

End-to-side Anastomosis on Digital Arteries: Just a Technical Choice or a Real Benefit?

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Background: High-quality evidence is currently poor regarding the benefits of end-to-end (ETE) or end-to-side (ETS) anastomosis in arterial and venous anastomoses, despite being postulated as a potential influence on outcomes. A sufficient microvascular anastomosis is indispensable for the success of any free tissue transfer. ETS microvascular anastomoses have been becoming increasingly important as they allow reconstruction even in patients with impaired vascular status. To the authors' knowledge, no studies have examined the choice of ETE or ETS anastomoses specifically for digital arteries.

Methods: We conducted a retrospective study of ETE and ETS anastomosis cases; the only inclusion criteria was that digital arteries (proper, common) were the recipient vessels.

Results: Fifty-seven cases met the inclusion criteria. All the venous anastomoses were ETE. Of these cases, four total intraoperative complications (immediate thrombosis) and only one case of complete failure were registered. The ETE group consisted of 49 patients and the ETS group of eight patients. A comparison of the mean ischemia time in the two groups showed no statistically significant difference ($P = 0.121$).

Conclusions: We observed no difference in the reconstructive outcomes of hand free flaps and reconstruction between ETE or ETS digital arteries anastomoses. The successful microsurgical reconstruction was independent of anastomotic technique. In particular, the results of our study demonstrated no statistically significant increase of the ischemia time; thus, no prolongation of operative time can be attributed to the higher technical challenge of the anastomosis. (*Plast Reconstr Surg Glob Open* 2022;10:e4535; doi: 10.1097/GOX.0000000000004535; Published online 30 September 2022.)

INTRODUCTION

In hand reconstruction, microvascular free flaps are the most versatile soft tissue reconstructive tool. They can cover complex defects of varying sizes, improve the venous and lymphatic drainage of the traumatized area,¹ and are

associated with earlier return to work and higher functional and aesthetic satisfaction.² This procedure is traditionally done to be further away from the zone of injury, to have a more facilitated and faster anastomosis by working with larger diameter vessels, and increased blood flow to meet the metabolic requirements of these free flaps.

The use of digital arteries as recipient vessels for free tissue transfer was mainly described in the finger replant literature. However, as the technical advances have progressed, there was an increased description of the use of multiple different flaps, such as small fascio-cutaneous perforator flaps and venous flow-through-flaps anastomosed to the digital vessels.³⁻¹¹

The importance of skilled surgical techniques in microvascular anastomosis and postoperative care have been previously stated.¹² However, there has been little high-quality evidence regarding the benefits of end-to-end (ETE) or end-to-side (ETS) anastomosis in arterial and venous anastomoses, despite being postulated as a potential influence on outcomes.¹²

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As the understanding of vascular anatomy and microsurgical skills improve, ETS microvascular anastomoses are increasingly important. Indeed, ETS microvascular anastomosis allows reconstruction even in patients with impaired vascular status.^{13–15} In other instances, an ETE anastomosis may be an equally effective method that is technically simpler to perform and arguably more hemodynamically efficient compared with ETS.^{14–18}

The decision to utilize an ETE or ETS anastomosis is often based on a series of factors that includes anatomical features, the configuration of the donor and recipient vessels, surgical techniques, and availability of expendable vessels.¹⁹ There is no certainty whether one of the techniques is associated with improved or diminished microvascular outcomes. ETS anastomosis has several advantages. However, from a practical standpoint, ETS may be more challenging than ETE anastomosis, and there is debate about the modalities to follow.¹³

While an ETE anastomosis is considered to be technically less complex and potentially beneficial regarding hemodynamics, ETS anastomoses enable reconstruction even in case of vessel diameter discrepancy or when preservation of perfusion distal to the anastomosis is of concern in an injured or vascularly impaired extremity.^{13,14,18,20}

Another essential factor is the possible flow disturbance and its effect in ETE and ETS. In vitro and computer simulation studies have reported that regions with a disturbed flow are at the heel, the toe, and at the floor of the distal end-to-side anastomosis.^{21–29} These disturbed flow regions correspond to those where pathologic studies have reported discrete development of neointimal hyperplasia at vascular anastomoses, a well-known complication in vascular surgery.^{21,30–33} Because of the localized nature of these lesions,^{21,30–33} various hypotheses on the influence of local hemodynamics have been proposed.^{21–23,30–33} In particular, the theories based on the influence of low or oscillating wall shear stresses at or near the anastomoses have gained attention.^{21–25,33} Investigations have also been reported on how the flow fields (including the regions of disturbed flow) change as a function of the anastomosis angle.^{23,25,26,28} If we consider that neointimal hyperplasia is at least associated with hemodynamic flow disturbances, any measures aimed at minimizing these disturbances should improve the performance of the bypass.

No research to date has examined the choice of ETE or ETS anastomoses, specifically regarding digital arteries. Therefore, the present study aimed at finding any significant difference between the ETE and ETS techniques.

METHODS

We have conducted a retrospective study examining a case series from May 2019 to December 2021. All the surgeries and anastomoses have been conducted by a single experienced microsurgeon (senior author LT). The inclusion criteria were that digital arteries (proper, common) were the recipient's vessels. A total of 57 cases met our inclusion criteria and were recruited for this study. The ETE group consisted of 49 patients, the ETS one of eight patients.

Takeaways

Question: Is there any difference in terms of results between end-to-side and end-to-end anastomosis in digital reconstruction?

Findings: The results show that both the techniques are safe and that there is no statistical difference in terms of results related to the type of anastomosis.

Meaning: The reconstructive surgeon should be able to use both techniques and choose the most appropriate one based on the defect to repair.

The decision to perform a particular flap was based on the primary surgeon's discretion, mainly referring to the area to reconstruct, the dimension of the defect and the qualities of the flap need (e.g., pliability, thickness).

Variables

For both study groups of patients, the following variables were revised: age, sex, type of flap, pathology (trauma, congenital, etc.), time of ischemia, complications.

Statistical Analysis

Continuous variables were expressed as mean \pm SD. Categorical variables were presented as frequencies and percentages. The Kruskal-Wallis test was used to compare the ischemia time between the two groups.

All data were collected and entered into an Excel database (Microsoft Office 2016; Microsoft Corp, Redmond, Wash.). The statistical analyses were performed using SPSS (IBM SPSS Statistics 25 version, Inc., Chicago, Ill.).

RESULTS

In the retrospective chart review, 57 cases met our inclusion criteria and were recruited for this study. The ETE group consisted of 49 patients; the ETS one consisted of eight patients. In the ETS group, six patients were men (75%); in the ETE group, 42 patients were men (85%).

The free flaps performed were 1% great toe pulp flap, 10.5% proximal ulnar perforator flap, 7% trimmed great toe flap, 5.3% transfer of the second toe, 3% dorsalis pedis fascial flap, 3.5% radial artery perforator flap, 1.75% free joint transfer, 1.75% anterolateral thigh perforator flap, and 1.75% vein graft for the palmar arch.

All recipient arteries were either the proper or the common digital artery. All the venous anastomoses were ETE. Of the considered cases, a total intraoperative complication was registered in 7% (immediate thrombosis), which was resolved by redoing the anastomosis or using a vein graft. Only one case of complete failure was reported (1.75%) in the ETE group.

The distribution of the diseases in the ETE and ETS groups is displayed in [Table 1](#). The mean age of the 57 patients at the time of surgery was 38.7 ± 17.5 years. The mean ischemia time for the 57 patients was 68.7 ± 30 minutes. The mean patient age and the mean ischemia time of the ETE and ETS groups are in [Table 2](#). The comparison

Table 1. Disease Distribution of the ETE and ETS Groups of Patients

Disease	ETE Group (N = 49) (n, %)	ETS Group (N=8) (n, %)
Trauma	44 (89.7)	5 (62.5%)
Congenital malformation	2 (4)	
Unstable scar of the first finger	1 (2)	
Recurrent glomus tumor of fingertip	1 (2)	
Retracting scar of the fourth finger	1 (2)	
Chronic osteomyelitis		1 (12.5)
Vascular malformation (palmar arch aneurysm)		1 (12.5)
Soft tissue loss of substance		1 (12.5)

of the mean for the ischemia time in the two groups showed no statistically significant difference ($P = 0.121$).

DISCUSSION

Given the anatomical characteristics of the upper extremity, pedicle flaps to the hand often are limited to reversed pedicle flaps, which may yield poorer results^{34–36} than free flaps.¹⁰ Additionally, pedicled flaps are limited by their arc of rotation, need for extensive pedicle dissection in the already traumatized extremity, and potential loss of a major blood supply to the hand if the ulnar or radial arteries are utilized. Comparatively, free flaps offer a plethora of possibilities in flap size and shape, tissue composition, and donor location. Additionally, they can revascularize otherwise devascularized tissues and remain soft and supple for improved function.³⁷ Furthermore, patients have been shown to have a shorter recovery.²

Free flaps to the hand were traditionally anastomosed to large vessels at the volar wrist (radial or ulnar artery) or snuff box (dorsal branch of radial artery).^{3–5} This vascular choice was in part due to microvascular technique limitations and concerns for increased complications. This approach, however, carries significant disadvantages, including greater donor site morbidity due to increased dissection to obtain a longer pedicle also of greater length and caliber, risk of devascularizing the hand by using one of the two main hand vessels (radial and ulnar arteries), potential for increased cold intolerance, and increased recipient dissection and scarring over sensitive and functional areas such as the thenar and hypothenar eminences, the palm, the wrist, and first web space.^{3–5} With microvascular and supermicrovascular advances, the literature of free flaps anastomosed to digital vessels in hand reconstruction has grown.^{3–11}

Anastomosing large free flaps to digital vessels (common and proper digital arteries, and volar and dorsal digital veins) carries concerns for the possibility of inadequate blood supply for the metabolic demands of large

composite flaps, arterial spasm, and the inadequacy of digital veins for drainage. Also, there are concerns over the need for increased microsurgical skill, the time required to anastomose to smaller vessels, and the proximity to the zone of injury. The concerns for increased microsurgical skill demand are valid but any hand or plastic surgeon with the ability to replant a finger should be able to perform this surgery. The anastomosis of vessels smaller than 1 mm can be performed with success, with limited need for proximal dissection.^{3,38,39} The time required for this more “difficult” anastomosis was not found and may be similar to that needed for the increased dissection of a donor with a longer pedicle and a recipient to the wrist.

One of the most demanding tasks in making an ETS anastomosis is the performance of perfect arteriotomy.⁴⁰ Many shapes of the arteriotomy have been described^{13,41–43} and the senior author routinely performs the triangular shaped one. An over large arteriotomy may produce severe and intractable bleeding from a suture line, which is made up of numerous open gaps, whereas an arteriotomy that is too small causes reduced blood flow.¹³ Due to vascular elasticity, slit incisions tend to make the placement of sutures difficult by their tendency to close the arterial opening during surgery.⁴⁴ One problem with elliptical arteriotomy is that there is a risk of cross-cutting where the two cuts meet. This could result in leakage and possibly a higher risk of vascular thrombosis.⁴⁰

The only advantage of the ETS over the ETE that many agree upon is overcoming the problem of vessel size discrepancy. As shown by Buecher et al,⁴⁵ the success rate in ETE anastomosis decreased as the vessel size discrepancy increased. Other advantages of ETS anastomosis over ETE anastomosis are the preservation of the vessels to the distal part of the limb, easier planning, and the avoidance of retraction and spasm in the supplying recipient artery.¹³

Regarding anastomotic patency rates, some found that ETS anastomosis is far superior to ETE.^{13,46,47} There are two reasons for this. First, the completely transected arterial stump tends to contract and retract, and bleeding stops eventually by blood clotting. On the other hand, a side arterial opening rarely closes spontaneously, and bleeding continues. In side arterial opening, the retraction of the partially severed smooth muscle of the media tends to widen the opening. Second, a 100% patency rate was obtained in the Gao study⁴⁸ in the ETS arterial anastomoses, in contrast to the ETE arterial anastomoses that showed vascular spasm in 10 cases and necessitated exploration followed by reanastomosis.

The Gao study⁴⁸ underlined that the flow disturbance was minimal when the inset angles were low. High inset angle may result in areas of boundary-layer separation, with corresponding adverse pressure gradients at the

Table 2. Mean Patient Age and Mean Ischemia Time in the ETE and ETS Groups

	ETE Group (N = 49)	ETS Group (N = 8)	P
Mean patient age (y)	38.7 ± 17.5 (2 minimum, 72 maximum)	38.5 ± 18.8 (21 minimum, 69 maximum)	
Mean ischemia time (min)	67.8 ± 31.6 (15 minimum, 180 maximum)	74.5 ± 17.7 (52 minimum, 100 maximum)	0.121

anastomosis site and consequent thrombosis, A 45-degree inset angle was proven experimentally to be the optimum angle to reduce the turbulence flow and the thrombosis to a minimum in ETS anastomoses.²⁶ Also, their study⁴⁸ shows that, despite their effort to enlarge the anastomotic lumen to increase blood flow, the results were negative. In fact, blood flow through anastomoses was significantly lower in big side anastomoses than in equal size anastomoses.

According to a meta-analysis⁴⁹ that highlights this, differences in rates of thrombosis and flap failure between ETE and ETS venous and arterial anastomoses are marginal and nonsignificant; also, the present study did not show any significant difference. The study by Godina¹³ has previously been quoted to justify the use of ETS arterial anastomosis preferentially in microsurgery. However, both ETE and ETS anastomoses can be associated with kinking and/or occlusion secondary to attaching vessels to a fixed recipient site. Vessel geometry is an essential consideration before performing either technique.⁵⁰ This analysis incorporated microvascular anastomoses performed in significantly different clinical settings.

The rate of flap failure reported by Damen et al⁵¹ showed a very low failure rate from 406 ETE arterial anastomoses in protocol-driven elective breast reconstruction. This contrasts with studies by Samaha et al,¹⁴ Piazza et al,⁵² and Cho et al⁵³ that describe higher failure rates following ETE arterial anastomoses in trauma, head and neck reconstruction, and lower limb reconstruction. The studies included in this analysis that measured outcomes following ETS arterial anastomoses had notably fewer cases than ETE anastomoses, likely reflecting the more frequent use of ETE anastomoses in clinical practice. The notable studies by Cho et al⁵³ and Samaha et al¹⁴ show many cases following lower limb trauma and complex trauma reconstruction. Predictably, the failure rates documented in these studies are far higher than in breast reconstruction using ETS arterial anastomoses.^{54,55} The variability of results between these large studies using the one anastomosis technique demonstrates many factors at play in free flap success rates. More broadly, Cho et al's⁵³ findings are supported by clinical evidence showing equivalent long-term patency rates for ETE and ETS anastomoses in free tissue transfer to various anatomic sites.²³

Experimental studies also demonstrate roughly equivalent results when vessels used in ETE anastomosis are roughly the same diameter, with ETS only providing a clear advantage when size discrepant vessels were used.⁵⁶

One of the *in vivo* animal model studies that has been conducted, investigating how the angle of the ETS anastomoses changes the flow disturbances,⁵⁷ confirms *in vitro* observation²⁶ that when the proximal outflow segment is occluded in a 15-degree anastomosis, the streamlines remain attached to the vessel walls as the fluid passed through the anastomosis. The study⁵⁷ also confirms the existence *in vivo* of flow disturbances at and downstream of vascular ETS anastomoses reported from hemodynamic *in vitro* studies.^{22, 24, 26, 28} Furthermore, it confirms that the anastomosis angle is a major determinant of the local flow fields *in vivo* and that, when an occluded artery segment is

bypassed, the 15-degree anastomosis is preferable from a hemodynamic point of view because no flow disturbances were detected at the toe or downstream of the toe in this anastomosis.

Experimental studies in rat and canine models have also shown no differences in flap failure, peripheral resistance, and blood flow when comparing ETE and ETS arterial anastomoses with no vessel size mismatch.^{19, 58–60} Still, another study on an animal model investigating the superiority of ETS anastomoses in arteries less than 1 mm (a good approximation for the digital arteries) has been conducted on an animal model.⁵⁰ Evaluating the angle of the ETS anastomosis, the study conducted on ETS anastomoses on arteries less than 1 mm size on an animal model concluded that (1) high blood flow rate and low incidence of thrombosis occurred more often in 45-degree than in 90-degree inset angle anastomoses and (2) the greatest blood flow was obtained in equal size end-to-side anastomoses.⁵² Its clinical application showed (1) 45-degree angle of inset in ETS arterial anastomoses; (2) equal size in terminal and side opening of transplant and recipient arteries; (3) side elliptical opening created by needle guidance technique having its longitudinal diameter three times longer than the transverse diameter; and (4) ETE venous anastomoses done.⁵⁰

Considering the distribution of neointimal hyperplasia at the distal ETS anastomosis, as reported by Sottiurai et al^{31, 33} and Bassiouny et al,²¹ which is viewed in relation to the flow patterns, it is seen that the sites of neointimal hyperplasia correspond with the locations of zones of low or reversed velocities. This is consistent with the theories based on the influence of local flow disturbances on development of neointimal hyperplasia at vascular ETS anastomoses.^{21–25, 33} Accepting that the development of neointimal hyperplasia at vascular anastomoses is indeed influenced by local flow disturbances, it may be possible to reduce this pathologic process surgically. Staalsen et al⁵⁷ concluded that the anastomosis angle has been found to be a major determinant of the local flow fields *in vivo*. This confirms the *in vivo* existence of regions with low and reverse velocities at the preferential sites in vascular end-to-side anastomoses where neointimal hyperplasia tends to form.

CONCLUSIONS

The hand is both a functional and aesthetic organ with special needs. The simplest reconstructive approach (healing by secondary intention) is often unacceptable due to exposure of tendons/bone/vessels, tissue desiccation, scarring, and compromised function.⁶¹ Local flaps such as cross-finger flaps or thenar flaps are infrequently a possibility given their proximity to the zone of injury, their limited size in upper extremity, and their potential for temporary disability to the patient's other digits.

Distant two-stage pedicle flaps, like the abdomen and groin, lead to unnecessary immobilization and have been shown to have poor overall results.^{62, 63} This leaves single-stage pedicle flaps and free flaps as the preferred reconstructive modalities.

The safety and quality of anastomosis on digital artery has been shown by Diaz-Abele et al,⁶⁴ but they only

performed ETE anastomosis. On the other hand, the authors aimed to prove the differences, if any existed, between ETS and ETE for digital anastomosis.

The present study investigated the outcome of free flap transfer for reconstruction of hand defects depending on anastomotic technique (ETE versus ETS) on digital arteries. Overall, our study demonstrates no discernible differences in the reconstructive outcomes of hand free flaps and reconstruction with ETE or ETS digital artery anastomoses and that successful microsurgical reconstruction is independent of anastomotic technique. In particular, the study managed to demonstrate that there is no statistically significant increase of the ischemia time, and consequently no prolongation of operative time that can be attributed to the higher technical challenge of the anastomosis.

This study has limitations, many of which are associated with its retrospective nature. First, we compared two microsurgical anastomotic techniques with different indications and inherent selection bias, which cannot be controlled in a heterogeneous patient population. Second, the decision to perform an ETE or ETS arterial anastomosis was predicated on factors we could not completely discern retrospectively, such as the extent of soft tissue damage, vessel quality and accessibility, and the location of the microvascular anastomosis relative to the zone of injury.

The choice of ETE or ETS microsurgical technique for arterial anastomosis should therefore be dictated by the clinical circumstances, patient factors, tissue damage, recipient vessel quality and accessibility. Anastomotic technique depends on surgeons' individual expertise and training. Decision-making concerning the anastomosis to be applied differs from surgeon to surgeon.

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