Original Article

Free Boomerang-shaped Extended Rectus Abdominis Myocutaneous flap: The longest possible skin/myocutaneous free flap for soft tissue reconstruction of extremities

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ABSTRACT

Background: A soft tissue defect requiring flap cover which is longer than that provided by the conventional "long" free flaps like latissimus dorsi (LD) and anterolateral thigh (ALT) flap is a challenging problem. Often, in such a situation, a combination of flaps is required. Over the last 3 years, we have managed nine such defects successfully with a free "Boomerang-shaped" Extended Rectus Abdominis Myocutaneous (BERAM) flap. This flap is the slightly modified and "free" version of a similar flap described by Ian Taylor in 1983. **Materials and Methods:** This is a retrospective study of patients who underwent free BERAM flap reconstruction of soft tissue defects of extremity over the last 3 years. We also did a clinical study on 30 volunteers to compare the length of flap available using our design of BERAM flap with the maximum available flap length of LD and ALT flaps, using standard markings. **Results:** Our clinical experience of nine cases combined with the results of our clinical study has confirmed that our design of BERAM flap consistently provides a flap length which is 32.6% longer than the standard LD flap and 42.2% longer than the standard ALT flap in adults. The difference is even more marked in children. The BERAM flap is consistently reliable as long as the distal end is not extended beyond the mid-axillary line. **Conclusion:** BERAM flap is simple in design, easy to harvest, reliable and provides the longest possible free skin/myocutaneous flap in the body. It is a useful new alternative for covering long soft tissue defects in the limbs.

KEY WORDS

Extended rectus abdominis free flap, longest myocutaneous free flap, soft tissue reconstruction of extremities

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INTRODUCTION

Soft tissue defects of the extremity that expose underlying critical structures like bone/tendon/joint require a flap cover. Many of these defects, especially if they are moderate to large in size, require free tissue transfer for a successful reconstruction. A soft tissue defect requiring a free flap which is longer than that provided by the conventional "large" free flaps like latissimus dorsi (LD) and anterolateral thigh (ALT) is a challenging problem.[1,2] Often, a combination of flaps is required. We have used the Boomerang-shaped Extended Rectus Abdominis Myocutaneous (BERAM) flap to reconstruct nine such defects. This flap has a robust blood supply, consistent anatomy and has caused acceptable donor morbidity.

The purpose of this study was to retrospectively analyse the outcome of nine such reconstructions (in terms of flap outcome, complications, donor site morbidity and functional outcome) performed in our unit during the last 3 years.

We also conducted a clinical study on 30 volunteers (10 males, 10 females and 10 children), where we used standard markings for ALT flap and LD flap and did a comparison of the available flap lengths with our design of BERAM flap.[1,2]

MATERIALS AND METHODS

We present nine patients who underwent coverage of long soft tissue defects with the BERAM flap in our unit in last 3 years [Table 1]. In five cases, the flap was used in upper extremity, and in four cases, it was used in lower extremity soft tissue reconstruction. The age of patients ranged between 8 years to 39 years and all were male patients. The defect sizes ranged between 25 and 39 cm in length and between 8 and 12 cm in width.

Surgical technique

The patient was positioned supine under general anaesthesia. The recipient defect was prepared and healthy recipient vessels were identified. A pattern of the defect was created, with the position of recipient vessels clearly marked. We believe that the most important measurement in this kind of situation is the distance from the location of the "ideal recipient vessels" to the distal-most point of the defect.

BERAM flap design and marking

A line was drawn from the pubic symphysis to the umbilicus, and extended upwards and laterally towards the inferior angle of scapula [Figures 1 and 2]. The proximal (inferior) vertical segment of flap extended from pubic symphysis to umbilicus and overlay the rectus abdominis muscle at paramedian position, and the width of the flap was kept limited to allow primary closure of this part of the defect in all cases. The distal (superior) oblique cutaneous segment was designed symmetrically on a line from umbilicus to inferior angle of scapula The distal limit of the flap was kept at the mid-axillary line in seven cases, and extended up to the posterior axillary line in the other two cases (case nos 4 and 6) The other usual flap sites (LD, ALT flap, groin flap, parascapular flap) were also marked according to standard measurements mentioned by "Mathes and Nahai" and maximum possible flap dimensions were noted.[1,2] In all cases, we found that BERAM flap provided the longest flap.

Flap dissection

Adrenaline in saline (1 in 200) was injected along flap margins. Distal cutaneous part of flap was raised from the chest wall starting from the distal tip of the flap and proceeding towards the umbilicus [Figure 3a]. Dissection

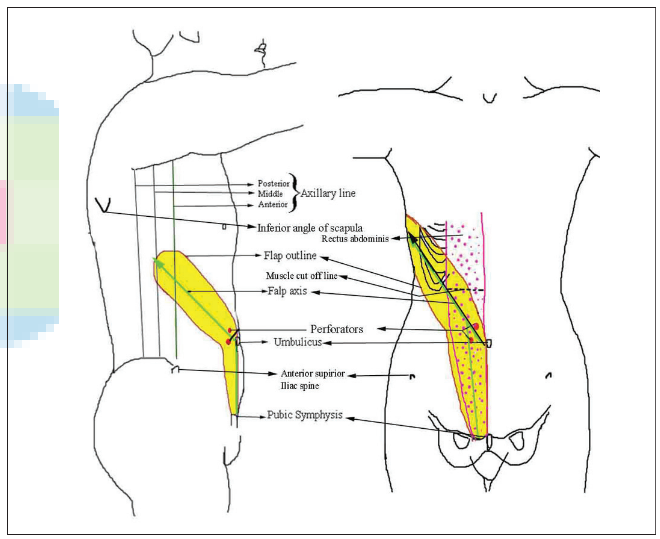

Figure 1: Diagrammatic representation of design and axis of the flap and local vascular anatomy

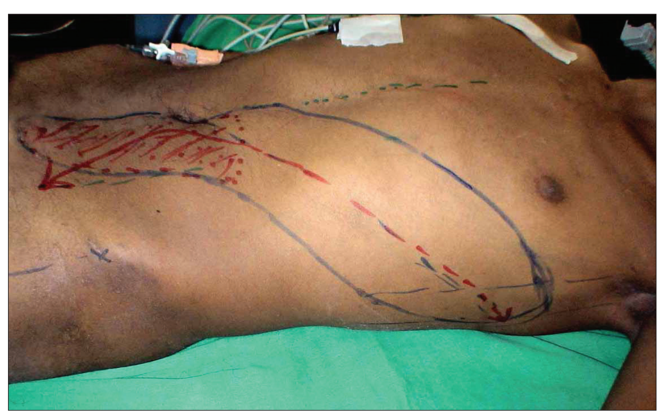

Figure 2: Picture depicting the flap design on patient

Table 1: Patients' master chart

Patient	Age(yr)/ Sex	Mode of injury	Defect location	Defect size	Associated injuries	Follow up period (months)	Complications	Secondary procedure	Final outcome
1	40/Male	Road traffic accident	Right forearm and arm	35x12 cm	Type III B open right radial head fracture with loss of lateral condyle of humerus with composite tissue loss extensor aspect	18	No	Flap debulking	Resume to his daily activity and work place
2	35/Male	Road traffic accident	Right leg and foot	47x8 cm	Raw area foot	7	No	No	Walking without support and joined work place
3	30/Male	Road traffic accident	Left forearm	35x10 cm	Comminuted fracture of left radius and ulna with bone loss with disrupted elbow joint and neurovascular injury	12	Chest infection	Flap debulking and bone grafting	Doing his daily activity and driving two wheeler
4	8/Male	Road traffic accident	Left leg and knee	35x10 cm	Avulsion injury right thigh	9	Distal 5 cm flap necrosis	Inferiorly based fasciocutaneous flap for necrosed flap site defect	Walking without support
5	10/Male	Thermal burn	Left forearam and hand	25x8 cm	Hypertrophic scar with multiple contracture all four limb and face	24	Hypertrophic scar flap donor site	No	Functionally rehabilitated, doing daily activity and writing
6	32/Male	Cracker blast	Left forearam	39x8 cm	Supracondylar fracture left humerus	9	Distal 4 cm flap necrosis	VAC followed by SSG	Resume to his daily activity
7	24/Male	Industrial accident	Left forearm	36x10 cm	Fracture both left forearm bone	8	No	No	Resume to his daily activity and work place
8	20/Male	Runover injury	Right leg and thigh	30x10 cm	Crush avulsion injury of right thigh and leg	13	No	No	Walking without support and no residual deformity
9	28/Male	Road traffic accident	Right leg and thigh	30x12 cm	Type III B fracture of right tibia with skin avulsion right thigh	12	No	No	Walking without support and no residual deformity

proceeded in the subcutaneous plane until the lateral border of the anterior rectus sheath was crossed and the first major paraumbilical perforator(s) encountered [Figure 3b].

A transverse incision was made in the rectus sheath just superior to the perforator(s) [Figure 3c] and another vertical incision made in the sheath just lateral to the major perforator(s). The rectus muscle was cut transversely a little above the umbilicus (preserving the main paraumbilical perforators in the flap. The medial skin margin of the flap was incised just lateral to the umbilicus, bringing the incision to the midline below the umbilicus. The lateral skin incision was also carried down to the pubic symphysis. Both the incisions were deepened to complete the flap dissection. The flap included the oblique supra-umbilical skin paddle, the lower half of the rectus muscle along with its overlying rectus sheath, fat and skin [Figure 3d]. As the rectus muscle was lifted off from its bed, the deep inferior epigastric vessels were identified and followed to their origin from the external iliac vessels [Figure 3e and f]. The pedicle was divided and the flap transferred [Figure 3g and h]. In all our cases, the

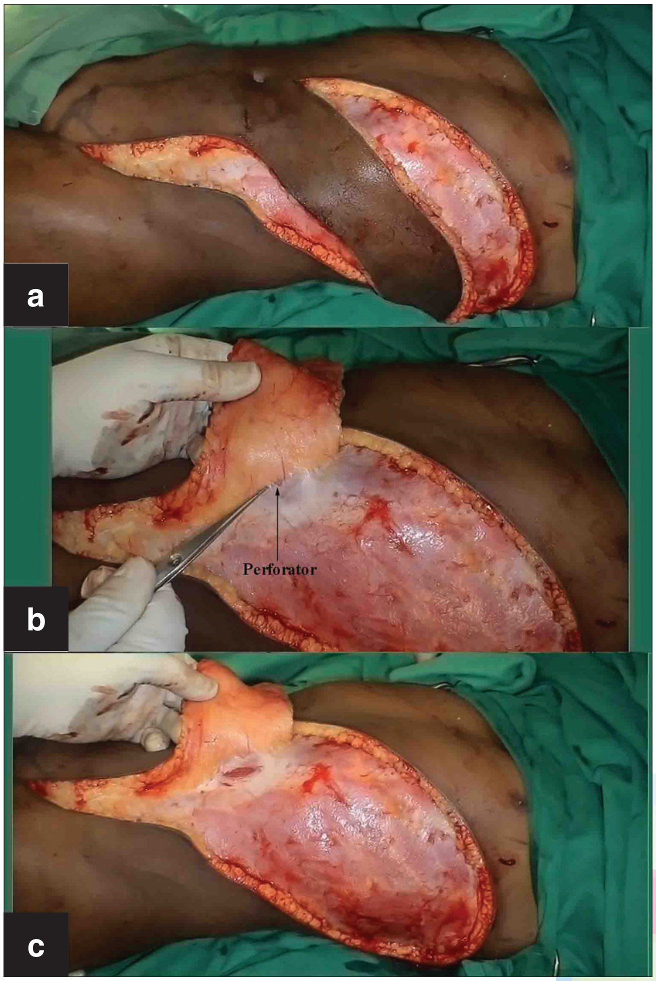

Figure 3: (a) Raised distal cutaneous segment of flap. (b) First major paraumbilical perforator identified. (c) Transverse incision at rectus sheath just superior to first paraumbilical perforator

rectus sheath was closed primarily. In all the seven adults, the closure was reinforced with an onlay polypropylene mesh. In the two children, the sheath was closed directly, without any reinforcement. Skin was closed in layers with a negative suction drain [Figure 3i]. In one patient, in whom the oblique cutaneous portion of the flap was broader, that part of the donor area was skin grafted.

CASE REPORTS

Case 1

A 40-year-old male presented with Type IIIB open fracture of radial head, loss of lateral condyle of humerus and composite tissue loss over the extensor aspect of the right forearm and distal arm [Figure 4a]. He underwent wound debridement, external fixator application, lateral collateral ligament reconstruction [Figure 4b] and coverage with a 35 × 12 cm BERAM flap [Figure 4c–g]. Flap debulking was done after 1 year [Figure 4h]. He was

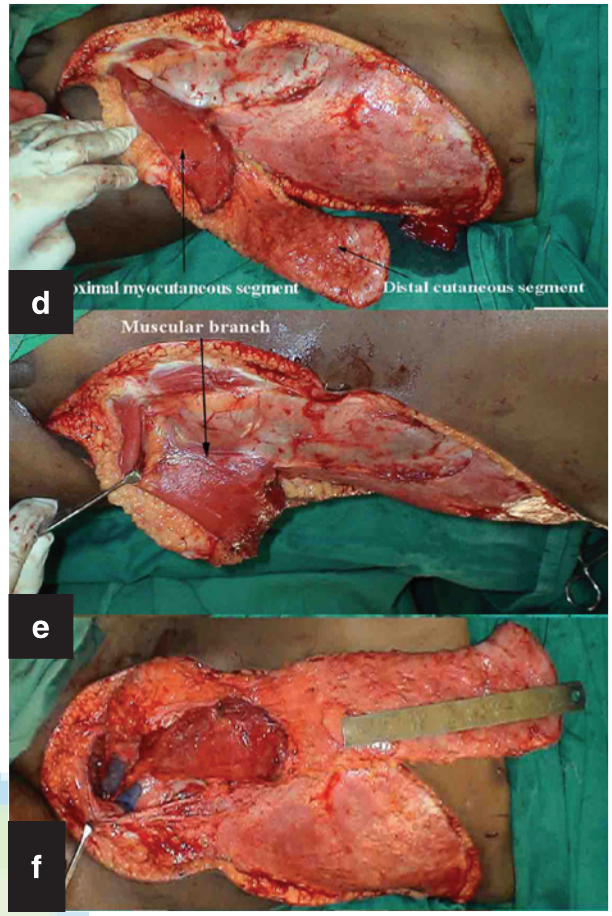

Figure 3: (d) Proximal myocutaneous segment of flap harvested. (e) Identifying the deep inferior epigastric artery on the deeper surface of the rectus muscle. (f) Completion of flap dissection showing comparison with 15 cm ruler and DIEA pedicle at its origin

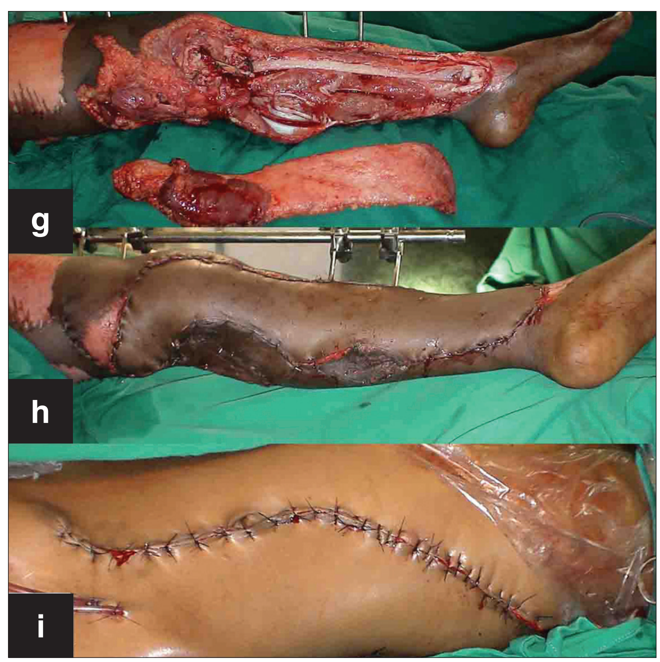

Figure 3: (g) Final defect after thorough debridement and harvested BERAM flap kept aside. (h) Intraoperative picture of final inset of BERAM flap. (i) Primary closure of the flap donor area

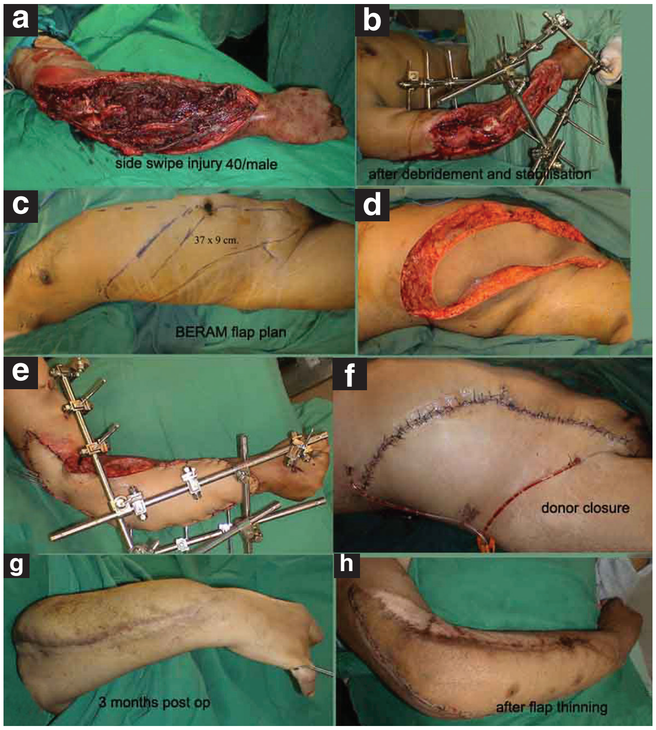

Figure 4: (a) Side swipe injury with composite tissue loss over the extensor aspect of the right forearm and distal arm. (b) After wound debridement and external fixator application. (c) BERAM flap design. (d) Harvested flap *in situ*. (e) Defect coverage with a 35 x 12 cm BERAM flap. (f) Primary closure of flap donor area. (g) Well-settled flap 3 months postoperatively. (h) After flap debulking at 1 year

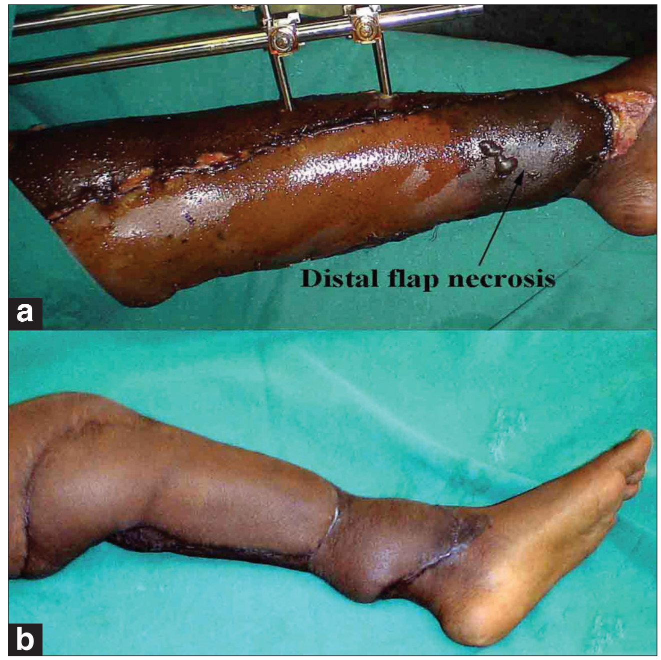

Figure 5: (a) 1 week postoperative picture of flap with partial distal necrosis. (b) Post debridement of necrotic segment of flap and coverage with inferiorly based local transposition flap

functionally rehabilitated and had resumed his original occupation.

Case 2

A 35-year-old industrial worker sustained a major crush injury with Type IIIB fracture in both bones of right leg, with metatarsal fracture with composite tissue loss (47 × 8 cm) over anterolateral aspect of right leg and foot. Patient underwent medial gastrocnemius muscle flap cover for proximal one-third of the right leg and free BERAM flap (43 × 8 cm) transfer for the critical raw area over the distal two-thirds of anteromedial aspect of the right leg and dorsum of foot. Anterior tibial vessels were used as recipient vessels. Residual raw area and superolateral part of flap donor area was covered with split skin graft. He started non–weight-bearing walking in 3 weeks and walking without support in 12 weeks.

Case 3

This was a 30-year-old male with severe crush injury of the left forearm following a vehicular accident. After debridement, we were left with a soft tissue defect of 35 × 10 cm. Considering the gross comminution along with bone loss, a decision was taken to create a single bone forearm by plate osteosynthesis between distal radius and proximal ulna. Wound was covered by a free BERAM flap (35 × 10 cm) with end-to-side arterial anastomosis to brachial artery and three end-to-end venous anastomoses. The bones united uneventfully. Later on, the patient underwent secondary flap debulking procedure. In his recent follow-up, he was found to be able to perform all his daily activities and was able to drive a bike using his single bone forearm..

Case 4

An 8-year-old male child had an avulsion injury of the anteromedial aspect of the left leg, extending from the knee to the distal third of leg, exposing subluxated knee joint and most of the tibia. Defect measuring 12 30 cm was covered by free BERAM flap. In this case, the flap marking had been extended beyond the mid-axillary line. Postoperatively, the distal 5 cm of the flap got necrosed [Figure 5a] which was debrided and covered with an inferiorly based local transposition skin flap [Figure 5b]. He was able to walk with support in 4 weeks time

Clinical study

We also conducted a clinical study with randomly selected 30 volunteers (10 children aged 4–15 years, 10 adult males and 10 adult females) [Figure 6]. The subject's height, standard flap marking and measurements were taken for ALT and LD flaps according to the standard measurements given by Mathes and Nahai, and

BERAM flap was marked according to above-described markings.[1,2] The comparison of possible flap length in relation to volunteer's height and comparison of LD and ALT flap length to BERAM flap length was done [Table 2].

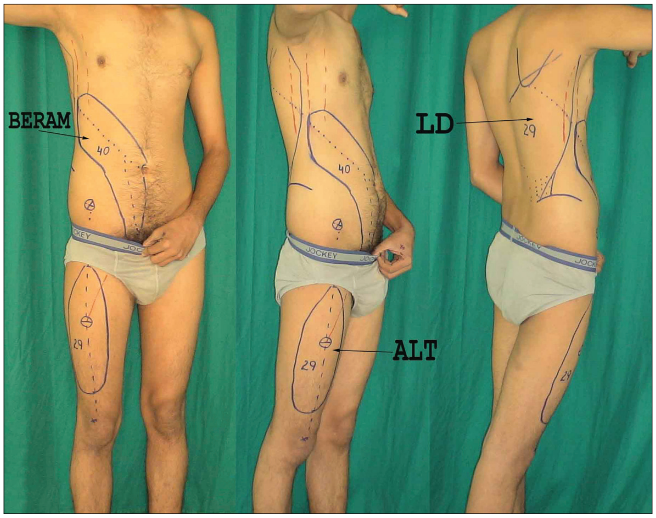

Figure 6: Representation of clinical study showing standard flap markings and comparison of different flap lengths in centimeters

RESULTS

- Our clinical experience of nine cases combined with results of our clinical study has confirmed that our design of free BERAM flap consistently provides a flap length which is an average 32.6% longer than the standard LD myocutaneous/skin flap and an average 42.2% longer than the standard ALT flap in adults. In children, BERAM is 71% longer than ALT flap and 46.7% longer than LD flap.
- The free BERAM flap was consistently reliable in all the seven cases in which the distal end did not extend beyond the mid-axillary line. In the two patients in whom the flap had been extended beyond the mid-axillary line, the portion beyond the mid-axillary line was lost.
- In our follow-up so far (minimum 1 year), no patient has reported a hernia or a weakness of the abdominal wall.

Table 2a: Clinical study: Children's measurements

Height (cm)	*ALT (cm)*	*% ALT to Height*	*LD (cm)*	*% LD to Height*	*BERAM (cm)*	*% BERAM to Height*	*Difference of BERAM and ALT/ value in %*	*Difference of BERAM and LD/ value in %*
126	21	16.67	25	19.84	33	26.19	12/ 57.14	8/ 32.00
130	20	15.38	22	16.92	33	25.38	13/ 65.00	11/ 50.00
134	23	17.16	26	19.40	27	20.15	4/ 17.39	1/ 3.85
146	30	20.55	24	16.44	34	23.29	4/ 13.33	10/ 41.67
100	13	13.00	25	25.00	28	28.00	15/ 115.38	3/ 12.00
116	16	13.79	23	19.83	29	25.00	13/ 81.25	6/ 26.09
125	19	15.20	18	14.40	31	24.80	12/ 63.16	13/ 72.22
122	18	14.75	17	13.93	29	23.77	11/ 61.11	12/ 70.59
101	12	11.88	17	16.83	28	27.72	16/ 133.33	11/ 64.71
125	16	12.80	17	13.60	33	26.40	17/ 106.25	16/ 94.12
Average		15.12		17.62		25.07	71.34(%)	46.72(%)

Table 2b: Adult Female measurements

Height (cm)	*ALT (cm)*	*% ALT to Height*	*LD (cm)*	*% LD to Height*	*BERAM (cm)*	*% BERAM to Height*	*Difference of BERAM and ALT/ value in %*	*Difference of BERAM and LD/ value in %*
162	33	20.37	38	23.46	42	25.93	9/ 27.27	4/ 10.53
152	29	19.08	39	25.66	44	28.95	15/ 51.72	5/ 12.82
147	32	21.77	35	23.81	47	31.97	15/ 46.88	12/ 34.29
144	31	21.53	36	25.00	49	34.03	18/ 58.06	13/ 36.11
154	29	18.83	35	22.73	43	27.92	14/ 48.28	8/ 22.86
149	34	22.82	38	25.50	49	32.89	15/ 44.12	11/ 28.95
151	30	19.87	31	20.53	42	27.81	12/ 40.00	11/35.48
148	35	23.65	32	21.62	51	34.46	16/ 45.71	19/ 59.38
154	29	18.83	31	20.13	42	27.27	13/ 48.83	11/ 35.48
154	29	18.83	38	24.68	46	29.87	17/ 58.62	8/ 21.05
Average		20.56		23.31		30.11	46.55(%)	29.69(%)

Table 2c: Adult Male measurements

Height (cm)	ALT (cm)	% ALT to Height	LD (cm)	% LD to Height	BERAM (cm)	% BERAM to Height	Difference of BERAM and ALT/ value in %	Difference of BERAM and LD/ / value in %
165	29	17.58	31	18.79	46	27.88	17/ 58.62	15/ 48.39
172	34	19.77	31	18.02	42	24.42	8/ 23.53	11/ 35.48
168	29	17.26	31	18.45	45	26.79	16/ 55.17	14/ 45.16
169	34	20.12	29	17.16	40	23.67	6/ 17.65	11/ 37.93
173	34	19.65	33	19.08	45	26.01	11/ 32.35	12/ 36.36
174	31	17.82	32	18.39	49	28.16	18/ 58.06	17/ 53.13
165	30	18.18	36	21.82	44	26.67	14/ 46.67	8/ 22.22
171	33	19.30	34	19.88	51	29.82	18/ 54.55	17/ 50.00
175	38	21.71	39	22.29	46	26.29	8/ 21.05	7/ 17.95
181	34	18.78	35	19.34	38	20.99	4/ 11.76	3/ 8.57
Average		19.02		19.32		26.07	37.94(%)	35.52(%)

- In our clinical study, we found that for adult men and women, the available flap length to (patient) height ratio for ALT, LD and BERAM flaps was on average 19.79%, 21.31% and 28.09%, respectively. The same values in children were 15.12%, 17.62% and 25.07%, respectively.

DISCUSSION

Pennington and Pelly in 1980 reported two successful rectus abdominis myocutaneous free flaps based on deep inferior epigastric artery (DIEA).[3] They mentioned a long pedicle with wide vascular lumen, easy harvest and aesthetic and functional acceptability as advantages. The disadvantages included the need to reconstruct anterior rectus sheath to prevent hernia formation and the bulk of the flap.

The vascular anatomy of the DIEA and its paraumbilical perforators has been well studied.[4-6] Variants of DIEA-based flaps like vertical rectus abdominis muscle/ myocutaneous (VRAM) and transverse rectus abdominis muscle/myocutaneous (TRAM) flaps have been described earlier.[7]

While technically our flap qualifies to be an "extended deep inferior epigastric free flap," the same name would be applied to most of the above-mentioned variants and modifications. We have called our design the "free Boomerang-shaped Extended Rectus Abdominis Myocutaneous" (BERAM) flap because the phrase "Boomerang-shaped" closely describes the shape of the flap and makes it easy to understand and remember.

Taylor in 1983 described the vascular territories of DIEA-based flaps.[8,-9] He observed that by including the paraumbilical cutaneous perforator(s), the flap can be designed with a diagonally placed upper skin island extending beyond the rectus muscle from umbilicus to costal margin, giving a long flap with an equally long vascular pedicle in a free flap and wide arc of rotation in case of a pedicled flap. This is because these perforators communicate by means of choke vessels to the anterior branches of the lateral intercostal vessels at a 45° angle to the anterior axillary line. Our BERAM flap was also designed based on this principle.

Boyd *et al.* performed cadaveric studies by dye injections, dissections, and barium radiographic studies to delineate the vascular territories of superior epigastric and deep inferior epigastric vessels and they observed that majority of the abdominal wall was stained through injection of the deep inferior epigastric system.[4] They showed that the largest perforating vessels were located in the paraumbilical area.

The BERAM flap has several attributes that make it unique and many interesting comparisons can be made to its cousins, the VRAM and TRAM flaps.[7]

First, the distal skin paddle is easy to mark and elevate. On an average, a 10–12 cm wide flap can easily be harvested with direct closure and the length-to-width ratio is around 3:1 in all these flaps.

The BERAM flap is simpler because of a more limited inclusion of rectus muscle (only the inferior half), while in VRAM flap the extra muscle dissection adds time to the procedure and probably increases postoperative pain.

In obese patients, owing to the characteristic distribution pattern of fat in the abdominal wall, the distal skin paddle in VRAM flap is likely to be bulkier than that of BERAM flap. This can lead to more difficult flap insets and requires extensive debulking of flap. The BERAM flap distal skin paddle (beyond the periumbilical area) is quite thin in most people, and in 67% cases, it has been less than 1 cm in thickness. This simplifies flap inset and needs less secondary debulking procedures.

The BERAM flap skin paddle donor site can be closed immediately without compromising the visualisation of the pedicle, unlike the TRAM flap, where closure of the donor site must be performed after harvest of the flap. The distal skin paddle which lies beyond the repaired rectus sheath can be made as broad as is required, and if necessary the donor area is grafted. The skin paddle donor site is closed without additional elevation of skin flaps as seen in the TRAM flap closure, which requires elevating and mobilising the upper abdominal skin. The rectus muscle and anterior fascial dissection is the same as a free TRAM flap, as opposed to the greater muscle dissection of the VRAM flap.

Boyd, Taylor and other investigators have shown the pedicled Extended Rectus Abdominis Myocutaneous flap to be versatile in its arc of rotation and very reliable, with no reported cases of distal flap necrosis.[8,-9] No significant long-term donor-site complications were noted in our study or in other studies.

Berish Strauch also described "Thoracoumbilical Flap" and a similar flap was described by Edmond and Franklyn as "Periumbilical Axial Flap" which was designed on an axis between the umbilicus and the inferior angle of the scapula running upwards laterally as far as the mid-axillary line or even the posterior axillary line.[10,-11] In our series, the flap had been extended beyond the mid-axillary line in two cases. In both these cases, we lost this portion of the flap.

All the above designs of flaps involve a proximal muscle with DIEA pedicle and a distal skin paddle of variable length. Our design of BERAM flap provides the longest continuous skin paddle of any flap in the body. We feel in certain situations having a skin paddle for the major part of the defect has definite advantages. These include ease of secondary surgery and better aesthesis. The myocutaneous flap is, however, bulkier than a muscle flap

Asko *et al.* did a comparative study of 51 patients operated by LD and rectus abdominis free flap and they found that average rectus flap skin island was larger than that used for the LD flap (maximal length 47 vs. 34 cm), which shows RAM flap to be 38% longer than LD flap, but in our clinical study we found that BERAM flap was 32.6% longer than LD flap in adults, using standard landmarks. In our surgical experience of over 200 LD muscle flaps, we have frequently noticed that if we transfer a complete LD muscle, the distal 3–4 cm of the flap does not survive, so the final length difference would be even more.[12]

Günter Germann and Markus Öhlbauer mentioned LD muscle dimensions: length 35 cm (range 21–42 cm) and width 20 cm (range 14–26 cm).[13] The average dimensions are 4–6 cm more in male patients than in female patients. Pa-Chuen *et al.* did a study of anterolateral femoral flap applied anatomy based on a Doppler analysis of 50 volunteer adults and cadaver dissections of 42 legs; vascular injection technique were used in 35 cadavers.[14] They found a cutaneous territory of 12 × 30 cm. In our study, we also found that ALT flap length varies between 12 and 38 cm (average 28.4 cm.) depending on the patient's height.

CONCLUSIONS

In our experience BERAM flap is the free flap which provides the longest skin paddle in the body. It is easy to harvest, has a long reliable pedicle, and causes minimal donor site morbidity. The flap is reliable as long as the standard markings are followed. Based on the findings of this study, it could be argued that BERAM flap would be the free flap of choice for coverage of long soft tissue defect over extremities in males, and females beyond child-bearing age. Owing to the significant scarring of abdominal wall, we would not recommend this flap for use in females of, or below child-bearing age.

More studies, including dye injection studies, are warranted to more precisely define the safe distal limit of BERAM flap. Larger prospective clinical studies along with long-term functional and quality of life evaluations are warranted to conclude that one flap is superior to other for reconstruction of extremity.

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