Vascularised Bone Transplantation in Upper Extremity Reconstruction

John Chia, M.B.B.S., F.R.C.S., Robert W H Pho, F.R.C.S., M.D.

Department of Orthopaedic Surgery, National University of Singapore
Department of Hand & Reconstructive Microsurgery,
National University Hospital, Singapore

INTRODUCTION

The early years of microsurgery in hand and upper limb surgery focussed mainly on replantation, revascularisation, nerve repair and nerve grafting. Over the past two decades, the use of microsurgery has allowed for elective transfer of various tissues from one part of the body to the hand and upper limb for various reconstructive procedures[1,2].

This article focuses on the current applications of vascularised bone transfer for upper limb reconstruction, based on the senior author's experience over the last 20 years.

The first vascularised bone graft was described by Huntington in 1905[3]. He performed an ipsilateral fibular transfer based on a muscular pedicle to bridge a large tibial bone defect. The advent of microsurgery in the 1960's led to work on experimental transfer of vascularised bone in 1973 by McCullough et al[4]. Taylor et al, in 1975[5], described the first free live fibular bone transfer based on the peroneal vessels. In 1979, Weiland and Pho independently reported the use of vascularised bone transfer in upper limb reconstruction[6,7].

INDICATIONS FOR VASCULARISED BONE TRANSFER IN THE UPPER LIMB

This procedure is now a widely accepted technique in upper limb reconstruction. The principal indication for vascularised bone transfer is for replacing bony defects when standard non-vascularised bone graft is not applicable or unlikely to succeed.

Traumatic Bony Defects

Currently, the upper limit of length of bony defects for standard non-vascularised bone graft to succeed is 6 cm[8-12]. However, this is not a strict rule but only a rough guideline. It is expected that defects as great as 10 cm can be managed by standard non-vascularised grafts provided that the surrounding soft tissue is healthy, sufficient bone graft obtained to adequately bridge the gap and the bone construct be adequately protected until sufficient bony consolidation takes place. However, where the soft tissue is of poor vascularity[13,14] and where there is a history of failed conventional grafting, the use of vascularised bone grafting has enabled a one-stage bony reconstruction with a shorter period of protection for the bony construct as the transfer vascular bone graft is expected to behave as a segmental fracture and is more resistant to resorption and maintains its original shape and size[15,16].

Correspondence should be sent to:
Dr Robert W H Pho
Dept of Orthopaedic Surgery
National University of Singapore
5 Lower Kent Ridge Road
Singapore 119074

Bony Defects from Tumour Resection

Tumour resection often results in bony defects exceeding 10 cm. In addition, the current treatment of bony sarcomas often involve the use of adjuvant or new adjuvant chemo or radiotherapy which may place non-vascularised bone grafts at a distinct disadvantage. In cases of extensive bony resection in bone sarcomas of the upper limb where the limb is potentially salvageable, the use of the vascularised fibular graft has enabled surgeons to bridge massive bony defect and yet bring in new vascularised tissue to an unhealthy bed[7,13,17-21].

Difficult Bony Non-Unions

There are a variety of indications for vascularised bone transfer where a bony non-union with a non-substantial defect may be a candidate for reconstruction by vascularised bone transfer[22,23].

These include:

Failed prior conventional bone graft

Where conventional bony grafting have failed due to local factors such as poor soft tissue environment, vascularised bone transfer may be considered. However potential regional problems such as local infection, inadequate skeletal fixation and inadequate postoperative protection of the bony graft must be excluded prior to embarking on further reconstructive surgery[12,24,25].

Post-irradiation fractures

Fractures following radiation present a challenging problem to the orthopaedic surgeon. The extent of external beam damage is dependent on the dose received. Radiation dose as low as 3000 rads can cause damage in the bone and soft tissue. When the dosage reaches 5000 rads there will be inevitable damage to the bone and soft tissue. The onset of radiation changes in the bone and soft tissue are often progressive and may not be fully manifest until several years post-irradiation[13,22].

Avascular Necrosis of Carpal Bones

Several techniques have been used in revascularisation of Kienbock's disease and avascular necrosis of the scaphoid. (Both traumatic & idiopathic)[6,14].

1. Transfer of the second dorsal metacarpal vessel as originally described by Hori and Tamai[26]. This is essentially use of a vascular bundle transplantation as a source of new blood vessel proliferation and new bone formation.

2. Pedicled muscular bone grafts as reported by Braun where part of the volar radial bone is elevated based on the pronator quadratus muscle. This graft is reportedly vascularised by a periosteal blood supply derived from direct muscle attachment[6].

3. Reversed pedicled dorsal radial bone graft described by Zaidenberg. Recent research work have showed that the dorsal distal radius has a rich, constant and robust blood supply. The various extraosseous vessels has allowed for the design of several pedicled vascularised bone grafts based on distal anastomotic connection which will reach the scaphoid or lunate for clinical use.

   The principle of the use of vascularised bone transfer in this situation is that structural support to prevent collapse and at the same time to allow for the revascularisation of the avascular carpal bone. The concept of revascularisation of the bone is an excellent one. However, based on the senior author's personal experience we have found it difficult to achieve complete revascularisation and yet prevent collapse. The insertion of the vascularised bone graft into the recipient carpal bone can be difficult. It is not easy to slot into the carpal bone cortical strip due to the large articular surface thus making seating of the graft and its pedicle very difficult. Should the technique succeed, symptomatic improvement are often achieved. This is most likely related to decreased synovitis from better carpal kinetics leading to increased wrist movements and grip strength.

Bridging Congenital Defects

The best known indication of the use of vascularised bone graft is the treatment of congenital pseudoarthrosis of the tibia or the ulna[22,27,28]. We have also transferred vascularised bone with concomitant physis with varying success in achieving physeal growth. This will be illustrated in one of our case reports later in the chapter. In the cases of longitudinal deficiency, the use of vascularised bone graft has been reported with varying success with regard to continued growth of the transferred physis. Hence its use in this situation is currently unclear.

Management of Osteomyelitis

Osteomyelitis often require aggressive and extensive bony & soft tissue resection to allow for adequate debridement of septic tissue. The use of a vascularised bone graft, often with concomitant soft tissues, allows for bony and soft tissue construction, obliterates dead space, brings in new blood supply and allows for wound closure. The use of the vascularised bone has enable us to salvage limbs which otherwise would have been needed to be amputated.

In addition, it must be stressed that microsurgical bone transfer is a technically difficult and long procedure not without potential complications. The surgeon must be familiar with conventional surgical procedures to achieve skeletal continuity. The humerus and forearm bones can be shortened up to 5 cm with residual good functional. The option of a single bone forearm must also be considered by the orthopaedic surgeon.

In cases of a single-bone forearm the surgeon should aim to preserve the proximal ulna for good elbow function and the distal radius for some wrist function.

DONOR SITES

Although any expendable bone with an identifiable constant vascular pedicle may be used for transfer, the vascularised fibula based on the peroneal vascular bundle and the anterior iliac crest bone based on the deep circumflex iliac vessels are currently used most commonly in upper limb reconstruction.

However many sites of vascularised bone transfer have been reported in the literature. These include 1) rib bone based on the intercostal vessels and used extensively in mandibular reconstruction, 2) lateral border of the scapular bone as a composite flap with the latissimus dorsi muscle based on the thoracodorsal vessels, 3) art of the radial bone as part of a composite radial forearm flap, 4) part of the 1st or 2nd metatarsal based on the dorsalis pedis vessels and 5) lateral border of the humerus as part of a composite lateral arm flap based on the posterior radial collateral vessels.

Free Vascularised Fibular Bone Grafts in Upper Extremity Reconstruction

Free vascularised fibular bone grafts have been an excellent workhorse in the senior author's experience for reconstruction of large bone defects in the upper extremity. The vascularised fibular bone graft has the following advantages:[29]

1. It is readily available and the length can reach 30 cm.
2. The fibula is a straight and relatively strong cortical bone, similar to the long bones in the upper limb.
3. The vascular pedicle consists of the peroneal artery and its two venae comitantes which, although short in length, are large enough for reliable vascular anastomosis.
4. The proximal part and its fibrocartilage can be harvested as a vascularised hemi-joint transfer.
5. The overlying skin, measuring up to 20 cm by 10 cm, can be included as an osteocutaneous transfer to provide soft tissue padding and skin cover. It can also be used as a monitoring skin paddle.
6. It is an expendable bone.

Blood Supply of the Fibula

The diaphyseal part of the fibula receives its blood supply from the peroneal artery through the musculoperiosteal vessels and the main nutrient artery[30] (Figures 1a & 1b).

The peroneal artery usually arises from the posterior tibial artery or the popliteal artery at varying levels, and can replace the posterior tibial artery as the dominant blood supply to the posterior compartment of the leg. Two venae comitantes run parallel to the peroneal artery, and provide for venous drainage from the fibula.

As intercommunicating branches, multiple longitudinal vessels run parallel to the long axis of the fibula, within and superficial to the periosteum. In adults, the fibular head receives adequate blood supply from the peroneal artery, via the musculoperiosteal vessels. In children, the contribution of epiphyseal branches from the descending genicular vessel and anterior tibial vessel may be significant in supplying the proximal fibular epiphysis.

The skin on the lateral aspect of the leg along the whole length of the fibula receives multiple fasciocutaneous branches from the peroneal vessel, which runs along the intermuscular septum between the soleus and the peroneal compartment. These branches are each accompanied by two venae comitantes. A large piece of skin can safely be raised together with the fibula, based on its peroneal vascular pedicle. When the skin flap is incorporated, the vascular pedicle should be lengthened using the short saphenous vein as a loop, to facilitate vessel anastomosis.

Bone Healing in Free Vascularised Bone Grafts

Free vascularised bone grafts should be regarded as similar to a segmental fracture, with preservation of the vascular supply to the middle segment. The healing process, therefore, should be comparable to this type of fracture, with the exception that during transfer the initial ischaemic time may range from 2 to 6 hours. The time taken for bone union is therefore comparable to normal segmental fracture healing[15].

Although free vascularised bone grafts can be regarded as being similar to segmental fractures, they are completely denervated. Therefore, when stress fracture develops, it may be painless, unless there is extraperiosteal compression of the surrounding tissues. This is a very important point to remember when using free vascularised bone grafts for reconstruction after tumour excision. The undisplaced stress fracture site may show swelling and increased temperature, but no pain, and may be mistaken for local tumour recurrence.

The clinical observation of bone healing in free vascularised bone graft indicates that the periosteum plays a major role in external callus formation. This may be related to preservation of musculoperiosteal blood vessels, as sometimes the harvested segment may not include the nutrient vessels of the bone.

Bone Fixation

The senior author has used four different techniques of bone fixation:

1. Direct plating with compression.
2. Step-cut osteotomy with screw or plate fixation.
3. Intramedullary fixation.
4. Periosteocortical flap.

In most cases, we advocate usage of minimal implants and small screws, to avoid splitting the fibula, damage to the periosteal vessels and the possibility of developing stress fracture. To protect the bony construct and provide immediate stability, one should reinforce with an external fixator whenever possible.

CASE ILLUSTRATIONS

We have used the vascularised fibular bone to replace bony defects in a variety of situations. We have found it to be a reliable workhorse and advocate it in cases when vascularised bone graft is needed and illustrate this in the following case examples.

In the first case we describe the use of the vascularised fibular graft both as a bony defect replacement and also as a use of epiphyseal transfer[31-33]. The aim of the surgery was also to provide normal longitudinal and latitudinal growth from the transferred epiphysis which should not close prematurely apart from its use as a bony defect replacement.

Case 1

Vascularised fibular graft with physeal transfer to replace defect after tumour resection in a growing child.

A girl aged eight presented with pain in the right forearm. Radiographs showed a lytic lesion of the distal radius. Open biopsy confirmed that this was an osteosarcoma (Figure 2a). CT scan of the chest was normal and bone scan showed no other lesions. CT scan of the forearm showed tumour extending to the mid-shaft of the radius and abutting against the inner border of the ulna but not extending into the carpus. En bloc excision of the distal two-thirds of the radius and ulna, with disarticulation at the wrist joint, was performed. The flexor and extensor tendons of the wrist and fingers

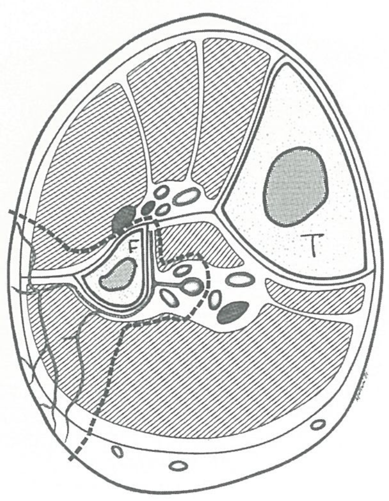

Fig. 1a - Cross section of fibular graft with peroneal vascular pedicle and fascio-cutaneous vessels and overlying skin

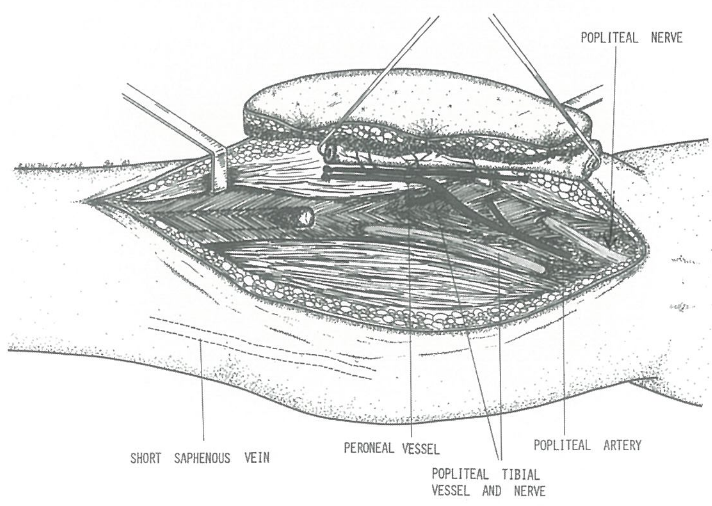

Fig 1b - Free vascularised fibular graft had been raised with peroneal vascular pedicle and overlying skin for replacement of large bone and soft tissue defects were preserved. Frozen sections from the remaining radius and ulna were clear of tumour. A 11.5 cm vascularised fibular graft with the upper fibular epiphysis, based on a peroneal vascular pedicle, was transferred to bridge the defect. The technique of harvesting the fibula based on the peroneal vessels has been described previously (Pho 1985). In this case the dissection involved a proximal extension of the wound to harvest the epiphysis. The proximal fibula was isolated, proximal tibio-fibular joint disarticulated and shaft divided depending on the length required. It was fixed proximally to the radius with a plate and distally with K wires. The pronator teres tendon was transferred to the fibula. Anastomosis of the peroneal vessels to the radial artery and cephalic vein was performed. The arm was immobilised in plaster. The K-wires were removed three months later, but the wrist deviated in an ulnar direction and a wrist centralisation with flexor carpi ulnaris reinserted to the base of the second metatarsal bone was performed (Figure 2b). This was further stabilised by reinsertion of longer K wires. A bone scan after two weeks, using technetium 99, showed increased uptake in the shaft and epiphysis. Radiography showed bony union at host-graft juncture at two months. Twelve months after operation, she had a full range of elbow movements, with three quarters of normal supination and one quarter of normal pronation due to retention of proximal radius. There was a 0.5 cm of longitudinal growth with a 20% circumferential hypertrophy of the graft. Since surgery she has been under follow-up on a yearly basis (Figure 2c). At the seven year period there was documented contributed growth of 3.6 cm by the transferred fibular epiphysis though the forearm was shorter by 2 cm as compared with the normal opposite forearm. However the wrist had deviated ulnarly to 30° which can be passively corrected to neutral position due to muscular imbalance and absence of contouring of the fibular head to support the carpus. A formal fusion of the wrist with centralisation of the carpus was carried out to improve the function of the wrist. At the last follow-up of ten years period she had excellent function of her elbow and hand. She also retained a functional range of pronation and supination of her forearm (Figures 3a & 3b).

This case can be considered a relative success where the vascularised bone also acts as a growing unit. The present role of vascular physeal transfer is yet unclear[28,31,34]. We have used it in the upper humerus and radial club hand (Figures 4a &4b) but the unit did not grow. Why this occur is still unclear but there are probably environment factors affecting the growing unit which are different in the proximal humerus as compared with the distal radius[35].

Case 2

Use of free vascularised fibular bone graft in difficult non-unions.

Non-union in a badly traumatic limb poses many problems to the orthopaedic surgeon due to poor soft tissue environment. The use of vascularised bone transplant is one of the few options available for salvage of the limb. It is important to have a sensate hand and functioning motor units in the upper limb for this technique to be viable. In addition, we have found it useful to carry out preoperative angiography in the recipient limb so that there is an adequate recipient blood supply for reliable vascular anastomosis (Figures 5a, 5b & 5c). We have used large osteocutaneous flaps along with lengthening of the vascular pedicle as a closed loop would allow the surgeon to perform the anastomosis at recipient vessels far away from scarred unhealthy tissues (Figures 5d & 5e).

Case 3

Use of the free vascularised fibular bone graft as an internal bony strut in abnormal bone.

Recently the senior author has used the relatively straight fibular bone transferred to be used as a strong bony strut or internal splint.

In cases of bony sarcomas which need extensive resection, the diseased bone is removed beyond the margins of tumour. The bone is then autoclaved for 10 minutes at 132° C to kill all living cells. The bone is then replaced and

Fig. 2a - Preoperative A/P and lateral forearm xray showing the osteosarcoma

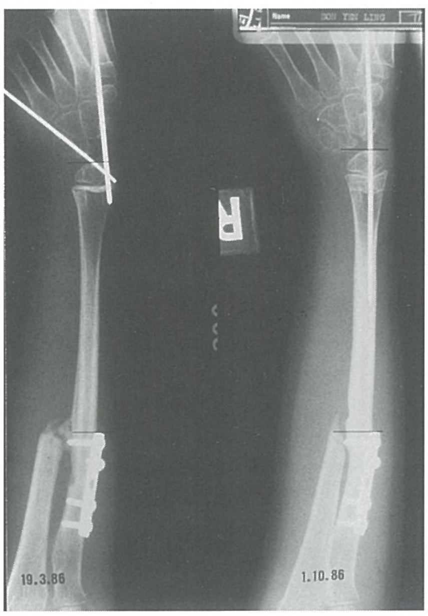

Fig. 2b - Progressive growth in fibular physis transfer

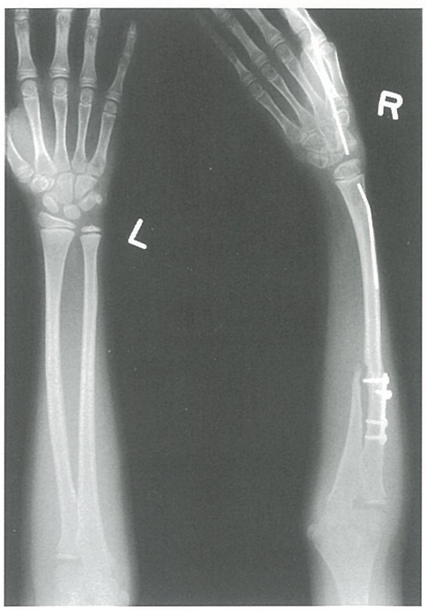

Fig. 2c - Postoperative xray comparing (R) and (L) side

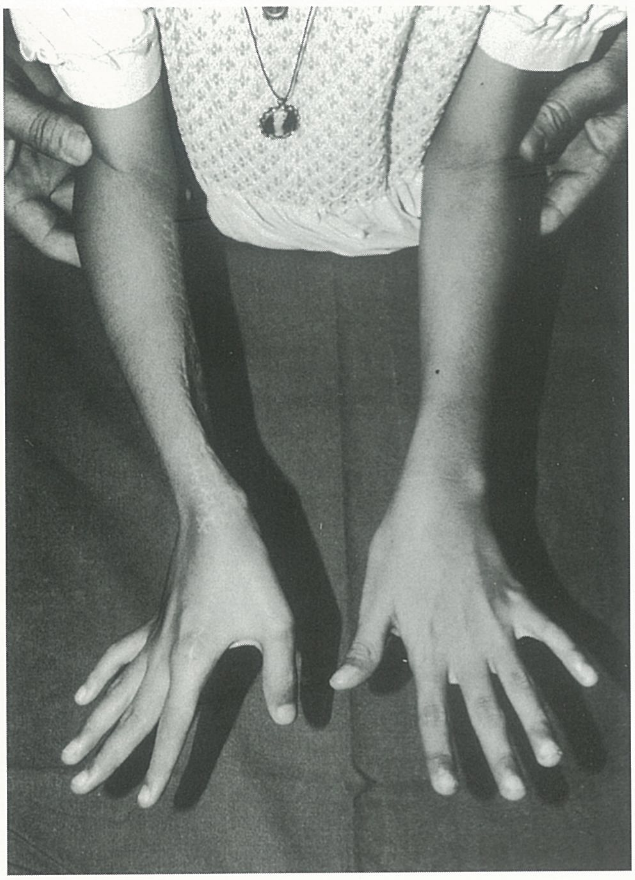

Fig. 3a - Comparison view of pronation of forearm

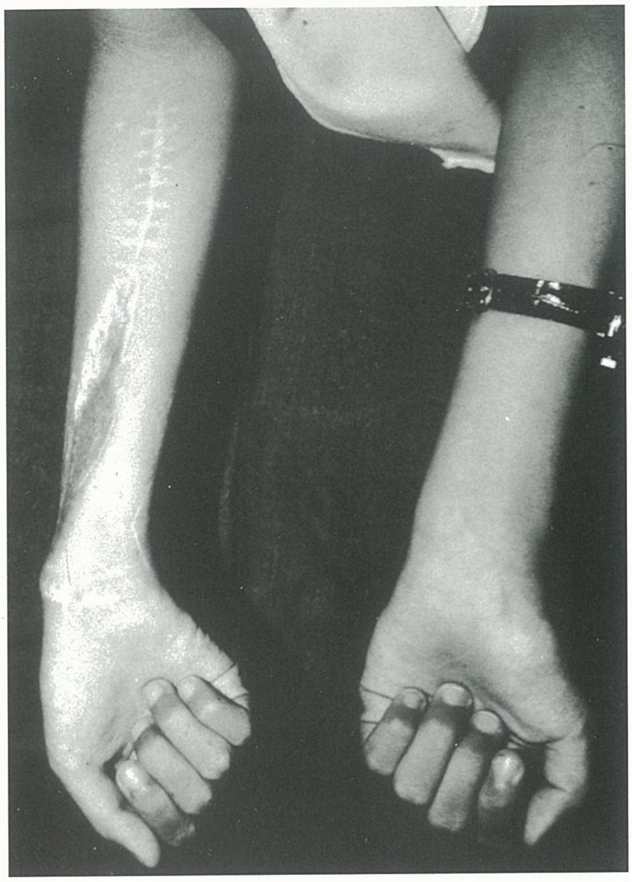

Fig. 3b - Comparison view of supination of forearm

fixed to the normal remaining tissue. The autoclaved bone provide for immediate bony stability and this is supplemented by a free vascularised fibular bone to provide for additional bony stability. In addition we have added autologenous bone marrow for rapid bone revitalisation. This technique allows for exact size fitting of the autoclaved bone back to the resected site, preserves the joint and is cost effective. Autoclaved bone by itself is however mechanically weak and requires a long period of creeping substitution. By supplementing with a vascular fibular graft we are able to provide for immediate stability allowing for early rehabilitation and joint movement.

The next case illustrates the use of this method as a internal bony strut in abnormal bone.

A 37 year old male was referred from overseas with extensive fibrous dysplasia affecting the right scapula, humerus and proximal 1/3 of the radius. He had complained of pain over the humeral shaft and plain radiographs also revealed a pathological fracture. He complained of pain at rest and also affecting his sleep. The pain had disabled the patient and affected the function of the right hand.

Clinical examination revealed a good elbow function with 30° to 90° ROM with 1/3 of normal forearm pronation and supination. Wrist and hand movements were essentially normal.

It was decided to provide an internal strut for this affected humerus with a 26-cm vascularied fibular graft. The tumour was partly debulked and at the same time we preserved the

Fig. 4a - Left radial club hand

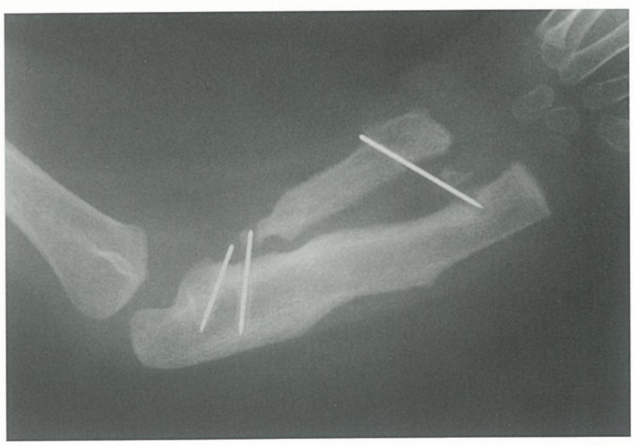

Fig. 4b - Vascularised fibula and its epiphysis transferred for carpal support to centralise the wrist. The fibula showed circumferential growth but no longitudinal growth

Fig. 5a - Preoperative picture of badly scarred forearm and contracture of flexor muscles

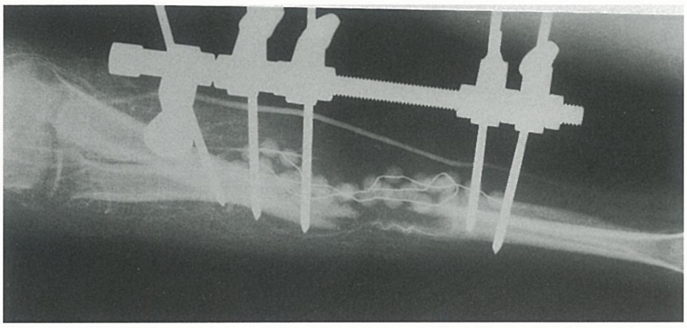

Fig. 5b - Postoperative xray of the osteomyelitis with bone gap and gentamycin beads

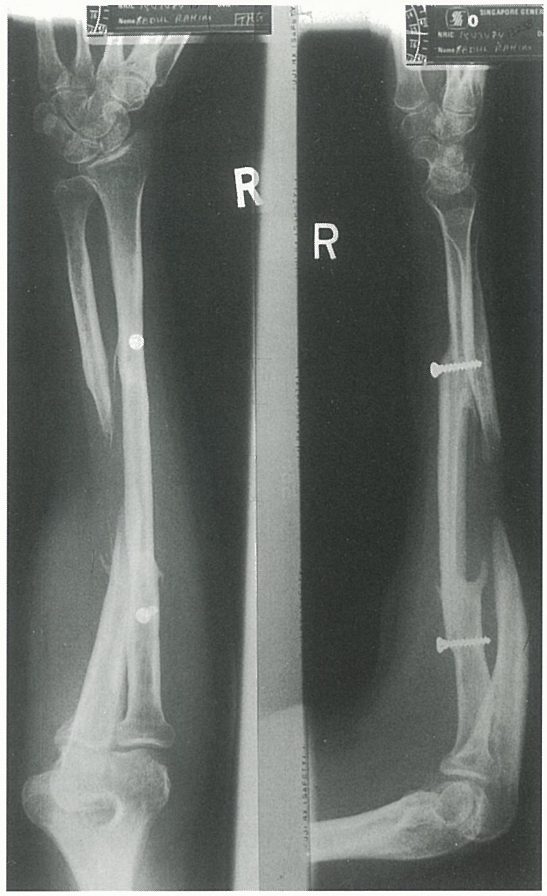

Fig. 5c - Postoperative xray of vascularised fibular graft bridging the radius

remnant gleno-humeral and elbow joints. The graft acted to provide strong longitudinal support.

A review one year post-surgery, revealed that he had benefited from the surgery as there is no pain in the humerus. The shoulder and elbow movement were functional and a CT scan of the humerus showed that the humerus had incorporated well. The use of a vascularised bone strut allows for rapid incorporation of the bony graft and at the same time the use of cortical bone gives the advantage of strong mechanical support (Figure 6).

DISCUSSION

Bone union leading to a successful clinical result has been reported in 81% to 88% of cases[15,36,37] for larger reported series of vascularised bone transfer. The most favorable results for salvage or reconstruction of a bony defect using a vascularised bone transfer has been reported for nonseptic defects[38]. Reconstruction for post-traumatic or congenital pseudarthrosis appears to have a slightly higher success rate than for tumour reconstruction. This is presumably due to the deleterious effects on bone healing of adjuvant and non-adjuvant chemotherapy or radiation therapy in the latter group. An average time to union for long bone reconstruction is approximately two months in children and four to six months in adults. If there is failure of the vascular anastomosis, the transfer graft would behave like an autologous cortical bone graft with musculoperiosteum. Its subsequent failure depends on the creeping substitution which will attempt to step in to revascularise the bone. Hypertrophy can only occur after the graft has been completely vascularised. As with any major reconstructive procedure, complications are frequent with vascularised bone transfer. Nonunion or delayed union has been reported as high as 39% of patients following the bone transfer procedure[5,39]. Secondary intervention to the nonunion site involving revision of the internal fixation and/or iliac bone autografting may be required in 20% to 30% of patients for final union. Patients should be advised of this possibility with the expectation that absence of union at one or both osteosynthesis sites by six months should merit consideration of reoperation. The causes of nonunion may be related to inadequate fixation, inadequate bone mass, local sepsis, or vascular thrombosis of the graft.

It is important for the surgeon to consider all the possible conventional method of reconstruction. Each patient will be different and all the alternatives must be explored. The use of vascularised bone graft has allowed the surgeon to achieve a one-stage rapid stabilisation of bony fragments separated by a large defect. This is especially significant in relative avascularity of the surrounding tissue which places conventional bone grafting at a disadvantage. In addition, the surgeon must be familiar with all the difficult microsurgical techniques available and most of all have a good team support as such procedures are often long and tedious with a risk of vascular anastomotic failure.

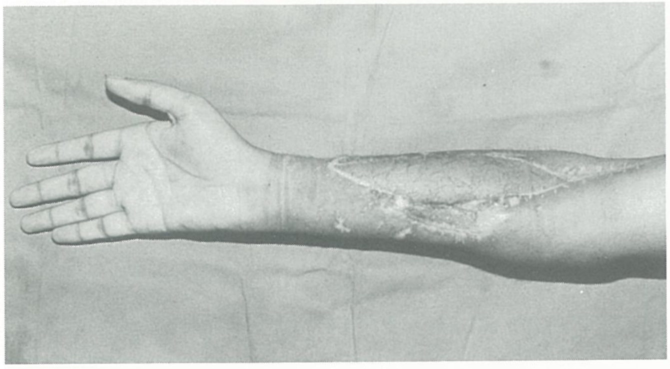

Fig. 5d - Picture showing digital extension and soft tissue coverage

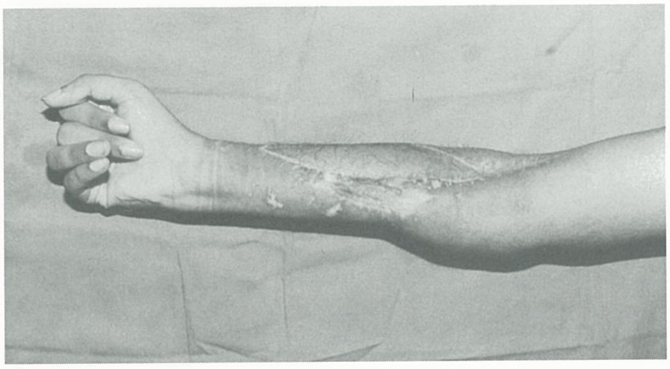

Fig. 5e - Picture showing digital flexion

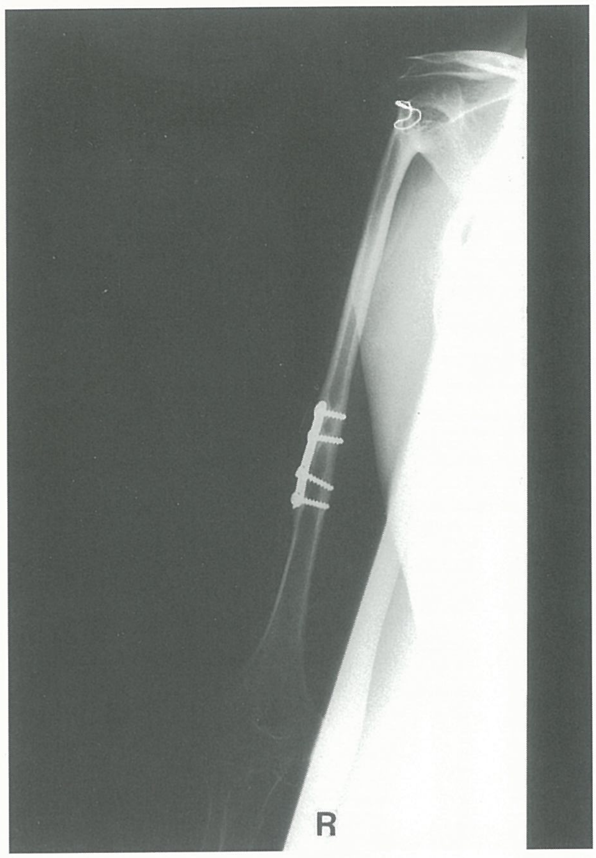

Fig. 6 - Postoperative view of transferred fibula replacing proximal 2/3 of humerus and showing bony union and hypertrophy

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