Chapter 17
Microvascular Anastomoses: Suture and Non-suture Methods

R.A.J. Wain, D. Hammond, M. McPhillips, J.P.M. Whitty and W. Ahmed

Abstract A plethora of methods have been proposed for coapting microvessels, with the mainstay being hand-suturing under an operating microscope. A broad range of hand-sutured techniques have been described and these are still evolving today. Alongside this, non-suture methods of microvascular anastomosis have gained popularity over recent years with numerous intra- and extravascular approaches being proposed. This section addresses the development of microsurgical suture technique for microvascular anastomosis, and continues to present the array of non-suture methods currently proposed as alternatives to standard suturing.

17.1 Microvascular Anastomoses

A microsurgical procedure is defined as one which would be otherwise impossible without the aid of magnification. Whilst the joining, or anastomosis, of blood vessels had been performed in the late nineteenth century, it was not until the mid-twentieth century that the operating microscope was introduced for repair of small blood vessels. Since this time, a wide range of methods have been proposed for coapting microvessels, and these are still evolving today. This section addresses the development of microsurgical suture technique for microvascular anastomosis, and continues to present the array of non-suture methods currently proposed as alternatives to standard suturing.

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17.2 Background of Microvascular Anastomoses

The first end-to-end arterial anastomosis was reported in 1889 [1], joining carotid arteries of sheep with fine silk thread and curved needles. Standardising the technique and gaining consistent success was the natural progression, as demonstrated by development of the triangulation technique (Fig. 17.1) by Carrel [2], work which would later secure him the Nobel Prize in Medicine and Physiology (1912). Despite this, vascular anastomoses were not performed for reconstruction or in repair of traumatic injuries for another 50 years, with the procedure remaining largely experimental till the end of World War II [3].

The first reported microvascular anastomosis was performed by Jacobson and Suarez in 1960 [5], achieving 100 % patency rates in vessels as small as 1.4 mm diameter. The key to success here was introduction of the operating microscope, which was first popularised by otolaryngology and ophthalmology several years previously, and of course development of finer instruments and sutures.

Microsurgical techniques became more widely practised over the next decade first with successful replantations of upper limbs [6] and then digits [7] being performed. By the early 1970s, free-tissue transfer was reported in a variety of specialist centres [8–10]. Since then, both surgical techniques and instrumentation have been refined to permit reconstructive options for the whole body and, most recently, allotransplantation of complex anatomical units has been achieved [11].

Whilst reliable results are now seen routinely with free-tissue transfer in the majority of centres, there is ongoing debate as to the best method of performing a vascular anastomosis. Characteristics of the ideal technique would be: (1) simple to perform and teach, (2) quick, i.e. minimises tissue ischaemia time, (3) avoids vessel wall trauma and (4) provides best short- and long-term patency rates [12]. As well as these qualities, it is vital that the principles of sound microsurgical practice are adhered to, in particular choice of a good quality vessel, tension-free repair, suture line eversion and direct intima–intima contact [12–14].

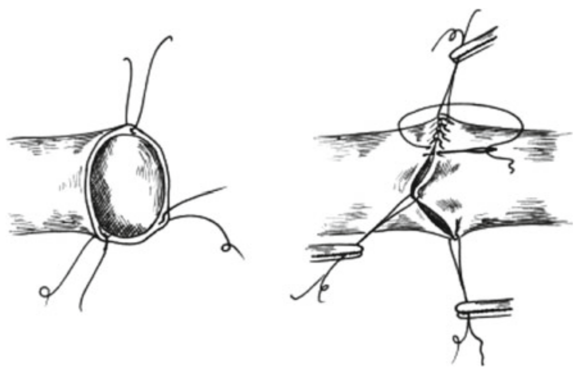

Fig. 17.1 Carrel's triangulation technique [2] (from [4])

17.3 Sutured Anastomoses

It remains conventional that the majority of microvascular anastomoses are performed using hand-sutured techniques, although use of the microvascular anastomotic coupler is widely accepted for venous anastomoses [15]. Since the 1960s, the interrupted (individual) suture method has been regarded as the gold standard [16, 17] for microvascular anastomosis. Whilst many suturing techniques are practised, a recent systematic review found no statistical difference in patency rates between them, provided the principles of microsurgical practice are followed [12].

17.3.1 Suture Properties

The number, type and material properties of the sutures are important considerations for success. Too few sutures will inevitably lead to leaking with subsequent haematoma formation, and too many can damage endothelial cells causing activation of the clotting cascade [18], and indeed weakening the anastomosis [19]. In addition, a recent computational study has demonstrated that closely positioned sutures causes high shear strain rates (SSR) at the vessel wall which itself can induce thrombus formation via activation of platelets [20].

Whilst both non-absorbable and absorbable sutures have been used for microvascular anastomoses, most surgeons favour a non-absorbable material such as polypropylene or nylon. The combination of an inert monofilament material and a sharp-tipped, round-bodied, curved and smoothly swaged needle permits accurate placement with minimal vessel trauma.

17.3.2 Suture Techniques

A wide range of suture techniques are available to the surgeon to coapt microvessels. These vary from the conventional interrupted suture method to complex horizontal mattress sutures (Fig. 17.2) which involve modifying the vessel ends. Other methods include continuous, locking continuous, continuous horizontal, interrupted horizontal, sleeve, interrupted spiral and posterior-wall first [12, 18]. Despite being faster to perform, the continuous methods have been criticised for their potential to purse-string, thereby narrowing the lumen and predisposing to thrombosis [16, 17]. Experimental models have demonstrated that this is not necessarily the case [21] and, as previously mentioned, a recent systematic review has found that a careful, precise microsurgical technique is the only determinant in achieving consistent, successful long-term results [12].

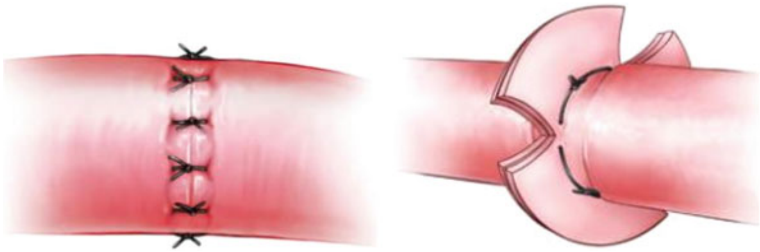

Fig. 17.2 Simple interrupted (*left*) and horizontal mattress (*right*) suture techniques [18]

17.4 Non-suture Anastomoses

Whilst advances in magnification, instruments and materials have resulted in reliable successful microvascular anastomoses, simply suturing involves a degree of vessel handling and therefore potential for intimal damage. In addition, the suture material itself, either polypropylene or nylon, remains within the vascular lumen. These factors, amongst others, contribute to a failure rate of sutured anastomoses of approximately 2–6 % [22–24], usually secondary to thrombus formation. Even for the experienced microsurgeon, microvascular anastomosis remains challenging and time consuming. Alternative methods to the conventional hand-sutured techniques have therefore been sought over the last half century, with some devices now being routinely used in clinical practice [15, 25–27]. Broadly speaking, these non-suture techniques can be divided into clips/staples, adhesives, laser-assisted anastomoses, stents, magnets, gels and ring-pin devices [4, 28].

17.4.1 Clips/Staples

The first use of clips to coapt blood vessels was in 1953 by Bikfalvi and Dubecz [29]. Several evolutions of this procedure took place over subsequent years with much work being carried out by Kirsch et al. [30]. His group modified previous devices to produce a series of non-penetrating clips which could be individually placed around an anastomosis. This work ultimately led to the development of the commercially available vessel closure system (VCS)[1] which is currently used in clinical practice. This system requires the positioning of a series of stay sutures and eversion of the vessel ends using a specialised instrument. The non-penetrating clips are then placed between the sutures which are then removed (Fig. 17.3). There have been multiple studies demonstrating the efficacy of this technique with equivalent patency rates to that of sutured and coupled anastomoses [26, 27, 31–33].

[1]AutoSuture, United States Surgical Corporation, Norwalk, Connecticut, USA.

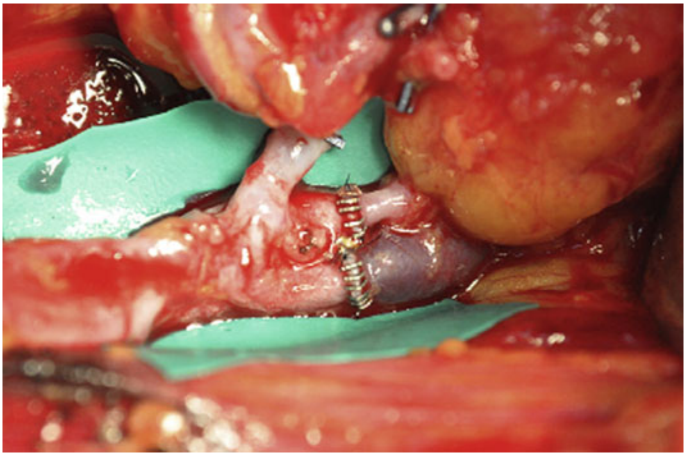

Fig. 17.3 Vessel closure system (VCS) arterial and venous anastomoses [26]

Another clip system has been developed for vascular anastomosis called the U-Clip.[2] This differs from the VCS as the clips are penetrating, in the same way as sutures would pierce the vessel wall. The advantage over a sutured anastomosis is there is no need to tie microsurgical knots; hence, the procedure is notably quicker. It does however mean that, unlike the VCS, there is foreign material within the vessel lumen. This system is not as widely used as the VCS, but does have a small body of evidence to support its use clinically [34–36].

17.4.2 Adhesives

There has been an upward trend in the use of glues and adhesives within surgery over recent years for a wide range of applications [37]. Broadly adhesives can be divided into two categories: 'cyanoacrylates' and thrombin-based 'fibrin-glues'. The fibrin-based glues contain components mimicking the final steps of blood coagulation [4] and are often used as an adjunct to a sutured anastomosis with the aim of reducing the number of sutures needed and anastomotic time, as demonstrated by Cho et al. cohort study [38]. There has been one large clinical study examining the use of fibrin glues for anastomoses in breast reconstruction patients with no reported increase in anastomotic failure [39]. Nevertheless, given the constituent of the glue itself, many surgeons are concerned about using a substance which could induce clotting in their microvascular anastomosis [40].

Cyanoacrylate-based glues were first used experimentally for vascular anastomosis in the 1960s [41]; however, within a relatively short space of time, several

[2]Medtronic, Inc.; Minneapolis, MN, USA.

problems with this method were identified. Green et al. [42] experiments demonstrated an early foreign body response with giant cell formation and later extreme thinning of the vessel wall. For these reasons, amongst others including the high heat expelled during polymerisation [4], cyanoacrylates have not been routinely used for microvascular anastomoses. It is important to note, however, that some of the newer generation cyanoacrylates do not exhibit the same tissue reaction seen in these studies, and indeed, actually show *less* foreign body response than a sutured anastomosis [43, 44].

17.4.3 Laser-Assisted Microvascular Anastomosis (LAMA)

Initial experimental attempts at coapting vessels using heat energy were carried out in the 1960s [45]; however, this method did not prove particularly effective, and there are no studies demonstrating its use clinically [4]. Lasers, on the other hand, have shown to produce some promising results in a number of studies [46–49]. One of the longest standing groups to utilise LAMA is that of Leclère who reported use of a 1.9-micron diode laser to perform welded anastomoses [50], typically requiring four sutures each. LAMA can therefore be viewed as a 'suture-reducing' technique rather than a 'non-suture' method. Fifty eight anastomoses were performed using LAMA and reported only one (1.7 %) failure as a 'rupture' possibly due to it being carried out in an irradiated field. Leclère has since reported a review of 30-years experience with the LAMA technique [49] and has stated that this method can be performed more quickly than conventional anastomosis, and the surgically induced vessel damage is limited. Whilst this method is largely confined to experimental findings and small clinical studies, further technical innovation will likely lead to its greater use in theatre over the coming years.

Although not classified as a laser-assisted method, the use of visible light has also been reported as an anastomotic technique [51]. Photochemical tissue bonding (PTB) combines photoactive dyes with visible light to create fluid-tight seals between tissue surfaces without causing collateral thermal damage. This study was carried out experimentally and found equal (80 %) patency rates between sutured and PTB anastomoses. One may argue that the sutured anastomosis group in this study had a higher than expected failure rate, given these are usually quoted at 2–6 % [22–24] rather than the 20 % experienced here, thereby over-emphasising the effectiveness of PTB anastomoses.

17.4.4 Stents

Whilst intravascular stents have been used since the late nineteenth century in one form or another, possibly the first microvascular anastomosis performed using a stent was in 1979 by Yamagata et al. [52]. This study compared three types of

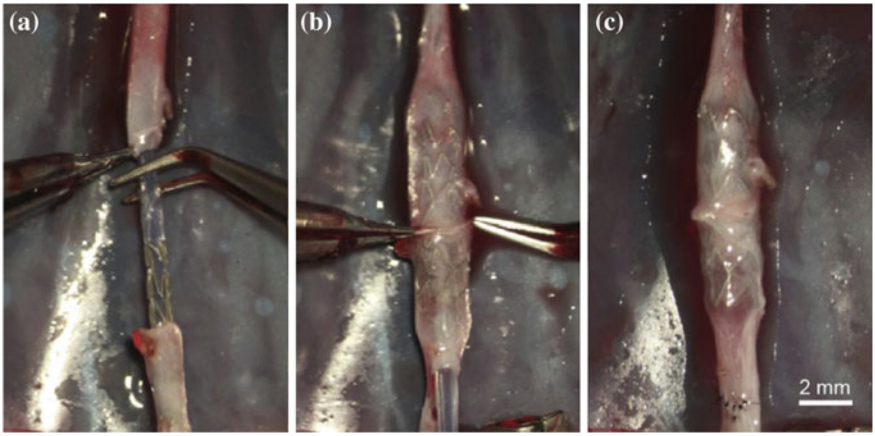

Fig. 17.4 Stainless steel intravascular stent insertion procedure [56]

soluble tube stent made of polyvinyl alcohol (PVA) used to anastomose carotid arteries in rats, along with the topical application of cyanoacrylate glue. Their bilayered stents demonstrated patency from 92 to 98 % for a maximum of six months. Further experimental studies have been carried out using absorbable stents in 0.35 mm vessels, again with the adjunct of adhesive, which showed immediate and short-term patency rates better than those associated with suture technique [53]. The work of Mikaelsson and Arnbjörnsson [54] used intravascular cylindrical stents to anastomose rat aortas, without the aid of adhesives, showing all to be patent and healed at 25 days. More recently existing metallic cardiac stents have been used to perform microanastomoses in a proof-of-concept study [55] with promising initial outcomes. This stent, however, relies on a balloon to expand it to the correct size, and hence necessary puncture of the vessel wall at a site distant from the anastomosis, which may not be ideal in many plastic surgical applications, e.g. free-tissue transfer. A similar study was carried out by Bauer et al. [56] using stainless steel stents in nine rat aorta anastomoses (Fig. 17.4). They reported one vessel tear, one complete thrombus occlusion and four anastomoses requiring additional sealant, e.g. with fibrin glue. These studies clearly demonstrate technical difficulties with expandable stenting and as such this remains purely experimental for the purposes of microvascular anastomoses.

17.4.5 Magnets

The approximation of vessel ends using magnets was preliminarily reported as early as 1978 by Obora et al. [57], with a full scientific paper published two years later by the same group [58]. This method involved passing the vessel ends through a hollow magnet and securing the everted edges on pins. The magnets then provided

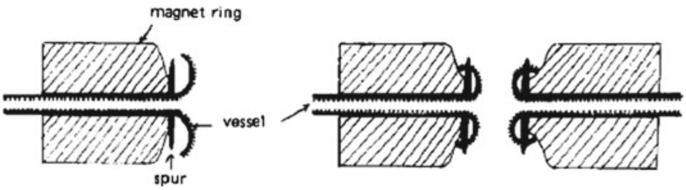

Fig. 17.5 Magnet ring anastomosis [58]

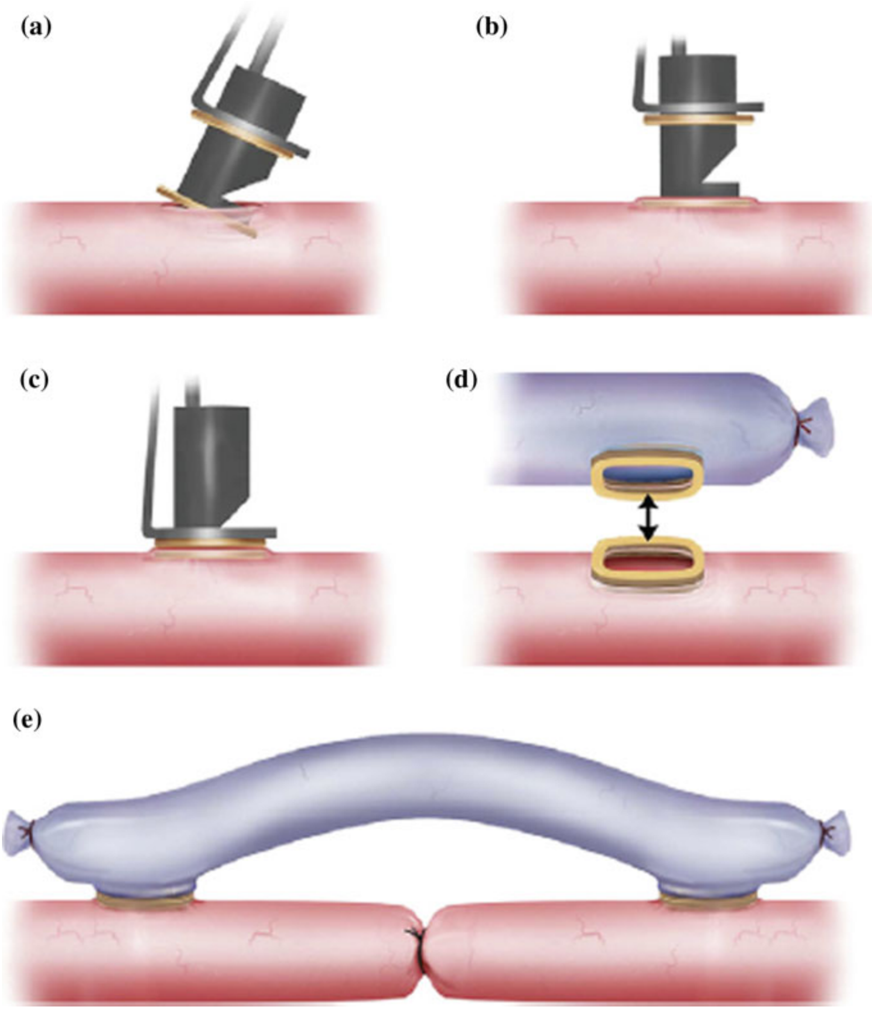

Fig. 17.6 Magnetic anastomosis for vein grafts [59]

the necessary force to coapt the two vessel lumens (Fig. 17.5). Results reported by this group demonstrated 90 % patency rates in vessels with a maximum diameter of 1 mm, with an average time for anastomosis of 8.0 min. Despite these apparently encouraging results, magnetic microvascular anastomosis has not become routine practice. Since then there have been isolated studies documenting the use of magnets for anastomoses in vein grafts [59] (Fig. 17.6), and also for non-suture anastomosis in a dog model using magnetised ring-pins [60].

17.4.6 Gels

Gels for microvascular anastomoses are principally used to produce a temporary 'bung' in the vessel ends with two purposes, first to negate the use of vascular clamps, and second to keep the vessel end open in order to facilitate the desired method of anastomosis. The gels themselves are composed of a range of substances which dissolve with exposure to high [43, 44] or low [61, 62] temperatures. The gel does not form the anastomosis properly; rather it assists with suture placement or application of an adhesive. Use of the commercially available LeGoo[3] has been well documented in cardiac surgery since 2010, and was used for microvascular anastomoses in rats by Manchio et al. [62] prior to this. However, it was only recently reported clinically in free-tissue transfer by Giessler et al. [61]. In this situation, the gel was used to facilitate a sutured anastomosis (Fig. 17.7) and subsequently was dissolved using topically applied cold saline. They reported no anastomotic failures and suggested that the gel was an attractive alternative to micro-clamps, especially for atherosclerotic arteries and confined anastomosis sites [61].

A uniquely formulated poloaxamer gel was used in the study by Chang et al. [43] to enable an adhesive-based anastomosis using cyanoacrylate glue with no sutures (Fig. 17.8). The gel was subsequently dissolved using a heat source applied externally. Qassemyar and Michel [44] used the commercially available LeGoo gel to perform an almost identical procedure; however, LeGoo does not require addition of an external heat source to dissolve, and as such is an overall simpler procedure. Both groups described approximately equal patency rates and significantly quicker anastomoses time when compared to their sutured controls. Whilst the LeGoo gel has been approved for clinical use, the unique poloaxamer gel from Chang et al. [43] remains experimental at this time. An important addition to this is that both groups found significantly less foreign body reaction in the cyanoacrylate anastomoses than the sutured ones. This is likely to be due to the specific newer generation of cyanoacrylates used compared to the original studies carried out in the 1980s [42].

[3]Pluromed Inc., Woburn, MA, USA, www.pluromed.com.

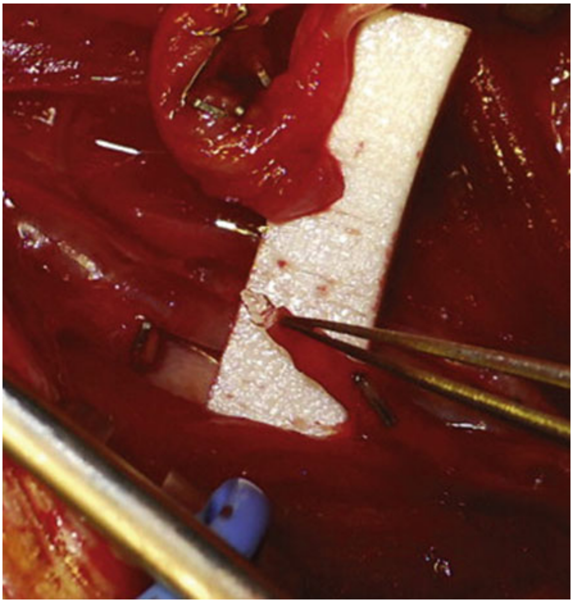

Fig. 17.7 Use of LeGoo gel for microvascular anastomosis in free-tissue transfer [61]

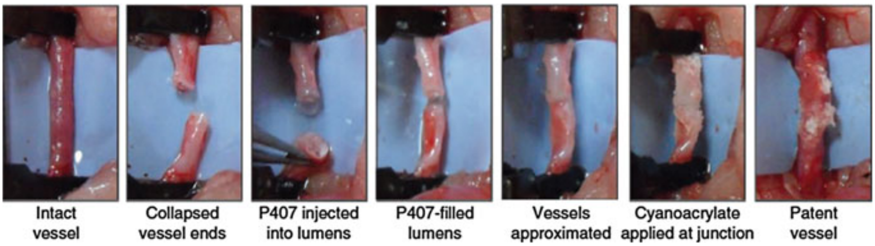

Fig. 17.8 Poloaxamer gel anastomosis with cyanoacrylate glue [43]

17.4.7 Bioabsorbable Pin Device

A further experimental method for microvascular anastomosis is that described by Ueda et al. [63]. This consists of an extra-lumenal cuff with hooks onto which the vessel wall is placed. It is composed of a bioabsorbable polymer and relies on one end of the vessel being reflected back over the cuff and onto the pins, whilst the other end then slips over the first, akin to an invaginating technique (Fig. 17.9). A suture is then placed around the outside of the vessel to secure the hooked walls in place. The experimental data suggest favourable patency rates and no significant impact of the bioabsorbable agent itself. Whilst these results are promising, they are purely experimental at this stage.

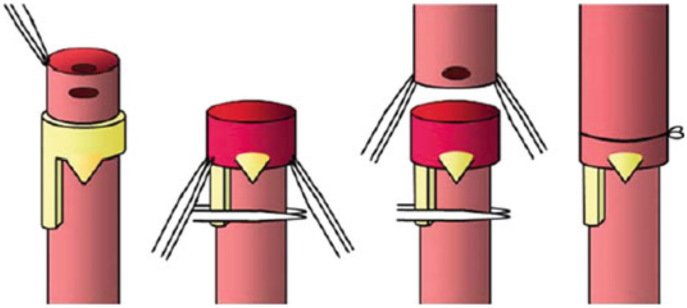

Fig. 17.9 Bioabsorbable pin device [63]

17.4.8 Ring-Pin Devices

The most popularly used ring-pin device is an evolution of the original design by Nakayama et al. in 1962 [64] (Fig. 17.10), although Payr had devised a strikingly similar device (Fig. 17.11) in 1900 furnished from magnesium [65]. In 1976 Ostrup [66] studied the Nakayama rings and found that anastomoses were performed in one

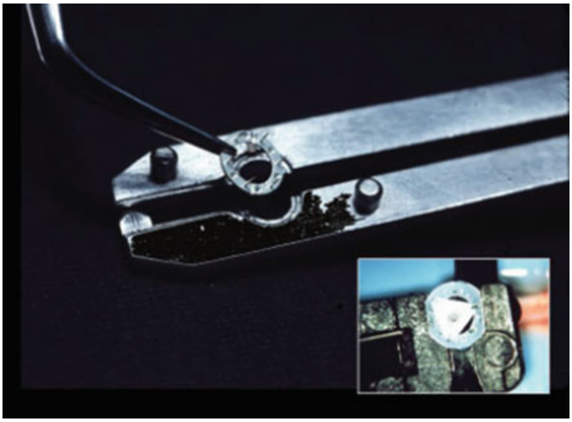

Fig. 17.10 Ring-pin coupling device developed by Nakayama et al. [64] (from [4])

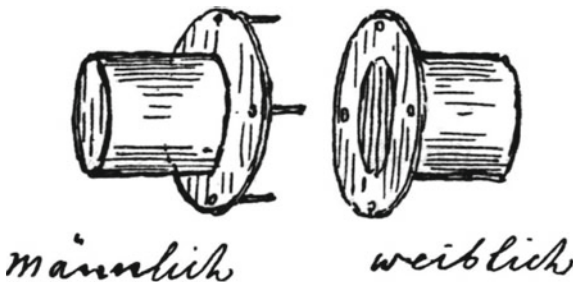

Fig. 17.11 Ring-pin coupling device as depicted by Payr (Fig. 17.7 from [65])

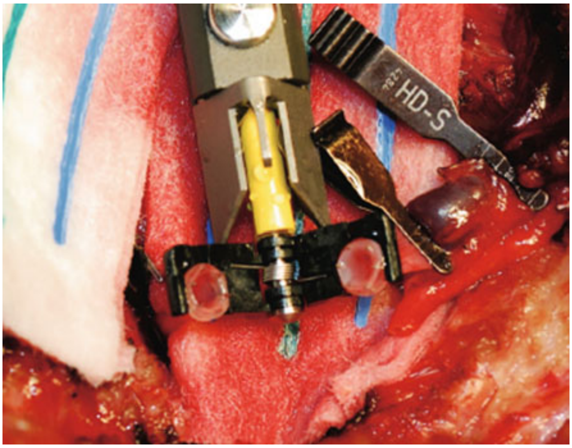

Fig. 17.12 Unilink microvascular coupler as described by Ostrup and Berggren [67] (from [15])

third of the time of a hand-held sutured anastomosis. He later developed an evolution of the Nakayama rings [67] which consisted of polyethylene rings and interlocking stainless steel pins (Fig. 17.12), whilst working alongside Unilink.[4] Each vessel end is passed through the polyethylene ring and reflected back over the steel pins. The two rings are then pressed together until the pins interlock. This device was suitable for coapting vessels as small as 0.8 mm and has since become the commercially available GEM Microvascular Anastomotic Coupling (MAC) System produced by Synovis[5] used in many microsurgical centres today. A large number of studies have been published demonstrating faster and simpler anastomoses, with similar, if not better, patency rates of coupled anastomoses when compared to the standard hand-sutured method [15, 33, 68–70].

Whilst the MAC System was not specifically designed for arteries, some groups have successfully performed microarterial anastomoses using this system [71–73], albeit with varying degrees of success. The more variable patency rates and technical difficulties associated with arterial coupling prevent it from becoming routine practice in many centres. Thicker and less-pliable arterial walls are most commonly implicated as the reasons for this as these characteristics make placement of the wall onto the pins challenging, often necessitating the use of a smaller diameter coupler.

More recently, another anastomotic ring-pin style coupler has been developed [74]. The Vascular Coupling Device (VCD) is similar in appearance to the MAC system; however, it has a series of hinged wings onto which the pins are fixed at an angle of 45° (Fig. 17.13). This simplifies the mounting of the vessel wall onto the pins themselves at which point the wings are closed to fully open the lumen and evert the vessel walls. The accompanying tools used to apply the device appear to

[4]3M Healthcare, 3M Center, St. Paul, MN 55144-1000, USA.

[5]Synovis Micro Companies Alliance Inc., 439 Industrial Lane, Birmingham, AL 35211, USA.

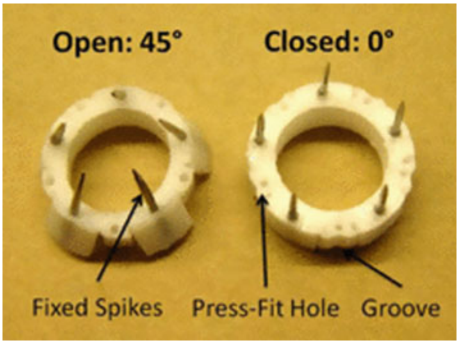

Fig. 17.13 Vascular coupling device (VCD) [74]

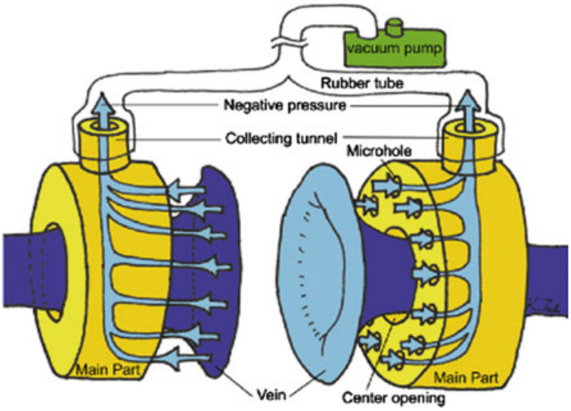

Fig. 17.14 Vacuum-assisted microvascular anastocoupler (VaMAC) [75]

offer greater manoeuvrability compared to the existing MAC System; however, the VCD is still in the developmental stages and is not in clinical use.

Though not strictly a ring-pin device, the vacuum-assisted microvascular anastocoupler (VaMAC) [75] has been developed as an alternative to the MAC system. It consists of two rings with micro-holes connected to a negative pressure system (Fig. 17.14). The vessel ends are then passed through the rings and held in place, everted by suction alone until the plastic rings are pressed together. The rings are then secured using sutures through holes in their periphery. The perceived advantages of this technology over the MAC, or in fact the VCD, is the avoidance of penetrating the vessel wall with pins, and the semi-automatic manner in which the vacuum locates the vessel wall onto the ring. As with the VCD, this technology is currently experimental only, but has shown promising initial results.

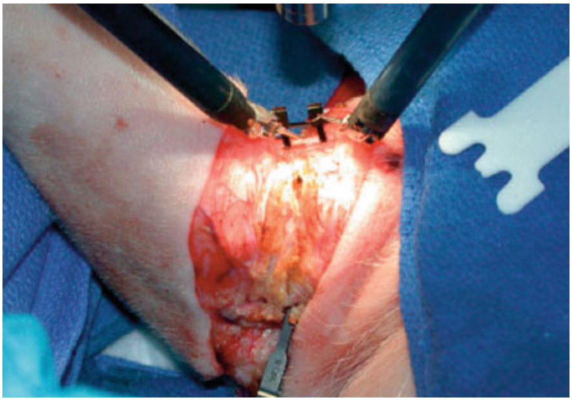

Fig. 17.15 Use of robotics in microvascular anastomoses [76]

17.5 Summary

The evidence in favour of both the MAC device and the VCS has reached level 2b as outlined by the Oxford Centre for Evidence-Based Medicine (CEBM) [4]. This signifies that benefits have been demonstrated for both techniques via well-constructed, cohort-controlled studies. Apart from the aforementioned study in breast reconstruction [38], there is very little evidence to endorse the use of laser-assisted anastomoses, adhesives, stents or gels in microvascular anastomoses.

Although not discussed here in detail, one of the next steps in advancing technology in practice is toward the integration of robotics into microsurgery, as has been the case for many other facets of surgery. There have been a select few studies demonstrating their use for microvascular anastomosis [76–78] (Fig. 17.15) with apparent good degrees of success. This will undoubtedly be one of the directions microsurgery is sure to adopt in the coming years.

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