Microsurgery—its role in soft tissue and bone tumour reconstruction

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The reconstructive management of severe limb trauma and evaluation of its functional outcome has provided much to the knowledge of limb salvage procedures. Francel (1992) showed that 93% of Gustillo IIIB and 70% of IIIC lower limb trauma cases could be salvaged by early and aggressive revascularisation and soft tissue reconstruction. Renewed interest in the exploration and repair of brachial plexus injuries (Narakas 1981) has provided invaluable information about reconstructive approaches and their functional outcome. Surgeons are now applying this knowledge to reconstruction and preservation of function associated with tumour surgery. Currently it is the paucity of nerve regeneration that limits limb salvage. Bone, skin, muscle and vessels are generally replaceable with autogenous tissue by microsurgical transfer. Paradoxically, in a field where vascularised composite allografts would offer unique opportunities, any consideration of immunosuppression in the tumour patient would be contraindicated. Saints Cosmos and Damian in the 4th century were accredited with the first limb transplant when the leg of a church worker was amputated for tumour and replaced by grafting a leg from a Moor. Needless to say as no immunosuppression therapy was required there was no compromise to the recipient's immune system.

Advantages of microsurgery are:

- a single stage procedure, even for compound reconstructions,
- wide variety of available tissues allowing highly selective choices to match the original,
- the size of tissue transfer can be extensive so that the tumour surgeon is no longer compromised in his resection margins by considerations of wound closure,
- vascular reconstruction at macro and micro levels permit resections without the fear of limb devascularisation,
- early mobilisation is possible,
- microvascular flaps can provide additional blood supply to the recipient area thus decreasing infection, improving healing especially to previously irradiated areas and even permitting re irradiation.
- the aesthetic result is often more acceptable,
- large prostheses and or allografts can be inserted without concerns about lack of soft tissue cover,
- dead space, common in tumour surgery, can be adequately filled,
- early post irradiation through skin flap tissue is possible.

Disadvantages of microsurgery are:

- increased operating time (although this can be streamlined with two operating teams),
- absence of recipient vessels especially in the limbs,
- the possible loss of the flap with thrombosis,
- necessity of well trained nursing staff for adequate post operative care.

Shaw (1983) collated multi-centre data for microvascular free tissue transfers which showed an overall success rate of 93%. Ten percent required reexploration and 40% of these were salvaged. Current data reflects similar findings.

Bone and soft tissue tumours and limb salvage

Several multi-institutional studies have shown that there is no statistically significant difference in the local recurrence rate and the long term survival of bone or soft tissue tumour patients treated with limb salvage compared to amputation (Lindberg et al. 1981, Simon et al. 1986) particularly in conjunction with adjuvant or neoadjuvant radiotherapy for soft tissue sarcomas and chemotherapy for bone sarcomas. The role of chemotherapy is less clear for soft tissue sarcomas.

In selecting the appropriate therapy, consideration must be given to the grade, site and size of the tumour. Low grade tumours can often be adequately treated with wide local surgical excision. For high grade or deeply seated tumours post operative radiotherapy is recommended, so that flap reconstructions which tolerate radiation are preferable to skin grafts; similarly with brachytherapy where rods need to be buried under thick, viable tissue.

Contraindications to limb conservation are:

- extremely large tumours with neurovascular in-

volvement,
- lesions with pathological fracture with contamination of multiple compartments,
- lesions of the distal limb where the functional result would be poor,
- extensive local recurrence after previous limb salvage procedures.

Recipient site

Vessels

Following large tumour resections access to vessels for free flap transfer is rarely a problem in the limb. Frequently major axial vessels pass directly through the defect permitting easy end to side anastomosis to these high flow vessels. Where key arteries have been sacrificed for tumour clearance the free tissue transfer can sometimes be utilised in a flow through fashion where the donor pedicle is anastomosed proximally and distally to restore blood flow to the limb and at the same time furnish bone or flap cover. In the sacral, hip, back and upper abdominal regions large recipient vessels are in short supply. Here the inferior epigastric, superior gluteal and intra abdominal vessels are options but vein grafts combined with long pedicled donor flaps may be the only solution. This substantially increases morbidity and is associated with higher flap failure.

Dead space

Dead space is an inevitable accompaniment of tumour resection. Furthermore, if bone grafts have been inserted to restore bony continuity the cavities surrounding the bone may be complex and if not filled with living tissue, predispose to haematoma infection and necrosis. The choice of flap is important in eliminating these problems and generally bulky, floppy muscle is the most appropriate choice. Suction drains and physical supportive bandaging help to eliminate dead space and suspension of the lower leg in a sling which allows the calf tissues to drop away from the reconstructed tibia by gravity can lead to disastrous problems of bone exposure and graft loss.

Donor tissues

The prime principle of donor tissue selection is that it should match the recipient defect as closely as possible without undue donor morbidity. The apogee of this is the opportunistic use of otherwise discarded tissue from an amputated limb. Examples include flayed skin flaps such as the forearm or sole of the foot to cover amputation stumps and so preserve length or the use of skeletal parts, such as the elbow transplanted to restore shoulder contour following a fore quarter amputation.

Rarely in patients who are already on long term immunosuppression for other reasons, such as renal transplantation, it is possible to consider vascularised allograft transplantation. Vascularised allograft nerves have been transplanted in this way (Berger 1994). Hemiplegics who are faced with losing their only good limb are candidates theoretically for transfer of their non functioning limb to replace the amputated one.

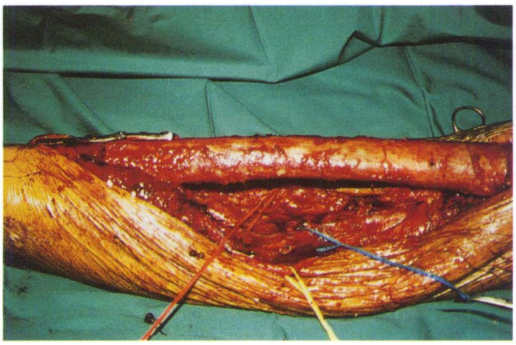
Skin

Skin flaps are generally selected for their size, colour, thickness and texture match but commonly in limb reconstruction the choice is limited to large flaps that have both large surface area and bulk for dead space. The latissimus dorsi, parascapular, rectus abdominis, tensor fasciae latae and anterior thigh flaps would generally be the most suitable. Muscle with skin grafts can substitute for skin flaps, especially where very large areas are required in order to minimise donor morbidity. Latissimus dorsi is the largest sheet of tissue available and its use allows direct skin closure at the donor site. Other useful muscles for this purpose are the rectus abdominis (Figure 1) and to a less extent the gracilis which can be opened out considerably by splitting its epimysium (Holle et al. 1995). The disadvantage in tumour surgery with muscle and skin graft is the delay that it causes for post operative radiotherapy. Pedicle length and vessel diameter are other important considerations in flap selection. For truncal full thickness body wall defects the tensor fasciae latae flap is ideally suited because of its underlying fascial layer. Free vascularised fascial grafts (forearm, temporal, fascia lata or lateral thoracic) covered by split skin are further alternatives to skin flaps and are particularly useful in the hand.

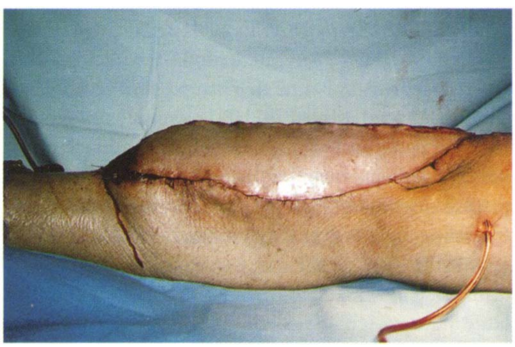
Bone

The fibula is unique as a donor because of its length. Whole lengths of non-vascularised fibula have been used to replace long bone defects (Sakellarides 1965) with unpredictable success. Pedicled, ipsilateral fibular transposition when available also provides excellent tibial reconstruction, but this also has enjoyed limited popularity. Vascularised bone transfers, especially the fibula (Taylor et al. 1975, Ueba and Fujikawa 1983) paved the way for reliable limb salvage. Studies demonstrate that for defects larger than 6 cm, vascularised bone is superior to non-vascularised grafts (Weiland 1981). Essentially vascularised bone heals as a fracture, while non-vascularised bone undergoes creeping substitution with cortical resorption. Breaking strength of vascularised bone is low until

Figure 1. A. Osteosarcoma of a tibial plateau.



B. Allograft inset following resection.



C. Free vascularised rectus abdominus used to cover the allograft.

hypertrophy occurs and the use of the fibula for tibial or femoral reconstruction is associated with a high rate of fracture if left unprotected. Ironically micro and hair line fractures are advantageous in that they facilitate rapid hypertrophy and increased strength. The fibula, now probably the most popular of the vascularised donor bones, is used extensively to reconstruct the mandible, for strengthening the vertebral column and as a strut after hemipelvectomy. The fibula can be osteotomized and folded on itself, thereby furnishing a double-barrelled graft, folded over on the same pedicle. This can be used either as a dual purpose reconstruction of the radius and ulna or to provide added strength (O'Brien et al. 1984). Furthermore, a limited sized cutaneous skin paddle can be included with the fibular transfer to provide soft tissue or to act as a monitor.

The iliac crest, the metatarsal bones, ribs, split radius, ulna, humerus and scapula have all been used for bony reconstruction. They are however limited by their volume and length for use in limb salvage.

Allografts

Bone allografts are becoming increasingly popular for long bone reconstruction especially in oncological surgery. If the tumour is confined to bone the options are generally vascularised bone or allograft. Recently a combination of free vascularised fibula and allograft has been described (Cappana 1994) where the fibula is centred within the allograft marrow cavity. This gives the combined benefit of the earlier rigidity and strength of the allograft bone stock with the increased bony end and endosteal blood supply of the vascular bone for early bone union and subsequent hypertrophy (Figure 2).

Epiphysis

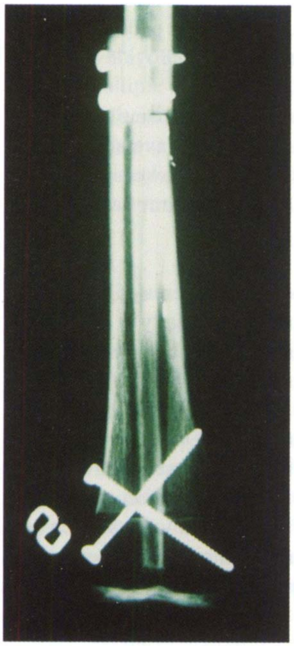
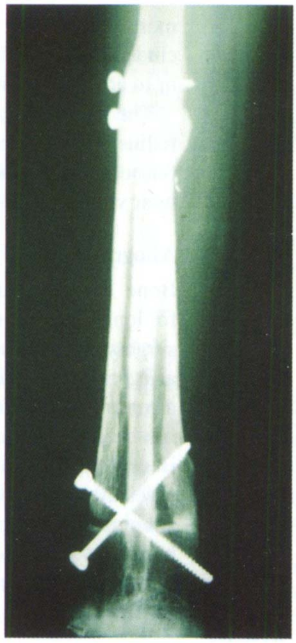
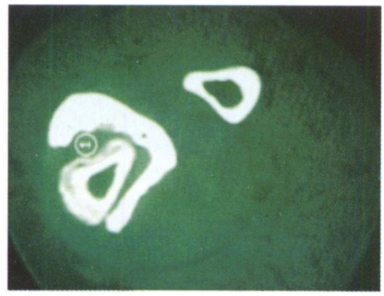
In children, epiphyseal resection or irradiation damage has severe consequences for growth. The upper end of the fibula has been transferred to replace damaged epiphyses and the detailed blood supply has been well documented as being derived from both the anterior tibial and the lateral inferior genicular vessels. Attempts at transferring the epiphysis on the peroneal vessels alone have not been as successful as was originally hoped for, with early fusion reducing the growth potential. (Kutz et al. 1981, Tamai 1984) Better growth potential was preserved by using the anterior tibial vessels (Taylor et al. 1988). Distraction lengthening would appear to be simpler and more practical for this purpose.

Joint

Finger joints have been successfully replaced by vascularised toe joints for many years (O'Brien et al. 1984). For hemijoint replacement the fibular head with its tendinous insertions for ligament repair has been used especially for radio-carpal reconstruction especially following giant cell tumour removal. Reasonable pain free mobility has been reported (Tsu-Min et al. 1992). Allograft joint arthroplasties, particularly hemijoints have been successfully used and more recently endoprostheses sometimes in combination with allografts allow reconstruction of major skeletal defects involving joints.

Periosteum

The periosteum is well known for its ability to stimu-

C. Postoperative CT scan of a vascularised fibula within an allograft.

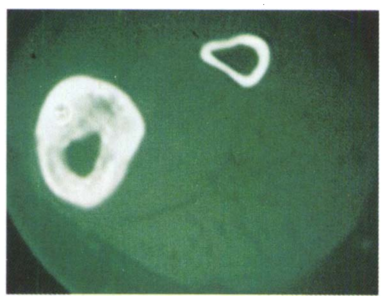


Figure 2. A. Plain radiograph of a vascularised fibula inset within an allograft for femoral reconstruction.

B. Radiograph at one year showing incorporation.

D. CT scan at one year showing incorporation.

late bone formation. Although it s use has been described as a pedicled and free transfer (Crock and Morrison 1992, Finley et al. 1978, O'Brien 1970) its true clinical application is debatable. It is currently being used in experimental trials in bone prefabrication.

Distraction

Following en bloc resection an alternative to bone grafting can be achieved by initial impaction of bone ends followed by distraction lengthening. Another form of this principle is the technique of bone transport where an osteotomy is performed at a distant or proximal site from the defect and progressive distraction away from the osteotomy site into the bone defect closes the bone gap. These techniques may require soft tissue microsurgical cover to permit safe bone movement.

Functional muscle

In the upper limb more so than the lower, the functional outcome will be considerably affected by the resection of muscle compartments and possibly neurovascular structures.

Conventionally, loss of muscles can be dealt with by tendon transfers. In circumstances where no tendons are available or the loss is so great that a tendon transfer cannot achieve a functional result, free vascularised muscle transfer is indicated. Transfer of free vascularised tendons, in situations where muscle is not required can also be performed (Morrison 1984, Vermeylen and Monallin 1991). Successful muscle transfer requires the presence of a functional motor nerve, adequate range of movement and stability of the proximal and distal joints, distal tendons capable of gliding and good quality proximal vessels. The gracilis is the most popular free muscle transfer because of its ease of dissection, limited donor site morbidity, large neurovascular pedicle and its unipennate long muscle fibres which provide a long excursion potential and make it suitable for most clinical settings, either for forearm or arm muscle reconstruction. Neurotisation of muscles, that is suturing the motor nerve directly into the muscle substance, has been reported by some to have useful results where direct nerve repair is impossible (Brunelli 1982).

Nerve

It has been shown experimentally that the functional results of non-vascularised and vascularised nerve grafts are similar. Although the vascularised grafts do not undergo central necrosis as occurs in non-vascularised grafts, Wallerian degeneration, scarring at the repair site and reduction in tubular diameter do occur. In large neurovascular resections the limit to reconstruction is the available donor source. Mackinnon

(1992) reported the clinical use of a human neve allograft for the repair of a traumatic defect of the sciatic nerve in an eight year old child using cyclosporin for two years until sensation appeared distal to the level of the graft. The donor had been matched for ABO group and MHC loci. Experimentally in rats, immunosuppression was required for the duration of nerve regeneration across the allograft after which time it was ceased. Due to the need for immunosuppression, nerve allografts are unlikely to have a role in tumour reconstruction.

The future

Tissue engineering and flap prefabrication are exciting research options. The ability to generate and manipulate tissue for specific requirements in reconstruction and by doing so, reduce donor site morbidity is the golden aim.

Tissue prefabrication was first described in 1966 by Diller, who showed that a patch of abdominal skin could be supported by the subcutaneous implantation of vascularised ileum in a dog. Recently, with increasing knowledge in the process of angiogenesis and the discovery of a multitude of tissue growth factors, a variety of prefabricated flaps, both simple and composite, have been able to be generated in laboratory animals and in the human clinical setting. These have included pedicled as well as free transfers.

To date clinically, the composite transfers have been aimed mainly at reconstruction of ears, noses and head and neck defects that have a difficult reconstructive requirement of thin durable skin with delicate cartilaginous framework. In cases of pure cutaneous requirements, tissue expanders have facilitated the ability to gain large skin flaps as well as increasing their viability by the process of delay. Thin expanded skin for the cover of distal limbs as free tissue transfer, has also been shown to be of benefit.

Recent advances in flap prefabrication, utilising the increasing knowledge in the field of recombinant technology, have allowed researchers to generate or transform non-existing vascularised tissues into desired shapes and sizes ie. produce vascularised bone and cartilage with the help of osteoinductive proteins.

In 1991, Khouri et al. (1992) transformed a simple muscle flap into vascularised bone graft in the rat model using osteoinductive proteins. In 1993, Kim et al. 1993) were able to produce vascularised bone around a vascular pedicle by transplantation of osteoblasts in a biodegradable polymer as the cell delivery system. Histologically, osteoid formation was present at 6 weeks and trabeculae were organised by 8.

Again, in 1996 Khouri et al. reported the induction of full endosteal bone formation in a free muscle transfer injected with bone morphogenic protein 3 in the rat model.

Cartilage, like bone, has been prefabricated in the animal model. Although it has not been applied to the production of articular cartilage this may well be a focus for the future.

In the oncological setting prefabrication as it exists in its embryological form today does not seem applicable. Generation of tissue takes time that is not available in tumour surgical management. Its exact role will be determined by future research.

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References

Abbase EA, Shnaq SM, Spira S, el- Falaky MH (1995). Prefabricated flaps: experimental and clinical review. PRS 96(5): 1218-25.

Berger A (1994). Peripheral nerve allografts; survey of present state in an experimental model of the rat. Microsurgery 15 (11): 773-7.

Brennan MF (1989). Managment of extremity soft tissue sarcomas Am J Surg 158:7

Brunelli G (1982). Direct neurotisation of severely damaged muscles. J Hand Surg (Am) 7; 572-9.

Buncke HJ, Daniller AI, Schultz WP, Chase RA (1967). The fate of autogenous whole joint transplantation by microvascular anastomosis. Plast Reconstr Surg 39: 33-341.

Cappana R (1994). The use of vascularised fibula in combination with allograft. Presented at the American Academy of Orthopaedic Surgeons Annual Meeting, New Orleans.

Cavadas P, Vera-Sempere F (1994). Prefabrication of a vascularised nerve graft by vessel implantation: preliminary report of an experimental model. Microsurgery 15: 877-81.

Cierny G, Zorn K, Nahaij F (1992). Bony reconstruction in the lower extremity. Clin Plast Surg 19(4): 905-15.

Cheng EY, Dysenbery KE, Winters MR, Thompson RC (1996). Soft tissue sarcomas: Preoperative versus postoperative radiotherapy. J Surg Oncology 6(2)2: 90-9.

Cordeiro P, Neves R, Hidalgo D (1994). The role of free tissue transfer following oncological resection in the lower extremity. Ann Plast Surg 33(1): 9-15

Crock JG, Morrison WA (1992). A vascularized periosteal flap; Anatomical study. BJPS 45(6): 474 - 8.

de Boer HH, Wood MB (1989). Bone changes in the vascularised fibular grafts. J Bone Joint Surg (Br) 71(3): 374-8.

Doi K, Akino T, Shigrtomi M, et al. (1994). Vascularised bone allografts; review of current concepts. Microsurgery 15 (12): 831-41.

Finley JM, Acland RD, Wood MB (1978). Revascularized periosteal grafts - a new method to produce functional new bone without bone grafting.

Foucher G, Hoang P, Citron N, et al. (1986). joint reconstruction following trauma: comparison of microsurgical transfer and conventional methods : a report of 61 cases. J Hand Surg (Br) 11(3): 388-93.

Francel T (1992). Salvage of the massively traumatised lower extremity. Clin Plast Surg 19(4): 871-9.

Ger R (1970). The managment of open fractures of the tibia with skin loss. J Trauma 10:112.

Gerner RE, Moore GE, Picken JW (1975). Soft tissue sarcomas. Ann Surg 181: 803.

Gustilo RB, Anderson JT (1976). Prevention of infection in the traement of one thousand and twenty-five open fractures of long bones.Retrospective and prospective analysis. J Bone Joint Surg (Am) 58A: 453.

Gustilo RB, Mendoza RM, Williams DN (1984). problems in the managment of type III (severe) open fractures; a new classification of type III open fractures. J Trauma 24: 742.

Holle J, Worseg A, Kuzbai R, et al. (1995). The extended gracilis muscle flap for reconstruction of the lower leg. BJPS 48 (6): 353-9.

Homma K, Sugihara T, Yoshida T, Ohura T (1995). Fascia - vascularised vs. muscle - vascularised prefabricated flaps using tissue expanders; an experimental study in the rat model. J Reconst Microsurg 11(3)3: 221-9,.

Ishida O, Tsai T (1991). Free vascularised whole joint transfer in children. Microsurgery 12: 196-206.

Khouri R, Upton J, Shaw W (1992). Principles of flap prefabrication. Clin Plast Surg 19(4): 763-71.

Khouri R, Brown D, Koudsi B, et al. (1996). Repair of calvarial defects with flap tissue; Role of bone morphogenetic proteins and competent responding tissues. Plast Reconstr Surg 98(1): 103-09.

Kim WS, Vacanti JP, Upton J, et al. (1993). Tissue engineered bone on a vascularised pedicle using cell polymer device. Presented at the 38th Annual Plastic Surgery Research Council Meeting, Houston, Texas.

Kutz J, Kleinert H, Tsai Tsu-Min (1981). Fibula with epiphysis for radial club hand deformity. Presented at VI International Society of Reconstructive Microsurgery, Melbourne.

Lindberg RD, Martin RG, Romsdahl MM, Barkly HT Jr (1981). Conservative surgery and post operative radiotherapy in 300 adults with soft tissue sarcomas. Cancer 47: 2391.

Mackinnon S, Hudson A (1992). Clinical application of peripheral nerve transplantation. PRS 90(4): 695-9.

Mankin HJ, Springfield DS, Gebhardt MC, Tomford WW (1992). Current status of allografting for bone tumours (review). Orthopedics 15(10): 1147-54.

McDonald D (1994). Limb Salvage surgery for the treatment of the extremities. AJR 163: 509-13.

Millesi H (1984). Brachial plexus injuries; Management and results Clin Plast Surg 11: 115-20.

Morrison WA. Free vascularised tendon transfer. Presented at the Fifth A.O.A International Symposium, Boca Raton, Fla.,1984.

Narakas A (1981). Brachial plexus Surgery. Orthop Clin N Am 12: 203-23.

O'Brien B McC, Morrison WA, Pribaz JJ (1984). Double fibular bone grafting for large bone defects. Presented at the Annual General Surgical metting RACS, Melbourne.

O'Brien B McM (1970). The maxillary periosteal flap in primary palate surgery ANZJS 40: 65-70.

O'Brien BMcC, Gould JS, Morrison WA, et al. (1984). Free vascularised small joint transfer to the hand. J Hand Surg (Am) 9: 634-41.

Peat BG, Bell RS, Davis A, et al. (1994). Wound heaking complications after soft tissue sarcoma surgery. PRS 93(5): 980-7.

Sakellarides H (1965). Extensive giant cell tumour of the lower end of the radius. A report of one case treated by resection and replacement with the fibular. Clin Orthop 42: 151-6.

Shaw WW (1983). Microvascular free flaps; the first decade. Clin Plast Surg 10; 3.

Simon M, Aschliman M, Thomas N, Manikin H (1986). Limb salvage treatment versus amputation for osteosarcoma of the distal end of the femur. J Bone Joint Surg 68-A (9): 1331-7.

Spiro SA, Oppenheim W, Boss W, et al. (1993). Reconstruction of the lower extremity after grade 3 distal tibial injuries using combined microsurgical free tissue transfer and bone transport by distraction osteosynthesis. Ann Plast Surg 30 (1) 1: 97-104.

Tamai S (1984). Vascularised fibular transplantation for congenital pseudoarthrosis and radial club hand. In: Symposium on clinical frontiers in reconstructive microsurgery, ch 31 (Eds. Buncke H, Furnas D). C. V. Mosby, St Louis.

Taylor GI, Wilson KR, Rees MD, et al. (1988). The anterior tibial vessels and their role in epiphysial and diaphyseal transfer of the fibular: Experimental study and clinical applications. BJPS 41(5): 45-69.

Taylor GI, Miller GD, Ham FJ (1975). The free vascularised bone graft. PRS 55: 533.

Tsu-Min Tsai, Wei-Zhong W (1992). Vascularised joint transfers; indications and results. Hand clinics 8(3): 525-35.

Ueba and Fujikawa (1983). Nine year follow up of a free vascularised fibular graft in neurofibromatosis - a case report and literature review. Jpn J Orthop Traum Surg 26: 595-600.

Vermeylen J, Monallin G (1991). The use of extensor indicis proprius as a vascularised tendon graft. Preliminary report. J Hand Surg (Br) 16 (2): 185-6.

Weiland AJ (1981). Vasularized free bone transplants. J Bone Joint Surg 63-A: 166-9.

Xenakis T, Malizos K, Beris A, et al. (1994). Vascularized bone grafts in the treatment of long bone defects. Microsurgery 15: 470-84.