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Review Article

Microvascular anastomosis of the forearm: a narrative review

Diana E. Gutiérrez Gómez*

Department of General Surgery, Hospital General de Zona No. 5, Nogales, Sonora, Mexico

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***Correspondence:**
Dr. Diana E. Gutiérrez Gómez,
E-mail: dianagugo19@gmail.com

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ABSTRACT

The forearm occupies a unique position in reconstructive practice: it is simultaneously the most frequent donor site for the radial forearm free flap and a common recipient bed for coverage of distal forearm and hand defects, and its 1–3 mm-caliber arteries and veins are the same vessels an angiologist evaluates when assessing perfusion, patency, or thrombotic risk in trauma and vascular disease. Yet the literature on forearm microvascular anastomosis is almost exclusively written from a reconstructive-surgical vantage point, with the hemodynamic and vessel-wall principles that govern patency treated as background rather than as an explicit angiologic framework. This narrative review synthesizes current evidence on suture-based anastomosis, mechanical coupling devices, venous salvage strategies, and emerging robotic and sutureless technologies in forearm and wrist microsurgery, and reframes each of these techniques against the hemodynamic and vascular-biology principles that are the traditional domain of angiology. Hand-sewn interrupted suture remains the reference technique, but systematic comparisons of suture configurations have found no consistent patency advantage of one over another, and continuous through-the-lumen suturing has achieved comparable patency with shorter execution time despite theoretical concerns about intraluminal thrombogenicity. Mechanical coupling devices have reduced anastomotic time and, for venous anastomosis specifically, have been associated with low thrombosis rates in large pooled series; arterial coupling remains more contested because arterial wall thickness, medial stiffness, and, in older or vasculopathic patients, atherosclerotic change increase the risk of intimal disruption and thrombosis — concerns that are fundamentally angiologic rather than purely technical. Venous outflow failure remains the leading cause of flap compromise in severe forearm and hand trauma, prompting salvage strategies such as dual venous anastomosis and a bone-anchored coupler technique that repurposes vascularized bone marrow as a recipient venous bed when conventional veins are unavailable. Robotic-assisted anastomosis and sutureless adjuncts show patency comparable to manual technique but remain limited by longer operative times and an immature evidence base. We argue that closer integration of angiologic assessment — vessel wall quality, flow dynamics, and pre-operative vascular mapping — into reconstructive planning may reduce technique-dependent failure and should be considered a natural extension, rather than a separate discipline, of forearm microsurgery.

Keywords: Microvascular anastomosis, Forearm reconstruction, Angiology, Radial forearm free flap, Microsurgical coupler, Venous thrombosis, Vascular anastomosis, Plastic surgery, Hand trauma, Vessel wall biology

INTRODUCTION

Microvascular anastomosis of the forearm sits at an anatomic and conceptual crossroads. For the reconstructive microsurgeon, the forearm is best known as the donor site of the radial forearm free flap and, less often, as a recipient region requiring free-tissue coverage of the distal forearm and hand after trauma, burns, infection, or tumor extirpation.[1-4] For the angiologist and vascular medicine specialist, the same radial, ulnar, and interosseous vessels are the objects of an entirely different clinical concern: native arterial and venous disease, post-traumatic vasospasm, thrombosis, and the hemodynamic consequences of vessel injury or occlusion.[5] Both

disciplines are, at bottom, managing vessels of comparable caliber — typically 1 to 3 mm in diameter — and both are ultimately concerned with the same outcome: sustained, non-turbulent flow through a vascular conduit that does not activate the coagulation cascade.[6,7]

Despite this overlap, the reconstructive and vascular-medicine literatures rarely speak to one another. Reviews of forearm microvascular anastomosis are written almost exclusively for a plastic and reconstructive surgery audience, framing patency, thrombosis, and flap failure as technical or device-related outcomes rather than as manifestations of the same vessel-wall and flow physiology that angiologists study in other contexts, such as arteriovenous access, peripheral arterial disease, or deep venous thrombosis.[8,9] This review attempts to narrow that gap. We summarize the current evidence on hand-sewn suture technique, mechanical coupling devices, venous salvage strategies, and emerging robotic and sutureless technologies for forearm and wrist microsurgery, and we deliberately foreground the angiologic principles — flow dynamics, endothelial injury, and vessel wall composition — that explain why these techniques succeed or fail.[4,10-12] Our intention is not to replace existing reconstructive-surgery reviews but to complement them with a vascular-medicine lens that we believe has practical value for anastomotic decision-making, particularly in patients whose forearm vessels are not "healthy" in the idealized microsurgical sense — the elderly, the diabetic, and those with peripheral vascular disease.[13]

METHODS

Literature search strategy and MeSH terms

A structured literature search was conducted in PubMed/MEDLINE, Scopus and Google Scholar for articles published in English up to October 2026, with no lower date limit so that landmark anatomical and vascular-biology studies could be included. The following Medical Subject Headings (MeSH) were used alone and in combination with the Boolean operators AND/OR: "anastomosis, surgical", "microsurgery", "forearm", "radial artery", "free tissue flaps", "vascular patency", "thrombosis", "venous thrombosis", "suture techniques", "replantation", "hand injuries", "wrist injuries" and "robotic surgical procedures". These were supplemented with the free-text keywords "microvascular anastomosis", "microvascular coupler", "anastomotic coupling device", "radial forearm free flap", "venous anastomosis", "continuous suture", "sutureless anastomosis", "shear stress" and "endothelium". A representative PubMed search string was: ("Anastomosis, Surgical" [MeSH] OR "microvascular anastomosis") AND ("Forearm" [MeSH] OR "Wrist Injuries" [MeSH] OR "Hand Injuries" [MeSH] OR "radial forearm free flap") AND ("Vascular Patency" [MeSH] OR "Thrombosis" [MeSH] OR "microvascular coupler"). Clinical series, systematic reviews and meta-analyses, preclinical trials and key vascular-biology reviews addressing anastomotic technique, patency or failure in the forearm, wrist or radial forearm free flap were included, and the reference lists of retrieved articles were hand-searched for additional sources. Non-English articles were excluded.

VASCULAR ANATOMY AND HEMODYNAMICS OF THE FOREARM: AN ANGIOLOGIC FOUNDATION

The forearm is supplied by the paired radial and ulnar arteries and their anterior and posterior interosseous branches, arising from the brachial artery bifurcation and running within well-defined fascial septa alongside venae comitantes.[1,2] Superficial venous drainage runs through the cephalic and basilic systems, while deep drainage parallels the arterial tree. This dual, redundant arterial and venous architecture is precisely what makes the forearm both a forgiving donor site — the radial artery can typically be sacrificed with the ulnar artery and palmar arch providing collateral perfusion to the hand, once confirmed by an Allen test or equivalent — and a technically demanding recipient bed after trauma, when one or more of these parallel channels may already be injured, thrombosed, or absent.[3,14] Because the Allen test has limited sensitivity as a screening tool, Doppler ultrasound assessment of the ulnar collateral circulation has been recommended as a more objective alternative before the radial artery is sacrificed.[14]

From an angiologic standpoint, three principles govern whether an anastomosis constructed in this vascular bed will remain patent. First, flow through a vessel of this caliber approximates Poiseuille conditions, in which resistance rises with the fourth power of any reduction in luminal radius; even modest anastomotic narrowing from purse-stringing, intimal flaps, or size mismatch between donor and recipient vessels therefore produces a disproportionate hemodynamic penalty.[6] Second, wall shear stress at the anastomotic line is a primary determinant of endothelial behavior: physiologic laminar shear promotes an antithrombotic endothelial phenotype, whereas the turbulence created by a technically imperfect suture line or an oversized coupler ring promotes platelet adhesion and local thrombus formation.[5,6] Third, Virchow's triad — endothelial injury, stasis, and hypercoagulability — applies as directly to a hand-sewn or mechanically coupled microanastomosis as it does to any other vascular reconstruction; every technique discussed in this review can be understood, at least in part, as an attempt to minimize one or more of these three variables.[7] Recognizing forearm microvascular anastomosis as an exercise in applied vascular hemodynamics, rather than purely as a suturing skill, is the conceptual bridge this review is built around.

SUTURE TECHNIQUES AND PATENCY OUTCOMES

Hand-sewn interrupted suture remains the recognized reference standard for microvascular anastomosis, even as

multiple alternative suturing configurations have been described and continue to be used according to individual training and preference.[8,15]

A widely cited systematic review compared six suture techniques — simple interrupted, continuous, locking continuous, continuous horizontal mattress, horizontal interrupted with eversion, and the sleeve technique — and found no clinically meaningful difference in short- or long-term patency across configurations, concluding that the choice of technique is appropriately guided by surgeon experience and comfort rather than by demonstrated superiority of any single method.[10] From an angiologic perspective, this finding is coherent with the hemodynamic principles above: what determines patency is not the suture pattern per se but whether that pattern reliably produces a smooth, non-stenotic, everted intimal apposition that preserves laminar flow.

A modified continuous through-the-lumen technique, applied across 2,346 anastomoses in 785 patients, achieved 100% immediate patency and a 96.4% flap success rate, with mean arterial and venous anastomosis times of approximately 7.5 and 10 minutes, respectively.[15] Despite these favorable outcomes, continuous suturing remains comparatively underused in practice, largely because of persistent concern that a running suture line can produce a purse-string constriction of the lumen and that intraluminal suture material may act as a nidus for thrombosis — concerns that map directly onto the shear-stress and endothelial-injury mechanisms described in the previous section, even where large series have not shown this theoretical risk to translate into worse clinical patency.[15] An intraoperative view of the forearm recipient field during microvascular anastomosis is shown in Figure 1.

MECHANICAL COUPLING DEVICES: VENOUS AND ARTERIAL APPLICATIONS

Mechanical anastomotic coupler devices align and evert two vessel ends over a pair of interlocking rings studded with fine pins, producing a mechanically standardized, intima-to-intima anastomosis without intraluminal suture material. Across multiple large series, coupling has been associated with significantly reduced anastomotic time and with vessel patency comparable to, or in some series better than, hand-sewn technique.[11,16,17] A widely cited systematic review and meta-analysis pooling data across dozens of studies and thousands of patients reported an overall coupler-related thrombosis rate for venous anastomosis in the low single digits, alongside a statistically significant reduction in both anastomotic time and postoperative flap failure risk compared with hand-sewn venous anastomosis.[11,18] The mechanical rationale is again an angiologic one: because the coupler ring maintains a fixed, non-collapsible luminal geometry, it removes the operator-dependent variability in eversion and tension that produces turbulence and endothelial trauma with a hand-sewn line.



Figure 1: Intraoperative view of the forearm showing the exposed recipient vessels during microvascular anastomosis.

Table 1 summarizes representative forearm- and wrist-specific applications of coupling devices reported in the literature, spanning acute trauma revascularization, replantation, and free-flap donor-site anastomosis.[19-22]

Table 1: Representative forearm- and wrist-specific applications of coupling devices reported in the literature, spanning acute trauma revascularization, replantation, and free-flap donor-site anastomosis.[19-22]

Application	Vessels/flaps	Key reported outcomes	Source
Wrist revascularization after trauma	22 arteries, 3 veins (coupled)	Mean coupling time ~7.3 min; 100% immediate patency; 88% long-term patency; higher complication rate when coupling arteries	Mai et al[19]
Upper-limb replantation	27 couplers (radial, ulnar, brachial vessels)	100% patency; mean anastomosis time ~4 min; all replanted limbs survived	Xia et al[20]
Arterial coupling, radial forearm free flap donor site (head and neck recipient bed)	90 radial forearm free flaps	97.6% flap survival; arterial insufficiency in a minority of cases	Chernichen-ko et al[21]
Venous coupling, radial forearm free flap donor site (head and neck recipient bed)	261 venous anastomoses (majority RFFF)	Complication rate under 5%; low early venous failure rate	Frederick et al[22]

Arterial coupling has followed a more cautious trajectory. In a wrist revascularization series, arterial coupling was associated with a higher long-term complication rate than venous coupling in the same cohort, including arterial narrowing and complete occlusion in a subset of vessels.[19] This asymmetry is well explained by angiologic vessel-wall biology rather than by any deficiency of the device itself: arteries are thicker-walled, less compliant, and — particularly in older patients or those with underlying atherosclerotic disease — may have intimal or medial calcification that resists the eversion the coupler requires, increasing the risk of intimal disruption and secondary thrombosis.[13,19]

A systematic review of arterial coupling across 20 included studies reported an overall efficacy of 92.1%, with the residual failures — requiring revision or conversion to a hand-sewn technique — occurring disproportionately in extremity reconstructions, where vessel caliber and wall characteristics are least favorable for a fixed-geometry device.[13] A separate systematic review of arterial coupling likewise reported a good success rate and low thrombosis rate, but only in selected patients and on the basis of evidence with a high risk of bias.[23] Microsurgeons therefore remain more comfortable reserving arterial coupling for selected cases, while treating it as standard for venous anastomosis.

VENOUS INSUFFICIENCY AND SALVAGE: AN ANGIOLOGY-INFORMED APPROACH

Venous outflow failure, rather than arterial inflow failure, is the leading cause of flap compromise in forearm and hand reconstruction, and this problem is magnified in severe trauma, where the usual complement of recipient veins may be thrombosed, avulsed, or simply absent.[4,24,25] In a large series of 1,193 free flaps, venous thrombosis was considerably more frequent than arterial thrombosis among flaps requiring re-exploration for pedicle thrombosis, although venous thromboses were also more often salvageable.[24] Performing two venous anastomoses rather than one is a commonly used strategy to reduce thrombosis risk by providing a redundant outflow pathway, although the published evidence on whether dual venous anastomosis meaningfully improves flap survival, as opposed to simply providing a hemodynamic safety margin, remains mixed.[4,25]

When no usable recipient vein exists, a novel salvage technique anchors a venous coupler device into a surgically created cortical window of the distal radius, using the vascularized cancellous bone marrow itself as the venous outflow bed. In a recent series of 12 patients undergoing free anterolateral thigh flap reconstruction for distal forearm and hand defects, this bone-anchored coupler approach was applied in a single case in which no conventional recipient vein was available, and provided effective venous drainage with complete flap survival.[4]

Conceptually, this technique substitutes the sinusoidal, low-resistance venous plexus of vascularized bone for a discrete extremity vein as the pressure sink for flap outflow — an elegant example of applying angiologic reasoning about alternative low-resistance venous pathways to solve a problem that pure microsurgical technique cannot.

EMERGING TECHNOLOGIES

Robotic-assisted anastomosis

The Symani surgical system achieved patency equivalent to manual technique in a preclinical trial, with less histologic tissue trauma but significantly longer execution time.[26]

The da Vinci system was used to perform 17 robot-assisted anastomoses in radial forearm free flap reconstruction, achieving 100% patency, although mean operative time was significantly longer than hand-sewn technique (38.4 versus 28.0 minutes).[12]

Sutureless adjuncts, including laser tissue bonding, cyanoacrylate-family tissue adhesives, and intravascular stents, reduce the amount of suture material required but carry their own risks of reactive inflammation and uncertain long-term patency.[9]

Each of these technologies can again be read through the same angiologic lens: robotic platforms and sutureless adjuncts are, in essence, engineering solutions aimed at reducing the same variables — mechanical endothelial trauma and turbulent flow at the suture line — that determine patency in conventional hand-sewn or coupled anastomosis, rather than fundamentally new physiologic mechanisms.

TECHNICAL ERRORS AND TRAINING: AN ANGIOLOGIC READING OF FAILURE

A systematic review of microvascular technical errors identified back-wall stitches, uneven luminal apposition, and excessive suture tension as the errors most consistently associated with reduced patency, underscoring the value of structured, error-based microsurgical training.[27] Each of these errors has a direct angiologic correlate: a back-wall stitch creates an intraluminal flap that disrupts laminar flow and exposes thrombogenic subendothelial collagen; uneven lumen apposition creates a step or ridge that generates local turbulence and flow separation, the same rheological phenomenon implicated in atherosclerotic plaque localization at arterial bifurcations; and excessive tension distorts the vessel wall, provoking vasospasm and further endothelial injury. Framing microsurgical error-based training explicitly around these hemodynamic consequences, rather than purely as technical checkpoints, may sharpen trainees' understanding of why a given error matters.

TOWARD AN INTEGRATED MODEL: WHY ANGIOLOGY BELONGS IN FOREARM RECONSTRUCTIVE PLANNING

Several of the findings summarized above point toward the same practical conclusion: anastomotic outcome in the forearm is not determined solely by which suturing or coupling technique is chosen, but by the baseline quality of the vessel wall being worked with.[4,13,19] Arterial coupling failure is concentrated in extremity reconstructions and is attributed, at least in part, to arterial wall thickness and atherosclerotic change; wrist arterial coupling in trauma patients shows a higher long-term complication rate than venous coupling in the same cohort; and venous salvage techniques exist precisely because native venous anatomy is frequently compromised in the patients who most need reconstruction. These are angiologic problems as much as they are technical ones, and they argue for a more deliberate incorporation of vascular-medicine assessment into forearm reconstructive planning: pre-operative duplex ultrasound vessel mapping to characterize wall quality and flow, not merely patency; explicit consideration of a patient's vascular risk profile (diabetes, smoking, peripheral arterial disease) when choosing between suture and coupler technique or between single and dual venous anastomosis; and closer collaboration between reconstructive surgeons and vascular medicine specialists in patients whose trauma or comorbidity profile suggests that the forearm vasculature itself, not just the soft-tissue defect, is compromised.[7,14] We suggest that this integration, rather than remaining an implicit background assumption, should be made an explicit part of how forearm microvascular anastomosis is taught and practiced.

LIMITATIONS

This is a narrative rather than a systematic review, and the underlying evidence base it draws on is heterogeneous: most series are retrospective and single-institution, sample sizes for arterial coupling and for the bone-anchored venous salvage technique in particular are small, and direct head-to-head randomized comparisons between suture technique, coupling, and robotic assistance in the forearm specifically are lacking. The angiologic framing offered here is intended as an interpretive lens to organize existing reconstructive-surgery findings rather than as a claim that new primary vascular-medicine data have been generated.

CONCLUSION

Microvascular anastomosis of the forearm is, in practice, applied vascular hemodynamics performed at millimeter scale. Hand-sewn interrupted suture remains a reliable reference technique, and alternative suture configurations, mechanical coupling, and emerging robotic and sutureless technologies each achieve comparable patency by minimizing turbulence and endothelial trauma at the anastomotic line, even though they do so through different mechanical means. Coupling devices have particularly strong evidence for venous anastomosis, while arterial coupling and robotic assistance remain promising but require further validation, especially in patients with unfavorable vessel-wall characteristics. Framing forearm microsurgery explicitly at the intersection of plastic surgery and angiology — attending to flow dynamics, vessel wall biology, and vascular risk profile alongside suturing technique — offers a more complete account of why anastomoses succeed or fail, and may help guide technique selection in the increasingly common scenario of forearm reconstruction in vasculopathic or heavily traumatized patients.

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