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The medial sural artery perforator pedicled propeller flap for coverage of middle-third leg defects

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Summary *Background:* Pedicled medial sural artery perforator (MSAP) flap has been described primarily for the coverage of knee and proximal-third leg defects. The technique for reaching the middle third and its use as a retrograde-flow flap were never demonstrated with clarity. This retrospective case-series aimed to report the author's experience in these regards.
Patients and Methods: Details of all patients who underwent pedicled MSAP flap for lower limb reconstruction over a 7-year period were collected. Surgical outcomes were examined retrospectively. For defects in the anterior middle third of the leg, the "pedicled propeller flap" design was utilized. To determine more distal defects beyond the reach of the anterograde-flow MSAP flap, retrograde-flow pedicled MSAP flaps were used.
Results: Eleven anterograde-flow pedicled MSAP flaps were used for defects ranging from the knee to the middle third of the leg. The etiologies of defects included trauma, chronic ulcer, and skin malignancy. All 11 anterograde pedicled MSAP flaps survived and achieved good outcomes. The mean pedicle length was 11.3 cm (range 7–18 cm), and the mean arc length after double pivoting ($n = 4$) was 29 cm (range 22–36 cm). Of three retrograde-flow pedicled MSAP flaps, two achieved the goal of wound coverage and one suffered complete flap loss.
Conclusion: The "pedicled propeller flap" design extends the reach of the anterograde-flow pedicled MSAP flap as far as the middle-third anterior leg defects. Our preliminary experience with retrograde-flow MSAP flap has mixed results. Further studies are required to examine its reliability.

Introduction

The pedicled medial sural artery perforator (MSAP) flap was considered as the evolution of the pedicled medial gastrocnemius muscle flap[1-4] for lower extremity recon-

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struction. Taylor and Daniel explored its potential use as a free flap donor sites in their early cadaveric studies in 1975.[5] It was not until 25 years later, Cadavas et al.[1], Hallock et al.,[2] and several others[6,7] studied the region further, with Cavadas demonstrating its clinical application with the first case series in the literature.[1] Although the MSAP flap gained popularity as a free perforator flap option primarily,[8] it was proposed as a useful pedicled island flap for knee and upper third defect by Hallock and Koshima in its earliest days.[2,9] In the first case series by Cavadas et al., a single case of pedicled MSAP flap use in reconstructing a knee defect was reported.[1] Several clinical series[4,7,10] followed, confirming its reliability and indications as a pedicled flap.

Although there were suggestions that the anterograde-flow pedicled MSAP flap may reach up to 3 quarters of the anterior leg[4] and the potential of retrograde-flow pedicled MSAP flap in reaching the distal-third leg defects,[10,11] these ideas were only speculations. The technical details were never clearly illustrated. Indeed, until recently, publications related to the pedicled MSAP flap remained focused on its use around the knee and upper-third leg.[12-14] Our unit has adopted the pedicled MSAP flap to cover the defects of the anterior leg since 2011 and is convinced that the pedicled MSAP flap is a more effective option than previously believed. By using the "pedicled propeller flap" design, we were able to extend the use of MSAP flap to cover middle third anterior leg defects in many occasions. The possibility of using retrograde-flow pedicled MSAP flap was also explored.

The purpose of this paper is to report the experience and outcomes of a case series utilizing both forms of the pedicled MSAP flap in the reconstruction of the leg defect ranging from the knee to the upper three-quarters of the anterior leg. The concept of "pedicled propeller flap" design will be described in detail. Finally, we will discuss our experience with retrograde-flow pedicled MSAP flap in defects beyond the reach of the anterograde-flow pedicled MSAP flap.

Patients and methods

This is a case series retrospectively examining outcomes of all patients that underwent anterograde and retrograde pedicled MSAP flap for lower leg reconstruction over a 7-year period at our institution. The reporting of the methodology and outcomes are compliant with the STROBE guidelines for reporting of cohort studies.

Patients

Utilizing patient database management system (Operation Notes version 7.6.2, Image Server), all cases of fasciocutaneous flap with relevant code (62054) performed between October 2011 and August 2018 were retrieved. In addition, all operating lists of surgeons within the date range were exported to excel spreadsheets and the term 'MSAP' was searched and retrieved. Relevant cases of lower extremity reconstruction with pedicled MSAP flap were collected by manually filtering these sources. Case notes were reviewed retrospectively to retrieve relevant information, including patient age, gender, and etiology of defect. Intraoperative details of pedicle length, flap size, postoperative complications, and follow-up were retrieved. The location of defects was divided into knee, proximal, and middle thirds. Cases with inadequate data were excluded from the review.

Surgical technique

Patients referred for open wound over anterior leg were reviewed preoperatively in outpatient or inward at our hospital. Perforators of the MSAP flap and the suitability of the pedicle MSAP flap were determined using handheld 8 MHz Doppler probe (Bidop ES-100V3, Hadeco, Inc, Japan). To increase the reach of the MSAP flaps in some cases, the "pedicled propeller flap" design was used (Figure 1 and supplementary figure 1). The arc of rotation of the flap could be extended by combining the arc of rotation of a pedicle flap with the arc of rotation of a propeller flap. At preoperative planning, the extent of the arc of rotation was estimated by doubling the distance of the distal perforator to the midpoint of the popliteal crease (Supplementary figure 1). Using a double pivot, the reach of the flap could be extended. This informed the surgeons if the pedicled MSAP flap was suitable for the defect. Pinched test was performed to assess if the donor site could be primarily closed. It is our preference to select a flap only if we could directly close the donor site. Patients are consented for the possibility of conversion to a free MSAP flap or an alternative donor site.

During the surgery, patients were placed in the supine position under general anesthesia. The hip was abducted and externally rotated, whereas the knee was flexed to allow access to the medial calf. Landmarks previously described were used.[7] A line is drawn from the mid-point of the popliteal crease to the medial malleolus prominence. A handheld Doppler probe was used to identify audible perforators starting in an area approximately 8 cm from the proximal point of the axis moving distally. The flap design is based on the most distal perforator, with the perforator placed eccentrically at the distal edge of the flap (Figure 1).

No tourniquet was used in our case series, and a medial incision was made to explore the perforators.[15] This allowed for the visualization of the perforator's pulsation. Several single drapes were placed under the calf to prop up the medial aspect of the calf. The preferred position by the surgeon was on the ipsilateral side of the donor site, although at times, surgeon may move to the opposite side for ease of certain steps of the dissection. Skin design may be altered after the exact locations of the perforators are identified. If no satisfactory perforator was found or if the perforator arises from the median or lateral sural artery pedicle, we would abandon the MSAP flap. An alternative flap (usually the anterolateral thigh flap) would be chosen.

Once a sizeable perforator with visible pulsation was found, the dissection proceeded proximally toward the anterograde flap using the deroofing technique until a satisfactory pivot point for swinging of the flap is reached. For the retrograde-flow flap, the dissection was performed both proximally and distally to determine the pattern of branch-

Figure. 1 *Anterograde-flow pedicled medial sural artery perforator flap (Case 4) demonstrating "pedicled propeller flap" technique with double pivoting.* A 52-year-old female with a middle third anterior leg infected wound post debridement. (Above, left) Middle third anterior leg defect with standard marking and perforator location. (Above, right) Completion of the pedicle dissection for medial sural artery flap with pivot point 1 and pivot point 2. (Below, right) Flap inset into middle one-third anterior leg defect utilizing the "pedicled propeller flap" technique. (Below, left) Appearance of flap at 2 weeks follow-up. (See supplementary Figure 1 for illustrated details of preoperative planning for pedicled propeller flap.).

Table 1 Patient details of the anterograde-flow pedicled medial sural artery perforator (MSAP) flap for reconstruction of the knee to middle third (1/3) anterior leg defects. Cases that utilized the "pedicled propeller flap" technique to reach the middle one-third leg defects are marked with asterisk (*). F, Female; M, Male.

Case	Age (yr)	Gender	Defect etiology	Site	Flap size (cm)	Pedicle length (cm)	Flap complications	Follow-up (mo)
1	45	F	Chronic ulcer	Knee	7 × 5	7	Donor-site wound dehiscence	4.5
2	13	M	Trauma	Knee	10 × 6	10	Nil	3.3
3*	25	M	Trauma	Mid 1/3	12 × 6	12	Nil	1
4*	52	F	Infected wound	Mid 1/3	18 × 6	17	Delay completion of inset	3.7
5*	63	M	Chronic ulcer	Proximal 1/3 to mid 1/3	12 × 5	18	Minor wound infection	1
6	73	F	Trauma	Proximal 1/3	10 × 5	9	Nil	2.6
7	19	F	Trauma	Proximal 1/3	10 × 5	9	Nil	6
8	30	M	Trauma	Proximal 1/3	12 × 5	10	Donor-site wound dehiscence (minor)	1
9	53	M	Trauma	Proximal 1/3	10 × 5	10.5	Partial flap loss (minor)	5.3
10*	32	M	Trauma	Mid 1/3	10 × 5	11	Nil	2.7

ing of the flap and for convenience should the conversion to a free MSAP flap was required. The distal pedicle dissection stopped just 2 cm from the inferior border of the contour of gastrocnemius muscle. This is an arbitrary landmark designated by the surgeon. A microvascular clamp was applied to the proximal pedicle before ligation to ensure the adequacy of the reverse flow. Any doubt about the perfusion of the flap will prompt the conversion to a free proximally based MSAP flap.

Results

Between October 2011 and June 2018, there were 11 anterograde-flow pedicled MSAP flaps and 3 retrograde-flow pedicled MSAP flaps performed for the reconstruction of lower extremity defects in 14 patients between two senior surgeons. One anterograde-flow pedicled MSAP for proximal third anterior leg defect was excluded due to insufficient data (no photo, flap size, or pedicle length) documentation on retrospective review, although complete flap survival

Figure. 2 *Anterograde-flow pedicled medial sural artery perforator flap at 1-year follow-up (Case 10).* A 32-year-old male with a middle third anterior leg wound secondary to trauma with associated compound fracture. (Above, left) Middle third defect before operation. (Above, right) Pedicled MSAP flap reaching mid one-third defect using "pedicled propeller flap" design after inset. (Below, left) Appearance of flap and satisfactory donor site approximately 3 months post surgery. (Below, right) Appearance of flap 1 year post surgery and after removal of external fixator.

and good outcome was documented in the records, thereby leaving a total of 13 patients included in the series.

Anterograde-flow pedicled MSAP flaps

The details of the patients treated with anterograde-flow pedicled MSAP flaps are summarized in Table 1.

The mean age of the patients was 40.5 years (range 13 to 73 years); 6 were males and 4 were females. For the anterograde-flow MSAP flaps, 2 flaps were used for knee defects, 4 for the upper third, and 4 for the middle third defects of the leg. The etiology of the defects included trauma ($n = 7$) and debridement post infection ($n = 3$). About 4 of the 7 traumatic defects had underlying bony fractures.

The mean flap length and width were 11.1 cm (range 7–18 cm) and 5.3 cm (range 5–6 cm), respectively. The mean pedicle length was 11.4 cm (range 7–18 cm). In 4 patients, the concept of "pedicled propeller flap" was applied in the design to enable the flap to reach the middle-third leg (Figures 1 and 2) for the reconstruction of middle-third leg defects. The mean arc of rotation after double pivoting was 29 cm (range 22–36 cm).

In 9 out of 10 cases, we were able to achieve direct closure of the donor site. In the only case that required split thickness skin graft for part of the wound, the flap width was 6 cm (12 cm in length).

All anterograde flaps survived with no major immediate postoperative complications. One of the 9 flaps required a delayed partial inset due to the flap bulk. The surgeon was concerned about the wound edge tension; thus, made decision to delay the inset of one side of the flap one week later.

The mean follow-up duration was 3.1 months (range 1–6 months). At follow-up, 1 flap suffered from minor partial loss, which healed with dressings alone. Two flaps donor site suffered from minor wound dehiscence, which also healed with dressings alone. One flap suffered from wound infection that settled with oral antibiotics alone.

Retrograde-flow pedicled MSAP flaps

The details of the patients treated with retrograde-flow pedicled MSAP flaps are summarized in Table 2.

Retrograde-flow pedicled MSAP flaps were used for the reconstruction of defects beyond the reach of the anterograde-flow MSAP flap of the anterior leg in 3 patients (Figure 3). Two were female and one was male. The mean age of the patients was 67 years (range 50–81 years). Etiology of the defects included trauma, infection, and malignancy ($n = 1$ each). The mean flap length and width were 16.3 cm (range 14–19 cm) and 6 cm (range 6 cm only), respectively. The mean pedicle length was 9.5 cm (range 5–16 cm).

All 3 flaps suffered complications. Case 11 suffered from partial flap loss with, fortunately, sufficient viable tissue in the wound bed for grafting (Figure 3). Case 12 suffered only

Table 2 Patient details of the retrograde-flow pedicled medial sural artery perforator (MSAP) flap for reconstruction of the anterior leg defects beyond the reach of anterograde-flow MSAP flap. F, Female; M, Male.

Case	Age(yr)	Gender	Defect etiology	Site	Flap size (cm)	Pedicle length (cm)	Flap complications	Follow-up (mo)
11	50	F	Trauma	Mid 1/3-Distal 1/3	16 × 6	7.5	Distal partial flap loss	19.6
12	81	M	Infection	Mid 1/3-Distal 1/3	14 × 6	5	Epidermiolysis	1
13	70	F	Malignancy	Distal 1/3	19 × 6	16	Total flap loss, venous congestion	12.4

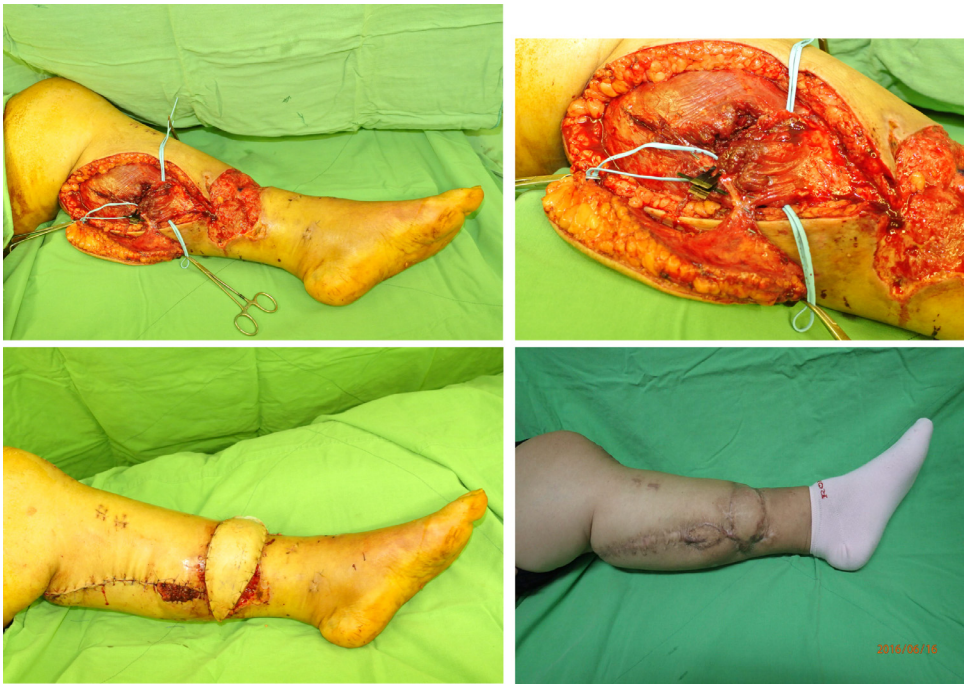

Figure. 3 *Retrograde-flow pedicled medial sural artery perforator flap (Case 11).* **A** 50-year-old female with middle-distal third anterior leg defect secondary to compound tibial fracture just beyond the reach of an anterograde pedicled MSAP flap. (Above, left) Proximal and distal pedicle dissected. Distal dissection stopped 2 cm above the distal end of medial gastrocnemius head. (Above, right) Proximal pedicle clamped prior to division to assess retrograde flow. (Below, left) Retrograde pedicled MSAP flap post inset. Flap suffered from distal flap edge necrosis postoperatively but left a graftable wound bed. (Below, right) Appearance of flap at 1-year follow-up.

minor complications with superficial epidermal loss, which healed with simple dressings (Supplementary Figure 2). Case 13 suffered from complete flap lost due to venous congestion. In all 3 cases, primary closures of the donor site were achieved.

Discussion

In this retrospective review of our case series, we confirmed the reliability of the pedicled MSAP flap in the upper third and knee reconstruction. A couple of gaps in the literature with regards to the pedicled MSAP flap for lower leg reconstruction was answered for, which included utilizing the pedicled propeller flap technique to reach middle third defects and the reliability of the retrograde pedicled MSAP flap for the lower-third leg reconstruction.

Anterograde-flow pedicled MSAP flap

The advantages of the anterograde-flow MSAP flap as a local option for lower extremity reconstruction had been well published.[3,4,7,10,12-14,16,17] Algorithm[16] and review articles[18,19] for utilizing a variety of perforator flaps for lower extremity reconstruction were previously published along with discussions of their advantages and disadvantages; thus, these are not the main focus of this paper.

A PubMed search with the term “medial sural artery perforator flap”, after manual filtering, yielded 7 publications with case series that utilized pedicled MSAP flap for the reconstruction of the lower extremity (Table 3).[4,7,12-14,16] Early case series by Umemoto et al.[10], Shim et al.,[4] and Kim et al.[7] confirmed and illustrated the reliability and reach of the pedicled MSAP flap in the reconstruction of the knee and proximal third of the leg. Although Umemoto et al. did report of a case of middle third anterior leg reconstruction

Table 3 Summary of the literature with case series using pedicled medial sural artery perforator flap.

Reference	Country	Source	No. of patients	Anterograde/ Retrograde flow	Defects reported
Current study, 2018	Taiwan	Current study	13	Anterograde ($n=10$) Retrograde ($n=3$)	Knee to distal third
Ling et al., 2018[15]	Switzerland	The Journal of Bone and Joint Surgery	17	Anterograde	Knee
Wong et al., 2017[16]	Taiwan	JPRAS	8	Anterograde	Upper-third leg
Chiang et al., 2016[17]	Taiwan	International Wound Journal	6	Anterograde	Knee
El-Sabbagh, 2011[2]	Egypt	Journal of Reconstructive Microsurgery	5	Anterograde	Upper-third leg
Shim et al., 2006[7]	South Korea	JPRAS	6	Anterograde	Knee to upper-third leg
Kim et al., 2006[10]	South Korea	Plastic and Reconstructive Surgery	3	Anterograde	Knee to upper-third leg
Umemoto et al., 2005[13]	Japan	Scandinavian Journal of Plastic and Reconstructive Surgery and Hand Surgery	4	Anterograde	Knee to middle-third leg

using pedicled MSAP flap, the conventional flap design necessitated the inclusion of tissue over the Achilles tendon distally. This ultimately required skin grafting of the donor site.[10] In a review by Xie and Chai,[8] it was implied that Shim et al.[4] showed that the pedicled MSAP flap was able to reach three quarters of the anterior leg. A detailed review of the paper by Shim et al. revealed that although one of the diagram in the paper did seem to allude to such claims, no middle-third leg defect case was presented in the paper nor was there a clarity in terms of explaining the technique of flap design to effectively reach the middle third anterior leg defects.[4] The conventional flap design of placing the perforator centered[14] or eccentrically proximal to the flap[12] was used more commonly up to recent years.

In this paper, the "pedicled propeller flap" design was illustrated and demonstrated. This design allowed the extension of the reach of the pedicled MSAP flap such that, when a favorable distal perforator was present, it can comfortably reach the middle third of the anterior leg (Figures 1 and 2). The skin paddle design places the MSAP flap always over the medial head of the gastrocnemius and, thus, within the angiosome of the medial sural artery. This ensured reliable blood supply of the flap and predictable primary closure. The flap can, thus, swing on its first pivot point at the midpoint popliteal crease (origin of the pedicle) and rotate up to 180° on its second pivot point (Supplementary Figure 1C and D). It was generally reported that there are two consistent perforators of the MSAP flap that lie 8 cm and 15 cm from the midpoint of the popliteal crease, respectively.[20] The location of the second perforator has been reported to range from 11 to 19 cm.[6,9,21,22] Thus, by doubling this figure, the "double pivot" design allows the flap reach up to 22 to 38 cm. In our case series, we demonstrated 4 cases of pedicled anterograde MSAP flap successfully used in the reconstruction of the middle third anterior leg defects with an arc of rotation ranging from 22 to 36 cm.

The limitations of the pedicled anterograde-flow MSAP flap are the availability and location of a sizeable perforator. In cadaveric studies from the 160 lower limbs that included only perforator more than 0.5 mm in diameter reported 2.5% (4 out of 160) of limbs with complete absence of perforator from the medial sural artery.[2,7,9,22-24] Kao et al. in their clinical series reported 3 out of 29 cases (approximately 10%), wherein they had to abandon the free MSAP flap due to no suitable perforator.[20] More importantly, to allow for further reach, a distal perforator is often required. In their cadaveric studies, Kim et al. reported that the incidence of the absence of second perforator is higher than the first, with 8 out of 40 limbs (approximately 20% of cases) without a second perforator. In our experience, approximately one-fifth of the time we would abandon a planned pedicled MSAP flap due to no perforator or a dubiously small perforator with no pulsation or perforator that is traced to the median or lateral sural system. An obviously sizeable and pulsatile perforator is an absolute necessity for a safe harvest of the MSAP flap. It is, thus, important to perform careful preoperative Doppler assessment and informed consent of the patient with regards to the possibility of utilizing an alternative donor site. In an ideal setting, computed tomography angiogram (CTA) would be an excellent tool in preoperative assessment of the perforators as previously shown.[24,25] However, due to local resource constraint and the socioeconomic status of the majority of our patients, this imaging option was not readily available. Finally, due to the retrospective nature of the study, the paper was unable to look at many occasions when the flap was intended but abandoned earlier in the planning phase due to the lack of Doppler signal at clinic. A prospective data collection is in progress to determine the actual figure of this occurrence.

Retrograde-flow pedicled MSAP flap

The retrograde-flow pedicled MSAP flap has the potential to reach the distal third anterior leg, thereby making MSAP flap extremely versatile. The earliest proposal of this use

was made by Umemoto et al., who observed retrograde flap perfusion after experimentally clamping the proximal pedicle in their cases.[10] This observation was supported by investigative anatomic studies done by Tsetsonis et al. who identified distal communicating vessels between the medial and lateral head of the gastrocnemius.[26-28] More recently, Persichetti et al. reported a single case of reverse flow MSAP flap as a V to Y advancement flap without dissection of the distal pedicle.[11] Our observation was consistent with these studies, as all three of our retrograde-flow MSAP flaps showed adequate perfusion when the proximal pedicle was temporarily clamped. However, we experienced a mixed result with the small case series of 3 retrograde MSAP flaps. Complications encountered ranged from superficial loss to complete loss. Although the number of cases is limited, it certainly questions the reliability of the retrograde-flow pedicled MSAP flap. Although retrograde flow appeared possible, sizes of the distal communicating vessels, described by Tsetsonis et al.,[28] may be too small to endure the twisting forces after transposing the flap. This might explain the flap loss in our case series due to venous congestion despite good flap perfusion with the proximal blood supply clamped. The flap that suffered from complete loss happened to be the flap with the longest distal pedicle dissected. In hindsight, we speculate that inclusion of the distal gastrocnemius muscle around the pedicle may improve venous drainage. Alternatively, venous supercharging using superficial venous system is worth an attempt. However, it should be noted that the reverse MSAP flap has very narrow indications. We only attempt it when free flap option was contraindicated and limb preservation is preferred. It should also be noted that when pedicle length was 5 cm, the retrograde-flow flap (Case 12) just pulled through with epidermiolysis; in the retrograde-flow flap with 7.5 cm pedicle length (Case 11), it suffers distal flap necrosis, suggesting there may be a potential of it reaching just beyond the anterograde-flow flap.

Conclusion

With an adequate planning and presence of an appropriate distal perforator, the pedicled anterograde-flow MSAP flap can reliably achieve coverage of anterior leg defects up to size of 6 cm in width, located from the knee to the middle third of the anterior surface of the leg using the "pedicled propeller flap" technique. The retrograde-flow pedicled MSAP flap is possible but the question remains with regards to the ideal technique and extent of the distal dissection of the pedicle to allow for reliable harvest. Its role in the coverage of distal third anterior leg defects requires further evaluation.

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Ethical approval

Not required.

Declaration of Competing Interest

None declared.

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Supplementary materials

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