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Role of Perforator Flaps in Leg and Foot Reconstruction

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ABSTRACT
Background: Lower extremity wounds have been always a challenge for reconstructive surgeons. Free perforator flaps are considered to be the best option for this problem but require the complexity of microsurgery. So, pedicled perforator flaps have emerged as an alternative option. The aim of the present study is the assessment of efficacy of perforator flaps (either free flaps or pedicled flaps) regarding the coverage of traumatic soft tissue defects on the leg and foot.
Patients and methods: A prospective study was conducted upon 40 patients with traumatic soft tissue defects in the leg and foot. The free flaps used were anterolateral thigh flap (ALT) and medial sural artery perforator flap (MSAP). In pedicled perforator flaps group, 10 cases were designed as propeller flaps, while the other 10 flaps were designed as perforator plus flaps. **Results:** Free flaps were mainly used for large sized defects; one case of partial flap loss and one case of complete flap necrosis. MSAP flap was the first option for coverage of large sized defects on foot and ankle as it's a thin and pliable flap, while ALT flap was used for coverage of larger defects on the leg. Pedicled perforator flaps were used mainly for small to medium-sized defects especially in the lower third of the leg; we had 3 cases of flap loss in propeller flap design while we had no cases of flap loss in perforator plus flap.
Conclusion: Perforator flaps have become a reasonable solution for soft tissue defects of the lower extremity. Careful assessment of the dimensions, location, patient comorbidities, availability of surrounding soft tissue and presence of adequate perforators are mandatory for proper perforator flap selection.
Keywords: Perforatr flap, Propeller flap, Perforaror plus flap, Anterolateral thigh flap, Medial sural artery peforator flap.

INTRODUCTION
Many severe lower extremity injuries that were formerly thought to be deadly can now be saved thanks to advances in trauma management technology [(1)].

Reconstructive surgeons have traditionally struggled with instances involving soft tissue lesions in the lower extremity, especially in the distal section of the leg since local flaps in this area are unreliable [(2)].

The angiosome was first described by **Taylor and Palmer** [(3)] as a three-dimensional vascular region supplied by an artery and a vein through branches for all the tissue layers between the skin and the bone, and showed that also demonstrated that there are numerous choked and true anastomotic arteries between the angiosomes [(3)]. The era of perforator flaps has begun following this evolution and as a result of the publications made by **Koshima and Soeda** [(4)] and **Kroll and Rosenfield** [(5)] in 1989, respectively.

Perforator vessels are the flaps where the blood vessel that supplies blood to the skin passes through the fascia that lies on top and covers the muscles where the source artery is deep [(6)].

The aim of the current study is the assessment of efficacy of perforator flaps (either free flaps or pedicled flaps) regarding the coverage of traumatic soft tissue defects on the leg and foot.

PATIENTS AND METHODS
This prospective study was carried out on 40 patients with traumatic soft tissue defects in the leg and foot with or without bone injury who were admitted in the Hand & Microsurgery Unit and the Plastic Surgery Department, Assiut University Hospital, Assiut University, between September 2017 and August 2019.

All polytraumatized patients with poor general condition and disturbance of conscious level were excluded from the study. Also, patients with chronic debilitating diseases like chronic renal failure and liver cell failure were excluded from the study.

The patients were divided into: *Group I* included 20 patients were managed by free perforator flap, 14 patients were treated with anterolateral thigh flap (ALT) and 6 patients were treated by medial sural artery perforator flap (MSAP), and *Group II* included 20 patients managed by pedicled perforator flap, 10 flaps were designed as propeller flaps while the other 10 flaps were designed as perforator plus flaps. Anterior tibial artery perforator flap, peroneal artery perforator flap, and posterior tibial artery perforator flap were the pedicled flaps.

Personal and medical histories details were taken from every patient. Careful local examination for any vascular injury, neurological deficit, bone fracture, size of the defect, and the condition of nearby soft tissues was done.

Surgical debridement with removal of all foreign bodies, necrotic muscle and dead bone with subsequent regular dressing was done for heavily contaminated and major sized wounds for successful control of infection, while surgical debridement with primary coverage was done for mild contaminated and small sized wounds.

Skeletal stability and repair of any vascular insult of the injured limb was achieved firstly. The type of flap was decided according to the site and size of the defect,

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the state of surrounding perforators and condition of the nearby tissues.

Microsurgical tools and magnifying loupes (3.5 – 4.0x) were used during the procedures. Perforator vessels were found around the donor site using an 8 MHz handheld Ultrasound Doppler. Following the perforator's discovery, the flap was constructed around it (or around the perforators in the event of a free flap) taking into account the defect's size and placement.

Without first exsanguinating the patient, a tourniquet was inflated, making it easier to identify the perforators because they are still engorged with blood. The perforator vascular is clearly visible following an exploratory incision made along the flap's edge into the skin, subcutaneous tissue, and deep fascia (sub-fascial approach). To correctly locate the perforator, the flap was always cut just on one side.

Meticulous dissection was done to the perforator with adequate release of any facial strands around it (to facilitate rotation of the flap without any kinking or constriction to the perforator in pedicled flaps) and dissection around the perforator in intermuscular or intramuscular plane was done. After deflation of the tourniquet, haemostasis was performed and viability of flap was evaluated.Microvascular anastomosis for one artery and one or two accompanying veins was performed in free perforator flaps under the operating microscope. Prior to the flap being inserted over the defect after anastomosis, rapid bleeding from the margin was detected.

In pedicled perforator flaps, 10 cases were designed as propeller flap where complete freeing of the edges of the flap was done with rotation of the flap around the perforator from 90 to 180 degrees, the other 10 flaps were designed as perforator plus flaps where the base of the flap was not incised and kept in place.

A negative suction drain was inserted under all the flaps (both free and pedicled perforator flaps).

The donor site was either covered with a split thickness skin graft harvested from the thigh or closed primarily according to the size.

Leg elevation, adequate hydration of the patient and maintenance of average blood pressure and temperature (to prevent spasm of the vessels) are critical for the first post-operative 48 hours.

Clinical monitoring of the flap to detect intrinsic vascular problems (vasospasm) as well as extrinsic causes of perfusion compromise (hematoma, seroma, tight stitches due to subsequent edema and external pressure) is essential for the patient’s successful outcome. The flap was monitored each hour during the first 24 hours and every 2 hours for the next 24 hour.

Careful follow up of the drain for any possible bleeding and hematoma formation, removal of the drain was done when the content of the drain less than 30cc serosanginous in 24 hours.

The first skin graft dressing is usually performed on the 5th postoperative day and flap sutures are removed on the 14th postoperative day.

Follow-up was done after one week, two weeks and one month postoperative.

Postoperative evaluation parameters were: (a) Flap viability was monitored regarding color, temperature, capillary refilling and congestion. (b) Donor site morbidity. (c) Overall aesthetic appearance of the flap which was evaluated by two plastic surgeons. (d) Duration of hospital stay. (e) Time to heal. (f) Presence or absence of complications (partial or complete flap loss, dehiscence, seroma, hematoma and infection).

Ethical considerations:

This study was approved by the Medical Ethics Committee of the Faculty of Medicine at Assiut University. Informed consent was obtained from each patient. This work was conducted in accordance with the Code of Good Practice and the guidelines of Declaration of Helsinki.

Statistical analysis

Our data are expressed as mean (SD) or median (range) in case of continuous data while nominal data are present as frequency (percentage).No comparsion was done, so no test was used.

RESULTS

Age and sex of the patients (patient demographics):

Mean age of patients was 21.5 years with range between 6 and 52 years the age groups were as the following; 6-10 years: 14 patients (35%), 11-20 years: 8 patients (20%), 21-30 years: 12 patients (30%), 31-40 years: 4 patients (10%) and 41-52 years: 2 patients (5%). Most of the patients were males (N 30; 75%) while female patients represented only one-fourth of the will sample (N 10; 25%).

A) Data of Group I (free perforator flap):

Only 4 patients were smokers. One case has chronic corticosteroids therapy for 10 years. Male patients were 14 cases, while 6 patients were females. In majority of patients (N 18), road traffic accidents were the major cause of defects while each of post-traumatic chronic ulcer and post-traumatic contracture were presented in 1 patient for each. Size of defects ranged between 11×5 cm and 33×16 cm. Dorsum of foot alone was affected in 6 patients, dorsum of foot with lower third was affected in 8 patients, lower third alone was affected in 3 patients, while middle and upper thirds were affected in 2 patients. It was noticed that sole of foot was affected in only one case **(Table 1)**.

Table (1): Characteristics of patients of group I (free perforator flap).

Variable	N=20
Smoking	4 (20%)
Sex	
Male	14 (70%)
Female	6 (30%)
Mode of trauma	
Road traffic accident	18 (90%)
Post-traumatic chronic ulcer	1 (5%)
Post-traumatic contracture	1 (5%)
Size of the defects (Range)	11×5 cm - 33×16 cm
Site of defects	
Dorsum of foot only	6 (30%)
Dorsum of foot with lower third of foot	8 (40%)
Lower third only	3 (15%)
Middle and upper thirds	2 (10%)
Sole of the foot	1 (5%)

Median duration of surgery in this group was 6 hours with range between 3 and 10 hours. ALT flaps were used in 14 patients, while we used medial sural flaps in 6 patients on dorsum of foot and ankle only. One venous anastomosis was done in 7 patients (5 with great saphenous vein, one with ant tibial vein and one with post tibial vein) while two venous anastomoses were done in 13 patients. In ALT flaps, 9 cases were elevated depending on one perforator and 5 cases on two perforators, while in MSAP flaps there were 2 cases elevated depending on one perforator and 4 cases on two perforators. In ALT flaps, the perforators had a septocutaneous course in 3 cases and a musculocutaneous course in 11 cases, while in MSAP flaps the course of the perforators were musculocutaneous in all the cases **(Table 2)**.

Table (2): Operative data of group I (free perforator flap).

Variable	N=20
Duration of operation (Hours)	
Average	6
Range	10-Mar
Type of flap	
ALT	14 (70%)
MSAP	6 (30%)
Number of venous anastomosis	
One	7 (35%)
Two	13 (65%)
Number of perforators	
ALT	
One	9 (45%)
Two	5 (25%)
MSAP	
One	2 (10%)
Two	4 (20%)
Type of perforators	
ALT	
S eptocutaneous	3 (15%)
Musculocutaneous	11 (55%)
MSAP	
Musculocutaneous	6 (30%) (all of them)

It was noticed that venous congestion has occurred in 2 patients (one perforator, two veins anastomosis) who was managed by leg elevation, warm blanket and local creams with subsequent spontaneous improvement in color without any secondary intervention.

Partial flap loss has occurred due to arterial ischemia in one case (in case of chronic use of corticosteroid, with two perforators and two venous anastomoses), and total flap loss occurred in 1 case (smoker, one perforator and two venous anastomoses) despite secondary intervention. Infection with subsequent dehiscence occurred in only one case which was managed by dressings and secondary stitches, while there were no cases complicated by hematoma or seroma. The one case of partial flap loss healed by secondary intention and didn't need split thickness skin graft (STSG). In case of total flap loss the wound was managed by VAC (Vacuum assisted closure with subsequent STSG.

Range of hospital stay was between 12 and 30 days with median stay was 14 days, while range of wound healing was between 10 and 30 days with median duration was 14 days (there was a delay in wound healing in smoker patients and in the patient on with chronic use of corticosteroid). In 19 cases the donor site needed STSG while only in one case (MSAP) the donor site was closed primarily. All cases of ALT flaps (male and female) needed another session of debulking except 2 cases (thin adult male patients), while no cases of MSAP needed debulking.

Table (3): Outcome of group I (free perforator flap).

Variable	N= 20
Complete flap survival	18
ALT (14)	12
Perforator plus flap (6)	6
Complications	
Venous congestion (reversible)	2
Partial flap loss	1
Total flap loss	1
Infection & dehiescence	1
Haematoma or seroma	0
Split thickness skin graft over flap loss	1
Donor Site	
STSG	19
Closed primarly	1
Duration of hospital stay (day)	
Range	12-30
Average	14
Duration of wound healing (day)	
Range	10-30
Average	14
Aesthetic appearance	
ALT	
Accepted	2
Need for debulking	12
MSAP	
Accepted	6
Need for debuking	0

B) Data of Group II (pedicled perforator flap):

Only 2 patients were smokers. 16 patients were males, while 4 patients were females. Mean age of patients in this group was 25.5 years with range between 6 and 52 years the patients were distributed to the age groups as the following; 6-10 years: 4 patients, 11-20 years: 4 patients, 21-30 years: 6 patients, 31-40 years: 2 patients and 41-52 years: 4 patients. In majority of patients (N 15, 75%), road traffic accidents were the major cause of defects while post-traumatic chronic ulcer presented in 3 patients and fire arm injury was the cause in 2 patients. Only two patients were smokers. Size of defects ranged between 3×4 cm and 11×6 cm. Lower third of leg was commonly affected in 11 patients followed by dorsum of foot and ankle joint which is affected in 5 patients, middle third of foot which is affected in 4 patients.

Table (4): Patient characteristics of group II (pedicled perforator flap).

Variable	N= 20
Smoking	2 (10%)
Sex	
Males	16 (80%)
Females	4 (20%)
Age	
Range	6-52
Mean	25.5
Mode of trauma	
Road traffic accident	15 (75%)
Post-traumatic ulcer	3 (15%)
FAI	2 (10%)
Size of defects (Range)	3×4 cm - 11×6 cm
Site of defects	
Lower third of leg	11 (55%)
Dorsum of foot and ankle	5 (25%)
Middle third of leg	4 (20%)

Median duration of surgery in this group was 1.5 hour with range between 1 hour and 2.5 hours. 10 cases were designed as propeller flaps, while the other 10 cases were designed as perforator plus flaps. In 10, 7, and 3 patients, the perforator emerged from post-tibial artery, peroneal artery and ant-tibial artery, respectively. The distance of the perforators above medial malleolus ranged between 4 and 12 cm from it, while above lateral malleolus it ranged between 3 cm and 7 cm.

Table (5): Operative data of group II (pedicled perforator flap).

Variable	N= 20
Duration of operation	
(Hours)	1.5
Average	1-2.5
Range	
Type of perforator	
Post-tibial	10
Peroneal	7
Ant-tibial	3
Site of perforator	
Above medial malleolus	
(post tibial)	1
12 cm	3
8 cm	6
4 cm	
Above lateral malleolus	
(peroneal & ant tibial)	2
7 cm	8
3 cm	

There were no cases of venous congestion, partial flap loss or total flap loss occurred in perforator plus flaps. In propeller flaps while there were 3 cases of venous congestion with subsequent 1case and 2 cases of partial and complete flap loss respectively, despite using conservative measures. There were no reported cases of infection or hematoma formation in this group.

In 19 cases the donor site needed STSG while only in one case (propeller flap) the donor site was closed primarily. In 12 patients, the flap had accepted aesthetic outcome while 8 patients, all of them were perforator plus flap, required debulking. Range of hospital stay was between 2 and 15 days with median stay was 4 days. Range of wound healing was between 10 and 21 days with median duration was 14 days.

Table (6): Outcome of group II (pedicled perforator flap).

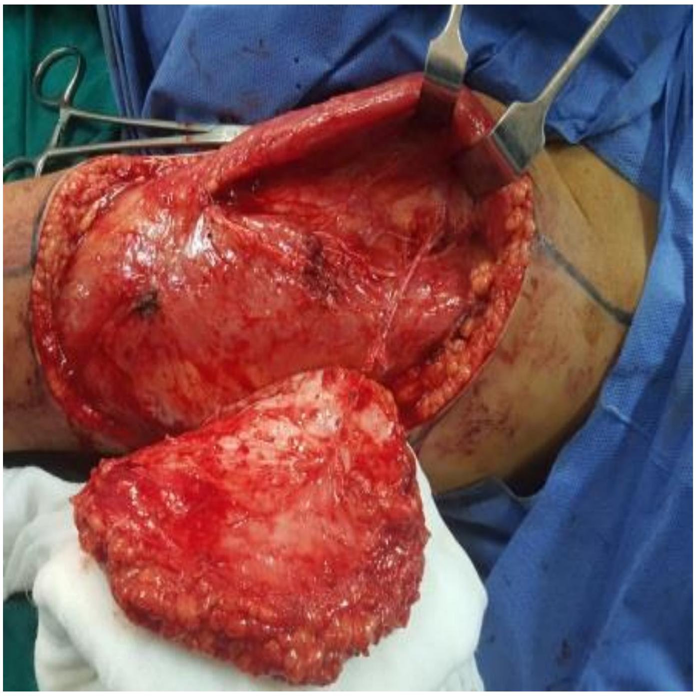
Variable	N= 20
Complete flap survival	17
Propeller flaps (10)	7
Perforator plus flaps (10)	10
Venous congestion	3
Propeller flaps (10)	3
Perforator plus flap (10)	0
Partial flap loss	1
Proeller flaps	1
Perforator plus flaps	0
Total flap loss	2
Propeller flaps	2
Perforator plus flaps	0
Infetion & dehiescenc	0
Haematoma & seroma	0
Split thickness skin graft over flap loss	3
Donor Site	
STSG	19
Closed primarily	1
Aesthetic appearance	
Propeller flaps (10)	
Accepted	10
Need for debulking	0
Perforator plus flaps	
(10)	2
Accepted	8
Need for debulking	
Duration of hospital stay (day)	
Average	4
Range	2-15
Duration of wound healing (day)	
Average	14
Range	10-21

Group I (Free flaps)

Figure (1): ALT flap.

A) Post traumatic raw area at lower third of leg and dorsum of the foot.

C) Post operative follow up showing bulky flap.



B) ALT flap elevation with one perforator.

D) After 2nd stage debulking

Figure (2): Medial sural artery perforator flap

A) P.T raw area at the dorsum of foot.

B) Design of medial sural artery perforator flap.

C) Flap elevation & intramuscular dissection for two perforators.

D) Follow up of medial sural artery perforator flap.

E) MSAP with one perforator show in the pedicle's length up to 11cm (another case).

F) Post-operative follow up showing complete flap survival.

Group II (Pedicled flaps)

Figure (3): Propeller flap

A) P.T raw area & design of posterior tibial artery propeller flap after detection of the perforator preoperatively.

B) Elevation of the flap with complete skeletonization of the perforator is mandatory for better flap survival with complete freeing of the edges of the flap.

C) Postoperative follow up, showing good flap survival and primary closure of the donor site.

Figure (4): Perforator plus flap

A) P.T chronic ulcer at lateral malleolus & design of perforator plus flap.

B) Complete isolation of the perforator and elevation of peninsular fasciocutaneous flap.

C) Postoperative follow-up showing good flap survival & closure of the defect by STSG.

D) P.T raw area at dorsum of foot and elevation of peroneal artery perforator plus flap, which its length is more than one third of the leg.

E) 5 days postoperative showing good viability of the flap with dog ear deformity at the distal part of the flap

F) 2nd stage debulking.

DISCUSSION

Traumatic soft tissue loss of the lower limb is a common problem in young age, especially males, in Upper Egypt as we demonstrated in our study that the majority of cases (85%) were between 6 years old and 30 years old. Beside the familiarity of the vascular anatomy of ALT flap for most of the microsurgeons, the long and sizable vascular pedicle allows safe anastomosis away from the trauma zone [(7)].

The anterolateral thigh (ALT) flap still considered the first choice especially for moderate or major sized wounds for microsurgery as practiced in the United States [(8)], while the smaller wounds are treated by pedicled perforator flaps [(9)].

This is concomitant with our study as we demonstrated the size of defects in free flaps ranged between 11×5 cm and 33×16 cm with majority in dorsum of foot and lower third (85%), while in pedicled flaps size of defects ranged between 3×4 cm and 11×6 cm.

For abnormalities at the foot and ankle, the optimal flap should be a thin, flexible cutaneous flap with a perfect tissue match [(10)].

The MSAP flap has a nearly constant architecture and is exceedingly adaptable. The following characteristics of this flap are advantageous: I preservation of the underlying gastrocnemius muscle; (ii) thin and malleable flap; (iii) length of the pedicle may reach 8 to 10 cm; (iv) quite sizable vessels that are about 1-3 mm; (v) if the flap is small in size, the donor site can be primarily closed; and (vi) it can be harvested while the patient is lying on his or her back [(11)].

As we demonstrated in our results, the ALT flaps usually needs a second stage deulking (Fig. 1 C&D), while the MSAP is a thin pliable perforator flap (Fig 2D&f), with long pedicle up to 11 cm (Fig. 2 E) so it is an excellent option for coverage of the defects on dorsum of foot and over ankle joint.

In a study done in 2010 by **Hanasono collaborators** [(12)] they revealed that, the blood velocity is reflexly increased when one venous anastomosis is performed, because the low-velocity state increases the probability of thrombosis, this result was incompatible with the routinely two venous anastomoses done in free tissue transfer, and they recommended when a technically adequate single venous anastomosis is done, the performance of a second venous anastomosis increases operative time unnecessarily.

In another study done in 2016 by **Heidekrueger collaborators** [(13)] they concluded that a successful free tissue transfer for lower limb reconstruction could be achieved independent of the number of venous anastomoses, although when two venous anastomoses are technically available they should be performed.

In our study there were 7 cases with one venous anastomosis (5 with Great Saphenous vein, one with anterior tibial vein and one with post tibial vein) with no cases of venous congestion or partial flap loss while there were two cases of venous congestion with two venous anastomoses which were treated conservatively, so we consider that the results are the same in case of one or two veins anastomosis, and the great saphenous vein is a good option for single vein anastomosis.

We also consider the Great Saphenous vein as a reliable option for venous anastomosis, in condition that the patient doesn't have any venous disease.

A study done in 2014 by **Grover collaborators** [(14)] on free DIEP flaps in breast reconstruction, claimed that the number of the perforators has no impact on survival of free perforator flaps, although they said that the rate of fat necrosis may be higher in DIEP flaps based on one perforator, and they recommended the usage of multiple perforators should be done if possible to decrease the risk of fat necrosis.

In our study we had 11 free flaps with one perforator (Figs. 1B & 2E), none of these flaps were lost or even partially lost, so we concluded, there is also no difference in flap survival (whatever the length of the flap) regarding elevating the flap based on one or two perforators.

In all the cases with free flaps the donor site was closed by skin graft except in one case (MSAP) where the width of the flap was 5 cm.

As we mentioned in our results, we used the pedicled flaps particularly for covering small to medium-sized defects in the distal third of the leg, Achilles tendon region and dorsum of foot.

The main advantages of pedicled perforator flap were, technically less demanding, because they are microsurgical procedures, but without microvascular sutures and shorter operating time [(15)].

In our study, there was a shorter operating time in pedicled perforator flaps (median duration of surgery was 1.5 hour with range between 1 hour and 2.5 hours) and a shorter hospital stay (median time of hospital stay was 4 days), compared with free flaps where median operating time was 6 hours with range between 3 and 10 hours, and median hospital stay was median stay was 14 days, with subsequent of saving resources and manpower.

In propeller flaps meticulous dissection of the perforator is mandatory to prevent complications. All the muscular branches must be divided and the perforator must be cleared of all fascial strands for at least 2 cm, so the twist of the pedicle after rotation to the recipient site will be gentle and distributed on the entire length of the pedicle.

In a 2010 study, **Mehrotra** [16] found that the "perforator plus" idea, which augments the blood supply to a flap from a perforator with blood supply from the flap base, can considerably lower failure rates of pedicled perforator flaps. This strengthens the venous outflow and gives a dual blood supply through the perforator and subdermal plexus [16].

In our early experience we had 3 cases of venous congestion with subsequent partial or complete flap loss in propeller flaps in which we noticed that the flap length was more than one third of the leg's length (from the head of the fibula to lateral malleolus), this was concomitant with the results of a study done by **Panse and collaborators** [17] in a 2011 who claimed that the maximum safe length of perforator propeller flap in leg is equal to or less than one third of the leg's length.

While we had no cases of flap congestion or flap loss in perforator plus flaps regardless the length of the flap (Fig. 4 A-F).

As a result of the above mentioned, we prefer to use perforator plus flap in case of the flap length exceeds one third of the leg length.

The only disadvantage of perforator plus flap was it needed another session for debulking the dog ear resulted after peninsular movement of the flap, as we had 8 cases of perforator plus flap needed 2nd stage debulking.

In conclusion, perforator flaps have become a reasonable solution for soft tissue defects of the lower extremity. Careful assessment of the dimensions, location, patient comorbidities, availability of surrounding soft tissue and presence of adequate perforators are mandatory for proper perforator flap selection.

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