Advances of Plastic & Reconstructive Surgery

Chapter 1

Microsurgery

Eliseo Sara[1]; Mansour Ahmed M[1]*; Miller Nathan F[1]; Mahajan Arnav, BS[2]; Ranganath Bharat[2]; Miles Marshall[1]; Wojcik Randolph[1]; Murphy Robert X[1]; Wallace Sean J[2]

[1]Division of Plastic and Reconstructive Surgery, Lehigh Valley Health Network, 1250 South Cedar Crest Boulevard, Allentown, PA 18103, USA.

[2]George Washington University Plastic Surgery; Division of Plastic & Reconstructive Surgery, The Medical Faculty Associates, 2300 M Street NW 6th Floor Washington DC 20037.

*[*]**Correspondence to: Mansour Ahmed M,** Division of Plastic and Reconstructive Surgery, Lehigh Valley Health Network, 1250 South Cedar Crest Boulevard, Allentown, PA 18103, USA.*

Email: Ahmed.Mansour@lvhn.org

1. Introduction

The field of microsurgery is unique in that it is both a surgical subspecialty and a technique. Microsurgical techniques are characterized by the utilization of magnification devices, such as operating microscopes and optical loupes, to enhance the ability to visualize what cannot be seen by the naked eye [1,2]. Typically, microsurgery aims to restore function of body structures by means of direct union or tissue transfer using anastomosis of small blood vessels, nerves, and lymphatics [1]. These skills can be translated and applied across many additional fields, including but not limited to hand surgery, neurosurgery, ophthalmology, transplant surgery, vascular surgery, otolaryngology, and gynecology [2]. Microsurgery is also one of the critical components of plastic surgery residency education in the United States. Beyond residency, plastic surgeons can further specialize in microsurgery fellowship to gain additional exposure and refinement in these techniques [3].

While the main purposes of microsurgery are in tissue replantation from one part of the body to another and the reattachment of amputated parts, it can also assist in the restoration of aesthetic and functional defects that resulted from trauma, cancer, and congenital abnormalities [2-4]. With a wide application potential and ever-expanding scope, microsurgical techniques powerfully enhance the armamentarium of plastic surgeons [3].

Fundamentals

As with any other surgical specialty, goals and plans must be in place, but adaptability and a broad reconstructive repertoire are essential to overcome obstacles that may arise. This variability allows reconstructive surgeons to use different methods/routes to get to the same destination. The following fundamentals of microsurgery are emphasized in training programs to produce safe, confident, and efficient surgeons:

- appropriate knowledge base and skillset
- adaptability of surgeon and surgical team to changing environment
- efficiency and precision
- access to appropriate magnification and instrumentation
- restoring form and function while minimizing donor site morbidity
- assuring minimal-to-no tension on tissues or vessels
- minimization of OR time

Aptitude in microsurgery requires dedication and practice, but several exercises and simulations of real-life anatomical situations help surgeons refine their skills and develop proficiency and confidence [5]. Prosthetic and virtual reality simulators, in addition to live and cadaveric animal models, are some of the frequently used modalities seen among microsurgical training programs [6]. Additionally, similar high-quality microscopes should be used for both practice and surgery. Familiarity and comfort working with the operative microscope will minimize the struggle to achieve optimal visualization [5].

Magnification

Magnification and illumination are crucial in providing an improved visualization of tissue, especially when handling ultrasmall vessels, nerves, and suture materials [5].

The use of magnification in surgery first began in 1876 when a German ophthalmologist created a simple pair of optical loupes by using simple convex lenses with a light source, mounted on a headpiece [7]. Other advancements followed shortly after, including the first vascular transplant in 1896, the development of the first operating microscope and surgery under monocular magnification in 1921, and the development of the binocular microscope in 1922 [1,2,7,8]. However, it wasn't until 1960 when Dr. Julius Jacobsen first used a microscope for microvascular anastomosis that the field of microsurgery truly began [7].

At a basic level, magnification can be calculated by multiplying focal length of binocular tubes by the magnifying power of an eyepiece, or by multiplying the focal length of an object by the magnifying power of a magnification changer. The typical working magnification for the reconstructive microsurgeon is between 3.5x and 12.5, and it can be achieved either by using surgical loupes or an operating microscope.

Surgical loupes usually have a magnification of 2.5x to 5x and should be custom made to take the corrected vision and interpupillary distance of the surgeon into account [9]. Loupes are frequently used for flap dissection with a minimum magnification of 2.5x, and microsurgical anastomoses or coaptation of structures greater than 1.5mm in diameter can be safely performed with loupes of 3.5x to 4x magnification [9]. However, this is usually reserved for larger blood vessels.

Many variations of operating microscopes exist. They provide stronger magnification than loupes, with most surgical microscopes magnifying from 6x to 12x and specialized scopes providing excellent resolution with a magnification of 40x [9]. The microscope should be fitted with eyepieces of 10x to 15x magnification and objective lenses of 200mm to 300mm of focal length, as well as a strong light source [5].

Other features of operating microscopes include display laser angiography technology and display monitors. Laser fluorescent angiography technology is seen with some operating scopes, which achieves deeper imaging depth while also evaluating patency after anastomoses are performed [10]. The enhancement of tissue visualization with magnification allows for the appreciation of fine anatomic details, which allows for more precise suture placement and instrument positioning [9]. Video output monitors are also used in the operating room to allow the clinical team to view the procedure with great detail. These displays are important in that they allow the scrub tech to follow and anticipate next instruments needed while also serving a teaching purpose for medical students and residents. This, in conjunction with comfort of the surgical team create a conducive environment for the surgery to take place.

Surgeon Positioning

Position and comfort level are directly correlated with performance when working with operating microscopes. A comfortable working distance prevents excessive angulation and strain of the body [9]. It is best that the surgeon is seated in a position with their neck and spine in a neutral position, and with forearms and hands resting on the operative surface to prevent fatigue and muscle tension, which can amplify native tremor [5]. Using a foot pedal to control zoom and focus may be beneficial because it leaves the hands free to concentrate on operating, rather than on adjusting the microscope [5]. By resting hands on sterile towels, the ball of the hand and small finger can be used as adjuncts for stabilization while operating. Fine motor control is of utmost importance when working with such delicate and small vessels. Such practices help surgeons comfortably use the specialized instruments and smaller sutures and needles required in microsurgery.

Instruments

Jeweler's forceps, microscissors, vessel dilators, needle drivers, and microvascular clamps are some of the instruments typically used in microsurgery and are illustrated in **Figure 1,** below. Though few in number, these tools are highly specialized to accommodate the pinch movements between thumb and index fingers that is required for microsurgery [1,5]. The small precision tips, light balance proportions, pinch closures, and nonreflective surfaces are some of the few features seen with microsurgical instruments [1]. Shape of the tools and tension of spring-loaded instruments are specifically designed so that fingertips can accommodate the tiny, pinch-like movements with comfort and control, and without excessive strain and loss of grip [5]. Below is a brief description of each of the basic instruments used in microsurgery.

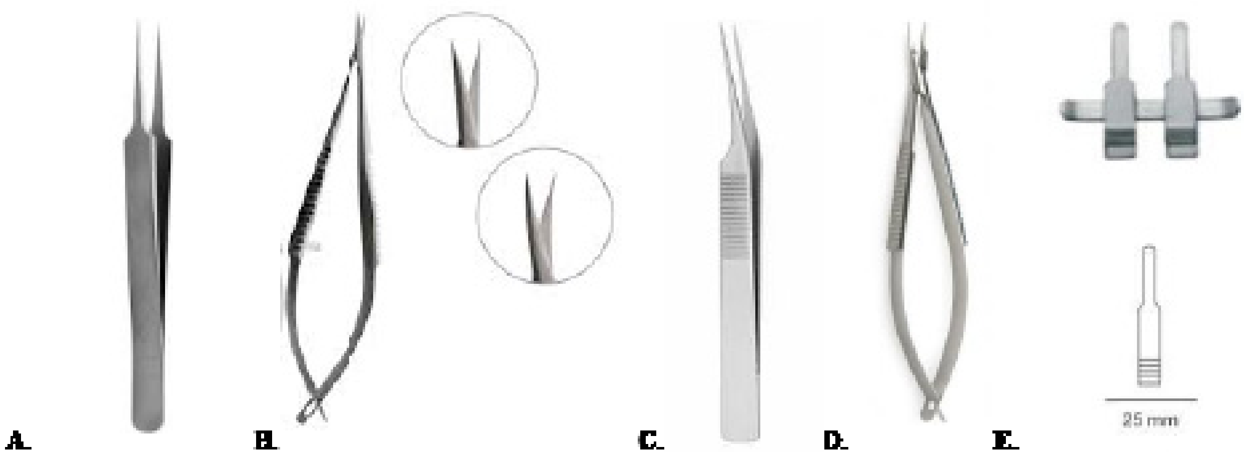

Figure 1: **A.** Jeweler's forceps **B.** Microscissors **C.** Vessel dilators **D.** Needle drivers **E.** Microvascular clamps

Jeweler's forceps: Jeweler's forceps are used for handling tissue. They may have round or flat handles and come in different lengths, ranging from about 4 to 6 inches. They are fine-pointed and delicate. Some have a flat platform on the inner surface of the tip designed for grasping suture, and others are angle-tipped to reach the undersurface of a vessel [5] (**Figure 1A**).

Microscissors: Microscissors are spring-handled and fine-tipped. They may be curved, or Bayonetted, in which case they are used for dissecting and trimming vessels. Scissors of this variation add complexity due to the increased length and angled handle [5]. Straight microscissors are more commonly used for cutting vessels, adventitia, or suture. They come in different lengths and may be sharp- or blunt-tipped (**Figure 1B**).

Vessel dilators: Vessel dilators are smooth, super-fine-tipped forceps that are used for intubating and dilating vessels in preparation for anastomosis. The tip on the dilators differ from that of the Jeweler's in that the tip is rounded and smaller to safely gain access into the lumen of the vessel (**Figure 1C**).

Needle drivers: Needle drivers are spring-loaded, may be curved or straight, but are non-locking in microsurgery, unlike the traditional needle drivers used in other surgery subspecialties. It is important to ensure that the jaws approximate and close in a parallel fashion over their entire length so that the needles and suture can be grasped securely [5]. Some surgeons will use Jeweler's forceps in place of the specialized needle drivers, due to the similar non-locking nature (**Figure 1D**).

Microvascular clamps: Microvascular clamps, otherwise known as Acland clamps, are used to gently occlude blood flow until the anastomosis is completed. They close with a pressure of less than 30g/mm^2 to prevent trauma to the endothelium of the blood vessel. These clamps come in single, double, and curved in shapes. The double clamp with a sliding approximator can be used for tension-free anastomoses (**Figure 1E**).

Other useful equipment includes micro-backgrounds, hemoclips, and cellulose spears. Micro-backgrounds are thin sheets of colored plastic, usually green colored, that maximize contrast of sutures and tissue. They frequently include a measuring grid to identify vessel diameter. Hemoclips come in a variety of sizes and are used in ligating small branches. Cellulose spears are sterile, highly absorbable sponges that are specially designed to absorb moisture in delicate procedures.

Sutures & Needles

Monofilament nylon microsuture is the most used suture when performing an anastomosis or coaptation. The suture size used depends on the size of the vessel or nerve that the surgeon is working with. Thin sutures are those that have the most zeros after them and range from 1-0 to 12-0, with 12-0 being the thinnest and having the least breaking strength [11]. In microsurgery, the suture sizes range between 8-0 and 12-0. The more delicate the medium being manipulated, the smaller the suture size used. Recommended suture sizes based on diameter of the blood vessel being handled is illustrated in **Table 1**.

Table 1: Recommended suture sizes based on vessel diameter.

Suture Size	Typical Vessel
8-0	Radial, ulnar, anterior tibial, peroneal
9-0	Internal mammary, dorsalis pedis, posterior tibial
10-0	Digitals
11-0	Children, perforators, lymphatics

The needles used for microsurgery ideally should have a tapered, noncutting point to prevent laceration of the edge of the vessel during suture placement. Microsurgery needles also have a flat body to be securely grasped and aligned properly [5]. Needles are named based on their shape, diameter, and chord length, respectively. The shape of the needle is labeled either BV, BVH, or ST, with BV indicating a 3/8-circle-shaped needle, BVH indicating a ½-circle-shaped needle, and ST indicating a straight needle. Next in the nomenclature sequence is the diameter, which is measured in microns and ranges from 75-140um. The last number in the sequence is for chord length, which measures the straight-line distance from where the needle attaches to the suture, otherwise known as the swage, to needle point measured in millimeters.

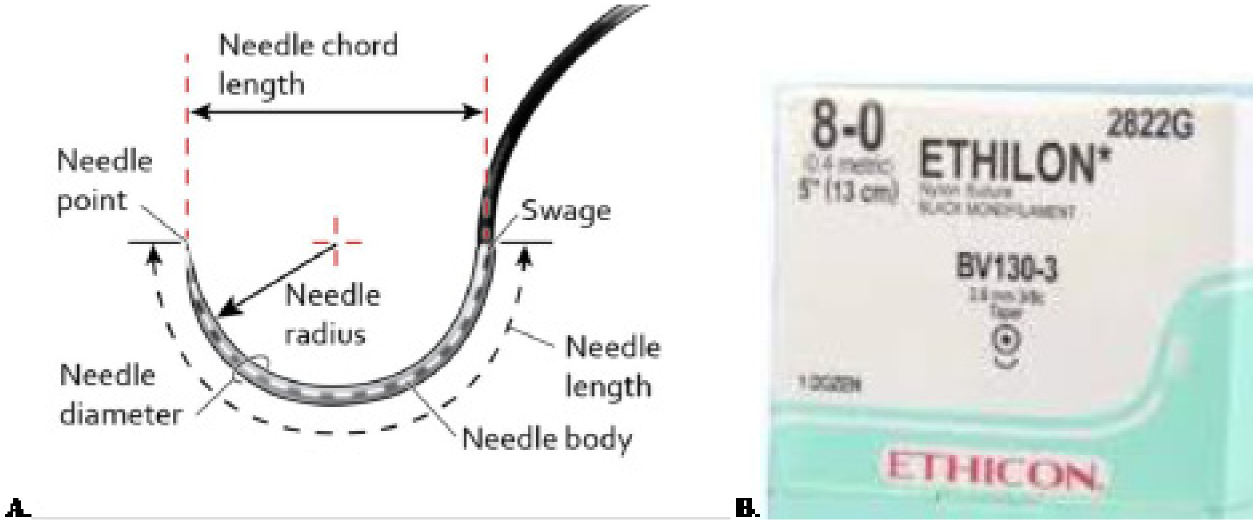

Figure 2: A. Labeled diagram of a suture and needle **B.** Example of an BV 130-3 needle on an 8-0 Ethilon suture.

Anastomotic couplers can be used in place of sutures and are becoming more widely used in free tissue transfer [12]. While arteries are always hand-sewn due to the high-flow hemodynamics and rigid vessel layers, the thin walls and low-flow state of veins make them suitable for anastomosis via coupler devices. The rigid-stent, interlocking ring-pin design of microvascular anastomotic coupling devices have demonstrated favorable tensile characteristics and healing of coupled vessels in animal studies, and while there have been no data to support superiority of hand-sewn versus coupled veins, couplers have been shown to decrease venous anastomosis and ischemia time [12-14]. Thrombosis rates are similar between techniques and is less than 1% in skilled hands [14].

Planning

Initial Considerations

When first assessing a wound that needs reconstruction, a thorough history and physical exam will help determine the best approach. It is important to identify any missing, exposed, or damaged structures. Imaging may be helpful as an adjunct to physical examination. Evaluation of functional deficits, underlying fractures, contamination, and blood supply sufficient for reconstruction are some of the essential factors to take under consideration, as they may need attention before moving forward, or may require that the reconstruction take place in multiple stages [15]. Fractures needing fixation and contaminated wounds needing debridement are some examples of what may need to be optimized, subsequently prolonging the time by which the reconstruction takes place.

Coverage

A durable soft tissue coverage requires consideration of anatomic location with regard to motion, sensibility, scar contractures, donor site morbidity, and potential need for revisions or secondary procedures. There are several wound coverage techniques ranging from simple closures to the more complex microsurgical approaches [15,16].

The concept of the "reconstructive ladder" highlights the importance of utilizing the simplest approach possible, beginning with primary closure and progressing through secondary intention healing, skin grafts, local flaps, distant flaps, tissue expansion, and ultimately microvascular free flaps [16]. However, reconstructions have become well developed as time progressed, and the reconstructive ladder has been updated to the reconstructive elevator (Figure 3). The theory behind the reconstructive elevator emerged to emphasize the flexibility in selecting the most suitable reconstruction method tailored to each patient's specific needs. While microsurgery was previously the highest rung on the reconstructive ladder, the reconstructive elevator employs that a surgeon may bypass the simpler steps, rending microsurgery and free tissue transfer no longer a last resort [16,17].

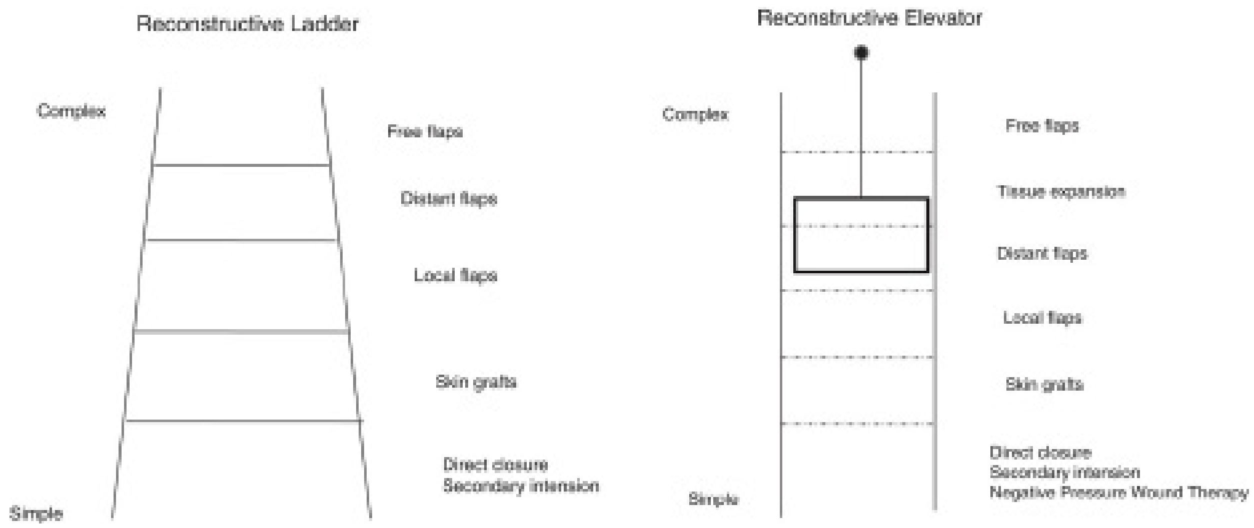

Figure 3: Reconstructive ladder and reconstructive elevator [18]. The easiest closure may not be the optimal for functional recovery, especially in hand and upper extremity defects. Traumatic injuries to the hand and upper extremity often involve multiple structures such as skin, bone, tendons, muscles, nerves, and blood vessels [19]. Special considerations include greater emphasis on sensibility and mobility, replacing palmar versus dorsal soft tissue and replacing like-with-like whenever possible. Ideal reconstruction of the hand should warrant movement of tendons and joints sufficient for the patient to return to work [19].

Indications and Contraindications

Microsurgery has many indications, some of the more common including reconstruction of complex or composite wounds after trauma, cancer extirpations, breast reconstruction, hand/digit replantation, vascularized bone grafting, functional muscle transfer, nerve repair, nerve reconstruction, and lymphedema surgery.

While there are no absolute contraindications to performing microsurgery, the patient should be healthy enough to tolerate prolonged general anesthesia. Patients with systemic comorbidities such as diabetes, kidney disease, heart disease, and/or lung disease can be candidates for microsurgery as long as their condition is well controlled to minimize morbidity [20]. As expected with most surgical procedures, active pregnancy and hypercoagulable disorders are considered relative contraindications, and these patients should be approached with caution. Some misconceptions include very young or advanced age, nicotine and tobacco use, and history of radiation treatment. Previously irradiated tissues should be approached with great care as they tend to be more friable and vessels are at higher risk of delamination [20].

Although nicotine and tobacco usage are not absolute contraindications, smokers should be counselled on smoking cession in the weeks before and after surgery to prevent wound healing complications [20]. The rate of wound-healing complications increases by 50% in tobacco users, and smoking after surgery has even been associated with up to 90% failure rates in digital replantation [21].

Technical Considerations

The most common reasons for a flap to fail depends on the technical aspects of microsurgery. Microsurgeon's success stems from experience obtained during and after training. Previous studies show that success rates after training can be as low as 72%, but as high as 97% after sufficient experience [22].

It is crucial to prevent tissue and vessel trauma to achieve successful reconstruction. Ensuring tension-free anastomoses is of utmost importance as it necessitates proper dissection and mobilization of the pedicle and recipient vessels from surrounding tissues. Once the anastomosis is completed, it is equally important to ensure proper positioning of the pedicle and anastomosis beneath the flap [23]. It is essential to avoid a lengthy and convoluted pedicle course, as it may result in twisting or kinking and subsequent flap failure.

Vessel Preparation

Vessel preparation techniques may vary among surgeons, but there is a consensus on selecting vessel locations outside the area of injury [23]. Once the flap has been elevated and the blood supply has been temporarily interrupted (ischemic phase), the vessels are prepared for anastomosis under the microscope.

Preparation of the vessels involves trimming the vessel end to a healthy appearance and removing the adventitia, which is the outer layer of the vessel that could potentially obstruct the anastomosis. It is recommended to trim the vessel edges to prevent exposure of the endothelium to the adventitia, as this can promote platelet aggregation. Flushing the vessel ends with heparinized saline is often performed to ensure clear visualization of the vessel's integrity and to identify any debris or clot that may obstruct the anastomosis [5]. At the recipient site, a spurt test is conducted to confirm sufficient blood flow before performing the anastomosis [23].

Establishing the Anastomosis

Performing a technically demanding anastomosis in microsurgery necessitates an optimal setup. Technique is imperative in establishing a successful anastomosis, and special attention should be paid to needle placement, knot tying, and tension on the vessels [5,23]. The needle should enter the vessel at a 90-degree angle, following the curve of the needle through the full thickness of the vessel wall. The needle tip should be visualized at all times, which can be achieved by intubation of Jeweler's forceps or dilators into the anastomosis. Many suture techniques are used based on surgeon preference, but the most used are either interrupted sutures or a single loose running stich with subsequent cutting and tying of loops [24]. The intima of the vessel edges should be precisely aligned without excessive tension or bunching. Bunching can lead to exposure of the endothelium to the adventitia, which can promote platelet aggregation.

End-to-End vs. End-to-Side

End-to-end: Various techniques have been described for end-to-end anastomoses, but two common approaches include the halving technique and the triangulation technique [25]. The halving technique involves placing the first two stitches 180 degrees apart. Subsequent sutures are then placed halfway between the first two stiches along the front wall and back wall of the vessel. The triangulation technique entails placing three stiches 120 degrees apart and then rotating the vessel to fill in the sutures between the original three stitches [25].

End-to-side: End-to-side anastomoses are often preferred when the size difference is 2:1 or greater. To perform an end-to-side anastomosis, and arteriotomy must be created on the recipient vessel [25]. This can be achieved using an 11 blade, tenting the vessel with a suture, or by using a 2.5mm vascular punch. The initial stitch should go through the heel of the donor vessel and the proximal end of the recipient vessel enterotomy [5]. From here, the rest of the suturing can proceed as either of the methods described above.

While end-to-end anastomoses are generally preferred, end-to-side anastomoses may be necessary in certain situations where there is a single vessel providing perfusion distally or a significant size discrepancy exists. Studies have shown comparable anastomotic patency rates between end-to-end and end-to-side techniques when the angle of the end-to-side anastomosis is performed between 30 and 75 degrees [could not find source for this, got info from Dr. Wallace's ppt].

Completing the Anastomosis

On completion of the anastomoses, the restoration of blood flow to the flap is achieved by releasing the microvascular clamps. It is generally recommended to release the vein first, followed by the artery, to avoid exerting excessive pressure on the microvascular circulation. To confirm the flow across the anastomoses, a “strip test” is performed [26]. The vessel is occluded distal to the anastomosis with forceps and then milked, causing it to collapse between the forceps. When the proximal forceps are released, the blood will fill the collapsed portion of the vessel, indicating successful blood flow [26]. Other tests to determine patency are the uplift test and the empty-and-refill test, both described by Dr. Robert Acland [25]. If any bleeding side branches are observed, superfine or micro hemoclips can be utilized to ensure hemostasis.

Anticoagulation, Solutions, and other Medications

Although no randomized controlled clinical trials have shown improved patency of anastomoses using anticoagulants, they are still commonly used in microsurgery with the idea that they reduce the chances of post-operative clotting at the anastomosis site [4]. Some of the commonly used medications in microsurgery are as follows:

Aspirin: Aspirin function by inhibiting platelet aggregation through the inhibition of the COX enzyme in the arachidonic acid cascade. Lower doses, such as 81 mg and 325 mg, have been shown to inhibit thromboxane but not prostacyclin. Aspirin may be initiated on the day of surgery and continued for 2-4 weeks postoperatively.

Intravenous Heparin: IV heparin acts by binding to antithrombin III, resulting in conformation changes that inhibit factor Xa [4]. IV heparin is not routinely used unless intraoperative anastomotic clot occurs. If it is started, it is generally continued for 5-7 days.

Topical Heparin (Heparinized Saline): Topical heparin, otherwise known as heparinized saline, is used for flushing vessels and irrigating the surgical field. Solutions are mixed anywhere from 10 to 100 units per milliliter in either normal saline or lactated Ringer’s solution.

Topical 2% Lidocaine: Topical lidocaine can be used as an irrigant to bathe vessels and alleviate vasospasm.

Topical Papaverine: Topical papaverine is a Phosphodiesterase (PDE) inhibitor that promotes vasodilation. It can be used full strength or diluted and is used to bathe vessels.

Intravenous 10% Dextran 40: IV 10% Dextran 40, while uncommonly used today, was previously used by microsurgeons because of its binding affinity to platelets, red blood cells, and the endothelial lining of the vessel wall. This binding property reduces platelet aggregation and the subsequent formation of clots. In the event of endothelial injury, certain elements are exposed, triggering platelet activation and their adhesion to the vessel wall and other platelets. This can lead to the occlusion of the vessel lumen.

After about five days, the endothelium heals and return to a “non-stick” state. Dextran 40 is typically administered during this critical period at a dose of 25 mL/hour for approximately five days following microvascular revascularization [4].

Postoperative Care

Monitoring the flap postoperatively is arguably just as important as performing the anastomosis, with ICU admission and hourly flap checks for the first 24-48 hours being common. Clinical evaluation of color, capillary refill, bleeding, temperature, and Doppler signals is the strongest tool for monitoring the flap postoperatively. Venous congestion may present as a blue and swollen flap, sometimes with petechiae. Arterial insufficiency may appear pale and feel cool to the touch with no bleeding on needle prick. Recognizing these signs clinically is vital in the event that the flap fails.

Flap Failure

Experienced surgeons achieve success rates of greater than 98% depending on the location and type of reconstruction. If concerns arise regarding flap vascularity, an immediate return to the operating room for exploration and assessment of the anastomoses can significantly increase chances of salvaging the flap. Flap failure, despite patent anastomoses, can sometimes be attributed to No-Reflow Phenomenon. This condition is believed to result from endothelial swelling, platelet aggregation, and leakage of intravascular fluid into the interstitial space [27]. Various preventative strategies have been described, along with pharmacologic and non-pharmacologic interventions aimed at improving microcirculatory blood flow. These interventions, such as intravascular adenosine and nitroprusside, have been extensively reviewed in cardiac literature.

Although complications do occur, accurate assessment and treatment of vascular compromise is key in optimizing surgical outcomes.

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