THE FATE OF FAT TRANSPLANTS IN OPERATIONS FOR PARTIAL CLOSURE OF THE GROWTH PLATE

CLINICAL EXAMPLES AND AN EXPERIMENTAL STUDY

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The cavities left after resection of bone bridges for partial closure of growth plates in children have commonly been filled with free fat grafts. Such cavities have been seen to elongate and thus enlarge during growth after the operation, but the fate of the grafts has been unknown.

Similar cavities, made in the tibiae of growing pigs were filled with autogenous fat and studied by radiography for periods of up to 9½ months. These cavities elongated in a manner similar to those in the clinical cases, and histological section showed them to be filled with living adipose tissue. The volume of this tissue had continuously increased in parallel with the growth in length of the bone. The fate of the grafts used in children may be similar to that seen experimentally.

Premature partial closure of an epiphyseal plate, if untreated, will cause a growth disturbance which progresses until the physis has closed (Salter and Harris 1963). On the basis of experimental research (Langenskiöld and Edgren 1950; Heikel 1960), unpublished observations by Langenskiöld and Michelson in 1960 and the extensive work of Lexer (1919), resection of a bone bridge between epiphysis and metaphysis and its replacement by a free fat transplant was first carried out in 1965 (Langenskiöld 1967). This case showed that circumscribed areas of premature epiphyseal closure could be treated, with a successful result.

This operative technique has been further developed on the basis of animal experiments (Österman 1972; Langenskiöld 1975; Langenskiöld and Österman 1979) and experience of the treatment of children (Langenskiöld 1975; Langenskiöld and Österman 1979; Langenskiöld 1981; Langenskiöld and Österman 1983). In over 50 operations for resection of bone bridges in the tubular bones of children, free fat transplants have successfully prevented reformation of the bridges. The operations have regularly restored a normal rate of growth with progressive correction of angular deformity.

Soon after an epiphyseo-metaphyseal bone bridge

has been resected and replaced with a free fat graft the radiograph shows a radiolucent area occupied by the fat transplant; this area usually has a round or oval shape (Figs 1 to 3, and see Fig. 9). When growth at the plate recommences the radiolucent area becomes elongated (Figs 4 to 7), and where a wide bridge has been removed a fairly large cavity is formed in the metaphysis (Figs 8 to 10). This phenomenon has not been clearly understood. The layer of dense bone which regularly forms around the cavity tends to strengthen the metaphysis. The width of the defect in the growth plate gradually becomes smaller by regeneration from the surrounding parts of the plate.

CASE REPORTS

Case 1. At nearly nine years of age, a boy sustained a Salter-Harris Type IV epiphyseal injury to the medial side of his distal left femur. The small displacement was not corrected and, one year after conservative treatment in a plaster cast (Fig. 1), there was an epiphyseo-metaphyseal bone bridge at the site of the fracture with a 15° varus deformity and 2 cm of shortening (Fig. 2). The bone bridge was resected 14 months after injury and the resulting cavity was filled with an autogenous free fat graft. The bone bridge had been about 2 cm wide and it extended through from the anterior to the posterior rim of the growth plate. The radiolucent area seen on tomography (Fig. 3) thus represents a cross-section of an almost cylindrical cavity. There was steady improvement (Figs 4, 5 and 6) and by the age of 12 years there was no varus deformity with a leg-length discrepancy of only 1 cm. The radiolucent area in the femur had gradually elongated. At the age of 16 years varus had recurred, the left leg was 1 cm shorter than the right and the growth plate was closing (Fig. 7). There had been 8 cm of growth

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from the injured growth plate since the resection of the bridge.

Case 2. A girl who had been treated for osteomyelitis in the proximal end of the right tibia at the age of 2 months had been under review from the age of 2 years for a slight varus deformity at the right knee. At the age of 10 years a wide bone bridge was seen radiographically in the central

part of the epiphyseal plate (Fig. 8). The varus deformity was 10° and there was 2.5 cm shortening. Six months later the bone bridge was resected through a window in the metaphysis and the resulting cavity was filled with a free autogenous fat graft (Fig. 9). There was gradual correction of the varus deformity and when the affected growth plate closed at the age of 13 years there had been

Fig. 1

Fig. 2

Case 1. Anteroposterior radiographs of the left knee of a boy who sustained a Salter-Harris Type IV epiphyseal injury at almost nine years of age. Figure 1—The original injury in plaster. Figure 2—After 14 months, at age 10 years, there is a bone bridge and increasing varus deformity. Figure 3—Tomograph taken two weeks after resection of the bony bridge and a free fat graft. Note the oval shape of the cavity and lines of growth arrest in femur and tibia. Figures 4, 5 and 6—gradual elongation of the lucent areas is shown, respectively at 11, 12 and 14 years of age. The growth arrest lines are disappearing and the varus deformity is correcting. Figure 7—At 16 years of age, 6 years after operation, there has been 8 cm of bone growth from the injured epiphyseal plate.

Fig. 3

Figs 4 to 7 ▶

Fig. 8

Fig. 9

Fig. 10

Case 2. Anteroposterior radiographs of the right knee of a girl who had osteomyelitis in infancy. Figure 8—There is a large bone bridge between epiphysis and metaphysis, and a varus deformity, but the bridge was completely ringed by healthy epiphyseal cartilage. Figure 9—Tomograph 3 months after resection of the bridge and a free fat graft, carried out through a window in the metaphysis. The arrow indicates a metal marker inserted at operation. Figure 10—Tomograph 2 years 4 months after operation. Note the correction of varus deformity and the reduced width of the defect at the level of the growth plate. There had been 2 cm growth at the epiphysis.

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

Minipig Leg 2. Figures 11 and 12—Radiographs of the upper tibia immediately after a cavity in the growth zone had been filled with a free fat graft. Figure 13—Lateral view 26 days after operation, showing about 6 mm growth of the metaphysis.

Minipig Leg 3. Anteroposterior radiograph and microtome section 26 days after fat implantation in a cavity in the proximal tibia. There has been 6 mm growth and the cavity has become enlarged since operation. It is filled by fatty tissue.

2 cm of growth from this plate since operation, leaving a leg-length discrepancy of 1.5 cm (Fig. 10).

These results are typical of those obtained in other suitable cases, such as those illustrated in other reports (Langenskiöld and Österman 1979; Langenskiöld 1981; Langenskiöld and Österman 1983). The round or oval radiolucent areas seen immediately after bridge resection often elongate and enlarge to a volume several times that of the transplanted fat.

The revascularisation and survival of transplanted free fat grafts has been demonstrated by several authors (Lexer 1919; Peer 1956; Montgomery and Van Orman 1967; Kiviluoto 1976; Langenskiöld and Kiviluoto 1976; Langenskiöld and Valle 1985). However, extreme elongation and thus enlargement of a cavity in a metaphysis containing a free fat graft has not been reported, and the fate of the transplant after bone bridge resection has not been studied. Enlargement of cavities as shown in Figures 3 to 10 was not seen in experiments on rabbits (Österman 1972; Langenskiöld and Österman 1979). The metaphyses of the tubular bones of rabbits contain little cancellous bone, so that the situation differs from that in children. For this reason the minipig was chosen as subject for experiments on the fate of fat grafts implanted in the growth zones of tubular bones.

side and the other half on the metaphyseal side of the plate. A round or oval cavity 6 to 7 mm in diameter was then made in the medial condyle and filled with a free transplant of autogenous subcutaneous fat taken from the buttock (Figs 11 and 12). The transplant, which protruded somewhat out of the cavity, was covered by subcutaneous tissue when the skin wound was closed with catgut sutures.

Anteroposterior and lateral radiographs were taken after operation, at monthly intervals, and after the animal had been killed. Resected tibiae were deep-frozen and later dissected, fixed in 10% formalin, decalcified in formic acid, and embedded in paraffin. Sections made at 7 µm were stained with alcian blue, haematoxylin and chlorantin light red. Table I lists the experiments (Figs 11 to 26), and gives the relevant figure numbers.

RESULTS

Radiographs taken immediately after operation show the cavities as round or oval radiolucent areas (Figs 11, 12, 16 and 21), which later became progressively elongated in a way similar to that seen after operation in children (Figs 13, 17, 22 and 23). This was seen in all 14 tibiae. In 9 of the 12 tibiae examined histologically the

MATERIAL AND METHODS

Minipigs of Göttingen strain aged 3 to 4½ months were premedicated with 0.05 mg/kg atropine 30 minutes before anaesthesia. This was induced with 0.5 mg/kg intramuscular azaperone (Stresnil) and 10 mg/kg intraperitoneal metomidate (Hypnodil). Additional doses of metomidate were given as required during operation.

At operation on 14 legs in 9 pigs a longitudinal incision was made over the anteromedial aspect of the upper end of the tibia. The proximal growth plate was exposed and anterior to the medial collateral ligament a round defect of 5 to 6 mm diameter was made in the surface of the bone at the level of the plate by means of a sharp spoon. Half of the defect was on the epiphyseal

Table I. List of experiments on 14 legs of 9 minipigs

Leg number	Age (months)	Follow-up (days)	Figure numbers	
			Radiographs	Histology
1	3	13		
2	4	26	11, 12, 13	
3	4	26	14	15
4	3	41		
5	3.5	74		
6	3.5	74	16, 17	18, 19, 20
7	4.5	119		
8	4.5	119		
9	3.5	141	21, 22, 23	24, 25, 26
10	3.5	141		
11	4.5	285		
12	4.5	285		
13	3	98		
14	3	98

Fig. 16

Fig. 17

Minipig Leg 6. Figure 16—Immediately after operation. Figure 17 Lateral radiograph 74 days after operation, showing 12 mm metaphyseal growth. Figure 18—Sagittal section showing state 74 days after operation. The cavity is about double the volume of that made at operation and is filled by living adipose tissue. Figures 19 and 20—Enlargements of areas A ($\times 50$) and B ($\times 70$) in Figure 18.

Fig. 18

Fig. 19

Fig. 20

Fig. 21

Fig. 22

Fig. 23

Minipig Leg 9. Figure 21—Immediately after operation. Note the position of the metal marker. Figures 22 and 23—Radiographs taken 141 days after operation showing 24 mm of metaphyseal growth. Figure 24—Frontal section showing state 141 days after operation. The metaphyseal cavity is about four times larger in volume than the original defect and is filled with living fat. Figures 25 and 26—Enlargements of areas A and B in Figure 24 ($\times 20$).

Fig. 24

Fig. 25

Fig. 26

elongated cavities were filled by living adipose tissue, with fat intermingled with strands of connective tissue and blood vessels (Figs 15, 18 to 20, 24 to 26). In the other tibiae, the cavities also contained living adipose tissue, but one showed a central area of necrotic fat about 3 mm in diameter (Leg 2) and two (Legs 1 and 4) had marginal areas of necrotic fat 1.5 to 2 mm in diameter. In one case (Leg 10) a bone bridge had developed. The volume of the cavities filled by adipose tissue had gradually increased in parallel with the growth in length of the bone. In two cases (Legs 9 and 10) the volume of living fat tissue in the cavity after 4½ months was more than three times the volume of the original transplant (Figs 21 to 26).

In two pigs metal markers were inserted in both tibiae but fat was implanted only in the right (Legs 13 and 14). Radiographs showed that the tibia on both sides of both animals grew about 10 mm at the proximal growth zone during a three-month period. This demonstrated that the cavities did not noticeably affect growth in length. Figures 13, 17, 18 and 22 show that the defect in the growth plate produced by operation was gradually reduced by regeneration of cartilage from the surrounding plate.

DISCUSSION

Comparison of the radiographic appearances after fat implantation in children with those produced in the pig shows great similarities in the development of the cavities. The cavities which had elongated during growth in the pigs have been shown to contain living adipose tissue, and to have enlarged to two to four times the volume of the original transplant in a few months. During this growth the number of fat vacuoles in the transplants increased and this favours the assumption that enlargement resulted from the multiplication of cells of the revascularised adipose tissue. The fate of the grafts implanted in children may be similar. Some theoretical aspects of the findings may be important, but they are not discussed here.

Further follow-up examination of patients will be needed to establish how the cavities may change after the

end of the growth period. Gradual reduction of the defect made in the growth plate in rabbits has been reported (Österman 1972; Langenskiöld and Österman 1979); signs of this phenomenon are seen in Figure 10 after resection of a bone bridge in a child. Regeneration of the growth plate has been faster in the rabbit than in the pig.

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