MICROVASCULAR SURGERY IN ORTHOPAEDICS AND TRAUMATOLOGY

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In the past ten years microsurgical techniques have been developed in the fields of neurosurgery, otolaryngology and plastic surgery. It is regrettable that most orthopaedic surgeons have shown little interest in such fine surgery. There are several situations where microsurgery would be of value in orthopaedic research and practice, especially the hand, nerves and small vessels. Research related to these fields has been reported by plastic surgeons such as Buncke and Schulz (1965, 1966), Buncke, Buncke and Schulz (1966), Smith (1966) and Cobbett (1967, 1969).

In our department microvascular surgery has been practised since 1964. This basic research led to the successful reimplantation of a thumb by repair of the digital vessels (Komatsu and Tamai 1968) and experimental free muscle transplantation in dogs by microneurovascular anastomoses (Tamai, Komatsu, Sakamoto, Sano, Sasauchi, Hori, Tatsumi and Okuda 1970).

The purpose of this paper is to review the history of microvascular surgery, to describe the instruments used, and to point out their usefulness in surgery of the musculoskeletal system. Modern trends in the experimental and clinical applications of these techniques will be presented, together with some of our experiences.

History of microvascular surgery—The fundamentals of vascular surgery were established in 1902 by Carrel who first reported the “three stay suture technique” using silk for anastomosing the vessels. In 1908 both Carrel and Guthrie performed extensive experiments on organ transplantation using the technique of suture which appeared in Guthrie’s monograph Blood Vessel Surgery and its Applications, published in 1912. During the next thirty years there were few developments in this field, but numerous methods of anastomosis were reported between 1948 and 1960. Various machines to facilitate the anastomosis of blood vessels designed in Canada, America, Russia and Japan generated great interest in vascular surgery. Even so, the results in vessels less than 3 millimetres in diameter were mostly unsatisfactory.

Jacobson and Suarez introduced microvascular surgery by demonstrating the value of the operating microscope in 1960. They also designed several special instruments and fine suture materials for this new technique. Further improvements in the instrumentation and suture materials were developed by Salmon and Assimacopoulos (1964) and by Buncke and Schulz (1965, 1966). The successful anastomosis of vessels with a diameter of only one millimetre became possible. Surgeons now had the tools for digital reimplantation or transplantation.

Instruments: Operating microscope—Vessels less than 3 millimetres in diameter are the object of microvascular surgery. The Carl Zeiss operating microscope, with a suitable focal distance depending on the surgeon’s height, is in our opinion the best instrument for this purpose (Fig. 1). Magnifications of 10 to 25 are generally used. A period of practice is necessary in order to coordinate eye and hand.

Microsurgical instruments—Ultrafine instruments, including spring-handled needle-holders and scissors, jewellers’ forceps and miniature vascular clamps with adjustable vice, are required (Fig. 2). These were initially designed and made by Jacobson, a pioneer in this field.
FIG. 1
A Carl Zeiss operating microscope being used for an animal experiment. A motor-driven type is now preferred.

FIG. 2
Some special instruments required for microvascular surgery (centimetre scale).
Jacobson’s needle-holder, 14 centimetres in length, is suitable for the anastomosis of limb vessels; for deep vessels, as in the brain, a length of 21 centimetres is better. A spring-handled scissors with curved blades is useful for cutting the adventitia of the vessel to be anastomosed. We prefer to use a straight type of forceps, but others prefer them curved. The pair of clamps should be of miniature size, suitable for 1-millimetre vessels, and atraumatic. An adjustable vice in combination with the clamps allows approximation of the cut ends of the vessel. The present authors use a simple vice and clamps (Scoville’s) and a 22- or 23-gauge (0.71 or 0.61 millimetre) hypodermic needle (Fig. 3). They are very satisfactory for miniature vessel anastomosis because of their smaller size and light weight. They are atraumatic and so inexpensive that they can be discarded after use.

![Image](image.png)

**Fig. 3**
To show the miniature vice and clamps used by the authors (centimetre scale).

*Fine suture materials*—Silk or monofilament nylon (8-0 to 10-0) mounted on an atraumatic needle is commonly used. Nylon is stronger than silk and much smoother for passing through the vessel wall; tissue reaction is minimal.

For vessels less than 1 millimetre, 10–0 monofilament nylon is used, and 8–0 or 9–0 for vessels between 1 and 3 millimetres. These fine suture materials have recently become available in most countries.

**TECHNIQUE OF SUTURE**

The needle-holder, the scissors and the forceps should be held by the thumb, index and middle fingers, with the ulnar side of the forearm on the table to steady the hand. The instruments are mainly manipulated by finger movement. The following is a description of our technique for anastomosing a vessel of 1 millimetre diameter. Under the microscope the vessels are clamped 2 to 3 millimetres from the ends. The adventitia is removed with microscissors. When a piece of the adventitia is pulled by a forceps as shown in Figure 4 and cut with a scissors, it is possible to remove a strip 2 to 3 millimetres in width. Any small tag of adventitia encroaching on the lumen at the site of suture may cause thrombosis, but excessive removal may result in necrosis at the site of suture from destruction of the vasa vasorum.

The lumen of the end of each vessel is then washed out with heparin in low molecular dextran (1,000 U/dl), using a syringe with a blunt needle. Every effort must be made to avoid traumatizing the intima and causing thrombus formation. The cut ends of the vessels are approximated using the adjustable vice. Two stay sutures are then placed at the points of 120 degrees (the “asymmetric biangulation” of Cobbett). Steady traction is applied with small mosquito forceps or a lead weight on the suture threads to avoid picking up the opposite intima with the needle during the placement of additional sutures.
FIG. 4
To show removal of the adventitia of an artery preparatory to end-to-end anastomosis.

FIG. 5
A needle being inserted in the arterial wall at the mid-point between the stay sutures.
As a rule, interrupted sutures are preferred for the anastomosis of vessels less than 3 millimetres in diameter. Eight to ten stitches using instrumental tying are placed around a 1-millimetre vessel. Continuous sutures may produce a critical constriction at the site of anastomosis. Another important point is that the needle should be inserted into the muscle layer only when suturing arteries (Fig. 5). Adhesion of fibrin on suture material in the lumen may cause thrombus formation. Intimal trauma is the critical cause of thrombus formation; pinching or grasping the intimal layer is never permissible. The muscle layer, however, may be gently grasped with a fine forceps.

With vein anastomosis it is difficult to insert the needle through only the muscle layer. Minimal exposure of the suture material inside the lumen may be inevitable, because the wall of a vein is thinner and more friable than that of an artery.

After suture of the anterior half of the vessel, the vice holding the vessel is turned through 180 degrees, allowing the posterior side to be sutured in the same fashion, with care that the needle does not catch the opposite wall. For this purpose the counter-pressor designed by Jacobson is very useful. When the arterial anastomosis has been completed, the distal clamp is removed first (Fig. 6). If there is no marked haemorrhage, then the proximal clamp is released. Gentle compression is applied with gauze, and oozing usually stops after a few minutes. After the anastomosis of veins the proximal clamp is removed first and then the distal. If after the re-establishment of the circulation there is some constriction or spasm at the site of anastomosis, more adventitia may be removed, or local antispasmodics applied. If a thrombus has formed, some stitches are taken out, the thrombus removed and the lumen irrigated.

The patency rate of our experimental 1-millimetre vessel repairs three months after operation with and without a microscope is shown in Table I. The rate is much higher for repairs performed under the microscope.
Small vessel surgery of the injured limb—As a rule, the management of small vessel injuries differs little from those of large vessels. There are, however, some differences in the handling of the small vessel itself, as described previously.

Injuries to muscles, tendons, nerves and bones of the upper extremity are often accompanied by arterial damage. If these vessels are 3 millimetres or less in diameter, their repair comes within the field of microsurgery. It is beyond argument that reconstruction of such arteries greatly improves the functional prognosis of the hand.

Kleinert (1969) and his associates gained thirty-one satisfactory results out of fifty-six digital artery repairs in severely injured fingers. They evaluated the circulation of the fingers using angiography and Allen’s test, and stressed the importance of efficient arterial repair on the functional results.

Limb and digit reimplantation—Reimplantation of severed limbs in animals and humans has been attempted by many surgeons since 1800. Those interested in the historical aspects are referred to the article by Engber and Hardin (1971). Microsurgical anastomosis of the digital vessels is absolutely essential to save an amputated part of a digit, except for the composite graft of the finger tip. The first experimental work by Buncke and Schulz in 1965, using the ear of the rhesus monkey, opened a new field of reconstruction of the traumatised hand. Single digital artery repairs have been achieved by many workers since then. The first successful reimplantation of a completely amputated thumb was accomplished by Komatsu and Tamai in 1968. Thereafter, Kleinert (1969), Polacek, Pagedas and Welsh (1968), Lendvay (1968) and O’Brien (1972) have succeeded in the reimplantation of a digit. Since 1965 we have had four cases of successful finger reimplantation. The external diameters of digital arteries and veins are about 1 millimetre at the basal phalanx and less than that at the middle and distal phalanges. A trained microsurgeon should be able to anastomose vessels 0.5 millimetre in diameter.

To avoid repetition the authors will limit the description to the reimplantation of a digit.

A clean-cut amputation is ideal for this type of surgery. Careful debridement is first performed. The amputated part is then irrigated with heparin in cold low-molecular dextran solution through a cannula inserted into a digital artery. One may encounter some difficulty in finding the artery of the severed finger; milking the amputated part from the distal to the proximal end may be helpful. Blood oozing from the cut end of the artery may be seen under the microscope. Cobbett (1968) believes that it is not necessary to wash out the amputated part prior to reimplantation, and thinks there is some risk of damage to the intima. In the authors’ experience this procedure can be performed safely by using a blunt needle carefully inserted. Such irrigation also makes identification of the dorsal veins easier.

The first step of the replantation is bone fixation by intramedullary Kirschner wire; stability of the finger is essential. After suture of the extensor tendon, the dorsal veins are repaired and then the volar artery. Single interrupted stitches of 10-0 monofilament nylon are used. A pair of volar arteries and a pair of dorsal veins should be repaired.

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Some authors repair the artery first to ensure an earlier blood flow. In digital reimplantation, however, ischaemia is not as dangerous as with a large part of a limb containing a quantity of muscle, when there is a risk of "reimplantation toxaemia" (Eiken, Nabseth, Mayer and Deterling 1964; Onji, Kohama, Tamai, Fukunishi and Komatsu 1967).

With satisfactory revascularisation the colour of the skin turns pink immediately. At least one volar digital nerve should be sutured. Digit reimplantation without nerve repair is of no value for the functional recovery of the finger. Occasionally spontaneous recanalisation of a nerve trunk will occur after coaptation during the arterial repair, as happened with our first thumb reimplantation. Repair of the flexor tendon is usually postponed, especially when the severance has been through "no-man's-land". The skin is closed very loosely and a bulky dressing is applied. Anticoagulant is used only locally during the operation, but afterwards, depending upon the condition of the digit, systemic heparinisation may be recommended for a few days. Stellate ganglion block or upper arm block is highly effective for improving the circulation of the digit.

We would like to present our recent case of digit reimplantation.

A miner aged twenty-two almost completely amputated the left index with an axe and was sent to our hospital three hours later. The finger was totally ischaemic, being attached only by a thread of skin near the proximal interphalangeal joint (Fig. 7). Crushing of the tissues was minimal but contamination by sand was present. The reimplantation was performed by our standard procedure as described above, under upper arm block anaesthesia. In this case we anastomosed a volar digital artery, a pair of dorsal veins and the radio-volar digital nerve. The extensor tendon was repaired but the flexor tendon not. Immediately after re-establishment of the circulation the colour of the finger was good but after a few hours it was slightly dark. Temporary disturbance of the blood flow was suspected and an intravenous infusion of heparin, 50 milligrams of low-molecular dextran solution, was started. Five hours after he returned to the ward we found his index finger to be a beautiful pink colour. The sympathetic block and the intravenous infusion of dextran were maintained for a week. At the time of writing we are planning a flexor tendon graft (Fig. 8).

In summary, we would like to emphasise the key points for reimplantation of a digit. In considering this operation, one must evaluate the local condition of the wounds, the patient's age, general condition and occupation and the surgeon's expertise. The patient must appreciate that several operations may follow. Total co-operation is essential.

When the finger tip has been amputated cleanly it is possible to reimplant it by a careful coaptation without vascular anastomosis. Douglas and Foster (1963) have pointed out the possibility of spontaneous recanalisation of blood vessels after accurate coaptation, and reported successful digital reimplantations in experimental animals. Freilinger (1966) achieved two
cases of successful digital reimplantation using this modified method, but without vascular anastomosis it is a highly speculative procedure.

**Toe-to-hand transfer (pedochyrodactyloplasty)**—There are two types of pollicisation for the patient with a thumb defect, whether congenital or traumatic. One is Littler’s operation (1966) in which a finger is transferred with its neurovascular bundle intact. The other is the classic toe-to-hand transposition reported in 1900 by Nicoladoni, who transferred the second toe to the stump of an absent thumb using a type of skin pedicle grafting. Davis (1964) has reported a modified Nicoladoni technique. This type of pollicisation is not popular because of the

patient’s difficulties with prolonged immobilisation in a plaster cast with hand and foot together. Trophic changes and the loss of skin sensibility are other disadvantages.

Recently Buncke et al. (1966) achieved the immediate Nicoladoni operation using micro-neurovascular anastomosis in the rhesus monkey. Cobbett (1969) reported this new operation on a patient with a defect of the left thumb, transferring the left great toe to the remaining stump; useful opposition and sensibility resulted.

**Fat-dermal graft with vascular anastomosis**—A fat-dermal flap together with the nutrient vascular bundle is excised from the chest wall, abdomen or thigh and transplanted to cover a skin defect in one stage, the transfer being accompanied by vascular anastomosis. This procedure was initially achieved in dogs by Krizek, Tani, Desprez and Kiehn (1965) and
developed for clinical use by Buncke (1970). This operation is generally used in the field of plastic surgery and may be applied for ideal skin cover of bone denuded by injury or for decubitus ulcer in paraplegics.

**Free muscle transplantation**—The transplantation of a completely devascularised muscle, never achieved in the past, has been accomplished by the present authors in dogs using a microsurgical technique (Tamai et al. 1970). The rectus femoris muscle, with its nutrient vessels and nerve, was completely isolated from the thigh (Fig. 9) and transplanted orthotopically or heterotopically. Figure 10 demonstrates a muscle transplanted to the opposite thigh one year previously. Figure 11 shows almost normal histological appearances. The functional recovery was also investigated using electromyography (Fig. 12).

Thompson (1971) has achieved the transplantation of an isolated muscle belly to the normally innervated muscle belly, both experimentally and clinically. His interesting approach is entirely different from ours. Only small thin muscles can survive as such free grafts.

Letts and Sorbie (1970) have reported the revascularisation and reinnervation of a muscle following the direct implantation of an artery and a nerve in experimental animals. The goal of their experiment must be autotransplantation of a muscle.

**Vascularised joint transplantation**—Experimental and clinical investigations on the homotransplantation of joints have been made by many surgeons since 1893. Most joints transplanted freely, even autologously, developed severe degenerative change and poor function. The changes may be caused by the absence of the blood supply in the early stage after transplantation. In homologous transplantation, these changes may be accelerated by immunological reactions.

In contrast, the joints of successfully reimplanted limbs of experimental animals have shown no radiographic abnormalities and good function. In view of this fact, the vascularised homotransplantation of the entire knee joint in dogs is currently being investigated by us (Fig. 13). A knee joint reimplanted autologously in this fashion showed no degenerative changes even after a year (Fig. 14). The knee joint homotransplanted without immuno-suppression usually develops anatomical destruction within a month. Slome and Reeves
(1966) in England have reported on the same experiment in dogs using immunosuppressive therapy. In our laboratory, the donor joint is frozen to —80 degrees Celsius for this purpose; such joints have gone for more than six months without macroscopic destruction. An article on this work will be published later. Vascularised bone transplantation may be possible as another application of this experiment; it might be used in cases of recalcitrant pseudoarthrosis of long bone.

SUMMARY

1. The history of microvascular surgery is reviewed; the necessary instruments and the technique of suture are described.
2. Modern trends in the experimental and clinical applications in orthopaedic surgery and traumatology are discussed.
3. The authors emphasise the usefulness of this technique in tissue transplantation and in the reconstruction of microvascular injuries of the musculoskeletal system.

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