The Free Medial Sural Artery Perforator Flap for Microsurgical Reconstruction of Limbs: A Systematic Review and Meta-Analysis of Flap Characteristics and Outcomes

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ABSTRACT

The medial sural artery perforator (MSAP) continues to gain popularity. Providing a versatile, thin and pliable alternative for commonly used workhorse flaps, it can be used to reconstruct extremities, with reduced donor site morbidity. This meta-analysis was conducted to analyse the current literature to help identify flap characteristics and outcomes. A systematic review was performed following the preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines and a literature search was conducted using Medline, Google Scholar and the Cochrane Library. The aim was to identify the outcomes of free MSAP flap reconstructions of upper and lower limb defects over a 10-year period from January 2010 to July 2020. The data was then tabulated and a meta-analysis was carried out. A total of 11 studies for lower limbs and 7 studies for upper limbs were reviewed and analysed with a total number of 257 patients. Limb reconstructions were primarily due to trauma. The most common site of reconstruction of the upper limb was the hand or wrist and the lower limb was the ankle or feet. The mean length of the flap was 9.6 cm. The mean width was 5.4 cm. The mean pedicle length was 9.7 cm. The mean flap thickness was noted as 5.9 mm. The number of perforators was an average of 1.5. The pedicle's mean arterial diameter was 1.9 mm (mean) and the vein's mean arterial diameter was 2.9 mm. 80% of donor sites were closed directly. Overall, the flap success rate was 98%. Our results find the MSAP flap to be a versatile, reliable, functionally and aesthetically good reconstructive option for both lower and upper limb defects with low donor site morbidity.

Keywords: Medial sural artery perforator flap, Microsurgical limb reconstruction, Donor site morbidity, Flap characteristics, Extremity defects

Introduction

The field of microsurgery has continued to grow since its experimental inception in the 1950s by Professor Sun Lee[1] and has become a vital tool for reconstructive surgeons.[2] Further work in 1987 introduced the angiosome concept by Taylor, which led to the use of perforator flaps.[2] Since then, further advancement has increased the popularity of perforator flaps, as they can be tailored to the reconstructive need of the patient, whilst also reducing donor site morbidity. When used in conjunction with the reconstructive elevator, microsurgical reconstruction can be the initial and correct reconstruction of choice in certain complex defects in extremities.[3]

Upper and lower limb reconstructions can prove difficult, as they require thin and pliable flaps. With this in mind, the radial forearm free flap (RFFF) became the workhorse for extremity reconstruction. Unfortunately, this often leads to significant morbidity to the patient's donor site, with the frequent use of a split-thickness skin grafting being a considerable disadvantage. This is why reconstructive surgeons are continually searching for alternatives.

The medial sural artery perforator (MSAP) flap was first described by Cadavas in 2001 and showed many advantages. This included a pliable, thin flap, with a long consistent pedicle, low complications and morbidity as donor sites in most cases will allow for a direct closure, thus avoiding the need for a skin graft.

Despite the MSAP flap increasing in popularity, the literature specifically looking at its use in extremities has been limited. Most studies are small case series, or articles illustrating cadaveric dissection and the anatomy of the flap itself.

This systematic review was conducted to analyse/collate the current literature to help identify the indication, flap characteristics, technique used for harvest and ultimately, outcomes.

Flap Anatomy and Design

The following are the currently described measurements generally stated in textbooks:

Flap Anatomy

- Flap dimension: Average flap 12.9 × 7.9 cm
- Origin of perforators: Medial sural artery (66% from the lateral branch and 34% from the medial branch) arises from the popliteal artery
- Number of perforators: 1–3 (mean 1.9)
- Site of perforators: Area between 7 and 18 cm from the popliteal crease (90% were at 10 ± 2 cm from the crease), 13 ± 2 cm, from posterior midline 2.5 +/– 1 cm
- Diameter of perforators: 0.3–0.8 mm
- Pedicle length: 10–17 cm (11.75 cm)
- Pedicle diameter: Artery 1.7—3 mm (2.2 mm), Vein 2.3–3 mm (2.6 mm).

Flap Design: (Figure 1)

- Draw a long axis from mid popliteal crease to the prominence of the medial malleolus.
- Locate the perforators and mark using a handheld Doppler (usually 6–18 cm from the popliteal crease along the axis mostly at 10 ± 2 cm)
- Draw a flap centred on the perforator using a template of the defect.

We have provided clinical pictures of a case carried out by the authors in Figures 2–6, with consent provided by the patient. In the present case, the injury was

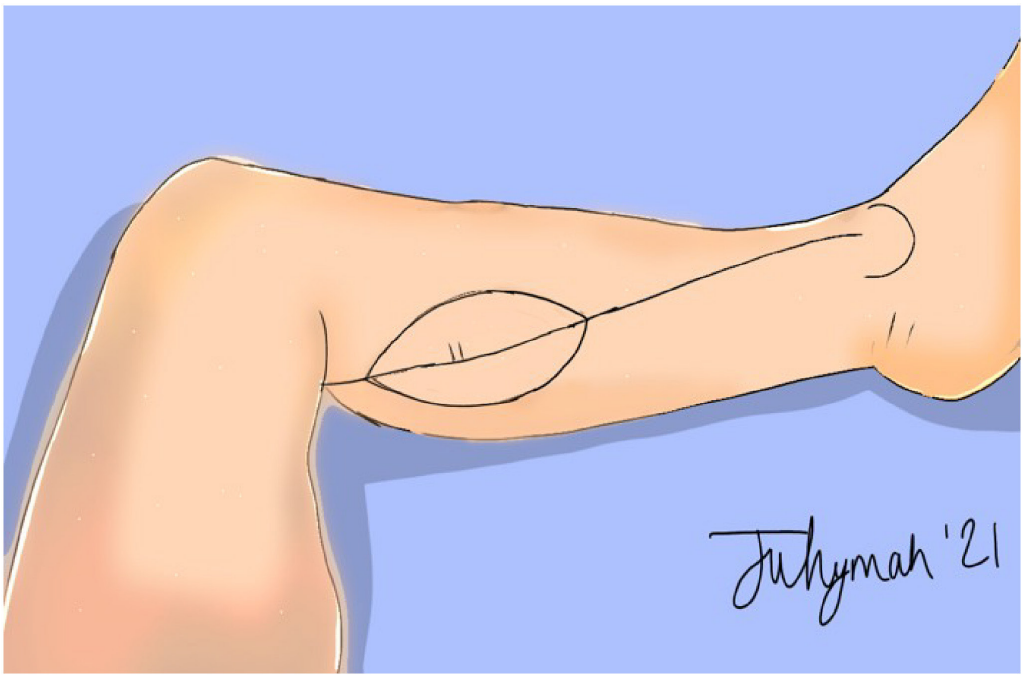

Fig 1 | MSAP flap markings schematic

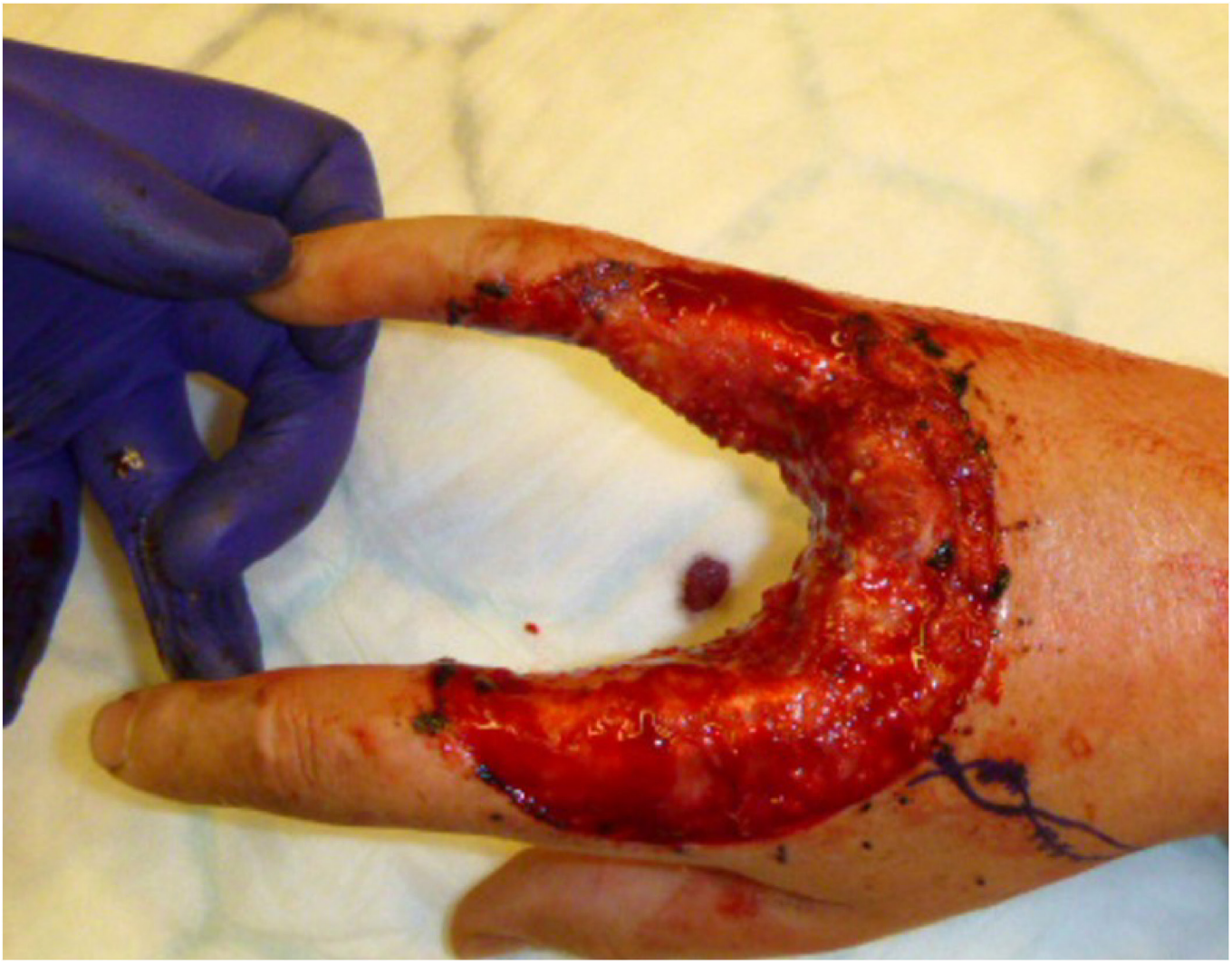

Fig 2 | Hand injury prior to reconstruction, exposed mid-shaft metacarpals

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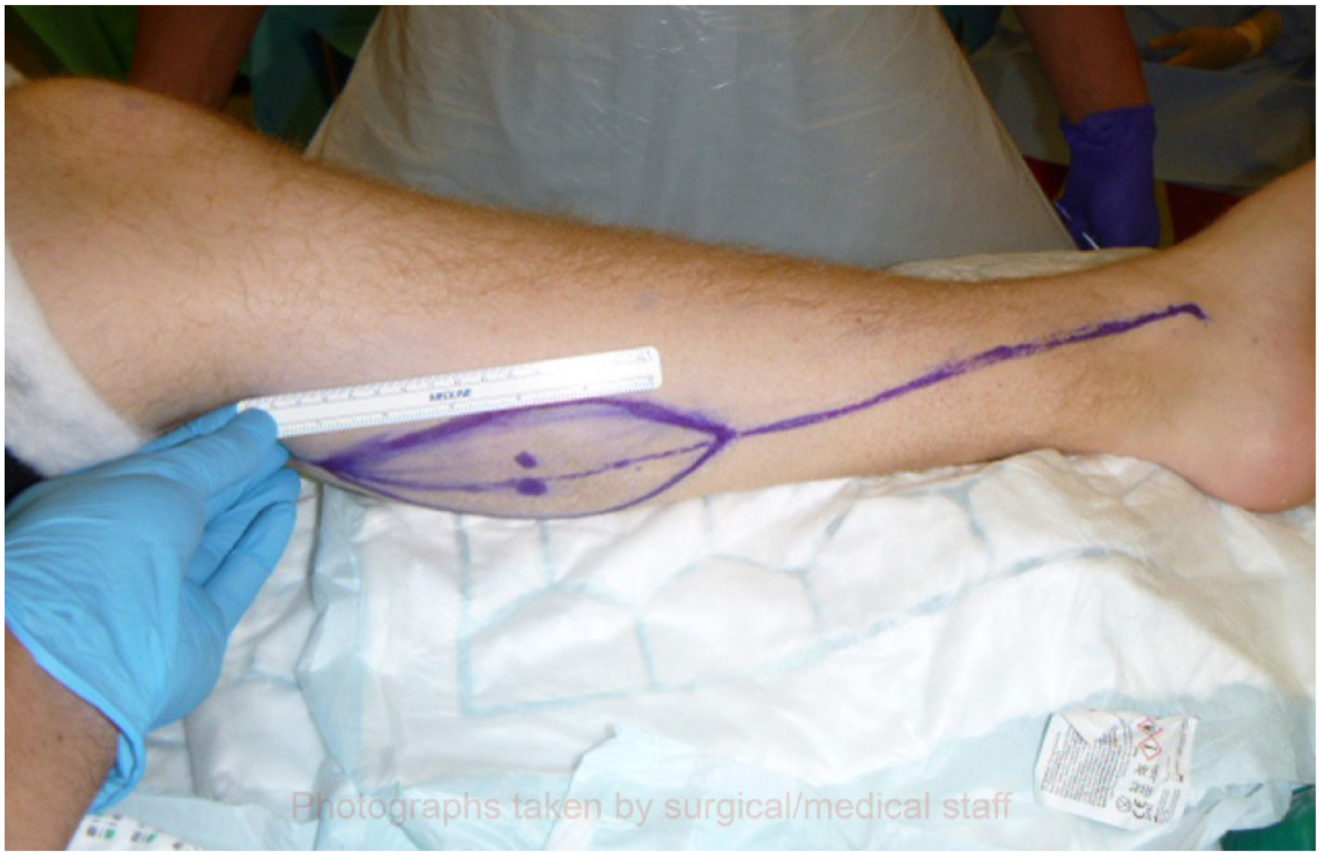

Fig 3 | Marking of the MSAP flap

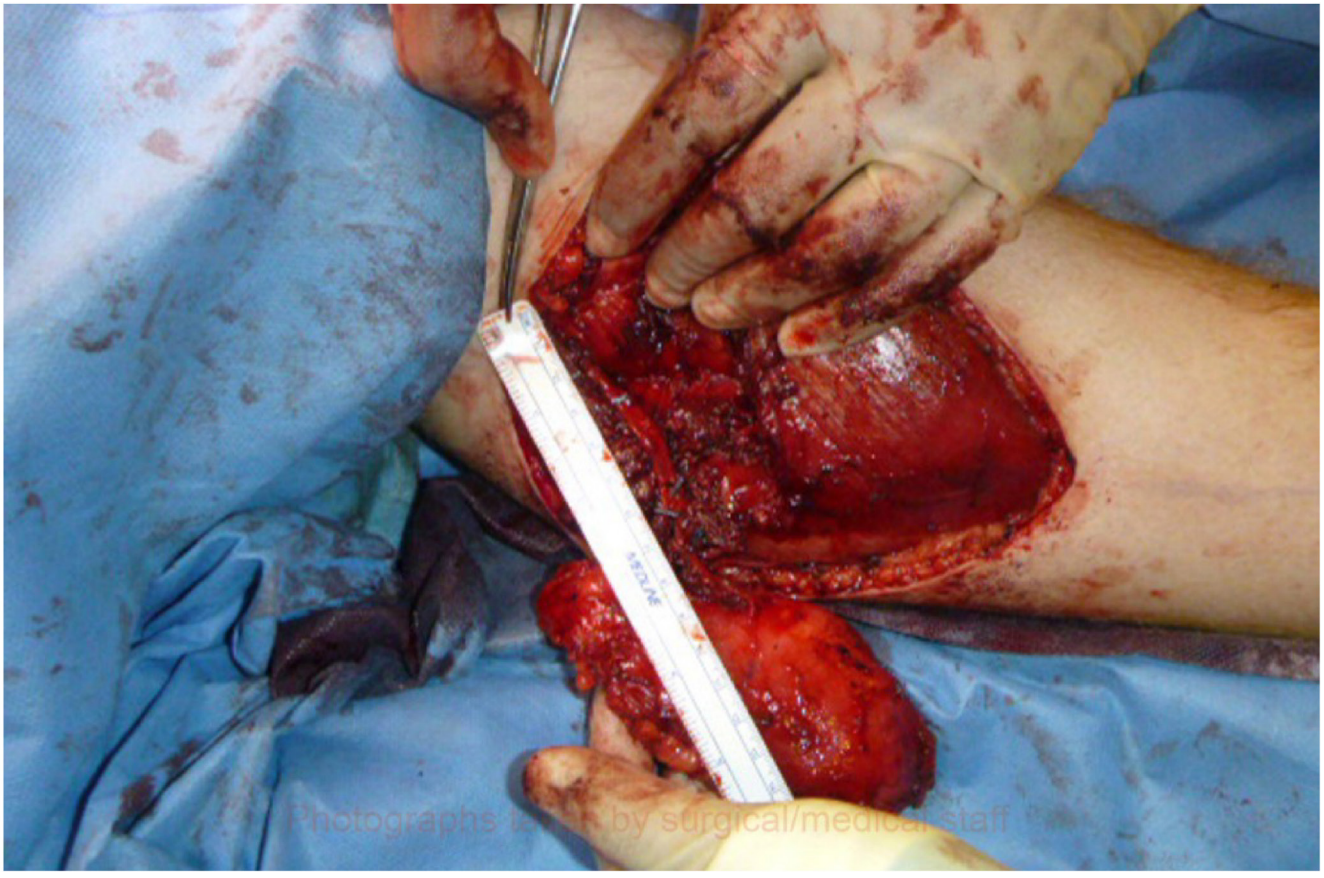

Fig 4 | Raising of MSAP flap

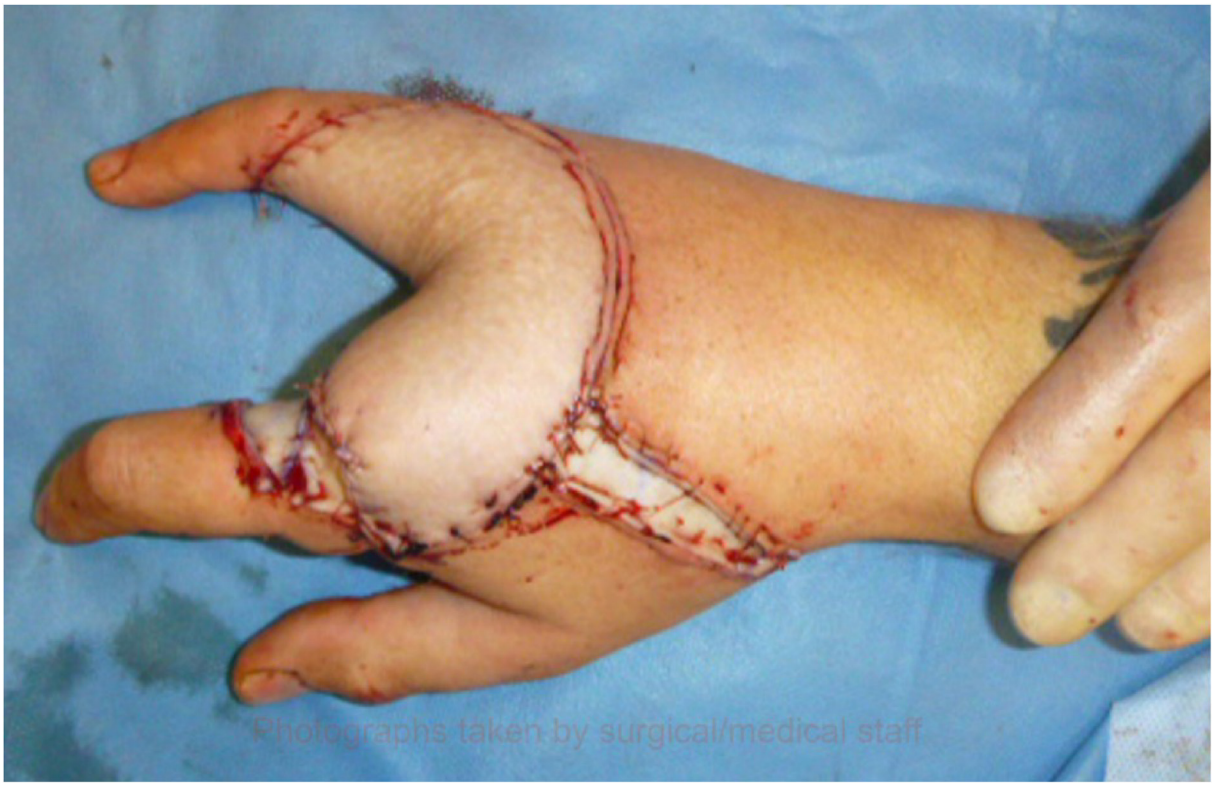

Fig 5 | Inset of MSAP flap with skin grafting

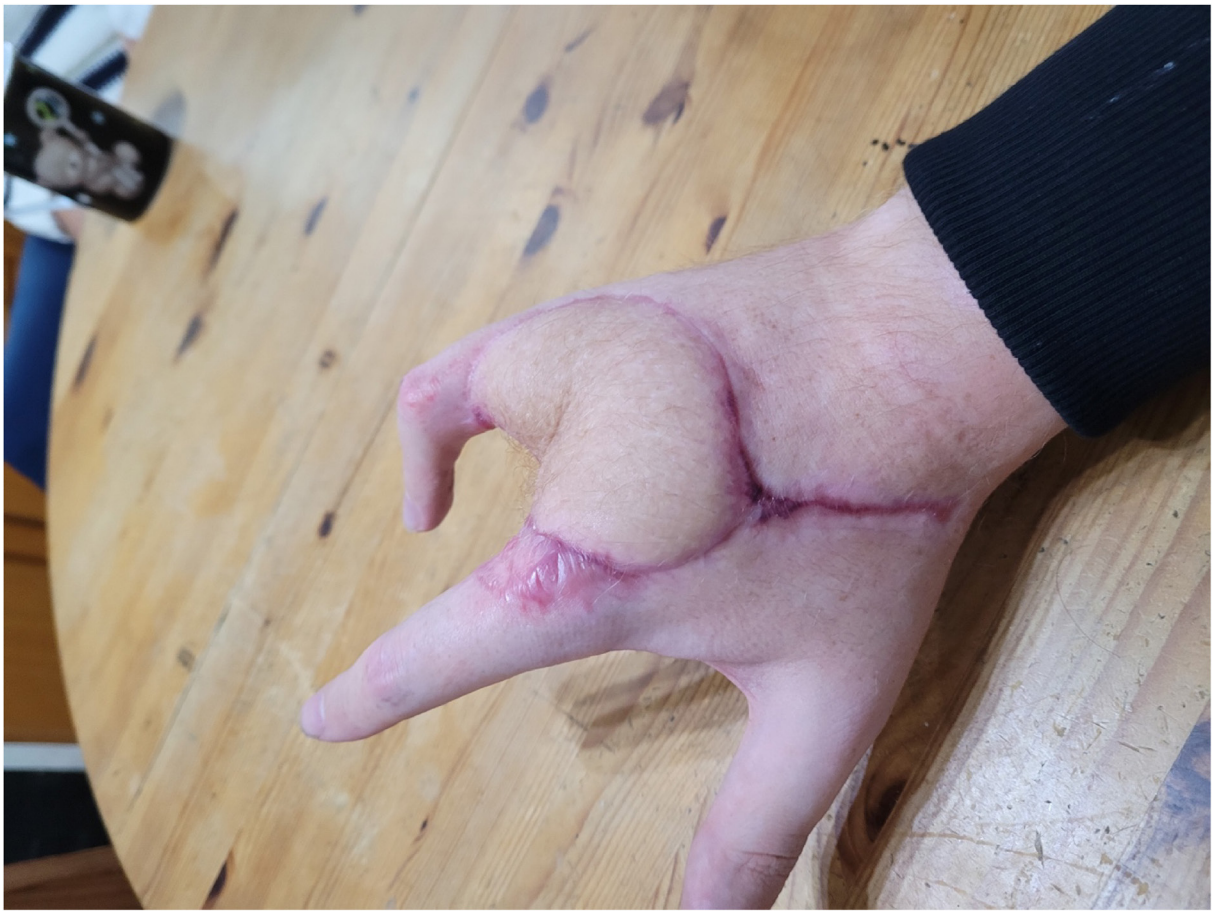

Fig 6 | Healed MSAP flap 2 months post procedure

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traumatic from a metal press, with no prospect of replantation as digits were lost at the scene.

Methods

This systematic review was performed in accordance with the preferred reporting items for systematic reviews and meta-analysis (PRISMA) system[4] and AMSTAR 2 checklist.[5] This research has also been registered through the research registry with ID: reviewregistry1891 https://researchregistry.knack.com/researchregistry#registryofsystematicreviewsmeta-analyses/registryofsystematicreviewsmeta-analysesdetails/66f592bdcaee7002cf0c730e/.

Table 1 | Three-Part Question

Patient characteristics	Patient with upper and lower extremity defects needing reconstruction
Intervention question	Reconstruction of defect with free medial sural artery perforator flap
Relevant outcome	Epidemiological, operative and functional outcomes

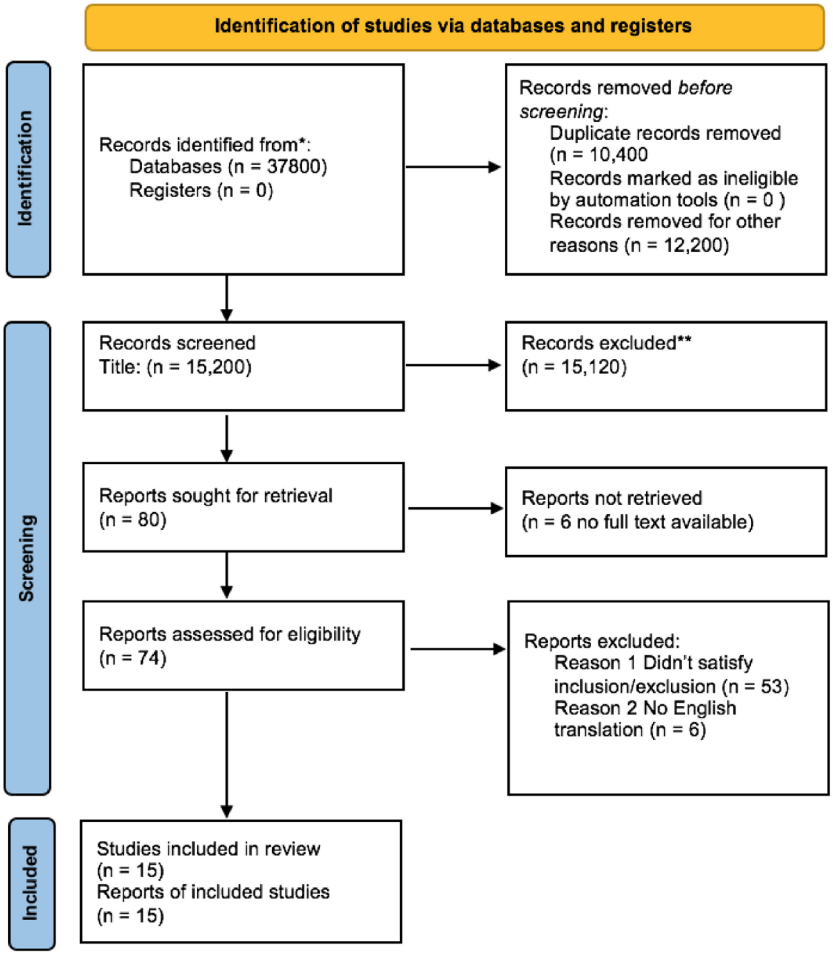

Fig 7 | PRISMA flow chart for new systematic review which included searches of databases and registers only

*Consider, if feasible to do so, reporting the number of records from each database or register searched (rather than the total number across all databases/registers).

**If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools.

The literary search was conducted in July 2020 and was performed using Medline, Google Scholar and the Cochrane library. The search looked at the outcome of free MSAP flap reconstructions to the extremities during the period of the last 10 years from January 2010 to July 2020. Relevant keywords were selected and combined.

The results were formulated according to the best BETs technique (Table 1).

Keyword Search

Search keyword for lower limb reconstruction cohort:

(((((((msap flap) OR (medial sural artery perforator flap)) OR (medial sural artery perforator free flap)) OR (free msap flap)) AND (lower limb reconstruction)) OR (lower extremity reconstruction))

Search keyword for upper limb reconstruction cohort:

(((((((msap flap) OR (medial sural artery perforator flap)) OR (medial sural artery perforator free flap)) OR (free msap flap)) AND (upper limb reconstruction)) or upper extremity reconstruction or hand reconstruction))

Inclusion Criteria

- Studies involving the use of the MSAP free flap

Exclusion Criteria

- Non-human studies
- Studies where the recipient area was not in the upper or lower limbs
- Studies where full text is not available
- Studies which have not been translated into English

Search Outcome

The search results are highlighted in total in Figure 7 (PRISMA flow chart). These have been further divided into those pertaining to upper and lower limb reconstructions, respectively.

For the lower limb reconstruction cohort, 20,180 studies were found. Among them, 57 studies were shortlisted after screening the titles; 14 studies were then found to be more relevant to lower limb reconstruction after screening the abstracts. Following the search, three papers were excluded due to the lack of English translation and unavailability of full texts. Finally, 11 papers were selected for review.

For the upper limb reconstruction cohort, 17,620 papers were found. After title screening, only 23 papers were shortlisted. Screening through the abstracts excluded another 13 papers due to the lack of relevance or no English translation. Three further studies were excluded because of the unavailability of full texts. Finally, seven studies were included in the present review.

All articles were independently reviewed by two authors and extracted as per the PRISMA flowchart. There were no sources of funding for this study. The risk of bias was assessed and deemed to be low risk.

Table 2 | Abbreviated Results of Lower Limb MSAPs

Author, Country, Journal, Year of Publication	Patient Group	Study Type (Level of Evidence)	Outcomes	Key Results	Study Weaknesses
Sarah Al-Himdani, Asmat Din, Thomas C wright, George Wheble, Thomas WL Chapman, Umraz Khan United Kingdom Injury, Feb, 2000[6]	It is a hybrid study Comprised anatomical and clinical parts. Anatomical study included, raising of MSAP flap on 10 cadaveric fresh frozen lower limb.	Combined prospective and retrospective study.	Limitation includes, long intramuscular and tedious dissection, accidental ligation of muscular branch. A 100% flap survival rate with two partial flap necrosis.	Thin pliable flap good choice for lower limb reconstruction especially foot and ankle. Less donor site morbidity with most of the time can closed directly if flap width ‹5.75 cm. Thin walled, tortuous and wide calibre vein can cause congestion, so care should be taken to avoid pressure on it.	Not a RCT and small sample size
E. Fitzgerald O'Connor, et al. United Kingdom. Foot and ankle Surgery, 2019[7]	Total 15 patients who received the same numbers of free MSAP flap to reconstruct the ankle and foot defects were evaluated. Among them, 11 were male and 4 were female. The mean age of patients was 47 years with a range of 21–66 years.	Retrospective consecutive case series of a single surgeon over 4 years from 2011 to 2015. They were demonstrating the use of versality of The free MSAP flaps at peri ankle wound reconstruction without the need for revision operation.	The flap survival rate was 100%. Only one flap has partial necrosis which has managed without the need for further free flap. All donor areas have closed directly Without complication. Overall outcome was satisfactory.	All 15 patients have defect at peri ankle area. Eight of them were due to trauma and remaining 7 were from infection. The mean flap length was 6.5 cm with a range of 4–12 cm. Flap width was 3–8 cm with a mean of 4.8 cm. Pedicle length ranged from 6 to 10 cm (mean 8 cm). Seven were anastomosed with posterior tibial artery, 4 with anterior tibial artery and 4 with dorsalis pedis artery. All of them were end- to-end except one. Mean flap raising time was 45 minutes.	Case series with small sample. Single surgeons experience and only included peri ankle reconstruction cohort.
Gloria R. Sue MD, Huang-Kai Kao MD, Mimi R. Borrelli MBBS, Ming-Huei Cheng MD Taiwan, Microsurgery, November 2019[8]	A total of 246 patients underwent 248 free MSAP flap to head and neck and extremities. Among them, 30 patients had flap on lower limbs. The mean age of patients was 47.5 years with a range of 15–76 years. Among them, 85.4% were male.	Retrospective study looking at the outcome and complications on consecutive patients undergone free MSAP flap reconstruction from 2006 to 2017 in a single centre.	No flap failure in lower limb reconstruction cohort. Complications rate was 16.7%. Common cause of immediate threat to flap was due to venous insufficiency (74%). Free MSAP flap shares many qualities with free radial forearm flap however had much less donor site morbidity compared to RFFF. Versality of reconstruction from head to toe, with favourable outcome with high patient satisfaction and minimal donor site morbidity.	Average flap size was 11.8 × 5.8 Cm, 12.5% developed arterial occlusion. The majority of donor site could close directly. An average pedicle length was 11.3 cm. The mean flap ischemia time was 110 minutes. No significant correlation between flap failure rate with patient age, gender or recipient site. However, location of reconstruction significantly affect the complications.	No clear outcome on lower limb reconstruction cohort. Most of the outcomes were combined and compared with H & N, upper and lower extremity reconstruction.
Farrukh Aslam Khalid, Saif ur Rehman, Ata Ul Haq, Ahsan Riaz, Muhammad Saleem, Muhammad Jibran Rabbani, Muhammad Amin, Abdul Malik Mujahid, Hamid FazeelAlvi, Moazzam Nazeer Tarar. Pakistan. J Ayub Med Coll Abbottabad, 2018[9]	A total of 18 patients had same number of MSAP flap reconstruction. Among them, only 5 patients had MSAP flaps to reconstruct the lower limb defects. Two of them were free flap. The mean age of the patients was 27.4 years with a range of 12– 36 years and all were males. Cause of defects were Mostly traumatic (3 patients) 1 was due to electric burn and 1 was from tumour excision.	Retrospective study looking for outcome of MSAP flap reconstruction in head and neck and lower limb defects. All cases have been done in a single centre between October 2016 and August 2017. Among them less a third cases were lower limb cohort (5 out of 18).	Only two free MSAP flap reconstruction to the lower limb with no flap failure or even partial loss. One of the three pedicle flaps has partial flap loss. One free flap had post operative venous congestion and one had arterial occlusion both were salvaged but didn't mentioned the site (H & N vs Lower limb).	Two free flaps both were to reconstruct foot/ankle defects. The causes of both defects were traumatic. Flap length ranged from 8 to 14 cm with the mean of 10.4 cm. Flap mean width was 9.6 with a range of 6–12 cm. The average pedicle length was 8.4 cm with a range of 8–9 cm. Both of the free flaps has anastomosed using anterior tibial artery as recipient artery. Mean flap raising time was 84.6 minutes.	Most of the outcomes were combined with head and neck reconstruction as well as some were pedicle flaps. Very little sample for lower limb cohort and outcome were complicate by including pedicle flaps. On title, they said reconstruction of head and neck and limbs. However, it only included lower limb cases and no upper limb cases were included so using the terms limbs bit confusing.

(Continued)

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Table 2 | Continued

Author, Country, Journal, Year of Publication	Patient Group	Study Type (Level of Evidence)	Outcomes	Key Results	Study Weaknesses
Kyu Nam Kim, Sang Il Kim, Won Ha & Chi Sun Yoon. South Korea, Journal of Plastic Surgery and Hand Surgery, January 2017[10]	10 Patients aged from 30 to 57 years (mean 43.7 years) received FMSAP from contralateral side to reconstruct the popliteal defect mostly from trauma. All of the patients were male.	Retrospective case series, 10 patients Received the same numbers of free MSAP flap to see the outcome of reconstruction for popliteal defect anastomosing end to end with medial sural vessels. Those have been done in a single centre over the period of 5 years between 2010 and 2015.	100% flap survival noted with only one case had partial flap loss (10%). No other obvious complication documented.	All patients had pre-operative CT Angiogram to assess the vascular status. The defects were mostly due to trauma except one, which was due to contact burn and all were in popliteal fossa. The mean flap length was 15.2 cm with a range of 17.5–12 cm. The average width of flap was 5.2 cm (range 4–7 cm). Pedicle length was 6–9 cm with an average of 7.5 cm, 90% of donor side closed directly but one who needed SSG.	It is a small case series from a single unit. Only Showed outcome of popliteal fossa reconstruction. Some operative data Specially operative time or ischemic time didn't mention.
Jyoshid R. Balan, India ANZ J Surg, 2017[11]	Seven patients who received 7 FMSAP flap for lower limb reconstruction. The mean age of patient was 42 years with a range of 19–72 years. All patients were male. Six of the defects were in foot and/or ankle and one was leg. All defects were secondary to trauma.	It is retrospective case series with FMSAP flap reconstruction were done in lower limb traumatic wounds over 2 years periods in a single centre.	All flaps have survived with only one has partial loss due to venous congestion. Two patients have donor site dehiscence. Most of the patient well satisfied from reconstruction.	Pre-operative perforator marking was done using doppler US. Mean flap length was 14.2 cm with a range of 9–21 cm. Flap width was 4–8 cm (mean 6.5 cm). Pedicle length was 3–14 cm with an average of 9.7 cm. Only one flap was anastomosed with anterior tibial vessel, other 6 were posterior tibial and dorsalis pedis 3 each. All anastomosis were end-to-end. Donor site had SSG in most cases (57%) and rest of 43% closed directly.	Small case series. The operations were done in what years not mentioned.
Zaher Jandali, Martin C. Lam, Kiomars Aganloo, Benedikt Marwart, Jouke Buissink, Klaus Muller, Lucian P. Jiga. Germany. Wiley Microsurgery, August 2016[12]	In total, 22 patients who were undergone FMSAP flap reconstruction for lower limb defects. Mean age of 59 years with a range of 31– 73 years. Among them, 15 patients were male.	Retrospective study comprised of 22 FMSAP flaps reconstruction on lower limbs of same number of patients over the period of 2 years from 2012 to 2014 in a single centre.	Over all flap survival rate was 100%. Only one patient had partial flap failure managed without further free flap. One patient had venous congestion needed return to theatre to salvage the flap. Overall patient satisfaction was good for all.	Most of the patients were suffered for PVD with or without DM. So cause of most wounds Those reconstructed were due to ischemia (16 patients). Rest of six were indicated for traumatic wounds. All wounds were involved foot and ankle and all patient had CT Angiogram preoperatively to delineate the vascular status of their legs. The mean flap length was 9.5 cm (range 6–21 cm), flap width was 4–9 cm with an average of 6 cm. Mean pedicle length was 7.2 cm (range 6.3 to 8.2 cm) More than half of them (***n*** = 12) were Anastomosed with DP vessels, 7 were with posterior tibial vessels and 3 were anterior tibial vessels. Nine of them were ETE and 13 were ETS anastomosis with recipient vessels. The average flap raising time was 139 minutes and the operative time was 293 minutes. A total of 14 donor sites were closed directly up to 9 cm wide gap. Eight of them needed skin graft. The mean hospital stay was 14 days. None of the flaps needed further adjustment.	This is the only study we found with unusual cohort of patient with PVD where as most of the studies showed the indication of reconstruction was trauma.
Xin Wang, M.D. Jin Mei, M.D. Jiadong Pan, M.D. Hong Chen, M.D. Weiwen Zhang, M.D. Maolin Tang, M.D. China. PRSJ January 2013[13]	A total of 34 patients received free MSAP flap. Among them, only nine patients have received the flaps for lower limb reconstruction at ankle and foot. Eight were male and one was female. The mean age was 35 years with a range of 23–48 years. An anatomical study was also performed on 10 cadaveric limbs to see the vascular anatomy of the MSAP flap.	Hybrid study which included an anatomical study on 10 cadaveric limbs and a retrospective clinical study of consecutive case series over the period of 3 years from 2007 to 2010 in a single centre. The study includes reconstruction of both upper and lower extremities. Among them, nine patients received FMSAP flap to reconstruct the lower limb defects.	In a clinical study, 100% flap survival with 2 partial flap loss. All patients were satisfied with the outcome.	The cause of all lower limb defects was from trauma. All patients had preoperative CT angiogram. All 9 patients received free flaps. The range of flap length was 5.5-12 cm with an average of 9.4 cm. The mean width of the flap was 5.3 cm with a range of 4.5 cm to 7 cm. Pedicle length was around 10 cm. Five of the donor sites were closed directly which were less than 5 cm wide. Four of them needed skin graft.	Complicated hybrid study which included anatomical study on cadavers as well as clinical study on patients. Only few of the patients had MSAP flap reconstruction to their lower limbs. It was difficult to extract the data about lower limb reconstruction cases. Small lower limb case sample.

(Continued)

Table 2 | Continued

Author, Country, Journal, Year of Publication	Patient Group	Study Type (Level of Evidence)	Outcomes	Key Results	Study Weaknesses
Geoffrey G. Hallock, MD. United States of America. J of Reconstr Microsurgery, October 2013.[14]	A total of 14 patients who had FMSAP flap to reconstruct their defects on lower limbs. 12 were male and 2 were female.	Retrospective study of 14 consecutive patients who received FMSAP flap to reconstruct their lower limb defects.	One patient had total flap loss which was replaced by another free flap. One flap has a problem with venous congestion and one patient had donor site complication. All patients were satisfied at the end.	The indications for reconstruction were traumatic wounds for all, but one who has unstable scar at club foot. All patients had the reconstruction at the ankle or foot. All 14 patients have received free flaps average length of flaps was 10.3 cm with a range of 5–17 cm. The range of width was 3–6 cm with a mean of 4.1 cm. In case of 7 patients recipient vessel was posterior tibial vessel, 5 were anterior tibial vessel, 2 were dorsalis pedis vessel. Nine donor sites closed directly (‹5 cm width) 5 needed skin graft.	Small case series.
Sun G, Nie K, Qi J, Annotations Jin W, Li S, Bulk Zhang submission download s Z, Wei Z, Wang D China. Chinese Journal of Reparative and Reconstructive Surgery, March 2016[15]	In total, 16 patients who received FMSAP to reconstruct their foot defects; 12 of them were male and 4 were female. The mean age was 35 years with a range of 16–58 years; 11 patients had traumatic wounds whereas 4 of them had burn wounds around ankle necessitated reconstruction.	Retrospective study to look at the outcome of 16 patients who were underwent FMSAP flap over the period of 5 years from 2010 to 2015 in a single centre.	Overall outcome was satisfactory with no flap failure or even no partial flap loss. Both donor and recipient sites were healed without any noticeable complications.	All 16 flaps were free flaps. Flap length was ranged from 5 to 11 cm and width was 4–8 cm. All flaps have survived with no complications.	Small case series. Article has written in Chinese only the abstract has found in English where we couldn't find all the information about the study.
M. Ives, B. Mathur, United Kingdom. Journal of Plastic, Reconstructive & Aesthetic Surgery, 2015[16]	In total, 18 patients who have received free MSAP to reconstruct their head and neck and limb defects. 4/18 patients received FMSAP for lower limb reconstruction. Among these four patients, two were male and two were female. The mean age of the patients was 37.7 years. The youngest patient in this cohort was 11 years old and the oldest one was 56 years old. All patients had their reconstruction for their traumatic wounds of their lower limbs. Two patients had reconstruction to their legs and other 2 patients had reconstruction to their foot and ankles.	It is a retrospective case series of 18 patients who received free MSAP flap for reconstruction of head and neck and limbs defects in a single centre, to see the outcome and complications.	All flaps in lower limbs have survived over 3 months follow-up period. Only one patient had donor site complication.	The mean flap length was 7.7 cm with a range from 4 to 12 cm. Flap width ranged from 3 to 6 cm with a mean width of 4.2 cm. An average pedicle length was 9.5 cm with a range from 7 to 12 cm. All patients had their donor sites closed primarily and none of them needed skin graft.	Small case series with a very small number of cases from lower limb cohort which was only four in number. Had multiple cohorts including reconstruction of head and neck and also limbs.

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Table 3 | Abbreviated Results for Upper Limb MSAPs

Author, Country, Journal, Year of Publication	Patient Group	Study Type (Level of Evidence)	Outcomes	Key Results	Study Weaknesses
Gloria R. Sue MD, Huang-Kai Kao MD, Mimi R. Borrelli MBBS, Ming-Huei Cheng MD Taiwan, Microsurgery, November 2019[8]	A total of 246 patients underwent 248 free MSAP flap to head and neck and extremities. Among them, 48 patients had flap on upper limbs. The mean age of patients was 47.5 years with a range of 15–76 years. Among them, 85.4% were male.	Retrospective study looking at the outcome and complications on consecutive patients undergone free MSAP flap reconstruction from 2006 to 2017 in a single centre.	There were 2 flap failure in upper limb reconstruction cohort. Among 48 flaps in upper extremities 10 have complications with a rate of 20.8%. Common cause of immediate threat to flap was due to venous insufficiency (74%). Free MSAP flap shares many qualities with free radial forearm flap, however, had much less donor site morbidity compared to RFFF. The versality of reconstruction from head to toe, with favourable outcome with high patient satisfaction and minimal donor site morbidity.	Average flap size was 11.8 × 5.8 cm; 12.5% developed arterial occlusion. The majority of donor site could close directly. An average pedicle length was 11.3 cm. The mean flap ischemia time was 110 minutes. No significant correlation between flap failure rate with patient age, gender or recipient site. However, location of reconstruction significantly affect the complications.	No clear outcome on upper limb reconstruction cohort. Most of the outcomes were combined and compared with H & N, upper and lower extremity reconstruction.
J.A. Jeevaratnam, D. Nikkhah, N.F. Nugent, A.V. Blackburn United Kingdom. JPRAS June 2014[17]	A 28-year-old man had index finger reconstruction with FMSAPF following high voltage electric burn injury.	Case report	Used palmaris longus tendon graft. Showed versality of flap use. No flap failure, no complication and patient showed very good functional and aesthetic results. No donor site morbidity.	The size of the flap was 8 × 4 cm. Donor site has closed primarily.	Only case report of a Patient
Cheng-Hung Lin, MD, Chih- Hung Lin, MD, Yu-Te Lin, MD, Chung-Chen Hsu, MD, Timothy W. Ng, BS, and Fu- Chan Wei, MD. Taiwan J of Trauma, March 2011[18]	This study included 14 patients who underwent free MSAP flap reconstruction to their upper limb. 11 of them were males and 3 were females. The mean age of the patients was 32.8 years. The oldest patient was 62 years old and the youngest one was 16 years old. The indication for reconstruction was traumatic defect in 13 patients and burns for one. All patients had their reconstruction on hand or wrist.	It was a retrospective case series with 14 patients who have treated with FMSAP Flap for their upper limb defect during the period of 2006 to 2008 in a single centre.	One out of 14 flaps has failed. One patient had wound related complication. All but one donor sites closed primarily and only one has needed split skin graft. There were no donor site complication noted.	The length of the flap ranged from 7 to 17 cm with a mean length of 10.9 cm. Flap width ranged from 2.5 to 8 cm with an average of 5.3 cm. Pedicle length was 6–12 cm (mean 10 cm). Most of the cases recipient artery was radial artery (***n*** = 12). In case of one patient, ulnar artery has been used as recipient artery and further one had UDA as recipient artery.	Small case series. No information about follow up period and duration.
Zheng H, Liu J, Dai X, Schilling AF. China JPRAS 2014[19]	In total, five patients who received conjoint or chimeric FMSAP flaps to reconstruct the jumping hand defects. All patients were male and aged from 19 to 38 years with a mean of 28 years. Three of them were due to trauma, burn and infection were one of each.	Retrospective case series over a period of 1 year from 2009 to 2010 in a single centre. Only patients with two perforators were included in the study. The follow-up was 6–24 months with an average of 13 months.	All flaps have been taken without any loss. One patient has wound dehiscence which has been managed conservatively. Overall, all patients were satisfied with a single stage of reconstruction, although three of them needed further surgery for revision and adjustment.	Five free MSAP each of which either split into two parts or raised as chimeric with multiple perforators. The average length of the flap was 6.5 cm (range 3–8 cm) and the width was 4.5 cm (range 2.5–6 cm) The pedicle size was 9–16 cm. The average thickness of the flap was 5 mm (4–8 mm). The mean arterial and venous diameters were 3 and 3.5 mm, respectively. Three out of five needed split skin graft.	Very small case series with modification of flap.
Xin Wang, M.D. Jin Mei, M.D. Jiadong Pan, M.D. Hong Chen, M.D. Weiwen Zhang, M.D. Maolin Tang, M.D. China. PRSJ January 2013[13]	A total of 34 patients received free MSAP flap. Among them, 25 patients have received the flaps for upper limb reconstruction at wrist and hands. 11 were male and 14 were female. The mean age was 35 years with a range of 19–52 years. Anatomical study also performed on 10 cadaveric limbs to see the vascular anatomy of the MSAP flap.	This is a hybrid study which included an anatomical study on 10 cadaveric limbs and a retrospective clinical study of consecutive case series over the period of 3 years from 2007 to 2010 in a single centre. The study includes the reconstruction of both the upper and lower extremities. Among them, 25 patients have received FMSAP flap to the upper extremity defects. Follow-up period is 6–21 months.	In a clinical study, 100% flap survival with three partial flap loss. All patients were satisfied with the outcome.	The main cause of upper limb defects was from trauma (21 patients). The rest of them were burns (4 patients). All patients had preoperative CT angiograms. All 25 patients received free flaps. The range of flap length was 7–14 cm with an average of 8.8 cm. The mean width of the flap was 5.6 cm with a range of 4.5–9 cm. Pedicle length was around 10 cm. Thirteen of the donor sites were closed directly which were less than 5 cm wide. Twelve of them were needed skin graft.	Complicated hybrid study which included anatomical study on cadavers as well as clinical study on patients. It was difficult to extract the data about lower limb reconstruction cases. There was less information about the operation.

(Continued)

Table 3 | Continued

Author, Country, Journal, Year of Publication	Patient Group	Study Type (Level of Evidence)	Outcomes	Key Results	Study Weaknesses
Eren F, Oksuz S, Karagöz H, Melikoğlu C, Ulkur E. Turkey. Hippokratia, 2015[20]	Two patients received FMSAP flap for reconstruction of post-burn contracture release of multiple fingers. Both were males and the average age was 21.5 years with a range of 21–22 years.	Retrospective case reports of 2 cases to see the outcome of FMSAP flap on volar wounds of multiple fingers with flexor tendons exposed after PBC release.	Both flaps worked well with even no partial failure. After 3 months of physiotherapy, patient achieved complete contracture release and adequate finger movements.	Both flaps were 6.5 cm long and 4.5 cm wide. Pedicle lengths were 8.3 and 8.8 cm with a mean of 8.5 cm. Both flaps anastomosed with radial artery as recipient vessel at anatomical snuff box. Both of the donor sites needed split skin graft. The author had an impression that donor defects could close directly if it was 5 cm or less.	Case report of two patients only.
M. Ives, B. Mathur, United Kingdom. Journal of Plastic, Reconstructive & Aesthetic Surgery, 2015[16]	A total of 18 patients reviewed those who had FMSAP for reconstruction of head and neck and limb defects. Among them, only one patient has had free MSAP for hand reconstruction. That was a 35-year-old female, who had traumatic skin loss to her hand and needed reconstruction with the FMSAP flap.	It is a retrospective case series of 18 patients with free MSAP flap reconstruction of head and neck and limbs in a single centre. Only one patient had the MSAP flap to her upper limb.	The flap has survived without any problem. However, donor sites have delayed healing issues over a 3-month follow-up period.	The size of the flap was 12 × 8 cm. The pedicle length was 7 cm. The donor site has closed primarily and does not need skin graft.	Only one patient from the upper limb cohort.

Table 4 | Publication Country of Origin

Country of Origin	Number of Studies	References
United Kingdom	4	6, 7, 16, 17
China	3	13, 15, 19
Taiwan	2	18, 21
USA	1	14
South Korea	1	10
Germany	1	12
India	1	11
Turkey	1	20
Pakistan	1	9

Note: Publication year ranged from 2011 to 2020.

Results

Table 2 presents the abbreviated results of lower limb MSAPs, while Table 3 presents the abbreviated results for upper limb MSAPs.

Grouped Upper and Lower Limb Analysis

From this 10-year review, we shortlisted a total of 15 papers to be reviewed and analysed. Among them, 11 papers for lower limbs and 7 papers for upper limb reconstructions (3 papers included both). Overall total number of patients was 257, 12 of these underwent pedicled flaps, while the remaining underwent free MSAP flaps.

These studies were carried out internationally, with five from the UK and three from China (Table 4).

Demographics of Patients

The age range was 11–79 years, with a mean age of 45.1 years.

Regarding the need for reconstruction, 104/151 (69%) reported cases were reconstructed for traumatic lower limb wounds. The next most common causes were burns and ischemia (13% and 11%, respectively).

The most common site in the case of the lower limb was the foot and ankle (77%) and the upper limb was the hands and wrist (100%).

Flap Characteristics

Flap length ranged from 3 to 22 cm. Flap width ranged from 2.5 to 12 cm. Pedicle length ranged from 3 to 16 cm.

Operation Details

End-to-end microsurgical anastomosis was used 65% of the time, with end-to-side anastomosis 35%. The mean flap raise time was reported as ranging from 45 to 139 minutes and the total operative time ranged from 282 to 293 minutes.[6,12]

Flap raising time was not recorded in the majority of articles. According to the five papers that did document this, the mean flap-raising time was 82 minutes.

Four articles reported mean operative time, which was approximately 5 hours, and 80% of donor sites closed directly.

Total flap failure occurred in 1.3% and partial flap failure in 5.8%. Congestion was reported in 3.2% with wound problems (4.5%) and donor site problems (2.6%). No patients reported being ‘unsatisfied’ with their results.

Additional Lower Limb Analysis

In this review, 11 studies were included with reference to MSAP reconstruction of the lower limbs. This included 161 patients, with the same number of MSAP flaps.

Among them, 149 were free flaps and 12 were pedicle flaps. In total, 125 (78%) were males and 36 (22%) were females. The range of age was 11–79 years with a mean of 41.8 years.

In terms of need for reconstruction (Figure 8), 88/131 (67%) cases were reconstructed for traumatic lower limb wounds. The next most common causes were burns and ischemia (13% and 12%).

The most common sites in lower limb reconstruction with a free MSAP flap were foot and ankle (77%). The

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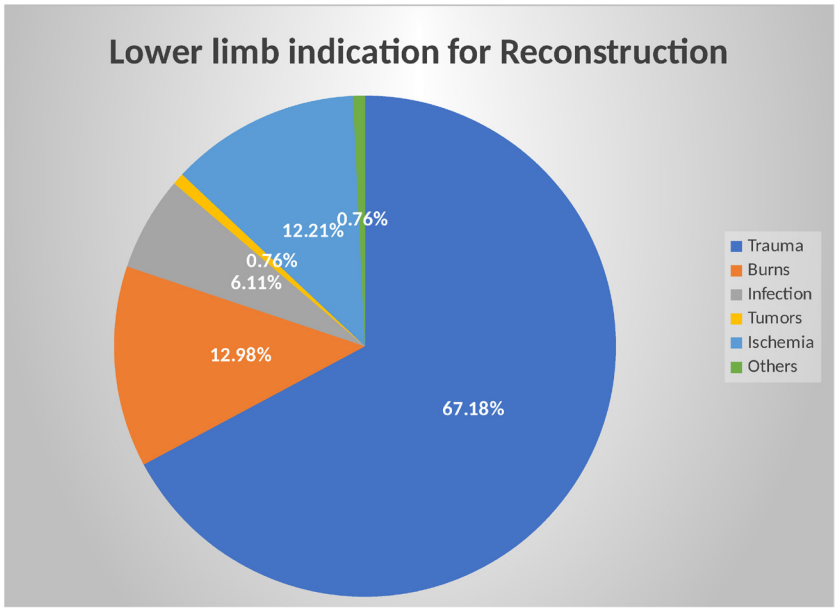

Fig 8 | Lower limb indications for reconstruction

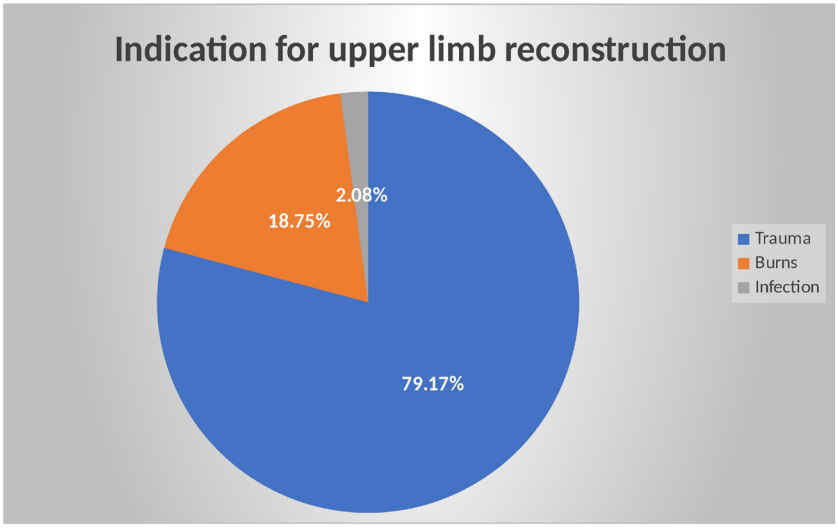

Fig 9 | Upper limb indications for reconstruction

average flap length was 10.5 cm, with a range from 3 to 22 cm.

Flap width ranged from 2.5 to 12 cm with a mean of 5.6 cm. Most of the authors agreed that the donor site could close directly if it is less than 6 cm in width. The highest documented width has closed primarily is 9 cm.

The pedicle of the flaps was found on average to be 8.8 cm; however, this was as high as 16 cm. The most common recipient arteries were the anterior tibial artery and posterior tibial artery. In 50% (n = 45/90) of cases, the recipient artery was anterior tibial or dorsalis pedis, 37% (n = 33/90) was posterior tibial and 13% of cases (n = 12/90) used other arteries (2 superior medial geniculate arteries and 10 medial sural arteries) (data available for 90 patients). Two-thirds (47/72) of the anastomoses were end-to-end and one-third were end to side (25/72).

One study[13] showed two perforators were used in four out of nine patients and one perforator was used in the remainder.

The mean flap raising time was 90 minutes[9,12,7] and mean ischemia time was 85 minutes.[21,6] Total operative time was on an average of 287 minutes.[12,6] In 76% (84/110) of cases, the donor site closed directly and 24% (26/110) cases required a split skin graft. The maximum size closed was 9 cm. The mean hospital day was 14 days.[12]

Only one free flap failed in 149 free flaps, giving a 99% flap survival rate. Eight patients had partial flap necrosis, five patients had venous congestion and five patients had wound-related complications. Donor site problems were noted in four patients. From the documentation of the studies included, all patients were satisfied with the outcome, excluding one flap failure.

Additional Upper Limb Data

In this study, seven studies were included with reference to MSAP reconstruction of the upper limbs.

Among these studies, which included 96 patients, all of them had free MSAP flaps to reconstruct hand and wrist defects. There were nearly twice as many males as female patients (M:F = 5:3). Patients were mostly young with a mean age of 32.5 years (range 15–76 years).

In the majority of cases, the indication for reconstruction was trauma (80% cases) 38/48, 18% were burn and 2% were due to infection. This is represented in Figure 9.

CT angiogram was only described in one study,[13] which was carried out in all 25 patients.

The mean flap length was 9.2 cm with a range of 3–22 cm. Flap width was ranged from 2.5 to 12 cm (mean 5.3 cm). The pedicle length was on an average of 9.4 cm (range 6–16 cm). The mean thickness of flaps was 5 mm (4–8 mm).[19] Most of the anastomosis has been carried out using the radial artery. In 87% of cases, the recipient artery was the radial artery[20] and in 13%[1] cases, this was the ulnar artery,[1] the mean flap ischemia time was 110 minutes.[21]

One study[13] mentioned that one perforator was used in 18/25 (72%) and two perforators were used in the remaining seven patients (28%).

Nearly two-thirds of donor sites closed directly in 30/48 cases (62%), and 38% of 18/48 cases needed split skin grafting.

Notably, 98% of cases had no donor site problem. Overall flap success rate was 97% (n = 3 flap failure) and partial flap loss occurred in 3% of cases (n = 3). Wound healing issues were encountered in 12.5% (12/96). Donor site problem was encountered in 1% (1/96).

Notably, 3% of patients needed further flap adjustment; however, all patients had satisfactory outcomes with reconstruction.[13,19]

Discussion

Flap anatomy: Many anatomical studies have been carried out for the MSAP flap.[8,22,23] In this study, we found mean flap length was 9.6 cm and width 5.4 cm which

correlated with the previous literature. The mean pedicle length was 9.7 cm. This compares to other studies citing this at 10.1 cm.[2]

With regards to the number of perforators, our study showed a range of 1–5, however, anatomical studies have provided a range of 1–8.[8,23,24] The average thickness of the flap was only 5.9 mm which has given its thin and pliability character.

Outcome measure: The donor site can close primarily in 80% of cases, which compares to other articles that have stated 76.2%.[2]

The overall flap success rate is 96%, with a total loss of 1.3% and a partial loss of 5.8% compared to other literature that stated 3.1% and 3.1%.[2]

Overall complications found in this study were 17%, whilst other studies found similar findings of 14.3%[2] and 16.7%. Donor complications: 2% compared to 1.9%.[2]

The most common cause of flap failure was venous congestion, which was similarly stated by Daar et al.[2]

The challenges associated with reconstructing lower and upper limb defects carry many similarities. Specifically, the scarcity of soft tissue bulk as well as, exposure of bone, tendons and neurovascular structures. Most of the cases were complex traumatic wounds with extensive zones of injury. The distant/distal blood supply and other vascular comorbidities can add further complicating factors that need to be considered when reconstructing extremities.

Keeping these concerns/challenges in mind, reconstructive surgeons should look for well vascularised, robust tissues that are durable enough to provide cover over the zone of trauma, as well as protection for infection-free bone healing, thus allowing for early mobilisation and recovery. Coverage needs to be thin and pliable enough to allow an easy gliding surface for tendons and sufficient movement of joints. Donor site morbidity is also important to reduce and enhance the recovery of patients.

Furthermore, the functional, psychological, social, financial and aesthetic importance of the upper and lower limbs puts an extra burden on the reconstructive plan. Therefore, the end functional and aesthetic outcome can have a significant impact on the patient's psychosocial and financial stability/well-being.

Free tissue transfer has become the gold standard for reconstructive options for lower limb reconstruction, especially for traumatic wounds which are the most common indication which was also reflected/echoed by our review.

The MSAP flap is one option that has already gained popularity in limb reconstruction. Survival of the flap is the most critical/vital factor, with our review demonstrating a 98% survival rate, indicating that the MSAP is a reliable flap.

Other advantages include its versatility, pliability, durability and long pedicle.[16,25,18] This is in addition to the reduced donor site morbidity, as the lower limb has less subcutaneous fat and the skin has additional slack, making it more amenable for direct closure compared to other donor sites which may require skin grafting.[26]

The MSAP flap appears to have significant advantages when compared to other workhorse free tissue flaps. The RFFF has significant donor site morbidity, while the anterolateral thigh flap can be bulky and often requires thinning, which may lead to vascular compromise.[27,28] The MSAP is also easy to monitor due to its skin paddle, in comparison to muscle and fascia only free flaps. Recent research has suggested laser Doppler imaging can also be used to monitor MSAP-free flap perfusion postoperatively.[29]

Our study does, however, have certain limitations. The sample size of the literature that was ultimately included was relatively small and additionally, all studies were retrospective in nature, potentially biasing the identification of predictors of flap complications.

The majority of the studies were single-centre series, with small sample sizes, thus limiting the strength and quality of our results.

Additionally, our review concentrated on the outcomes of the MSAP flap, rather than directly comparing it to other workhorse flaps.

A larger, prospective and multicentre trial comparing multiple flaps used to reconstruct the upper and lower limbs would provide even more useful data and more precise outcomes.

Nevertheless, it should be pointed out that the aim of our work was to review the literature on the MSAP flap alone and our results provide a summary of the characteristics of the MSAP flap and its outcomes.

Advantages and Disadvantages of the MSAP Flap

Advantages

- Flap is thin, pliable and versatile flap designing
- Long vascular pedicle helps to anastomosis away from the zone of injury and radiotherapy
- Reliable pedicle with a good number of perforators with satisfactory size
- Minimal donor site morbidity (2%), more than 80% of cases can be closed directly
- Can raise as chimeric, can harvest with vascularised fascia and can act as a gliding surface.[30]
- Consistent anatomy
- Can raise as a sensate flap with the saphenous nerve or sural nerve
- Less need for flap thinning or adjustment operation
- No donor site functional limitation.

Disadvantages

- Variations in perforator anatomy
- Tedious intramuscular dissection
- Cannot be used for large area reconstruction (on an average flap size of 9.6 × 5.3 cm)
- Scar stretching or notching, skin graft can leave scar with poor cosmesis, which is an important drawback of this flap.

Conclusion

This meta-analysis has shown the MSAP flap to be a versatile, reliable, functionally and aesthetically acceptable flap for both lower and upper limb reconstructions with maximum patient satisfaction and

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minimal donor morbidity. The overall combined flap success rate was 98%.

The MSAP is a useful flap, bearing in mind the thin, pliable skin paddle, good pedicle length and ability to carry out a two-team approach, with low donor site morbidity.

Our evidence suggests that the increasing popularity of the MSAP flap is justified and this flap is an excellent option for soft tissue extremity defects.

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