated flap-size, also, decreased than that of the designed flap either due to skin retraction, design re-adjusting or both. Once more the Final flap-size was decreased due to flap-excess excision and tailoring, debridement of flap necrosis, or pedicle separation (Cross-leg and Interpolation cases).

The total flap wastage-size was measured by calculating the difference between the elevated flap and final defect sizes. This wastage reflected the excess flap size than the defect that trimmed, debrided, or returned to donor-site post pedicle separation. This wastage inversely represented the flap efficacy which ranged from 35 to 86% (Mean 60±18 SD %).

Flap length to narrowest flap reached 6:1 without flap complications in one case and with distal flap loss in another case. Flap narrowest-width reached to be 38% of the widest width (Mean 61±14 SD %). This allowed for a greater arc of rotation and flap reach.

Complications and outcome analysis: Dividing complications into majors and minors based on re-intervention or flap loss was found to be deceptive and subjective; distal flap loss sometimes is considered minor and sometimes lead to coverage failure and then should be considered major. The most logical outcome is whether or not the wound is adequately covered. Complications such as hematoma and infection may occur, but if the flap survived, they usually still had no effect on the final outcome.

As a result, complications in this study were divided into donor-site complications, flap complications, and complications that related to the recipient site. This was interpreted further as early post-operative complications and late outcome. The outcome also categorized into Satisfied-Good, detonating smooth reach to the desired result; Satisfied-Fairly, detonating difficult reach to the desired result with further time and/or intervention; and Unsatisfied (Poor) outcome.

The donor-site in 100% of cases was covered with Skin Graft (STSG); this was traced to the leg scanty nature to tissues, decreased tissues redundancy, and large areas being harvested. The donor-site showed a partial skin graft loss (15%), which was caused by an infection in 2 cases and hematoma in 1 case (Myo-Cutaneous case). Fortunately, skin re-grafting was performed during the flap pedicle separation in one case (Cross-leg Flap case), and dressing alone was sufficient in the other two cases.

Flap complications (20%) were represented by congestion in 2 cases (10%), which developed with a notable pattern being involved in the flap's distal tip and lower margin, resulted in a partial loss. This congestion that if maybe explained by delicate-adipofascial pedicle twist in a 3-years-old child, it couldn't be explained in the other case that had a relatively small-size flap.

Ischemia (10%) accounted for the other half of flap complications (2 cases). One case, (case No.15), suffered a partial distal loss, which may be explained by the smoking history, query limb vascularity, prior extensive trauma and the perforator's relative proximity to the defect. The other, (case No.20), experienced full-thickness distal loss (during the flap delay period), which may be explained by extensive trauma and the perforator's proximity to the defect, which may shift the perforasome one-step backward. The congestion-related partial loss was managed conservatively by dressings, while the ischemia-related partial loss formed dry eschar that debrided and covered by STSG. The full-thickness necrosis was debrided during the flap transfer stage (after 1-week of delay), and fortunately, with a minimal dissection flap reached to cover the defect without tension.

Flap's aesthetic outcome was Satisfied-Good in almost all patients, with homogenous contour with surroundings, except 3 cases (15%) that needed further pedicle separation (interpolation flaps) or debulking. Surprisingly, no dog-ear disfigurement was observed in either of the cases.

In the recipient site, complications (20%) were considered minors that managed by dressing only, with exception of one flap (Case No. 10) that needed re-approximation, which was done in the outpatient clinic under local anaesthesia effect.

Local wound infection was appeared in 6 cases (30%); 5 from the 6 cases (25%) had long hospital stay ≥21 days (including the 3 Cross-leg flap cases and the case of the post-acute firearm injury; 2 of them, (Case No.3 and 7), additionally, were had a complex injury Gustilo IIIB), the 5th case, (Case No.15), of the long hospital stay (klebsiella-MDR) was presented to us with the infection from outside the hospital (Infected Intra-Medullary Nail). All infection cases managed by frequent dressings and antibiotic course according to the culture and sensitivity (except the klebsiella-MDR, which was managed with frequent dressing only).

The desired final recipient-defect outcome was achieved successfully in 100% of cases, with only 20% that was Satisfied-Fairly. Fortunately, the flap survival outcome (15% Satisfied-Fairly and 5% Poor) didn't affect the defect coverage with failure.

Time Analysis: Delay before flap elevation, in acute and subacute cases (n=7), was ranged from 0 to 17 days (Mean 10±7 SD days). 2 of them, (Cases No. 7 and 14), were unstable (Post-RTA) and admitted to the ICU. The others showed unready wounds to coverage either due to complexity or infection. Only one, (Case No. 15), of the chronic cases, had a 21-day delay until flap elevation due to orthopaedic debridement and intervention.

31 operations were performed to the total 20 cases; only 1 of the 31 operations that was performed to manage a complication; the other 10 operations were performed either for defect management by debridement or flap work completion (as in flap delay, pedicle separation or flap debulking).

Total Operation/s time, for every case, ranged from 1.25 to 6 Hours (Mean 3±1.4 SD Hours). Flap-elevation mean time (starting from the exploration) was 40.5±13 SD Minutes. This detonating relatively short operation/s time and quick flap elevation time, even with un-experienced hands.

Hospital-stay mean was 13.6±12 SD Days, indicating a relatively short hospital stay and, as a result, a lower cost. Even there were 3 cases (15%) that managed on a "Day-case" basis.

Healing-time mean was 32±10 SD days, suggesting a reasonably fast recovery. And this was the rule except in the complicated cases (30%) and Cross-leg cases (15%) that revealed longer healing time.

A relatively long follow-up period (Mean 9.6±7.3 SD weeks) revealed no neural troublesome reporting by any patient at the donor-site or distally at the foot. In addition, no persistent oedema at the foot or ankle was reported.

Results in view of literature:

A- *Complications:*

We had flap-survival complication in 20% of cases, (10% congestion and 10% ischemia), which represented distal partial necrosis (15%) and distal full-thickness loss (5%). In the literature review of Free and Perforator Propeller flaps, we found that partial flap necrosis and venous congestion results were comparable to ours, with more increase in their complete failure rate and the needfor further surgery for complication management or further coverage.

Free flap, more recent microsurgical literature, cited failure rates from 1% to 9% **[28]**. In a retrospective analysis, Fischer et al., **[29]** revealed total flap failure in 5.9% of complex reconstructions of the lower limb utilizing Free flaps. Recently, Moullot et al., **[30]** in a single-centre, retrospective study of 47 patients with distal lower limb open fractures that managed with LD or ALT flaps, noted partial flap failure (2%), total flap failure (6%).

Innocenti et al., **[31]** studied 74 patients of lower limb reconstruction with Perforator Propeller flaps and reported that the most frequent complication was venous congestion (17%), and superficial necrosis (11%), while total flap failure was (1.5%). Schaverien et al., **[32]** performed 106 PTA-based Perforator Propeller flaps for lower leg, ankle, and foot coverage, and found a partial flap failure rate of 12% and complete failure in 8.5%. Shen et al., **[33]** reported reconstructions of the lower leg and heel region with 36 PA-based Perforator Propeller flaps, which showed venous congestion in 25% of cases and partial flap loss in 2 cases (5.6%).

Reverse Sural Artery Flap, also showed a near-similar complications rate, in a systematic review for Daar et al., **[6]** (43 studies, 479 patients, 481 flaps). Overall, they found 8.1% flap venous congestion, 15.4% partial flap loss, and 3.1% total flap loss.

B- *Further intervention:*

Innocenti et al., **[31]** in their study of Perforator Propeller flaps, showed 42% complications (n=28/66). Of the 28 complicated flaps, 64% healed with no further intervention, 29% had skin grafting, and 3% (n=2) required complex secondary surgery (free flap). Moullot et al., **[30]** using Free LD or ALT flaps, needed revision surgery for thrombosis 17%, where 6% (n=3) flaps were un-salvaged, and coverage was achieved, in two cases, using two longitudinal bi-pedicled fasciocutaneous flaps and in another case with an LD free flap.

In our study, we needed further intervention only in 20% of cases; 2 cases (10%) were managed during the flap transfer stage, one was managed at OPC, and only one needed intervention on a separate occasion. We didn't need any further flap coverage, as we had no complete flap failure or a flap failure that affected the defect coverage success.

C- *Donor-site closure and functional sequelae:*

Bekara et al., **[34]** in their meta-analysis of 428 perforator pedicled propeller flaps, found that the donor-site needed a skin graft coverage in 30.3% of the patients (n=67/221). In our study, due to the harvested relatively large surface area, we couldn't self-close the donor-site and all cases needed skin graft coverage. Less redundant tissues in the limbs influence not only the perforator patency and stability, resulting in flap complications but also donor-site repair methods. Due to a paucity of leftover soft tissue around the flap harvest site in the limbs, an extra skin graft is frequently required to close the donor-site.

Moullot et al., **[30]** using Free LD and ALT flaps, had 23% (n=11/47) secondary remodeling and 21.3% (n=10) functional donor-site sequelae (9 in LD group and 1 patient in the ALT group). In our study, we had no functional donor-site sequelae, and 2ry flap remodelling was needed for 3 cases 15% (2 already done), in the form of pedicle separation ± debulking.

D- *Free-style and perforator-plus flaps:*

Free-Style approach, especially in the lower limb, showing a tendency for more complications. Paik and Pyon [35] in their study of Free-Style Propeller Flaps (n=55) showed overall complete flap survival (81.8%). Flap survival complications (18.2%, n=10), included 12.7% flaps with superficial partial necrosis, 3.6% flaps with full-thickness distal necrosis, and 1.8% flap with total necrosis.

In addition, Qian et al., [36] found similar findings in their systematic review and meta-analysis of 17 articles, representing 453 Free-Style flaps (3.3% Free flaps, 96.7% pedicled flaps), where defects in the lower limb represented 21%. They found 91.8% complete flap survival; with 2 risk factors were identified, limb defects and single perforator flaps. There were no significant differences found across the following criteria: Age >60 years, gender, chronic aetiology, flap size >100 cm^2, perforator skeletonization, or flap rotation. Of all the limb defects repaired with Free-Style flaps, 21.4% experienced complications and 2.4% resulted in total necrosis.

When Lu et al., [37] evaluated 18 PA-based perforator flaps in the lower leg and foot, (11 propeller flaps and 7 were peninsular flaps (Perforator-Plus) and advancement flaps), they found that complications were seen almost entirely from the propeller flaps with venous congestion in 22% (n=4/18), flap tip congestion in one case (5.6%) and partial flap loss in one case (5.6%) that needed additional skin grafting.

Also, Rajkumar et al., [38] in their study of Perforator flaps (n=47) that were used in the reconstruction of the lower leg, foot, and ankle region, (27 Perforator Propeller flap and 20 Modified Perforator-Plus flap), they found 29.6% (n=8/28) of the traditional propeller and 5% (n=1/20) of the modified Perforator-Plus flaps were presented with complications. They found that the Modified Perforator-Plus flap group had a statistically significant lower venous congestion incidence. As a result, Rajkumar et al., [38] recommended the modified Perforator-Plus flaps as a more convenient solution to reconstruct foot and lower leg defects as they have a lesser complication rate than the traditional propeller flaps.

In another study, Yoon et al., [39] conducted a retrospective comparison of patients who had pressure sores reconstruction using Perforator-based island flaps versus Free-Style Perforator-Plus and reported that all flaps were totally survived in both groups. However, they noted that the Free-Style Perforator-Plus Flap had a simpler and faster technique than the perforator-based island flap.

With a similar technique "Free-Style Perforator-Plus Flap" we showed near similar results to Peng et al., [40] except for the names, as the Free-Style approach, in our study, was what so they called the "Anterograde-retrograde" approach in their study.

Peng et al., [40] retrospectively analyzed Distally-based PA Perforator-Plus Fasciocutaneous Flaps (DPAPF) (n=56) for the distal forefoot reconstruction. The patients' average age was 37.4 years (range, 2-81). Trauma was responsible for 87.5% (n=49/56) of the defects, while the non-traumatic causes included chronic osteomyelitis (n=6/56) and soft-tissue tumour (n=1, well-differentiated squamous cell carcinoma). Overall, they reported 84% complete flap survival, 16% flap partial necrosis, and no case of complete necrosis. 10.7% (n=6/56) of the remnant defects were successfully repaired using skin grafting, and in two other cases, the remnant defects were repaired with secondary suturing, with only one remnant defect (1.8%) was repaired using a local flap. Their reconstruction outcomes of the 48 flaps were excellent in 38 cases (79%), good in eight cases (16.7%), and fair in two cases (4.3%).

E- *Osteomyelitis:*

In our study, we successfully treated 5 cases (25%) of osteomyelitis, 3 cases (15%) of which were (Superficial/Stage2/Host Type-A) and 2 cases were (Localized/Stage3/Host Type-BL), according to Cierny-Mader classification. Persaud et al., [41] presented a systematic review of Reverse Sural Artery Flap for treatment of defects with underlying osteomyelitis and found a failure rate of 8.9% in 110 patients from 5 studies. Luo et al., [42]. Using Distally-based PA Perforator-Plus Fasciocutaneous (DPAPF) flaps, reconstructed soft tissue defects in the setting of chronic osteomyelitis in the lateral malleolus in 17 patients. Of the 17 flaps, 16 survived uneventfully, except one (5.9%) encountered partial necrosis, and the remnant defect was covered successfully by another local flap.

F- *Flap risk factors analysis:*

1- *Perforator system:*

Lese et al., [43] used Perforator Propeller flap (n=26) for reconstruction of traumatic defects at the distal leg, with 46% (n=12) flaps PTA-based, and 54% (n=14) flaps were PA-based. They noted 34% post-operative complications; 8% (n=1/12) were for PTA Flaps, and 57% (n=8/14) were for PA Flaps. All complications were managed non-surgically, but only 11.5% (n=3) needed revision surgery. In our study, we used the PTA 14 times (70%) and PA (20%) and ATA (10%). Flap complication was encountered in 3 cases of 14 PTA (21%) and 1 of 4 cases of PA (25%). Luo et al., [19] in a comparative study (227 patients) between Distally-based PA (DPAPF, n=150) and PTA (DPTAPF, n=82) Perforator-Plus Fasciocutaneous Flaps for the reconstruction of the lower limb, found that The DPAPF flap was superior to the DPTAPF flap in terms of reliability and decreased donor-site morbidity. The partial necrosis rate in the Peroneal group (15.3%, n=23/150) was lower than that in the Posterior Tibial group (19.5%, n=16/82), however, the difference was not statistically significant, except at the distal of the foot.

2- *Rotation angle:*

Gir et al., [44] in their systemic review found that the most common arc of rotation was 180° for propeller flaps, ranging from 70° to 180°. Bekara et al., [45] in their meta-analysis, found that the mean arc of rotation was 163.5º. Rajkumar et al., [38] found that the mean degree of rotation was significantly higher in the Modified Perforator-Plus Flap group (155°) than in the propeller flap group (137.6°). Paik and Pyon, [35] in their study of Free-Style Perforator Propeller flaps showed that complication rates were higher in flaps with the arc of rotation between 150 and 180 degrees, especially in limbs. In Our study, the rotation angle ranged from 25 to 160º (Mean 85±44 SD º), and of the 10 cases (50%) that showed rotation ≥90º, 5 cases (25%) showed complications at distal contact with the defect, in the form of flap distal partial loss or recipient wound dehiscence.

3- *Flap size:*

Chang et al., [46] proposed limiting the skin dimensions of a Free-Style flap based on a single perforator to 8cm by 20cm. Qian et al., [36] in their Systematic Review of 453 free-style flaps, with Free-Style flaps sizes mean 78.6 (±87.6 SD) cm^2, found that flap sizes >100cm^2 did not raise the risk of complication, suggesting that Free-Style flaps are appropriate for both major and small-to-moderate defects. In our study, designed flap sizes were ranged from 40 to 175cm^2 (Mean 93±41 SD cm^2); the complicated flaps (20%) sizes were <100cm^2 (ranged from 40 to 80cm^2), While 9 of the 20 flaps (45%) had a size ≥100cm^2, ranged from 100 to 175cm^2 (Mean 130±SD 26.7cm^2), yet showed no flap complications.

4- *Flap delay:*

In their Systematic Review of Reverse Sural Artery Flap, Daar et al., [6] found that both Partial and total flap loss rates in non-delayed and delayed flaps were not significantly different. In our study, one delayed flap survived completely, while another delayed flap suffered from distal full-thickness loss, but the waiting aid in demarcation that later was debrided and the flap was transferred to cover the defect successfully.

5- *Dynamic nature:*

Based on the perforators of the Anterior Tibial, Posterior Tibial, and Peroneal vessels, a variety of perforator flaps have been described. As of now, there are no studies, guidelines nor mathematical rules to define the safe extent of the perforator flap. The undoubted ability of any single perforator to supply a perforator flap, sufficiently, is understood only after flap complete elevation and tourniquet release. As a result, predicting the size of the skin area vascularized by a single perforator is difficult or impossible [31].

Despite its high flow and robustness, a very large perforator may fail to supply a flap positioned away from its Perforasome [47]. The survival of a flap is influenced by the anastomotic vessels between perforasomes, either choke (unfavourable) or true (favourable) anastomoses on the arterial side (arterial perforasomes); valves arrangement and valveless oscillating veins on the venous side (venous Perforasomes); and indeed on the unpredictable dynamic nature of these vessels and accordingly the perforasomes.

G- Time analysis.

I- *Operation time:*

In Wong et al., [28] study, Free flap have an operative time mean of 478.6±239 SD min. While Perforator flaps (Propeller and V-Y advancement), in Brunetti et al., [48] study, have a mean operative time of 140min (range, 60-240 min). In Dhamangaonkar and Patankar study [49] of Perforator-Plus Reverse Sural Fasciocutaneous flap to cover distal lower limb soft-tissue defects, they had a mean duration of surgery 121.29±31.16min, (including defect preparation, flap elevation, viability verification, re-scrubbing and draping for the skin graft donor-area, and skin grafting), with the mean time to elevate the flap alone being 34.24±9.34min. Peng et al., [40] had 33min mean flap elevation-time for the Distally-based PA Perforator Plus Flaps.

In our study, we had Total Operation/Operations time for every case ranged from 75 to 360 Minutes (Mean 183±86.6 SD Min), and in hours presentation ranged from 1.25 to 6 Hours (Mean 3±1.4 SD Hours). Operation time included orthopaedic work (if there), and plastic work including defect management, flap elevation and insetting, donor-site management (STSG ± partial 1ry closure), and other reconstruction (if there). Flap elevation time (starting from the exploration) was ranged from 30 to 60 Minutes (Mean 40.5±13 SD Minutes). The ratio of flap elevation time to total operating time ranged from 1:2.5 (40%) to 1:11 (9%) (Median 29%, Mean 26±10 SD %). Because of the reduced operating time, anaesthesia was often shorter and less invasive.

II- *Hospitalization time:*

In Moullot et al., [30] study, the mean hospital stay for free flaps was 24 days. According to Lese et al., [43] the mean hospital stay for Perforator Propeller flaps was 11.2±3.6 days (range from 7 to 23), with patients who had post-operative complications requiring more weeks until complete healing and staying in the hospital longer. Free-style Perforator-Plus of Yoon et al., [39] for pressure sore reconstruction, had a mean hospital-stay of 20.1±2.62 SD days (range: 18-26 days) in comparison to perforator-based island flaps mean 22.9± 5.25 SD days (range: 18-35 days). In our study, the Hospital-stay mean was 13.6±12 SD Days.

III- *Healing time:*

Lese et al., [43] in their study showed a mean healing-time of 5.9 weeks (range, 2 to 32 weeks). Demiri et al., [50] in their retrospective comparative study between Reverse neuro-cutaneous (Reverse Sural and Lateral Supramalleolar) versus Perforator Propeller flaps for reconstruction of diabetic wounds at foot and ankle, had a mean healing-time of 48.1 (6.9 weeks) for neurocutaneous and 40.7 (5.8 weeks) days for Perforator Propeller flaps. Our mean healing time was 4.55 weeks ± 1.4 SD, with a range of 3 to 8 weeks; in days-presentation, the Healing-time mean was 32±10 SD days.

Conclusion:

The Free-Style, Perforator-Plus Flap is reliable with relative efficiency, versatile, and has a modest rate of failure and need for secondary surgery. Capable to reconstruct small to relatively large, complex defects (exposed bone or hardware and chronic osteomyelitis) in the distal Leg two-thirds, Tendo-Achilles, and Ankle regions. The Flap has a higher degree arc of rotation, replaces like with like, with less donor-site morbidity, and satisfying aesthetic appearance. The procedure, on the other hand, is relatively easy-can be performed with a resident plastic surgeon-with minimal need for perforator dissection, and no need for microvascular anastomosis or special facilities. Besides, the smooth post-operative follow-up, the less need for general anaesthesia, and the relatively short operation and hospital stay make the procedure being cost-effective.

Study limitations:

One of the limitations of this study was that the used images were not perfectly standardized; another limitation was the size of the study population. Moreover, it was an observational uncomparative study. This makes further studies are inevitable.

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Conflicts of interest:

There are no conflicts of interest.

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