THE EFFECT OF EPIPHYSIAL STAPLING ON GROWTH IN LENGTH OF THE RABBIT'S TIBIA AND FEMUR

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In a previous communication (Hall-Craggs 1968) the results of experimental epiphyseodesis of the upper and lower ends of the rabbit tibia were reported. It was found that when growth in length at either the proximal or distal extremity of the bone was restricted by epiphyseodesis a reduction in the normal deceleration of growth rate occurred at the opposite end. As a result the undamaged epiphysis contributed a greater amount to the final length of the bone than the corresponding epiphysis of the other limb of the animal.

These findings, together with the fact that no change in foot length was observed in the experimental limb, suggested that the phenomenon was limited to the experimental bone, and that it provided evidence of a local growth-controlling system. Although the additional contribution made by the uninjured epiphysis was never sufficient to compensate for the loss which followed epiphyseodesis, there was reasonable evidence to suggest that the degree of failure of the injured epiphysis to grow was directly related to the additional contribution at the other end of the bone. As each experimental bone was submitted to the same degree of trauma whatever the success of the epiphyseodesis, it was also argued that the trauma *per se* was not responsible for the increase in growth. However, one sequel to the epiphyseodesis was the formation of a bony bridge between the epiphysal and metaphysal bone, which established a new vascular communication between these regions and thus introduced an additional variable that was not present on the control side.

Further experiments have therefore been performed to test the local nature of the response to arrested epiphysal growth which at the same time eliminated the vascular communication established between epiphysis and diaphysis after epiphyseodesis.

MATERIAL AND METHODS

The experimental animals were rabbits of mixed breed of between three and four weeks of age. Under general anaesthesia, induced with Nembutal and continued with open ether, the experimental tibia was exposed. Through a single incision the upper fibular epiphysal cartilage was resected and a stainless steel staple inserted into both medial and lateral aspects of the upper end of the tibia so that one limb of the staple lay above and one below the epiphysal cartilage. A small stainless steel pin was placed in the shaft of both the experimental and the control tibia. Both pins and staples were fashioned from 21 S.W.G. stainless steel wire. The animals were radiographed immediately after operation and subsequently at intervals until no further growth could be measured. A tube-plate distance of 100 centimetres was used and the animal was positioned, with thigh and foot at right angles, on a platform bearing adjustable spring-loaded arms. The film used was Kodak "Kodirex."

The length of the tibia was measured parallel to the shaft from the tibial plateau to the most proximal point of the concave articular surface at the talo-crural joint. To determine the growth in length at each epiphysis the distance between these points and the level of the tip of the marker was also recorded.

In a second group of animals a procedure similar to that described above was carried out, but in addition a pin was placed in the shaft of each femur. The distance between the tip of this pin and the distal articular surface of the femur was recorded on each occasion that the animal was radiographed.

The growth of a further group of animals was followed in which, after the insertion of staples into the upper end of the tibia, these were either intentionally removed at a second operation or cut out after the expected changes in the growth rate at the distal experimental epiphysis had become established.

The premature death of one animal allowed histological examination to be made of the site of implantation of the staple. This material was decalcified, dehydrated, double embedded and sectioned. The sections, cut at a thickness of 10 μ m, were stained with Mallory's trichrome stain.

RESULTS

Thirteen animals which had undergone the first experimental procedure survived until maturity. Of these, eleven showed a deficiency in growth at the experimental epiphysis of more than 80 per cent; one showed a deficiency of 68 per cent; and in one it was only 14 per cent. Except in one animal in the group of eleven with severe defect in growth, the lower undamaged epiphysis contributed at least 30 per cent more to the total length of the bone than the contralateral epiphysis. In the animal in which the arrest in growth was only partial the additional growth of the lower epiphysis was correspondingly reduced, and in that in which the arrest was minimal the addition was insignificant.

In Table I the initial tibial lengths, the increments of growth measured at each epiphysis at maturity and the difference of these increments expressed as a percentage of those of the control tibia are shown. In Figure 1 a typical growth curve of control and experimental tibia is shown graphically.

Histological examination of an experimental epiphysis showed that there was a normal pattern of trabecular bone around the site of implantation of the staple and no evidence of

TABLE I
INITIAL LENGTHS OF TIBIAE AND THE GAINS IN LENGTH AT THE EPIPHYSES OF RABBITS AFTER UPPER TIBIAL EPIPHYSIAL STAPLING

Rabbit number	Initial length of tibiae (centimetres)		Gain at proximal epiphyses (centimetres)		Gain at distal epiphyses (centimetres)		Difference in gain between experimental and control epiphyses as a percentage of control	
	Experimental	Control	Experimental	Control	Experimental	Control	Proximal	Distal
1	5.65	5.70	0.50	2.65	2.15	1.65	81.1	30.3
2	5.20	5.15	0.20	2.70	2.10	1.75	92.6	20.0
3	5.25	5.25	0.20	2.45	1.85	1.30	91.8	42.3
4	5.25	5.25	0.25	2.45	1.85	1.30	89.9	42.3
5	5.55	5.55	1.00	3.10	2.20	1.90	67.7	15.8
6	5.50	5.50	2.90	3.30	2.20	2.15	13.8	2.3
7	4.50	4.50	0.25	3.00	2.30	1.75	91.7	31.4
8	4.55	4.55	0.25	2.95	2.40	1.75	91.5	37.1
9	4.55	4.55	0.20	3.00	2.30	1.75	93.3	31.4
10	4.85	4.85	0.30	3.10	2.45	1.95	90.3	25.6
11	5.05	5.05	0.35	3.25	2.55	1.90	89.2	34.2
12	4.85	4.85	0.20	3.05	2.25	1.70	93.4	32.4
13	4.85	4.85	0.25	3.05	2.10	1.65	91.8	27.3

abnormal cellular reaction or hyperaemia (Fig. 2). The epiphysial cartilage plate showed shortening of the cartilage cell columns and some irregularity in their alignment; the juxta-epiphysial trabeculae were also more mature (Figs. 3 and 4).

Of the group of animals in which the growth of the distal femoral epiphysis was recorded after proximal tibial epiphysial stapling, seven survived to maturity. The procedure was followed by varying success in both arrest of growth at the proximal epiphysis and stimulation at the distal. In no animal was the femoral epiphysis, adjacent to a stapled proximal tibial epiphysis, found to contribute more to the length of the femur than that on the control side.

FIG. 1

Graph representing the rate of gain of the upper and lower epiphyses of control and experimental tibiae after stapling of the upper epiphysis of the experimental tibia. (Rabbit number 3.)

In one animal the contribution was the same, and in six it was less on the experimental side, the difference being between 0.5 and 3.5 millimetres. The animal showing the greatest difference had developed a considerable degree of genu valgum due to uneven growth of the proximal tibial epiphysis, and the final radiographs for measurement were taken after death and disarticulation of the knee joint. The results of this experiment are set out in Table II.

In the final group growth of the tibiae was followed, after removal of the staples from the proximal epiphysis and after an increase in growth at the distal epiphysis had been observed, or in a number of animals in which the same end was achieved when staples became displaced or cut through the epiphysis. An example of a growth curve following the planned removal of staples is shown in Figure 5. In this animal arrest of growth of the proximal epiphysis was established and some increase in growth demonstrated at the distal epiphysis at twenty-one days. Removal of the staples was followed by a marked increase in the rate of growth of the stapled epiphysis, which was largely maintained. The distal epiphysis on the experimental side showed a slight increase in rate after removal of the staples, but growth was subsequently nearly parallel to that of the control epiphysis. A similar picture was seen in the other animals included in this group, and there was no evidence that after release from the staples the proximal epiphyses were able to maintain a growth rate faster than that on the control side. The results of this experiment appear in Table III.

In Figure 6 the results of all the experiments are combined with those recorded following epiphysiodesis of the upper tibial epiphysis (Hall-Craggs 1968). A direct relationship between the reduction in gain at the experimental epiphysis and the excess gain at the epiphysis at the other end of the bone now appears more firmly established.

FIG. 2

Photomicrograph of the site occupied by a staple on the diaphysal side of an upper tibial epiphysal cartilage plate. (Mallory's trichrome stain, $\times 470$.)

FIG. 3

FIG. 4

Figure 3—Upper tibial epiphysal cartilage plate and adjacent bone following stapling. (Mallory's trichrome stain, $\times 708$.) Figure 4—Upper tibial epiphysal cartilage plate from bone serving as control for that illustrated in Figure 3. (Mallory's trichrome stain, $\times 708$.)

TABLE II
GAINS IN LENGTH AT TIBIAL AND LOWER FEMORAL EPIPHYSES OF RABBITS AFTER UPPER TIBIAL EPIPHYSIAL STAPLING

Rabbit number	Gain at proximal tibial epiphyses (centimetres)		Gain at distal tibial epiphyses (centimetres)		Difference in gain between experimental and control epiphyses as a percentage of control		Gain at distal femoral epiphyses (centimetres)	
	Experimental	Control	Experimental	Control	Proximal	Distal	Experimental	Control
14	1.80	3.85	2.95	2.50	53.2	18.0	3.75	3.75
15	1.05	4.00	3.20	2.55	73.8	25.5	3.85	3.90
16	0.45	3.70	3.20	2.60	87.8	23.1	3.55	3.60
17	2.55	4.00	2.70	2.50	36.3	8.0	3.80	3.85
18	1.35	3.90	3.00	2.65	32.1	13.2	3.50	3.85
19	0.55	3.60	2.90	2.30	84.7	26.1	3.30	3.50
20	2.40	3.85	2.80	2.45	37.7	14.6	3.75	3.80

TABLE III
INITIAL LENGTHS OF TIBIAE AND GAINS IN LENGTH AT THE EPIPHYSES OF RABBITS AFTER UPPER TIBIAL EPIPHYSIAL STAPLING WITH PREMATURE RELEASE

Rabbit number	Initial length of tibiae (centimetres)		Gain at proximal epiphyses (centimetres)		Gain at distal epiphyses (centimetres)		Difference in gain between experimental and control epiphyses as a percentage of control	
	Experimental	Control	Experimental	Control	Experimental	Control	Proximal	Distal
21	3.65	3.65	4.10	4.55	2.95	2.90	9.9	1.7
22	3.85	3.85	4.05	4.60	3.10	2.95	12.0	5.1
23	3.80	3.80	2.45	4.55	3.20	2.90	46.2	10.3
24	3.60	3.60	3.50	4.40	3.10	2.90	20.5	7.0
25	4.15	4.15	2.55	4.00	2.80	2.55	36.3	9.8
26	4.35	4.35	3.45	4.05	2.60	2.55	14.8	2.0

DISCUSSION

In the series of experiments originally described it was found that when destruction of the epiphysal cartilage plate was used as a method to arrest growth at one epiphysis of the tibia, a bridge of bone became established between the epiphysis and diaphysis. It must be assumed that this bridge and its vascular tissue would provide a possible source of communication between the epiphysal and diaphysal regions, or produce an alteration to their blood supply which was not present on the control side. As an alternative to epiphysodesis, stapling of the upper tibial epiphysis has been used to produce arrest of growth. As a result surgical arrest of epiphysal growth has been obtained with minimum operative disturbance of the epiphysal cartilage plate. In a number of animals the method proved extremely effective and a reduction in the normal deceleration of growth was obtained at the distal epiphysis in a manner similar to that following epiphysodesis. It seems, therefore, that a change in the vascular supply of the epiphysal and diaphysal regions plays no part in the production of

this change in growth rate, and that mechanical arrest of growth and the consequent failure of the cartilage cells to multiply and mature are more directly implicated.

It has been argued that this phenomenon may be a general response of the whole limb

FIG. 5

Graph representing the rate of growth of the upper and lower epiphyses of control and experimental tibiae after stapling of the upper epiphysis of the experimental tibia and subsequent removal of the staples. (Rabbit number 23.)

FIG. 6

Graph showing the additional growth at the distal experimental epiphyses expressed as a percentage of the growth of contralateral control epiphyses plotted against the reduction of growth of the injured epiphyses similarly expressed.

to both trauma and shortening. Some evidence that this was not so was provided originally by the fact that no increase in the metatarso-tarsal length of the foot was observed. This evidence has now been amplified by following the growth at an epiphysis immediately adjacent

to the arrested epiphysis, but not forming part of the same bone. This was achieved by placing a marker pin in the shaft of both femora and at the same time carrying out the stapling procedure. The success of the procedure varied, but in each animal a greater contribution to the length of the tibia was made by the lower epiphysis on the experimental side. However, in no animal was any additional growth of the femoral epiphysis adjacent to the stapled epiphysis recorded, even when an increment of 25 per cent of the control was found at that of the lower end of the tibia. In two animals the femoral epiphysis on the experimental side showed an appreciable deficit and no reason for this is apparent. These results indicate that the lower femoral epiphysis is not stimulated by arrest in growth of the upper tibial epiphysis, and that the ability that the arrest of this epiphysis has to stimulate growth is limited to that bone.

The experiments recorded in this paper also add to the idea that the additional growth is related to the success of the procedure used to arrest growth. It seemed, therefore, worth while to look more carefully at the progress of growth in a number of animals in which the staples cut out prematurely or were intentionally removed. In each case arrest of growth had been initially obtained at the proximal epiphysis of the tibia and evidence of an increase in growth recorded at the distal epiphyses. On the cutting out of the staples or their removal, the growth of the proximal epiphysis again approached that on the control side and to a large extent maintained this during the growth period. At the distal epiphysis the expected reduction in the deceleration of growth rate, although established initially, was not continued, and the rate followed that of the control side, showing only a small final increment. There was no evidence that the proximal epiphysis could maintain a rate of growth exceeding that on the control side and thus in any way compensate for its earlier arrest. This could well be due to some permanent damage sustained by the epiphysis, but it may on the other hand mean that when both epiphyses are growing at a normal rate, when compared with the control side, their potential for growth is at its limit or a stimulatory or inhibitory balance has been reached.

SUMMARY

1. Arrest of growth at one proximal tibial epiphysis of young rabbits was obtained by stapling.
2. Radiopaque markers allowed the subsequent growth of both proximal and distal epiphyses of the experimental and contralateral tibiae and of both lower femoral epiphyses to be followed radiographically.
3. The reduction in the normal deceleration of growth rate at the distal epiphysis found after epiphysiodesis of the proximal epiphysis was again observed.
4. This change in growth rate was not encountered in the distal femoral epiphysis lying adjacent to the stapled tibial epiphysis.
5. Removal of the staples after the change in growth rate had become established at the distal tibial epiphysis was followed by a return to an approximately normal growth rate by both proximal and distal epiphyses.
6. It is concluded that a direct relationship exists between the additional growth at the uninjured epiphysis and the deficiency in growth obtained at the stapled epiphysis, and that this change in growth rate is limited to the experimental tibia.

We would like to express our thanks to Professor J. Z. Young for his helpful criticism of this paper. We should also like to thank Professor Sir Herbert Seddon for his encouragement.

REFERENCES

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