Journal of Plastic, Reconstructive & Aesthetic Surgery (2019) 72, 188–193

ELSEVIER

JPRAS
An International Journal of Surgical Reconstruction
www.JPRASurg.com

Effects of pedicle torsion on dynamic perforasome survival in a multiterritory perforator flap model: An experimental study

Long Wang[a], **Hongqiang Wu**[a], **Chen Lin**[a], **Zihuai Huang**[a], **Renhao Jiang**[a], **Xianyao Tao**[b], **Jian Ding**[a], **Weiyang Gao**[a,*]

[a] *Department of Hand and Plastic Surgery, The Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical University, 109 West Xue Yuan Road, Lu Cheng District, Wenzhou 325000 China*
[b] *Department of Hand and Plastic Surgery, Wuxi 9th People's Hospital, Wuxi, China*

Received 25 December 2017; accepted 28 October 2018

KEYWORDS
Perforator flap;
Propeller flap;
Flap survival;
Pedicle torsion

Summary *Background:* Necrosis of propeller flaps is a problem in clinical practice. This study was performed to investigate the effects of pedicle torsion on dynamic perforasome survival using a multiterritory perforator flap model in rats.
Methods: Intercostal artery perforator flaps (IC flaps) containing two adjacent dynamic perforasomes were applied to both sides of the dorsum in 15 rats. The IC vessels were dissected carefully under $10\times$ magnification. A 360° arc of pedicle torsion was applied to the right IC flaps, which comprised the rotary group. Left IC flaps were used as controls. Flap perfusion, viability, and angiography were compared between the two groups.
Results: Sodium fluorescein angiography showed that there was blood supply to the flap in both groups on postoperative day (POD) 1, and laser Doppler images indicated that flap perfusion increased daily after surgery. The differences in perfusion of dynamic perforasomes between the two groups were not significant. The mean survival rate of the rotary group was not significantly different from that of the control group ($98.94 \pm 1.24\%$ versus $99.03 \pm 1.86\%$, respectively, $p > 0.05$) on POD 7. Angiography showed that dilated choke vessels connected the three perforasomes in both groups.
Conclusions: The 360° arc of pedicle torsion had no detrimental effect on dynamic perforasome perfusion or survival in a multiterritory perforator flap model after meticulous surgical dissection of the pedicle in this study. The dilated choke vessel connected adjacent perforasomes,

* Corresponding author.
E-mail addresses: wanglong0927@yeah.net (L. Wang), 1552753462@qq.com (H. Wu), 67174237@qq.com (C. Lin), 418280866@qq.com (Z. Huang), 405928404@qq.com (R. Jiang), 524839206@qq.com (X. Tao), dingdingdang9770@163.com (J. Ding), weiyanggaoi@126.com (W. Gao).

https://doi.org/10.1016/j.bjps.2018.10.005

and the dynamic perforasome survival still adhered to the perforasome theory after pedicle torsion.

Introduction

Based on perforasome theory and greater knowledge of the cutaneous vasculature network,[1,2] an increasing number of surgeons are now utilizing perforator flaps. Depending on the type of skin defect, a perforator flap can be used as a free or local flap.[3,4] The perforator propeller flap is a type of local flap used to cover a skin defect by flap rotation.[5] However, propeller flap necrosis, usually partial, remains an unresolved problem in clinical practice. Some authors suggested that the risk of flap necrosis increased gradually as the degree of pedicle torsion increased,[6,7] but others suggested that torsion had no effect on vascular patency, and that torsion of less than 360° had no effect on flap survival.[8-11] Although some authors demonstrated that torsion of 360° did not affect perforator flap viability,[12-14] they included only one perforasome in their flap models. Larger skin defects caused by severe trauma may require larger flaps, which often include the adjacent perforasomes.

Based on the perforasome theory, the perforasomes of a multiterritory perforator flap can be divided into three types: anatomical, dynamic, and potential perforasomes.[2,15] Some authors reported that contiguous perforasomes were usually connected by choke vessels.[16] Because of the balanced pressure between contiguous perforasomes, blood cannot flow through the choke vessel. Thus, the choke vessel is a reduced caliber, resistant vessel.[16,17] After flap elevation, choke vessels will gradually dilate and remodel into true anastomoses with no changes in caliber according to activation of fluid stress. The dilated choke vessel allows survival of the dynamic perforasome.[18] There have been no related studies regarding whether dynamic perforasome survival is affected by the combined effects of pedicle torsion and a resistant choke vessel in a multiterritory perforator flap.

Therefore, this study was designed to investigate the effects of pedicle torsion on dynamic perforasome perfusion and survival using a multiterritory perforator flap model in the rat dorsum.

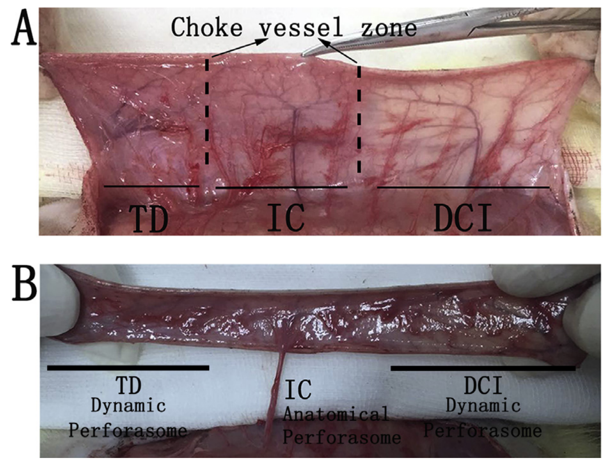

Figure 1 Intercostal artery perforator flaps in rats. (A) Thoracodorsal (TD) vessels, intercostal (IC) vessels, and deep circumflex iliac (DCI) vessels. The choke vessel zone between two perforasomes. (B) View of IC immediately after dissection. Based on IC, the IC perforasome is an anatomical perforasome, and the TD and DCI are dynamic perforasomes.

Materials and methods

Animals and flap model

A total of 15 Sprague-Dawley rats (250–300 g each) were purchased from the Experimental Animal Center of Wenzhou Medical University, China (License No. SCXK [ZJ] 2005-0019). The rats were treated according to the Guide for Care and Use of Laboratory Animals of the National Institutes of Health of China, and the experimental protocol was approved by the Institutional Review Board of Wenzhou Medical University (No. wydw2014-0015). All rats were housed in separate cages and supplied with rat food and tap water.

Rats were anesthetized by administration of 3% sodium pentobarbital (60 mg/kg) and additional doses were used when necessary. Dorsal fur was removed using an electric shaver and depilatory agent, and all surgeries were performed under sterile conditions. In this study, the designed intercostal artery perforator flap (IC flap) model was based on the IC vessels, extended cranially to the thoracodorsal (TD) vessels and caudally to the deep circumflex iliac (DCI) vessels, and was standardized by bony landmarks on the rat dorsum.[19] The IC vessels were dissected carefully under 10 × magnification of the area between the penetrating points in the deep fascia and panniculus carnosus, to ensure that the fascia did not cause external compression of the IC vessels after flap rotation (Figure 1). In each rat, the right IC flap was rotated clockwise by 360° and comprised the rotary group. The left IC flaps constituted the control group. The penetrating points of the TD, IC, DCI, and choke vessel zones were identified through transillumination, and the length of the IC pedicle was measured. The flaps were then sutured back into their original sites using 4–0 silk. Over the course of 3 postoperative days (PODs), 100,000 units of penicillin G were administered intramuscularly to prevent infection, and a fentanyl patch (75 μg/hour) was used for pain relief.

Sodium fluorescein angiography

Under anesthesia, 10% sodium fluorescein (1.0 mL) was injected into the external jugular vein through a silicone rubber catheter in three rats on POD 1. A camera was used to record blood flow under a Wood's lamp.

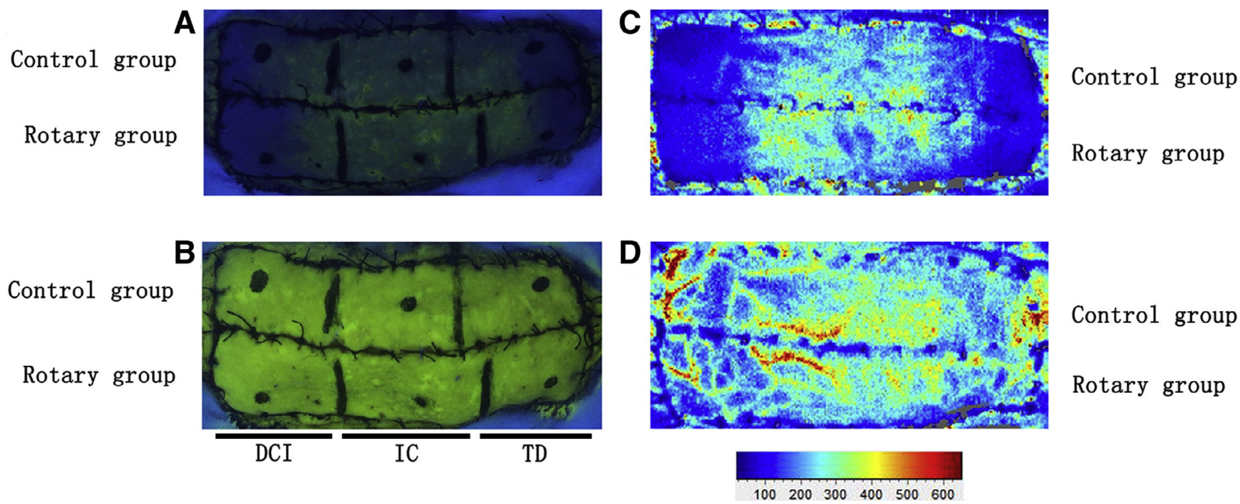

Figure 2 Blood perfusion evaluation in the control and rotary groups. (A) Ten seconds after injection of sodium fluorescein on POD 1. (B) Final fluorescein staining on POD 1. (C) Full-field laser perfusion images on POD 1 (red denotes high perfusion, blue denotes low perfusion). (D) Full-field laser perfusion images on POD 7. Scale bar represents the color for the perfusion value. DCI, deep circumflex iliac vessels; IC, intercostal vessels; TD, thoracodorsal vessels.

Flap perfusion laser Doppler imaging

On PODs 1, 3, 5, and 7, full-field laser perfusion images were measured under anesthesia in a warm and quiet environment using a laser Doppler instrument (Moor Instruments, Axminster, UK), as described previously.[20] The perfusion images were processed to provide a color-coded live flux image. Blood flow in perfusion units (pu) was measured at the central area of each perforasome ($n = 6$). Each measurement was repeated three times and the mean value was used. The observer, who measured the blood flow, was blinded to the purpose of the study.

Estimation of flap survival

Flap viability was evaluated on POD 7 using a digital camera. Image-Pro Plus imaging software (ver. 6.0; Media Cybernetics, Rockville, MD, USA) was used to determine the survival area. Survival was measured as a percentage of the total flap area.

Lead oxide-gelatin angiography

Six rats underwent whole-body angiography. The contrast agent (50 mL/kg), which included gelatin, lead oxide, and water, was perfused into the common carotid artery through a silicone rubber catheter on POD 7. After 24 hours of fixation, the flaps were obtained and radiographed (54 kVp, 40 mA, 100 s exposure) using a soft X-ray machine.

Statistical analyses

All data are presented as means ± standard deviation. The data from the two groups were compared using Student's *t*- test and one-way repeated measures analysis of variance. Statistical significance was established at $p < 0.05$ (two-tailed). SPSS software (ver. 19.0; SPSS Inc., Chicago, IL, USA) was used for the statistical analyses.

Results

Flap perfusion

On POD 1, fluorescein staining showed that all three perforasomes had a blood supply in both the rotary and control groups, and that the blood flowed gently from the IC to TD and DCI (Figure 2A and 2B). Laser perfusion images are presented in Figure 2C and 2D (red denotes high perfusion and blue denotes low perfusion). In both groups, perfusion of the IC perforasome showed a continuous growth increase that peaked on POD 7 (Figure 3A). Perfusion of the TD and DCI perforasomes in the rotary and control groups increased markedly on PODs 1-3, and these increasing trends were maintained until POD 7 (Figure 3B and 3C). There were no significant differences in perfusion of the TD, IC, and DCI between the rotary group and their counterparts in the control group (all $p > 0.05$). On POD 7, the level of blood perfusion at the TD (rotary: 355.49 ± 4.04 pu; control: 356.72 ± 5.6 pu) and DCI (rotary: 358.86 ± 11.8 pu; control: 357.42 ± 9.96 pu) reached the levels recorded at the IC on POD 1 (rotary: 364.63 ± 12.64 pu; control: 363.78 ± 14.24 pu) (all $p > 0.05$).

Flap survival and angiography

All rats survived until the end of the experiment without any postoperative infection, and regions of survival and necrosis were clearly demarcated in each group. The survival rate of the rotary group was not significantly different from that of the control group (98.94 ± 1.24% versus 99.03 ± 1.86%, $p > 0.05$) (Figure 4A and 4B). A total of three rotary flaps and two control flaps developed peripheral flap necrosis.

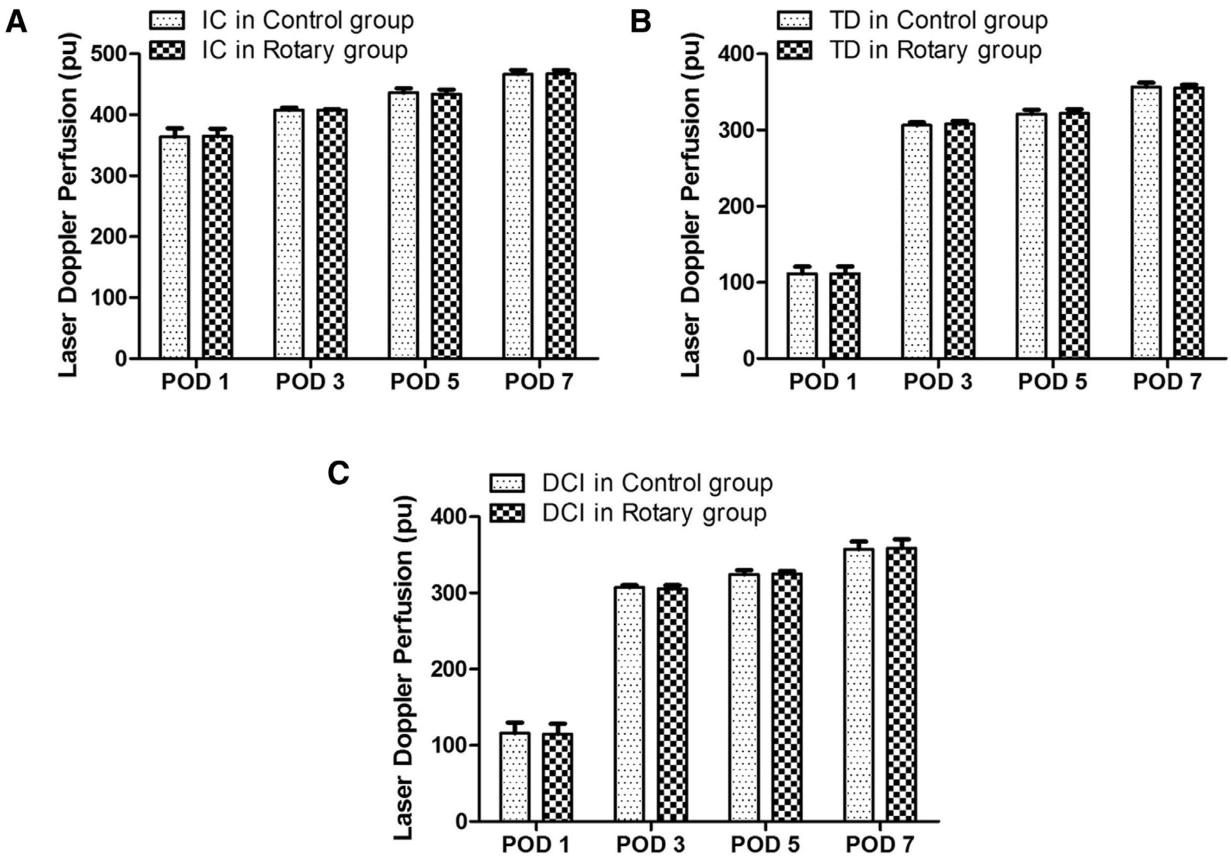

Figure 3 Comparison of perfusion in the control group versus the rotary group. (A) Comparison of perfusion of the intercostal (IC) perforasome in the two groups. (B) Comparison of perfusion of the thoracodorsal (TD) perforasome in the two groups. (C) Comparison of perfusion of the deep circumflex iliac (DCI) perforasome in the two groups. The differences in perfusion between the control group and the rotary group were not significant (all $p > 0.05$). Perfusion increased daily after surgery in each perforasome (all $p < 0.05$). POD, postoperative day. $n = 6$ per group.

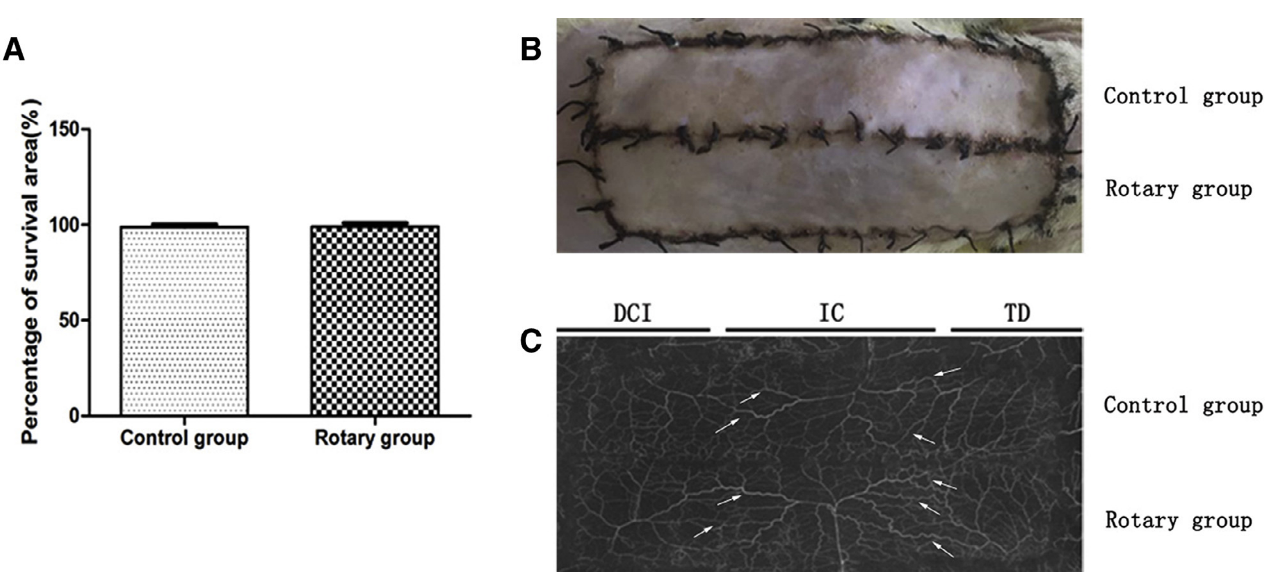

Figure 4 Flap viability and angiography in the control and rotary groups. (A) Histogram of survival rates in the control (99.03 ± 1.86%) and rotary group (98.94 ± 1.24%). $n = 6$ per group. (B) Digital photographs showing the postoperative flaps of the control and rotary groups on postoperative day (POD) 7. (C) Contrast angiography on POD 7. White arrows indicate dilated choke vessel. DCI, deep circumflex iliac vessels; IC, intercostal vessels; TD. Thoracodorsal vessels.

Angiography showed that the whole vasculature was filled with contrast agent in the rotary and control groups, except for the necrotic area. Dilated choke vessels connected the three perforasomes (Figure 4C). The IC vessels had a length of approximately 24.1–32 mm, which did not affect the dynamic perforasome survival rate after 360° pedicle torsion.

Discussion

The term 'perforator flap' refers to a flap that is based on a cutaneous perforator with a caliber of 0.5 mm or greater. Blood can flow from the anatomical to the dynamic perforasome through the dilated choke vessel, thus allowing the dynamic perforasome to survive and necrosis to occur in the potential perforasome.[21-23] Because of greater knowledge regarding their survival mechanism, perforator flaps can now be used as free or local flaps. In addition, these flaps can be made into thin or composite flaps using muscle and bone.[24,25]

The conventional propeller flap is based on a perforator that is located close to the skin defect. It can cover the skin defect by a degree of rotation and allow quick recovery, good esthetic outcomes, and reduced cost.[26] Although the perforator propeller flap is widely used, there is debate regarding the effect of pedicle torsion on flap survival. This study was performed to assess the effects of pedicle torsion on dynamic perforasome survival in a multiterritory perforator flap model. We used an IC flap with two dynamic perforasomes to model a propeller flap. In clinical practice, the normal maximum arc of rotation is 180° clockwise or counterclockwise.[7,10,27,28] We applied a rotation of 360° because the tolerable arc of rotation varied among previous studies.[6-11,29] Thus, we speculated that a rotation of 360° would have no effect on dynamic perforasome survival. It is unnecessary to perform 360° rotation in clinical practice.

Our results showed that the mean flap survival rate after rotation of 360° was not significantly different from that in the control group, and peripheral flap necrosis developed in both groups. Therefore, we inferred that pedicle torsion of 360° did not have any effect on dynamic perforasome survival or choke vessel dilation. Angiography showed a visible vasculature network in the flap with dilated choke vessels connecting the three perforasomes.

We found that perfusion of each perforasome increased postoperatively in both groups. After surgery, the IC had to support two extra dynamic perforasomes. The increased perfusion may result from tissue load.[30,31] On POD 7, perfusion of the TD and DCI reached the level of the IC on POD 1. This increased perfusion may have been due to blood restoration in the TD and DCI. Consistent with a previous report by Dhar and Taylor,[16] the caliber of the choke vessel increased markedly for a total of three PODs, and our results showed that the perfusion increased substantially during the same period in the TD and DCI perforasomes. On the basis of adjacent perforasome survival, the increased caliber of the choke vessel inevitably resulted in enhancement of perfusion. There were no significant differences in perfusion of each perforasome in the rotary group compared to their counterparts in the control group. This further demonstrated that a pedicle torsion of 360° had no effect on blood supply to the dynamic perforasome.

Our study emphasized that the pedicle should be dissected carefully because the torsional force was distributed along the entire length of the dissected vessel.[8,32] If care is not taken, the external tension from the fascia would lead to vascular closure in the pedicle. Moreover, the length of the pedicle would also affect the result of torsion, as a greater torsional force would be transmitted to a shorter pedicle.[8,14] In an experimental study conducted by Gokrem et al.[12] the pedicle length was 10 mm and torsion of 360° had no effect on the viability of the flaps containing one anatomical perforasome, while Bektas et al.[13] reported that torsion of 360° affected flap survival using a small pedicle of the same length. Thus, the effect of torsion on flap viability may not be due only to the degree of torsion.[33,34]

In clinical practice, necrosis sometimes occurs in propeller flaps and the complication rate has not improved over the last several years.[7,10,26,35] Although the tolerable arc of torsion varied among studies, several clinical and experimental studies indicated that pedicle torsion of 180° had no effect on flap viability.[10,13,35-37] Our results showed that peripheral flap necrosis also developed in the dynamic perforasome boundary of the two groups. Based on the perforasome theory introduced by Taylor et al.,[38] necrosis always occurs in the adjacent vascular perforasome boundary. Therefore, we speculated that the partially necrotic area may belong to the potential perforasome. Excessive torsion resulted in vessel closure and tension arising from the fascia traction rendered the vessel more vulnerable to torsion.[39] Thus, we performed meticulous surgical dissection, and the dynamic perforasome survival was not influenced by torsion of 360°.

Using meticulous surgical dissection, a torsion of 360° distributed the torsional force along the pedicle and did not affect dynamic perforasome perfusion or survival in our multiterritory perforator flap model. The design of the propeller flap should adhere to the perforasome theory that the dynamic perforasome should survive, and necrosis occurs in the potential perforasome because of choke vessels. Further investigations are required to determine the relationships between dynamic perforasome survival and the combined effects of different degrees of pedicle torsion, pedicle diameters, and pedicle lengths.

Financial disclosure

The authors declare that no conflict of interest exists.

Funding

This study was supported by Zhejiang Province Medical Science and Technology Project of China (2014ZDA015) and Zhejiang Province Natural Science Foundation of China (LY15H060010).

References

1. Taylor GI, Corlett RJ, Caddy CM, Zelt RG. An anatomic review of the delay phenomenon: II. Clinical applications. *Plast Reconstr Surg*. 1992;**89**(3):408–16 discussion 417-408.

2. Saint-Cyr M, Wong C, Schaverien M, Mojallal A, Rohrich RJ. The perforasome theory: vascular anatomy and clinical implications. *Plast Reconstr Surg* 2009;**124**(5):1529–44.
3. Allen RJ Jr, Lee ZH, Mayo JL, Levine J, Ahn C, Allen RJ Sr. The profunda artery perforator flap experience for breast reconstruction. *Plast Reconstr Surg* 2016;**138**(5):968–75.
4. Maciel-Miranda A, Morris SF, Hallock GG. Local flaps, including pedicled perforator flaps: anatomy, technique, and applications. *Plast Reconstr Surg* 2013;**131**(6):896e–911e.
5. Angrigiani C, Rancati A, Artero G, Escudero E, Khouri RK Jr. TDAP: Island versus propeller. *J Plast Reconstr Aesthet Surg* 2016;**69**(4):506–11.
6. Endean ED, DeJong S, Dobrin PB. Effect of twist on flow and patency of vein grafts. *J Vasc Surg* 1989;**9**(5):651–5.
7. Paik JM, Pyon JK. Risk Factor Analysis of Freestyle Propeller Flaps. *J Reconstr Microsurg* 2017;**33**(1):26–31.
8. Topalan M, Bilgin SS, Ip WY, Chow SP. Effect of torsion on microarterial anastomosis patency. *Microsurgery* 2003;**23**(1):56–9.
9. Demirseren ME, Yenidunya MO, Yenidunya S. Island rat groin flaps with twisted pedicles. *Plast Reconstr Surg* 2004;**114**(5):1190–4.
10. Bekara F, Herlin C, Mojallal A, et al. A systematic review and meta-analysis of perforator-pedicled propeller flaps in lower extremity defects: identification of risk factors for complications. *Plast Reconstr Surg* 2016;**137**(1):314–31.
11. Amoroso M, Ozkan O, Bassorgun CI, et al. the effect of normovolemic and hypervolemic hemodilution on a perforator flap with twisted pedicle model: experimental study in rats. *Plast Reconstr Surg* 2016;**137**(2):339e–346e.
12. Gokrem S, Sarifakioglu N, Toksoy K, Terzioglu A, Aslan G. Effects of 360-degree pedicle torsion on island skin flaps: experimental study in rats. *J Reconstr Microsurg* 2005;**21**(5):313–16.
13. Bektas G, Ozkan O, Cinpolat A, Bassorgun IC, Ciftcioglu MA, Ozkan O. Comparing the effects of pedicle torsion on axial or perforator flaps; improving the perforator flap resistance to pedicle torsion with delay phenomenon. *J Reconstr Microsurg* 2014;**30**(8):531–8.
14. Chang CH, Lim SY, Pyon JK, Bang SI, Oh KS, Mun GH. The influence of pedicle length on the viability of twisted perforator flaps in rats. *J Reconstr Microsurg* 2009;**25**(9):533–8.
15. Cormack GC, Lamberty BG. A classification of fascio-cutaneous flaps according to their patterns of vascularisation. *Br J Plast Surg* 1984;**37**(1):80–7.
16. Dhar SC, Taylor GI. The delay phenomenon: the story unfolds. *Plast Reconstr Surg* 1999;**104**(7):2079–91.
17. Izquierdo R, Dobrin PB, Fu K, Park F, Galante G. The effect of twist on microvascular anastomotic patency and angiographic luminal dimensions. *J Surg Res*. 1998;**78**(1):60–3 15.
18. Miyamoto S, Minabe T, Harii K. Effect of recipient arterial blood inflow on free flap survival area. *Plast Reconstr Surg* 2008;**121**(2):505–13.
19. Yang D, Morris SF. An extended dorsal island skin flap with multiple vascular territories in the rat: A new skin flap model. *J Surg Res* 1999;**87**(2):164–70.
20. Sun Y, Li QF, Zhang Y, Hu R, Jiang H. Isoflurane preconditioning increases survival of rat skin random-pattern flaps by induction of HIF-1alpha expression. *Cell Physiol Biochem* 2013;**31**(4-5):579–91.
21. Taylor GI, Minabe T. The angiosomes of the mammals and other vertebrates. *Plast Reconstr Surg* 1992;**89**(2):181–215.
22. Callegari PR, Taylor GI, Caddy CM, Minabe T. An anatomic review of the delay phenomenon: I. *Experimental studies. Plast Reconstr Surg*. 1992;**89**(3):397–407 discussion 417-398.
23. Taylor GI, Chubb DP, Ashton MW. True and 'choke' anastomoses between perforator angiosomes: part i. anatomical location. *Plast Reconstr Surg* 2013;**132**(6):1447–56.
24. Thomas CV. Thin flaps. *Plast Reconstr Surg* 1980;**65**(6): 747–752.
25. Hayashida K, Saijo H, Fujioka M. Peroneal perforator-based peroneus longus tendon and sural neurofasciocutaneous composite flap transfer for a large soft-tissue defect of the forearm: a case report. *Microsurgery* 2018;**38**(1):85–8.
26. Sisti A, D'Aniello C, Fortezza L, et al. Propeller flaps: a literature review. *In Vivo* 2016;**30**(4):351–73.
27. Ozalp B, Aydinol M. Perforator-based propeller flaps for leg reconstruction in pediatric patients. *J Plast Reconstr Aesthet Surg* 2016;**69**(10):e205–11.
28. Schonauer F, La Rusca I, Di Monta G, Molea G. Choosing the correct sense of rotation in 180 degrees propeller flaps. *J Plast Reconstr Aesthet Surg* 2008;**61**(12):1492.
29. Bilgin SS, Topalan M, Ip WY, Chow SP. Effect of torsion on microvenous anastomotic patency in a rat model and early thrombolytic phenomenon. *Microsurgery* 2003;**23**(4):381–6.
30. Lorenzetti F, Kuokkanen H, von Smitten K, Asko-Seljavaara S. Intraoperative evaluation of blood flow in the internal mammary or thoracodorsal artery as a recipient vessel for a free TRAM flap. *Ann Plast Surg* 2001;**46**(6):590–3.
31. Lorenzetti F, Suominen S, Tukiainen E, et al. Evaluation of blood flow in free microvascular flaps. *J Reconstr Microsurg* 2001;**17**(3):163–7.
32. Salgarello M, Lahoud P, Selvaggi G, Gentileschi S, Sturla M, Farallo E. The effect of twisting on microanastomotic patency of arteries and veins in a rat model. *Ann Plast Surg* 2001;**47**(6):643–6.
33. Selvaggi G, Salgarello M, Farallo E, Anicic S, Formaggia L. Effect of torsion on microvenous anastomotic patency in rat model and early thrombolytic phenomenon. *Microsurgery* 2004;**24**(5):416–17.
34. Lee HJ, Lim SY, Pyon JK, et al. The influence of pedicle tension and twist on perforator flap viability in rats. *J Reconstr Microsurg* 2011;**27**(7):433–8.
35. Yu S, Zang M, Xu L, et al. Perforator propeller flap for oncologic reconstruction of soft tissue defects in trunk and extremities. *Ann Plast Surg* 2016;**77**(4):456–63.
36. Demir A, Acar M, Yldz L, Karacalar A. The effect of twisting on perforator flap viability: an experimental study in rats. *Ann Plast Surg* 2006;**56**(2):186–9.
37. Guven E, Aydin HU, Kuvat SV, Berkoz O, Topalan M. Effects of microarterial anastomosis torsion on survival of oblique groin flap in rats. *J Plast Surg Hand Surg* 2012;**46**(6):379–82.
38. Taylor GI, Corlett RJ, Dhar SC, Ashton MW. The anatomical (angiosome) and clinical territories of cutaneous perforating arteries: development of the concept and designing safe flaps. *Plast Reconstr Surg* 2011;**127**(4):1447–59.
39. Selvaggi G, Anicic S, Formaggia L. Mathematical explanation of the buckling of the vessels after twisting of the microanastomosis. *Microsurgery* 2006;**26**(7):524–8.