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RESEARCH ARTICLE

Therapeutic Use of Vascularized Bone Transfer for Bone Reconstruction

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ABSTRACT

Reconstruction of bone is often required for large bone defects and also in cases of impaired bone regeneration. Vascularized bone transfer has been widely used for reconstruction, especially for segmental mandibular defects, and for reconstruction of long bones of the upper limb and lower limb after trauma or after significant bone resection for tumour. It has also been used in cases of scaphoid non-union, cases of congenital pseudarthrosis of the tibia or forearm and chronic osteomyelitis. In this review, the clinical indications, types of graft and outcomes of the procedure are discussed further.

Keywords: reconstruction of bone, vascularized bone transfer, clinical indications, outcomes.

1. INTRODUCTION:

Reconstruction of bone is often needed for large bone defects where normal bone regeneration is insufficient to repair the quantity of bone required, or in conditions where bone regeneration is compromised, for instance due to impaired blood supply, thus rendering intrinsic bone repair in these conditions difficult. In such cases there is recourse to other alternatives such as vascularized and non-vascularized cortical or cancellous autologous bone grafts, cadaveric bone allografts, and bone graft substitutes amongst others [1]. Autologous bone grafts including vascularized bone transfers have been frequently performed in orthopaedic surgery in the last 4 decades. Vascularized bone transfer was introduced in the 1970s following rapid advances in microvascular techniques which allowed anastomosis of small blood vessels during transplantation. This allowed circulation to be immediately established after surgery in the transplanted area. Reports published on the first successful uses of vascularized fibula for bone reconstruction were by Ueba and Fujikawa [2], Ostrup and Fredrickson [3] and Taylor *et al* [4]. The latter described the successful utilization of free vascularized bone grafting in humans for leg salvage in cases of lower limb injuries. Studies further confirmed the success and demonstrated the superiority of microsurgically revascularized autografts as compared to other autografts and allografts showing faster bone repair, greater strength and stiffness in vascularized bone grafts [5, 6].

Bone is well known to have the potential to regenerate completely. There are three important mechanisms that underlie bone grafting that need to be emphasized: osteogenesis, osteoinduction and osteoconduction. Osteogenesis is new bone formation that results from the inherent activity of osteoblasts. Osteogenesis is possible only with donor grafts which can provide the required osteoblasts. Osteoinduction occurs when the donor bone graft stimulates the osteoprogenitor cells from adjacent tissues of the recipient to proliferate into osteoblasts and commence new bone formation. Osteoconduction involves the donor bone graft acting as a scaffold for host osteoblasts from the margins of the defect to migrate within the graft and start laying bone. A vascularized bone graft allows all three processes of osteogenesis, osteoinduction and osteoconduction to take place thus

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enhancing bone repair [1]. As with any other transplanted material, the same immune mechanisms come into play in bone grafting with similar allograft rejection mechanisms. Hence autografts (bone harvested from one site of the body and transferred to the required site of the same person) are more successfully accepted by the recipient than allografts (bone transfer from other people) where rejection is mediated by T cells to donor major histocompatibility antigens [7, 8]. In addition, the type of bone in autograft, whether it is cancellous or cortical bone, also influences the outcome of the graft. Cancellous bone is vascularized more promptly and completely than compact bone whereas compact bone provides more mechanical strength [8]. Vascularized bone transfer usually refers to an autograft of bone which is transferred to another part of the body whilst maintaining either its original blood supply (pediculated bone graft) or having a reconstituted blood supply at the grafted site. The latter is known as a free vascularized bone graft. In this review, we discuss recent developments in the use of vascularized bone transfer for reconstruction.

2. MATERIALS AND METHODS

A literature search was performed of the U.S. National Library of Medicine National Institutes of Health PubMed database using the following search items: "vascularized bone graft". Inclusion criteria included the following: A) Articles discussing the use of vascularized bone graft (free or pedicled) for reconstruction B) Articles discussing human subjects. Articles which were excluded were: A) Articles discussing non-vascularized bone grafts or prosthesis B) Articles discussing aspects other than the use of vascularized bone grafts. 307 abstracts on vascularized bone graft were reviewed out of which 24 abstracts were selected as they fulfilled the inclusion criteria and full articles were viewed.

3. RESULTS

Uses for vascularized bone grafts included the reconstruction of mandibular defects, salvage reconstruction of temporomandibular joint, reconstruction of bones in the upper limb (humerus, radius, ulna, metacarpal bone) or lower limb (femur, tibia, foot) and treatment for scaphoid non-union. The results of reviewed articles [9-32] are summarised in Table 1. Clinical indications included segmental bone defects greater than 6-8 cm following trauma or post- resection of bone tumours or radical resection for osteomyelitis; failure of bone healing resulting in non-union of bone and cases of congenital pseudarthrosis of the tibia or forearm.

	Authors	Clinical indications	Type of graft	Recipient site	Number of patients	Outcomes
1	Sarukawa *et al.,* 2012 [9]	Reconstruction of segmental mandibular defect	Bare bone graft of vascularized iliac crest	Mandible	11	Good
2	Okada *et al.,* 2011 [10]	Reconstruction of ulna fracture after resection of tumour	Reversed lateral upper arm flap with vascularized distal humerus	Ulna	1	Good
3	Zhen *et al.,* 2011 [11]	Reconstruction of severe tibial shaft fractures	Free vascularized fibula or osteocutaneous fibular flap	Tibia	38	Good outcome with mean healing time of 21 weeks in 31 cases and of 32 weeks in 7 patients
4	Hamdi *et al.,* 2011 [12]	Treatment of scaphoid non-union	Pedicled vascularized bone graft from volar surface of lower radius	Scaphoid	26	Procedure successful in 23 patients with bony union obtained after 12 weeks
5	Tharayil & Patil, 2011 [13]	Reconstruction of foot with extensive giant cell tumour	Free vascularised fibular graft	Foot	1	Good outcome resulting in a functional foot
6	Hariri *et al.,* 2010 [14]	Bone reconstruction of lower limb defects after resection of malignant bone tumour	Free vascularised fibular graft	Lower limb	38	Bony union successful in 89% of cases with a mean time to union of 1.7 years
7	Nouri *et al.,* 2010 [15]	Knee arthrodesis for limb reconstruction after resection of tumour	Vascularised fibular rotatory graft	Lower limb	13	Union of arthrodesis in 7 cases at an average of 36

						months
8	Bürger *et al.,* 2009 [16]	Management of avascular necrosis and non-union of scaphoid	Corticocancellous transplant from distal medial femur	Scaphoid	15	Complete healing of scaphoid pseudoarthrosis in all cases
9	Kotwal *et al.,* 2008 [17]	Reconstruction of bone after recurrent giant cell tumour of head of second metacarpal	Vascularised toe joint transfer	Second metacarpal	2	Good outcomes in both cases with good function
10	Muramatsu *et al.,* 2004 [18]	Reconstruction of bone after large bone defect due to either tumour resection (11 cases) or post traumatic non-union of femur (6 cases)	Free vascularised fibular graft	Femur	17	94% of patients had confirmed bone union and good function
11	Bond *et al.,* 2004 [19]	Salvage reconstruction of temporomandibular joint	Free vascularised second metatarsal	Temporo-mandibular joint	5	Out of 7 reconstructions, 6 were successful with good pain-free function
12	Akin & Durak, 2002 [20]	Reconstruction of bone following chronic osteomyelitis of proximal tibia	Pedicled vascularised double-barrel fibular flap with a muscle flap	Tibia	1	Good outcome with bony union at 4 months
13	Sundaresh *et al.,* 2000 [21]	Reconstruction of diaphyseal defect of humerus due to osteomyelitis	Pedicled vascularised rib graft	Humerus	2	Good outcome in both patients
14	Cordeiro *et al,* 1999 [22]	Reconstruction of segmental mandibular defects	Fibula (90%) Radius (4%) Scapula(4%) Ilium (2%)	Mandible	150	Good outcome with free flap success rates of 100% and bony union in 97% Good functional and aesthetic results
15	Hsu *et al.,*1997 [23]	Reconstruction of massive skeletal defects after resection of tumours either in upper limb (15 cases) or lower limb (15 cases)	Free vascularised fibular grafts	Upper limb and lower limb	30	Union in 27 cases at an average of 7.6 months
16	Santanelli *et al.,* 1996 [24]	Reconstruction of bone following traumatic bone loss of radius and ulna	Free vascularised fibula graft to produce a single flap with 2 vascularised bone segments	Radius and ulna	1	Good outcome with good function
17	Kumta *et al.,* 1995 [25]	Reconstruction of upper extremity defects after excision of malignant tumours (6 cases) and benign tumours (30 cases)	Vascularised bone grafts	Upper extremity	36	Good outcome with bony union in 33 patients at 4 months
18	Savant *et al.,* 1995 [26]	Reconstruction of mandibular defects after resection for cancer	Vascularised iliac crest transfer	Mandible	18	Good outcome in 15 cases with good functional results
19	Boutault *et al,* 1992 [27]	Reconstruction of mandibular defects after resection for cancer	Free vascularised fibular grafts	Mandible	5	Good outcome in 4 cases
20	Olekas & Guobys, 1991 [28]	Reconstruction of defects or pseudoarthroses of forearm bones	Free vascularised fibular grafts (10 cases); radial grafts (3 cases); humeral grafts (2 cases)	Forearm bones	15	Good outcome in 13 cases with primary bony union in 3-6

						months
21	Lee *et al,* 1991 [29]	Reconstruction of bone following chronic osteomyelitis of tibia with extensive bone loss	Vascularised osteocutaneous fibular transfers	Tibia	25	Satisfactory outcome with primary bony union in 3-4 months
22	Mixter & Wood, 1983 [30]	Reconstruction of bone for a large defect of femur	Compound free forearm transfer	Femur	1	Satisfactory outcome
23	Chen *et al,* 1979 [31]	Treatment of congenital pseudoarthrosis of tibia	Vascularised fibular transfer	Tibia	12	Satisfactory outcome
24	Pho, 1979 [32]	Reconstruction of lower radius after massive resection for giant cell tumour	Free vascularised fibular graft	Lower radius	1	Good outcome

Table 1. Summarized the clinical uses of vascularized bone transfers

4. DISCUSSION

The vascularized bone graft most often consists of a transfer of bone but may include a combination of skin, fat and muscle as a free flap which is transposed to the recipient site where the blood supply is reconstituted. Such free osteocutaneous flaps are commonly used in reconstructive surgery.

4.1 Donor sites:

Donor sites for vascularized bone grafts have usually been the fibula, the iliac crest, the rib, the metatarsal bone, the radius and the scapula with the fibula and iliac crest being used more frequently as donor grafts. Specifically the fibula is commonly used for the reconstruction of a long bone and the iliac crest graft considered for the reconstruction of the mandible and other curved bones. However the bone grafts can be shaped as per needs at the recipient site [33]. Recent researchers have also focussed on "new" donor sites such as the clavicle, the lower limb, the thorax and the cranium [34]. The potential for these "new" donor sites to provide vascularized bone grafts still remain to be studied further.

4.2 Donor site morbidity:

Complications at the donor site may occur and may potentially include pain, neurovascular injury, extensor hallucis longus weakness, and ankle instability for vascularised fibular grafts or persistent pain, neurovascular injury, hematoma, infections, hernias, ureteral injuries and pelvic instability amongst others for iliac bone graft harvesting [35]. Where vascularised fibular grafts are concerned, some studies have reported acceptable donor site morbidity and preservation of foot and ankle function in a follow-up of 14 patients [36] whilst other studies have reported significant complications at the donor site in a follow-up of 102 patients namely transient palsy of the superficial peroneal nerve in 3 patients, contracture of flexor hallucis longus in 2 patients and valgus deformity of the ankle in 3 patients [37].

4.3 Outcomes:

Vascularized free bone grafts have been reported to result in good outcomes in mandible reconstruction using both fibular flaps and iliac crest flaps [38]. In recent times osseous free flaps have been preferred for mandibular reconstruction with the fibula donor site being chosen for large bony defects and the radius and scapula selected for large tissue defect with smaller bony defects [22].

In the upper limb, local pedicled vascularized bone grafts have successfully been used in the management of selected carpal conditions including scaphoid non-union, lunatomalacia and osteonecrosis of the scaphoid [39]. Vascularized bone transfer of the proximal fibula together with its growth plate has been used for distal radius reconstruction after tumour resection and has had a satisfactory functional outcome in seven patients aged between 2 and 11 years. This procedure was found to be the most effective surgical option in dealing with upper-limb bone defects involving the distal radius in children as it allowed both reconstruction of the bone defect and restoration of the growth potential [40].

In the lower limb, free vascularized bone grafts are considered valuable for long term reconstruction of large skeletal defects following resection of a tumour. Such grafts cater for the growth potential of children where long term survival is anticipated [41]. In cases of resection of bone sarcomas in young children, limb-sparing surgeries with reconstruction of bone defects using vascularized osteocutaneous fibular grafts have yielded satisfactory results although fractures were a common complication [42]. Again in the paediatric population, free vascularized fibula grafting was found to be useful for the treatment of congenital ulnar pseudarthroses, allograft non-union and osteonecrosis of the femoral head [43].

In other clinical settings, vascularized bone grafts have had good outcomes. For instance, problematic non unions of fractures after several surgical procedures in the presence of bone atrophy and damage of the surrounding soft tissue with or without infection have been shown to be successfully managed by free vascularized fibular grafts [44]. A recent publication also describes the use of the vascularized medial femoral corticoperiosteal flap for difficult fracture non-union. Its well-vascularized and highly osteogenic structure as well as its thin and pliable nature makes it well adapted to small non-union recipient sites where a more bulky vascularized graft would be unsuitable to fit into the recipient site. In addition donor site morbidity has been shown to be minimal and out of 46 cases reviewed, 87% had achieved bony union successfully [45]. Complex spine reconstruction is another domain where the use of vascularized bone grafts is considered useful [46].

4.4 Complications:

Vascularized bone transfer has largely been successful but there have been a few reports of complications. In a 3.2 year follow-up of 20 patients with free fibula flap transfers, there were many further surgical procedures for haematoma evacuations, delayed union or non-union and unsuccessful graft outcomes [47]. Other authors report on early complications following long bone reconstruction using vascularized fibula graft. These include anastomotic venous thrombosis, superficial wound infection, and transient common peroneal nerve palsy amongst the most common complications [48]. Long term complications have included stress fractures and graft hypertrophy [49]. Complications of vascularized bone transfer need to be studied further to improve clinical outcomes in patients.

5. CONCLUSION

Vascularized bone transfer is a technique that has known much progress since its introduction in the 1970s and is a widely used procedure especially in reconstructive surgery. It is commonly used for the reconstruction of mandibular defects, the reconstruction of bones of the upper limb and lower limb as well as for scaphoid non-union. It has had good outcomes in the reconstruction of large bony defects (greater than 6-8 cm) which commonly result from trauma or after the resection of bone tumours. Cases of congenital pseudarthrosis of the tibia or forearm and chronic osteomyelitis have also had recourse to vascularized bone transfer with some success. It is anticipated that the potential availability of new donor sites and improvements in surgical techniques will further expand its use in future.

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