Bone Growth after Free Vascularized Grafting of the Upper Radius including its Epiphysis in Puppies

Soo Bong Hahn

The radius including the proximal epiphysis was transferred in puppies. Growth in the vascularized long bone grafts in growing animals was significantly greater than in the non-vascularized grafts, not equal to normal growth.

In the non-vascularized grafts the epiphyses closed one month postoperatively, compared to 5 months in the vascularized grafts and 6 months in the normal controls. This data suggests that, in transplantation of growing bone, revascularization is essential to maximize continuing growth. This study is an initial step in the development of a technique for the transfer of a free vascularized growth plate. This information would be beneficial in predicting growth patterns of free vascularized bone transfers for growth disturbances, congenital anomalies and trauma in youth.

Key Words: Vascularized, bone, epiphysis; grafts.

In the past, the reconstruction of massive segmental bone defects has been a difficult orthopaedic problem. Recently, however, the continued improvement of microsurgery has made it possible to restore the circulatory supply to bone grafts and ensure viability. With the blood supply preserved, the osteocytes in the graft can survive, permitting rapid healing at the graft-recipient bone junction and early hypertrophy of the grafted bone segment without the replacement of the graft by creeping substitution.

Taylor et al. (1975) were first to report the successful use of a free vascularized fibular graft to reconstruct a traumatic defect of the tibia. Their report was followed by several cases in which the concept was applied (Chung-Wei et al. 1979; Doi et al. 1977; Weiland and Daniel 1979; Weiland et al. 1977; Weiland et al. 1979). Also rib and iliac crest have been employed to provide free vascularized bone grafts or free osteocutaneous flaps (Buncke et al. 1977; Hammack and Ennecking 1960).

The first successful clinical epiphysial transplant without revascularization was reported by Straub (1929). Other reports have followed over the decades (Barr 1954; Eades and Peacock 1966; Freeman 1965; Spira and Farin 1964; Wenger 1945). Wilson (1966) reported eleven cases of autogenous epiphyseal transplants to the hand with evidence of longitudinal growth in three patients. Whitesides (1977) reported that normal longitudinal growth had occurred in a transplanted epiphysis without revascularization.

Snowdy et al. (1980) have shown that he performed a free epiphyseal transplant of toe phalanx to finger with apparent longitudinal growth at 8-year follow-up.

Taylor et al. (1975) suggested that inclusion of the upper growth plate in the vascularized fibular graft may provide continuing growth in children. Recently, Donski et al. (1979) performed revascularized ulnar grafts in puppies. By reestablishing the endosteal and periosteal blood supply with microvascular anastomosis, the transplanted distal ulnar epiphyses were able to show growth and averaged two-thirds of the achieved by normal control ulnas.

The purpose of my investigation was to establish that epiphyses do survive and grow when they preserve the endosteal and periosteal blood supply in free vascularized long bone including epiphysis grafts.

MATERIALS AND METHODS

Model Selection

The radius of a puppy is a good model for studies after long bone including epiphysis graft because its blood supply is well defined and it is strong enough
Fig. 1. The nutrient artery enters the radius medially at the junction of the proximal and middle thirds of the bone. The diameter of the artery is approximately 0.3 mm.

Fig. 2. The proximal 8 cm of the radius was removed.

Fig. 3. The radius was transferred to the opposite leg and microvascular anastomoses performed. The arrow indicates the anastomotic site.
Bone Growth after Free Vascularized Grafting of the Upper Radius including its Epiphysis in Puppies

for weight bearing. The nutrient artery to the radius arises from the palmar interosseus artery and enters the medical surface at the junction of the proximal and middle thirds of the radius (Fig. 1). So the radius including proximal epiphysis transfer seems desirable.

Surgical procedure

Sixteen mongrel puppies, approximately 3 to 4 months old, weighing between fifteen and twenty pounds, were used in the experiment. The experimental design of this investigation involved two groups of animals.

Group I (Heterotopic Radius Transfers)

On 8 puppies bilateral, heterotopic radius transfers were performed by exchanging the proximal 8 cm approximately of the radius from one foreleg to the opposite one (Fig. 2). In one foreleg the palmar interosseus artery and a concomitant vein were anastomosed to the recipient site vessels after bone fixation (Fig. 3), while in the other one vessels were not anastomosed (Fig. 4).

Group II (Orthotopic Radius Transfers)

Eight puppies were used. In one foreleg, the proximal 8 cm approximately of the radius was excised and replaced to the original site with vascular anastomoses. In the other one, radiopaque metal marker was inserted in the shaft about 8 cm distal to the radial head for radiological investigation of growth (Fig. 5). No attempt was made to locate this marker precisely since it was the changes in distance between the radial head and the marker on serial scanograms of a given limb that were used to assess growth.

The puppies were sedated by an intravenous injection of Surital (thiamylal sodium) and general

Fig. 5. Marking and orthotopic transfers (Group II).

Fig. 6. Arteries of right antebrachium, caudalateral aspect (The shaft of the ulna is removed).
anesthesia was administered through an endotracheal tube using Halothane with a Harvard animal ventilator.

After aseptic skin preparation and draping of both forelegs, anterior longitudinal incision was made along the medial border of the radius extending from the elbow joint to the distal part of the forearm. Using loupé magnification, the common interosseus artery and vein were identified and dissected distally to follow the palmar interosseus vessels. The proximal 8 cm approximately of the radius, including epiphysis was resected. The palmar interosseus vessels were then clamped and divided just distal to the common interosseus vessels (Fig. 6). The periosteum on the radius was left intact.

As soon as the bones were completely free they were transferred to the opposite foreleg in Group I and replaced to the original site in Group II. Each transferred proximal segment of the radius was fixed to the remaining distal segment of the bone with stainless steel wire loop fixation. The radial head was stabilized by closure of capsule and other soft tissue with multiple interrupted sutures.

In vascularized forelegs, microvascular anastomoses of the palmar interosseus artery and a concomitant vein were performed under an operating microscope with 100 × suture materials.

The function of the anastomosis was observed for at least ten minutes. The muscles were then reaproximated and the skin was closed, leaving the deep fascia open.

The ischemia time for the revascularized grafts averaged 90 minutes. The limbs were immobilized in padded long leg plaster casts with the elbow flexed at 30° for two weeks. Tight long leg casts were then applied and worn for an additional three weeks. Postoperatively, all of the puppies received daily an intramuscular injection of Combictic (procaine penicillin G in dihydrostreptomycin sulfate solution 3.0 ml) for one week.

Evaluation

All animals were followed with serial scanograms immediately, 2 weeks and 4 weeks postoperatively, and then monthly for 6 months after surgery until their epiphyses had closed to determine survival and growth of transplanted long bone with epiphysis.

Brachial arteriograms were made four months after operation by gently infusing Renografin-76 into the branchial artery to determine the patency of the anastomoses after anesthesia with intravenous sodium pentobarbital and ventilation with a Harvard animal ventilator via endotracheal tube. Determinations of growth were made by measuring the distance between the radial heads and centers of the fixation wire loops in the transferred radii and between the radial heads and radiopaque markers in normal control radii on scanograms. Growth was calculated by subtracting the measured distance on the immediate postoperative scanogram from that on the final scanogram.

For purposes of statistical analysis, growth was expressed as a percentage increase over the initial total length of the radius to minimize differences due to phenotype.

At the time of sacrifice, radii were excised for histological study to determine viability of bone.

Longitudinal sections of the radial heads were prepared for histological study.

RESULTS

In group I and II, X-ray showed solid bony unions at the osteotomy sites. The vascularized transplants showed radiologically normal architecture, and osteotomy sites healed more rapidly. Growth was progressing. The non-vascularized transplants appeared thin in the cortex and early atrophy in some cases. Growth was ceased in early stage.

In all 16 instances of vascularized bone grafts, the anastomosed vessels were patent on arteriograms performed 4 months postoperatively (Fig. 7). The proximal radial epiphyses closed in 2 limbs at 2 weeks and in 6 limbs at 1 month in non-vascularized heterotopic grafts. In vascularized heterotopic grafts the epiphyses closed in 1 limb at 4 months, in 5 limbs at 5 months and in 2 limbs at 6 months. In vascularized orthotopic grafts the epiphyses closed in 1 limb at 4 months, in 6 limbs at 5 months and in 1 limb at 6 months. In normal controls the epiphyses closed in 1 limb at 5 months and in 7 limbs at 6 months (Figs. 8 and 9).

In the vascularized heterotopic grafts the longitudinal growth of grafted bones averaged 1.5 cm (12% increase of the initial entire radii) (Fig. 10). In the vascularized orthotopic grafts the longitudinal growth averaged 1.6 cm (13% increase) (Fig. 11). In the non-vascularized heterotopic grafts the growth averaged 0.3 cm (3% increase) (Fig. 12) and in the normal controls the growth averaged 2.4 cm (21% increase) (Tables 1 and 2, Figs. 13 and 14). The growth in the vascularized heterotopic graft was 63% of normal growth of the radius, and the growth in the vascularized orthotopic graft was 67%.

The final growth in the vascularized heterotopic grafts or the vascularized orthotopic graft was
Bone Growth after Free Vascularized Grafting of the Upper Radius including its Epiphysis in Puppies

Fig. 7. Arteriogram in a heterotopic vascularized graft at 4 months demonstrating patent anastomosis. The arrow indicates the anastomotic site.

Fig. 8. At 5 months postoperatively the epiphysis closed in vascularized orthotopic grafts, but did not closed in normal controls.

Fig. 9. Time of proximal radial epiphyseal closure.

significantly more than that in the non-vascularized grafts (p<.010, p<.005). The growth in the vascularized heterotopic grafts or vascularized orthotopic grafts were less, however, than that in the normal controls (p<.010, p<.025). No significant differences were found between the vascularized heterotopic or orthotopic transfers (p>.500).

By histological examination the physis from all group I and group II have already closed and replaced by normal bone tissue.

The articular cartilage from the normal controls was thin and trabeculae of subchondral bones were thick. But in non-vascularized heterotopic grafts, the articular cartilage was thick and trabeculae of
Fig. 10. Group I. Scanograms of an anastomosed heterotopic graft.

Fig. 11. Group II. Scanograms of an anastomosed orthotopic graft.

Fig. 12. Group I. Scanograms of a heterotopic graft without anastomoses.
Bone Growth after Free Vascularized Grafting of the Upper Radius including its Epiphysis in Puppies

![Image: Scanograms of a normal control.](Fig. 13)

![Image: Percentage of longitudinal growth of transplanted bones to initial radii.](Fig. 14)

![Table: Longitudinal growth of transplanted bones in group I](Table 1)

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<td></td>
<td>Growth (cm)</td>
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<tr>
<td>I–1</td>
<td>1.5</td>
<td>14</td>
</tr>
<tr>
<td>I–2</td>
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<tr>
<td></td>
<td><strong>Average</strong></td>
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![Image: Photomicrographs of radial heads from group I and group II 6 months after operation (hematoxylin and eosin, x40).](Fig. 15)


Number 4  289
Table 2. Longitudinal growth of transplanted bones in group II

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<th>Dog</th>
<th>Vascul. trans.</th>
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<td></td>
<td>Growth (cm)</td>
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<td>1-1</td>
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<td>Average</td>
<td>1.6</td>
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subchondral bones were thin because of less ossification in hypertrophic zone of the articular cartilage due to poor blood supply. The thickness of the articular cartilage from the vascularized grafts was intermediate between the normal controls and the non-vascularized grafts (Fig. 15).

**DISCUSSION**

This study shows that consistent survival and growth are possible in transplanted growth plates by re-establishing the endosteal and periosteal blood supply with microvascular anastomoses.

Epiphyseal growth has been noted in clinical microvascular transplant of the fibula (Weiland et al. 1979) and in replanted digits in children (Van Beek et al. 1979). Clinical reports of toe to thumb transfers in children have indicated good radiographic evidence of growth.

This study confirms previous studies (Donski et al. 1979; Donski and O'Brien 1980) which indicated survival and growth that averaged two-thirds of normal after experimental free vascularized epiphyseal transfers in puppies. Unlike previous studies, in this study we used radii including the proximal epiphysis instead of ulnae including the distal epiphysis and also used scanograms for more accurate radiological evaluation of growth.

Growth in the vascularized long bone grafts in growing animals was significantly greater than in the non-vascularized grafts, but not equal to normal growth. In the non-vascularized grafts the epiphyses closed one month postoperatively, compared to 5 months in the vascularized grafts and 6 months in the normal controls.

It is felt that relative vascularity was the major difference explaining this observation. This data suggests that, in transplantation of growing bone, revascularization is essential to maximize continuing growth.

**REFERENCES**


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Volume 27