Acta Orthop Scand 57, 163–167, 1986

Pedicled scapular apophysis transplantation

Growing grafts studied in dogs

Twenty-eight immature dogs, divided into three groups, have been studied to determine the possibilities of pedicled epiphyseal transplantation from a rarely used donor site area, the scapula. One group of 8 immature dogs were studied anatomically using India ink and Batson's compound injection methods. We identified the vascular pattern of the diaphyseal portion of the graft, consisting of the lateral crest or border of the scapula. In two groups of 10 immature dogs, this area was used as a pedicled island graft to rebuild the semiresected or totally resected proximal humerus. There were marked differences between these two groups on the basis of morphologic, histologic, histochemical and electron microscopic aspects of the samples. Preservation of normal growth appeared to be directly related to the compressive forces applied to the graft. Preservation of the cartilage was also related to the biomechanical situation; fibrocartilage and signs of arthrosis were noted 1 year after the operation in several animals whose humeri had been fully subjected to normal stresses. Both the diaphyseal and epiphyseal areas had increased one- to fivefold in volume, but longitudinal growth was markedly deficient.

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Introduction

Experiments in dogs by Donski et al. (1979), Brown et al. (1982), and more recently by Nettelblad et al. (1984a) have shown that growth potential can be preserved in the proximal end of the fibula when physeal vasculature is retained and the graft is reimplanted in the same area. Heterotopic transplantation to the foreleg of the animal (Nettelblad et al. 1984a) did not achieve the same results, suggesting that the graft should not be subjected to excessive mechanical stress. We have previously (Teot et al. 1982b) studied transplantation of the pedicled iliac crest to the distal end of the femur in immature dogs after resection of the central part of the growth plate. There was normal growth when the graft was replaced in its bed, provided the vessels were repaired. When the graft was heterotopically transplanted to the distal end of the femur, it was subjected to adverse mechanical conditions of the recipient site and failed to grow. In further experiments (Teot et al. 1983) involving the transplantation of the pedicled iliac crest to the resected acetabulum in immature dogs, we were able to demonstrate good remodeling and growth of the graft. The mechanical conditions of the recipient site must thus be taken into account in heterotopic transplantation.

We have previously reported (Teot et al. 1982b) the possibility of using the lateral crest or border of the scapula in plastic and reconstructive surgery and described some of the clinical applications. In growing animals and children, there is large area of hyaline cartilage at the inferior angle of this bone, including a typical growth plate vascularized by proper physeal vessels. An epiphyseo-diaphyseal piece of bone can be removed from the remaining lamellar portion of the scapula. Our objective was to investigate the development of the apophysis transplanted from this new donor site area in dogs.

Materials and methods

Twenty-eight 3-month-old dogs were used. The anatomic characteristics of the graft were studied in 8 dogs. The lateral border of the scapula, between the insertion of the triceps above and the inferior angle of the scapula below was round in its upper portion and straight at the lower end. The cross-section was triangular in the upper portion, consisting of cortical

Figure 1. Lower apophysis of the scapula (polarized light image, × 10) showing the hyaline cartilage markedly penetrated by the insertion fibers of the major teres muscle (arrow).

bone surrounding a medullary cavity, as in long bones. Several strong muscles were inserted around the lateral crest. The inferior angle of the bone was covered by the large apophysis with a hyaline portion in which a histologic study demonstrated a typical growth plate (Figure 1).

The vascular supply of the lateral crest was studied by injection techniques via the subclavicular artery. Four dogs were injected with India ink and four others with Batson's compound (Figure 2).

In Group I of 10 dogs, a longitudinal portion of the proximal humerus was resected (Figure 2). A posterior approach was made from the inferior angle of the scapula to the glenoid cavity, extending along the posterior part of the foreleg to the middle of the shaft. The lateral crest was first dissected out and stripped of the infraspinatus, teres and subscapularis muscles, taking care to preserve the diaphyseal and epiphyseal vasulature from the subscapular vessels. The bone was longitudinally sectioned with an osteotome from the insertion of the long head of the biceps above to the inferior angle of the bone below. The shoulder joint was then opened, the posterior part of the proximal humerus was stripped of muscular insertions and half of the bone was longitudinally resected with an osteotome. A tunnel was opened through the supraspinatus and deltoid muscles. The graft was inverted following the axis of the pedicle and passed trough the tunnel as an island graft. The graft was then inserted into the humeral defect. The hyaline cartilage of the angle was placed in contact with the glenoid cavity and aligned with the cartilage of the humeral physis. A transverse diaphyseal screw fixed the graft. Through a contralateral incision, a metal marker was fixed at the level of the insertion of the long head of the triceps to check the length of the normal bone during growth. The incisions were closed. The dogs were immobilized for 3

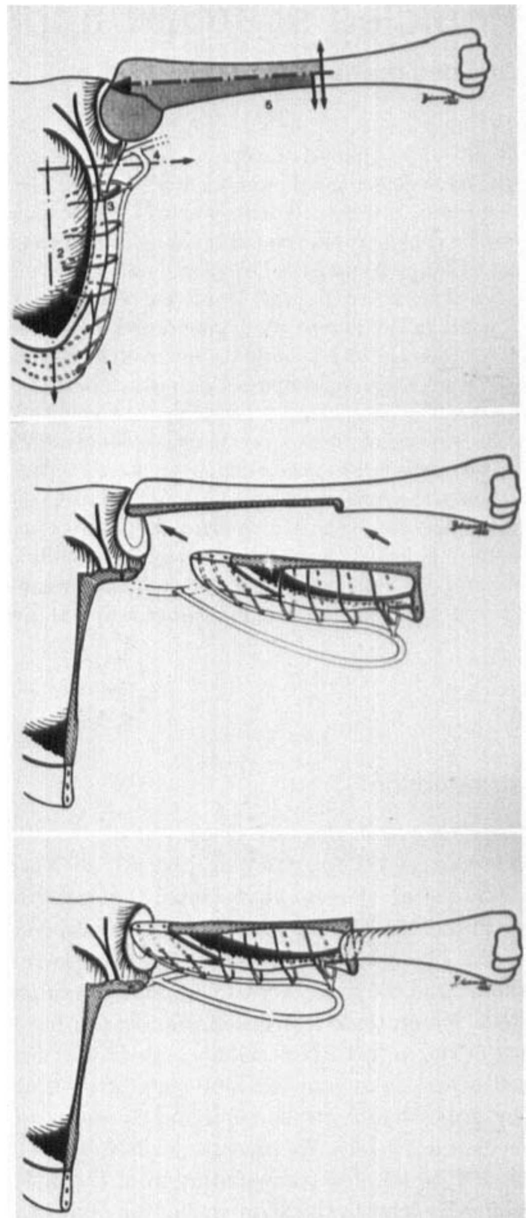

Figure 2. Vascular supply of the lateral scapular crest apophysis (A) and the two methods of transplantation, Group I (B) and Group II (C). 1) Apophyseal vasculature. 2) Cortical-periosteal vessels. 3) Nutrient centromedullary vessels. 4) Subscapular artery originating from the axillary artery. 5) Bone resected in the two groups of dogs.

weeks postoperatively in plaster casts and then allowed to walk freely.

In Group II of 10 dogs the same technique was used, but the proximal humerus was totally resected (Figure 2). The graft was inserted into a U-shaped longitudinal 3-cm osteotomy of the remaining humerus and fixed with two screws. The dogs in both groups were killed at monthly intervals from 2 months to 1 year after a radiographic examination including an arteriogram. Oxytetracycline (60 mg/kg) was given 1 week postoperatively and 1 week before death. The morphologic study of the samples included a comparison between the two humeri and a comparison of the length of the transplanted scapula with the contralateral side.

Samples were fixed in 10 per cent formalin, decalcified for 4 weeks with ethylenediatetraacetic (EDTA) solution, embedded in paraffin, cut into 10-μ sections, and stained with hematoxylin eosin. Histochemical analyses were performed by staining eosin samples with safranine O. Polarized light studies were performed on the safranine slides.

Small samples of cartilage were fixed in glutaraldehyde and sodium monophosphate, decalcified with EDTA solution, postfixed in 1 per cent osmium tetroxide, and embedded in araldite. The transmission electron microscopic study was performed with a Philips 301 electron microscope.

The dogs were killed after 3–12 months and the transplants were studied histologically, histochemically, and by electron microscopy. The three main focal points were changes in the diaphyseal portion, remodeling of the hyaline cartilage and growth of the transplant.

In the grafts that replaced the proximal humerus, the volume and diameter adapted to the new biomechanical situation; a one- to five-fold increase in volume involved both the cartilaginous and diaphyseal portions (Figure 4).

The articular surface was usually modified. In 2 cases, hyaline cartilage remained and in 8 fibrocartilage was observed under the electron microscope; chondrogenesis had decreased (Figure 5), fibroblastic cells were noted, and elastin fibers had replaced the collagenous substance.

The growth plate showed signs of disorganization 3 months after transplantation; the number of cells in each column was higher than on the normal side and the total surface of the growth plate had increased in proportion to the lateral growth of the graft. Polarized light studies showed the presence of large collagenous fibers arranged along an irregular pathway inside the hyaline cartilage.

The new humerus grew 25 ± 5 per cent less than the normal bone. The graft was 50 per cent smaller than the contralateral side.

In all grafts arteriograms showed preservation af bone vascularization and a good permeability of the subscapular vessels.

Results

Total necrosis of the graft was observed in 1 dog which was excluded. In the group where two hemiepiphyses were joined to form a new composite bone the diaphyseal diameter of the graft remained unchanged. Each graft retained its own characteristics. The cortical bone was unchanged and two distinct medullary canals remained.

The cartilage surface remained hyaline. Chondrocytes were still present 1 year after transplantation (Figure 3). Fibroblastic cells were observed in some cases. The growth plate kept its histologic characteristics.

The humerus that was operated on grew 15 ± 5 per cent less than normally. The transplanted scapula grew 10 per cent less than the contralateral portion between the metallic marker and the lower angle of the scapula and more slowly than the remaining portion of the humerus.

Discussion

Most experimental studies of hereotopic transplantation have focused on the possibilities for normal growth of the graft. It seems possible to solve the vascular problem by preserving the

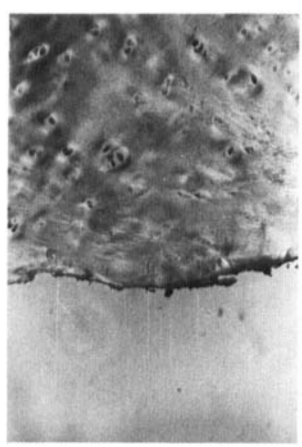

Figure 3. Viable chondrocytes in the hyaline surface of a 6-months (Group I) graft (hematoxylin-eosin-safranine O, polarized light study, × 25).

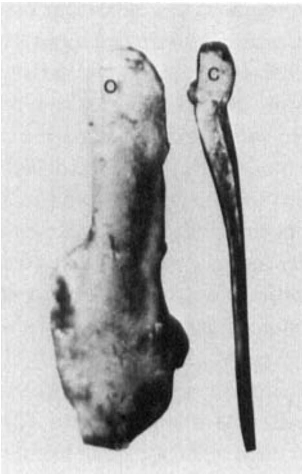

Figure 4. Comparison between the side operated on (0) and the control side (C). Note the one- to fivefold increase in the volume of the transplanted apophysis, at both the epiphyseal and diaphyseal levels (Group II).

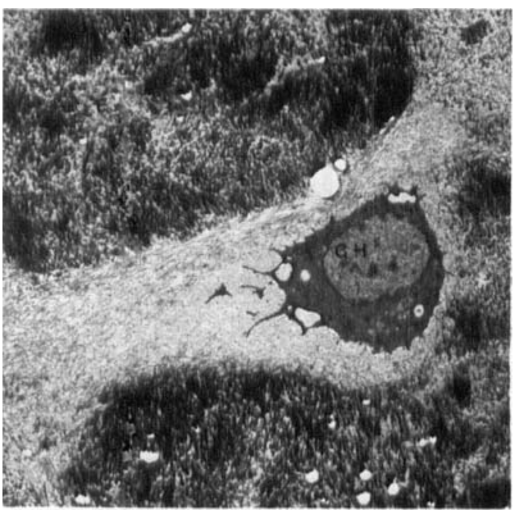

Figure 5. A chondrocyte in the hyaline cartilage 3 moths after transplantation (Group II). Elastin fibers surround a modified chondrocyte (transmission electron microscopy. × 4500).

whole epiphyseal-physeal vasculature, but few donor sites have been proposed.

The proximal end of the fibula has a peculiar vasculature (Restrepo et al. 1980), arising from different sources, and it is impossible to retain all the epiphyseal vessels. Using only one of the three epiphyseal sources, Nettelblad et al (1984b) recently demonstrated increased blood flow in a freshly pedicled proximal fibular epiphysis compared to the normal side, attributed to vasodilatation following the pedicle dissection. This observation favors a communicating epiphyseal vascular network. However, it has been suspected for some time that each region of the epiphyseal spongy bone has its own specific vascular system, which might cause several pathologic conditions in children. In spite of this problem, the fibular physis has considerable growth potential and can be proposed for upper arm bone defects in children.

The iliac crest exhibits a mode of growth that has been defined by Ponseti et al. (1968) as being an epiphysis during the first years of life. Subsequently, the combined action of the abdominal and thigh muscles makes it grow like any other apophysis. We have previously studied the iliac crest and its epiphyseal vasculature (Teot et al 1982a). It grows less than the proximal portion of the fibula. The surface removed is adjustable in length, but the shape is not strictly round.

The scapula, recently described as a new donor site area for pedicle bone has a considerable growth potential at the inferior angle comparable to the iliac crest. A large number of cells were counted in each column of the growth plate. There are numerous muscle insertions on the inferior scapular apophysis; and thick Sharpey's fibers can be seen inside the cartilaginous area, suggesting a strong interaction between muscle and cartilage, comparable to the situation in the iliac crest.

This portion of hyaline cartilage does not have a definite epiphyseal morphology, with a joint cartilage, a perichondrial ring, and an ossification center. The nonspecific character of the structure facilitates its adaptation to a new biomechanical situation. When the pedicle graft was placed in a mechanically protected situation, it grew approximately like the normal side, preserving its hyaline surface for as long as 12 months. When the graft was subjected to the total compression usually exerted on the proximal humeral epiphysis most of the adaptive effort hade a transverse orientation. We found that when the hyaline cartilage was subjected to the full stress of normal weight bearing, its shape adapted by means of cell multiplication and increased synthesis of ground substance. The ultrastructural aspects of the newly formed chondrocytes and the new ground substance were normal. This observation agrees with previous reports on the consequences of hyperpressure on growth plates (Peruchon et al. 1980, Trueta and Trias 1961).

It appears to be possible to solve the vascular problems of pedicled epiphyseal transfer by extensive anatomic studies and suitable microsurgical tenhniques. However, the biomechanical conditions of the donor and recipient sites are still difficult to determine completely. Each epiphysis of the human body has its own biomechanical environment and possesses its own particular growth potential. Classical biomechanical studies cannot alone solve this problem. According to the studies of Shapiro et al. (1977) and Speer (1982), morphologic analysis will have to define each component of the heterogeneous structure of the epiphysis. Moreover, the development of each donor site area after transfer must be exactly defined by extensive experiments.

Acknowledgements

The authors wish to thank Mrs Fonquernie, Mrs Cros, and Miss Legrand for their technical assistance.

References

Brown, K. L. B., Cruess, R. L., Daniel, R. K., Lyczakowski, T. & Marie, P. (1982) Free epiphyseal transfer using microvascular anastomosis. *J. Bone Joint Surg.* **64**-B, 6–21.

Donski, P. K., Carwell, M. D. & Sharzer, L. A. (1979) Growth in revascularizerad bone graft in young puppies. *Plast. Reconstr. Surg* **64**: 239.

Nettelblad, H., Randolph, M. A. & Weiland, A. J. (1984a) Heterotopic microvascular transplantation of proximal fibular epiphysis to a radial defect. *Transactions Orthopaedic Research Society* p. 242.

Nettelblad, H., Randolph, M. A. & Weiland, A. J. (1984b). Physiologic isolation of the canine proximal fibular epiphysis on a vascular pedicle. *Microsurgery* **5**, 98–101.

Peruchon, E., Bonnel, F., Baldet, P. & Rabischong, R.(1980). Evalution and control of growth activity of epiphyseal plate, *Med. Eng. Comput.* **181**: 396.

Ponseti, I. V., Pedrini Mille A. & Pedrini, V.(1968). Histological and chemical analysis of human crest cartilage. *Calcif. Tissue Res.* **2**: 297.

Restrepo, F., Katz, D. & Gilbert, A. (1980). Arterial vascularization of the proximal epiphysis and the diaphysis of the fibula, *Int. J. of Microsurg,* **2**: 49–54.

Shapiro, F., Holtrop, M. E. & Glimcher, M. J. (1977). Organization and cellular biology of the perichondral ossification groove of Ranvier, *J. Bone Joint Surg.* **59-A**: 703–723.

Speer, D. M.(1982). Collagenous architecture of the growth plate and perichondrial ossification groove, *J. Bone Joint Surg.* **64-A**: 399–407.

Teot, L., Bosse, J. P., Mouffarrege, R., Papillon, J. & Beauregard, G. (1981) The scapular crest pedicled bone graft, *Int. J. of Microsurg.* **3**, 257–262.

Teot, L., Gilbert, A., Katz, D., Pous, J. G., Carlioz, H. & Bonnel, F. (1982a). Vascularization des epiphyses en croissance. Etude préalable á la transplantation, *Rev. Chir. Orthop.* **68**, 357.

Teot, L., Bosse, J. P., Gilbert, A. & Tremblay, G-R. (1982b). Pedicle iliac crest epiphysis transplantation, *Clin. Orthop.* **180**, 206–218.

Teot, L., Dussault, F. G., Bosse, J. P. & Pous, J. G. (1983). Acetabuloplasty using pedicle iliac crest epiphysis transplantation in puppies. *Int. Orthop.* **7**, 1–9.

Trueta, J. & Trias, A. (1961) The vascular contribution to osteogenesis IV. The effect of pressure upon the epiphyseal cartilage of the rabbit. *J. Bone Joint Surg.* **43-B**, 800–813.