Distraction effects on the physis in rabbits

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Gradual physeal distraction by external fixation was performed on the distal femur in 19 growing rabbits. The rate of distraction was 0.5 –1 mm once daily. Distraction was continued for 1–21 days until killing. Lengthening of the femur and latitudinal growth of the distraction area were measured in radiographs. Morphologic changes in the physes were studied in histologic preparations.

The length gained by distraction was maximally 5 mm. Latitudinal overgrowth was noted in specimens distracted for more than 13 days. Hyperplasia of the hypertrophic chondrocyte zone was seen after 1 day of distraction. Separation of the epiphysis from the metaphysis, mostly through the hypertrophic zone, occurred in 11 specimens. Both hyperplasia and separation were often seen in the same physis. In the separation gap, early signs of bone formation into a collagen frame were seen from the 7th day on. An accessory physis, located in the metaphysis and apparently growing interstitially, was noted in 1 specimen.

Gradual distraction of the growth plate of a long bone by external fixation results usually in a fracture of the physis with separation of the epiphysis from the metaphysis (Ring 1958, Monticelli and Spinelli 1981, Peltonen et al. 1984, Connolly et al. 1986, Ilizarov 1989). In the rabbit, hyperplasia of the hypertrophic zone, without separation, has been noted after slow-rate distraction (De Bastiani et al. 1986) or low force (Sledge and Noble 1978, Spriggins et al. 1989).

Fracture of the physis usually occurs through the hypertrophic zone (Connolly et al. 1986, de Pablos et al. 1986, Peltonen et al. 1984, Peltonen 1989), but extension of the fracture to the proliferative zone (Connolly et al. 1986) and to the metaphysis (Peltonen et al. 1988) has been described.

Little is known, however, of the reaction of the physis to distraction during the first few day. We studied the effects of gradual distraction on the physis during the initial 3 weeks.

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Material and methods

A total of 25 growing rabbits, 6–10 weeks old, were operated on. Six animals were excluded because of technical failure or fracture of the femur. The contralateral limb served as a control in all but 3 rabbits, in which both femurs were operated on; thus, 22 femurs were distracted.

The rabbits were anesthetized with Hypnorm® (Phillips, Duphar) 0.5 mL/kg i.m. Incisions were made on the lateral side of the femur, and two threaded, 2-mm fixation pins were inserted parallelly horizontally in the epiphysis and two pins were inserted vertically in the diaphysis. A unilateral external fixation device (Mini Hoffman®, Jaquet Orthopédie S.A., Switzerland) was applied (Figure 1). Gradual distraction at a rate of 1 mm once daily was started and continued for the first 3 days, after which the distraction rate was 1 mm in animals with a distraction time under 13 days and 0.5 mm in the remaining animals. Distraction was continued for 1–21 days after which the animals were killed with an overdose of intravenous pentobarbital.

After dissection of the soft tissues with the fixator in place, both femurs were radiographed. The length of the femurs and the latitudinal diameter of the physes were measured from radiographs. The distal parts were sawed in the coronal plane. The speci-

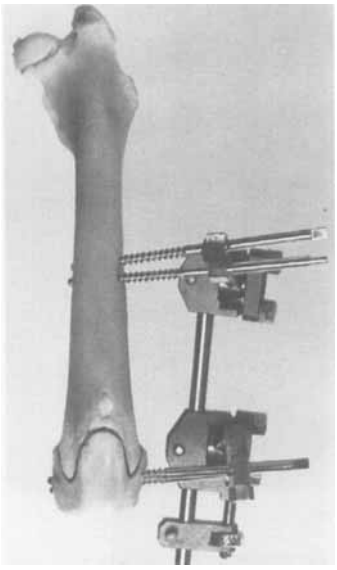

Figure 1. The external fixator applied to the rabbit femur.

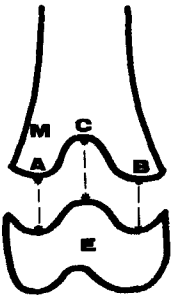

Figure 2. Using a measurement scale in the microscope ocular, the height of the physis at points A, B, and C was measured. Measurements were made from three sections of each specimen. The height of the separation gap was reduced from the measurement to achieve the true height of the physis. E epiphysis, M metaphysis.

mens were fixed in formalin and embedded in paraffin after mineralization. Sections of 6–8 μ were stained using hematoxylin and eosin, van Gieson, and Alcian-blue staining methods.

The height of the physis was measured from histologic sections with a scale in the microscope ocular. The physis was considered hyperplastic when at least a 100 percent increase in thickness was noted when compared with the controls (Figure 2).

Results

Separation of the epiphysis from the metaphysis was seen radiographically in 11 femurs first after 2 days of distraction. The separation was asymmetric in 6 specimens (Figure 3). In 4 of the 6 rabbits distracted for more than 9 days, bowing of the femur without separation was seen.

The lengthening gained by distraction was maximally 5 mm. Latitudinal overgrowth of the distraction area, ranging from 0.5 to 3 mm (5–27 percent) was noted in all the specimens after 13 days of distraction and correlated positively with the distraction time.

Hyperplasia of the physis could be seen histologically after 1 day of distraction (Table 1). It was most

Table 4. The different stabilometric parameters given as mean and range

Rabbit [a]	A	B	C	D	E
1R	1	+	–	R	
1L	1	+	–	R	
2R	2	+	H, M	I	
2L	2	+	H	R	
3R	3	+	H	R	
3L	3	+	P	R	
4	4	–	–	N	
5	4	+	–	R	
6	4	+	H, M	I	
7	5	–	H	R	
8	5	+	H	I	F
9	6	–	–	R	
10	7	–	H, P	R, A	F, C
11	8	+	H	I	F, C, E
12	8	+	H	I	F, C, E
13	9	–	–		
14	13	–	–	B, N	
15	14	+	–	B	
16	15	–	H	N	
17	21	–	–	N	
18	21	–	–	A	
19	21	–	–	N	

[a] R right, L left femur,
A Distraction time (days)
B Physeal hyperplasia
C Physeal separation
H separation in hypertrophic zone,
M separation in metaphysis,
P separation in proliferative zone,
D Appearance of physis
R palisades regular
I palisades irregular
N physis narrow, possibly imminent closure
A part of physis dislocated to metaphysis: accessory physis
B bone bridge
E Collagen and early bone formation
F fibroblasts
C collagen
E early bone formation.

A

B

Figure 3 A. Separation of the physis through the base of the hypertrophic zone (arrow). Marked hyperplasia of the hypertrophic cell layer and disturbance of the palisade organization. Specimen distracted for 5 days. Alcian blue, x20.

B. Control physis. Alcian blue, x20.

A

B

Figure 4. Collagen and early bone formation.

A. Collagen bundles and fibroblasts (arrows) are seen in the distraction gap after 7 days of distraction. Van Gieson, x240.

B. New bone (arrows) is formed into the collagen template. Specimen distracted for 8 days. Van Gieson, x140.

A

B

Figure 5. The accessory physis in the specimen distracted for 21 days.

A. The accessory physis (A) has separated from the main physis (P) and is left behind in the metaphysis (M). The accessory physis is larger than the defect in the main physis. Alcian blue, x6.

B. The defect in the primary physis. Columns of palisading chondrocytes seem to encroach on the defect. Alcian blue, x16.

pronounced in the hypertrophic zone. The height of the physis was greatest after 4–5 days' distraction, and maximally was four times that of the control. The palisade organization in the hypertrophic zone was often disturbed (Figure 3).

Physeal separation occurred in 11 specimens distracted for 2–12 days. In 8, the separated physis displayed hyperplasia. The separation involved usually only part of the width of the physis, occurring mostly in the hypertrophic zone, but in 2 specimens it ex-

tended to the primary spongiosa and to the proliferative zone (Figure 3).

The distraction gap first filled with hematopoietic cells, disorganized fibers, and fibroblasts. From the 7th day on, collagen fibers were organized in the direction of the distraction and early bone formation was evident (Figure 4).

In all the physes distracted for 13 days or more, local disturbances and narrowing was noted. A local bridge across the physis developed in 2 cases.

Small intrusions of hypertrophic chondrocytes were seen in the metaphysis in 1 specimen. In another after 21 days of distraction, a larger part of the physis, which apparently was continuously growing, was left behind in the metaphysis (Figure 5).

The perichondrium and periosteum remained intact in all the specimens, and even in cases with separation. Four specimens displayed no physeal changes, e.g. hyperplasia, separation, or disturbances.

Complications

Pin-tract infection was seen in 7 and knee-joint infection in 2 specimens. The animals were treated by giving therapeutic doses of i.m. Streptocillin® (streptomycin and procaine penicillin G).

Discussion

The length gained by distraction did not correspond to the distraction rate, and the distractional effect was often asymmetric, apparently related to the frame configuration and elasticity.

The primary response of the physis to distraction was hyperplasia of the hypertrophic chondrocyte zone in accordance with observations by Connolly et al. (1986). If the rate of distraction is increased, the physis fractures (De Bastiani et al. 1986). The force applied across the physis also plays a role: after low force, hyperplasia, and after higher force, fracture and separation have been seen (Sledge and Noble 1978, Spriggins et al. 1989). It has also been suggested that fracture of the distracted physis may be secondary to increased growth, which makes the zones of degenerating cartilage and primary ossification more fragile (Sledge and Noble 1978). Experiments in sheep showed that the age of the animal affected both the mode of separation and the force needed (Peltonen et al. 1988). The relatively wide range of age of our animals may explain the extent of changes seen in the physes even during the first 9 days.

In the distraction gap, collagen fibers seemed to be preceded by fibroblasts. Bone formation probably started as soon as sufficient collagen fiber organization was established. The formation of new bone seems to occur similarly in the separation gap and in metaphyseal lengthening (Aronson et al. 1989).

The undulating contour of the distal femoral physis makes it vulnerable to shearing and compressive forces during asymmetric distraction, probably explaining the physeal disturbances seen after 13 days.

According to Langenskiöld et al. (1989), the growth plate has the capability of interstitial latitudinal growth. In their studies, a defect of the central part of the physis regenerated, apparently by interstitial growth. Also, Meikle (1975) and Herrt (1972) support the idea of interstitial latitudinal physeal growth. In our study the accessory physis evidently originated from the distracted main physis, in which the defect seemed to have diminished by growth of physeal cells.

After physeal distraction, an increase in the diameter of the distracted area has been reported by several authors (de Pablos et al. 1986, Fjeld and Steen 1988, Peltonen et al. 1988). The reason for this is not clear; a suggestion of increased vascularity in the perichondrial area has been made (Peltonen et al. 1988). Disorganization of the palisades during distraction may enhance interstitial growth of the chondrocytes and result in latitudinal expansion of the physis. The possible role of the fixation pins remains open, because there were no sham-operated on controls.

The clinical use of physeal distraction is still restricted for fear of later growth disturbances. A fracture of the physis, if confined to the hypertrophic chondrocyte zone, in most cases does not affect growth capacity (Dale and Harris 1958, Ogden 1982). It is possible, however, that distraction disturbs the vascular supply of the epiphyseal area. Vascular impairment in the metaphysis is known to cause hyperplasia of the physis (Yabsley and Harris 1965, Siffert 1966, Trueta and Amato 1960), thus resembling the primary distractional response.

Acknowledgements

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