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Tibial deformities and failures of anterior cruciate ligament reconstruction in immature rabbits

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Abstract: We evaluated the effects of anterior cruciate ligament (ACL) reconstruction on growth and development of the knee in immature New Zealand white rabbits (8 weeks old). In 25 rabbits, the ACL was reconstructed with an autogenous iliotibial band (ITB), and in 31 rabbits an autogenous patellar tendon bone (PTB) graft was used. Reconstructed ACLs failed in 20 of the 25 animals in the ITB group and in 26 of 31 in the PTB group. Gross and histological examinations in the animals with successfully reconstructed ACLs (5 in the ITB group and 5 in the PTB group) showed significant tibial deformity and tibial shortening, with progressive thinning of the epiphyseal plate and disorders of the cartilage column on the medial side of the tibia. These abnormalities were not observed in rabbits whose ACLs were torn. This experiment showed that successful ACL reconstruction in young animals with an open physis may result in deformities and/or shortening of the leg. Accordingly, we believe that special care should be taken when surgically reconstructing an ACL in a young patient whose physes are still open.

Key words: epiphyseal plate, tenoepiphysiodesis, ACL reconstruction, deformity, growth disturbance

Introduction

Anterior cruciate ligament (ACL) injuries in adolescents are not as rare as has previously been reported.[2,3,23] Conservative treatment (such as bracing) and primary repair, have been used in patients with ACL-deficient knees and open physes, but have produced unsatisfactory results.[17,23]

However, ACL reconstruction in skeletally mature patients is a standard procedure with excellent long-term results. ACL reconstruction in young patients with open physes is now controversial.[1,6,7,13,17,20] The reconstruction involves drilling through the epiphyseal plate, which can result in postoperative angular deformities and limb-length discrepancies.[18]

There have been many studies on epiphyseal damage caused by drilling and gouges. Key and Ford[12] reported epiphyseal damage caused by nailing in experimental animals, but they observed no growth disturbances. Nordentoft[16] showed that relatively small drill holes (3-mm diameter) did not cause growth disturbance. Stadelmaier et al.[21] showed that transepiphyseal holes filled with material such as the iliotibial band did not affect bone growth in dogs. Although all these authors reported that intraarticular reconstruction of the ACL in knees with an open physis was safe, ACL-deficient knees with open physes have usually been treated by modified methods without transepiphyseal drilling. In general, there is a reluctance to drill through the growth plates. However, to our knowledge, there have been no reports on the long-term results of these procedures. The purpose of the present experimental study was to evaluate the influence of intraarticular ACL reconstruction with transepiphyseal drilling on open physes in rabbits, and to discuss the safety of this procedure if used clinically.

Materials and methods

Fifty-six New Zealand white rabbits (NZW), approximately 8 weeks of age and weighing 1.2–1.4 kg, were used. At the time of surgery all rabbits had open epiphyseal plates, confirmed by radiographic examination. Surgery was performed with the animals anesthetized with intravenous pentobarbital. The original ACL was resected and a 3-mm drill hole was made

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at the femoral insertion of the ACL. A tibial drill hole was made from the center of the origin of the ACL to 5mm medial to the tibial tuberosity in each knee. The ACL was reconstructed with an autogenous graft. Isometricity was checked with a silk suture that was passed through the tibial tunnel to the femoral attachment. A difference of 2mm or less between flexion and extension with range of motion of the knee was considered acceptable. All operations were performed on the right front knees, with the left knees serving as the control. Serial radiographs were taken to evaluate postoperative changes. The animals were divided into two groups.

Iliotibial band (ITB) group (n = 25)

The ACL was reconstructed with an autogenous iliotibial band (ITB), 7.5cm long and 3.0mm wide, obtained from the ipsilateral side. The graft was placed across the tibial epiphyseal plate and in an over-the-top position on the femur. It was then passed across the tibial epiphyseal plate and sutured to the periosteum of the tibia with nonabsorbable 1-0 silk sutures.

Patellar tendon bone (PTB) group (n = 31)

An autogenous patellar tendon bone (PTB) graft, 2.5cm long and 3.0mm wide, with bone plugs at both ends, was obtained from the contralateral extremity, and used to reconstruct the ACL. The graft was placed on the femur through the over-the-top route and fixed to the tibia by a bone-anchoring method using 1-0 silk sutures and a small plastic button.

The animals were killed with an overdose of sodium pentobarbital (120mg/kg) at 1, 2, 4, 8, 16, and 24 weeks after the operation. The right and left tibias were removed, and the lengths measured and radiographs taken. The bones were then fixed in 10% buffered formaldehyde, sliced, stained with hematoxylin-eosin, and examined under a light microscope. We did not examine the femoral epiphyseal plates, because they were not affected by drilling during surgery.

Results

In the ITB group, the reconstructed ACL failed in 20 of the 25 rabbits, and in the PTB Group, the ACL failed in 26 of the 31 rabbits (Table 1). In the ITB group, no tearing of the reconstructed ACLs was seen within 4 weeks after the procedure. Eight weeks after surgery, the ACL had failed in 2 of 4 rabbits examined. One of four ACLs failed after 16 weeks, and two of three specimens were found to be torn after 24 weeks.

Table 1. Number of animals killed and ratios of failed reconstructions

Group	1	2	4	8	16	24	Total
ITB	4/4	5/5	5/5	2/4	3/4	1/3	20/25
PTB	4/4	4/5	6/6	4/6	5/6	3/4	26/31

Ratios represent the number of animals in which reconstructed anterior cruciate ligaments (ACLs) failed to the number of animals examined at each time period.
ITB, Iliotibial band; PTB, patellar tendon bone.

Table 2. Shortening and varus deformity of the tibia in rabbits with successfully reconstructed ACLs and in those with torn ACLs

Group (*n*)	Shortening (%)[a]		Varus deformity[b]	
ITB, intact ACL (5)	5.02 ± 1.88	※	9.0° ± 2.0°	※
ITB, torn ACL (20)	0.20 ± 0.10		2.0° ± 5.0°	
PTB, intact ACL (5)	3.00 ± 3.23	※	12.0° ± 5.0°	※
PTB, torn ACL (26)	0.40 ± 0.21		2.0° ± 2.5°	

※ $P < 0.05$.
[a] Shortening: {1-(Right tibial length of specimen/left tibial length of specimen)} ×100. Values are means and SDs.
[b] Varus score: Right tibial varus angle − left tibial varus angle. Values are means and SDs. A two-sample *t*-test was used for comparisons.

In the PTB group, no tears were found 1 and 6 weeks after surgery. Two weeks after surgery, one of five specimens had failed. Two of six, one of six, and one of four specimens were found to be torn at 8, 16, and 24 weeks, respectively, after operation.

Five animals in each group had successful ACL reconstructions, but all ten of these animals showed significant shortening and deformity of the tibia. Those animals in which the reconstructed ACL failed showed no limb-length discrepancy or angular deformity (Table 2). Tibial length discrepancy between the operated side and the control side is shown in Table 3. In the ITB group, the discrepancy in length ranged from 2.6 to 7.0mm (average, 4.6mm). In the PTB group, it ranged from 0.7 to 9.1mm (average, 3.0mm). Varus deformity ranged from 5 to 10 degrees in the ITB group, and from 5 to 20 degrees in the PTB group (Table 4, Fig. 1). Differences between the right and left side were significant (Table 2). All rabbits in which the ACL reconstruction was successful had stable knees. No bony bridge was found in animals with successful reconstructions in either group. In one animal in the PTB group, the bone plug of the graft was adjacent to the growth plate, but it had had no influence on bone growth.

Table 3. Tibial length discrepancy in animals with successful ACL reconstruction

		Length of operated side (mm)	Length of non-operated side (mm)
ITB Group			
Animal	1	102.1	107.1
	2	101.6	104.0
	3	94.0	101.0
	4	101.6	107.5
	5	101.5	105.0
PTB group			
Animal	6	98.9	100.5
	7	105.9	108.0
	8	92.2	93.5
	9	107.5	108.8
	10	95.0	104.1

Table 4. Varus deformity of the tibia in animals with successful ACL reconstruction

		Varus angle (°) of operated side	Varus angle (°) of non-operated side
ITB Group			
Animal	1	0.0	−10.0
	2	20.0	10.0
	3	5.0	−5.0
	4	0.0	−5.0
	5	20.0	10.0
PTB Group			
Animal	6	0.0	−15.0
	7	−10.0	−15.0
	8	0.0	−10.0
	9	0.0	−10.0
	10	20.0	0.0

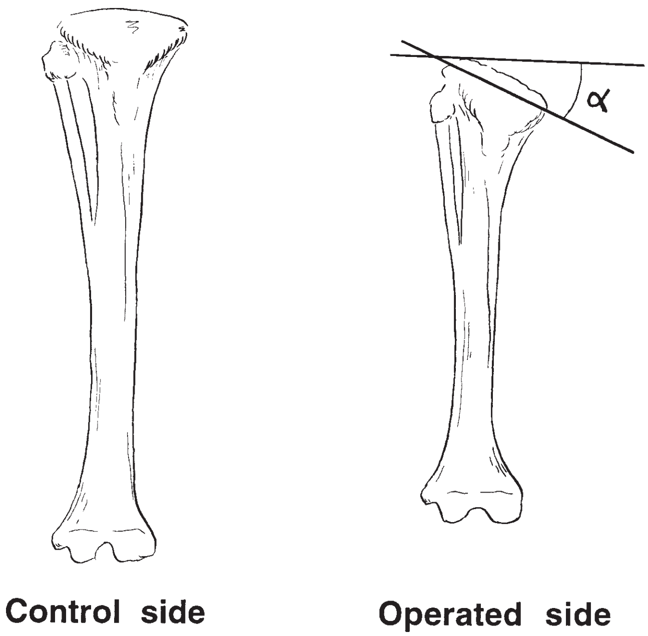

Fig. 1. On the operated tibia, the joint surface was tilted medially. We determined the varus angulation (α)

Two of the animals in the ITB group and two in the PTB group with tibial deformities showed progressive thinning of the epiphyseal plate. In addition, in these animals, the cartilage columns lacked parallelism in the medial zone of the tibias, but not in the lateral zone (Figs. 2–5). In the PTB group, the bone plug was present in the tibial tunnel, but the appearance of the epiphyseal plate was similar to that in the ITB group. The deformities were more prominent in animals killed 16 and 24 weeks after surgery.

Discussion

A previous study, carried out by Minamide et al.[15] has reported the pathology of reconstructed ACLs in skeletally mature NZW rabbits. They reconstructed the ACL with an autogenous ITB graft placed in an over-the-top position, and none of the reconstructed ACLs failed during the study period. However, in the present study, 46 of the 56 reconstructed ACLs were found to have torn with growth during the experimental period. Therefore, we believe that continued growth may explain our higher failure rate, as it may have caused the reconstructed ligaments to tear.

Karbowski et al.[10] reported on epiphysiodesis in pigs in which metal staples were used. In their study, the growth plates were subjected to longitudinal pressure, and 2 months after the operation, atrophy of the cartilage and lack of parallelism of the cartilage columns were noted in the growth plates. Such pathological findings were similar to those we observed in our rabbits

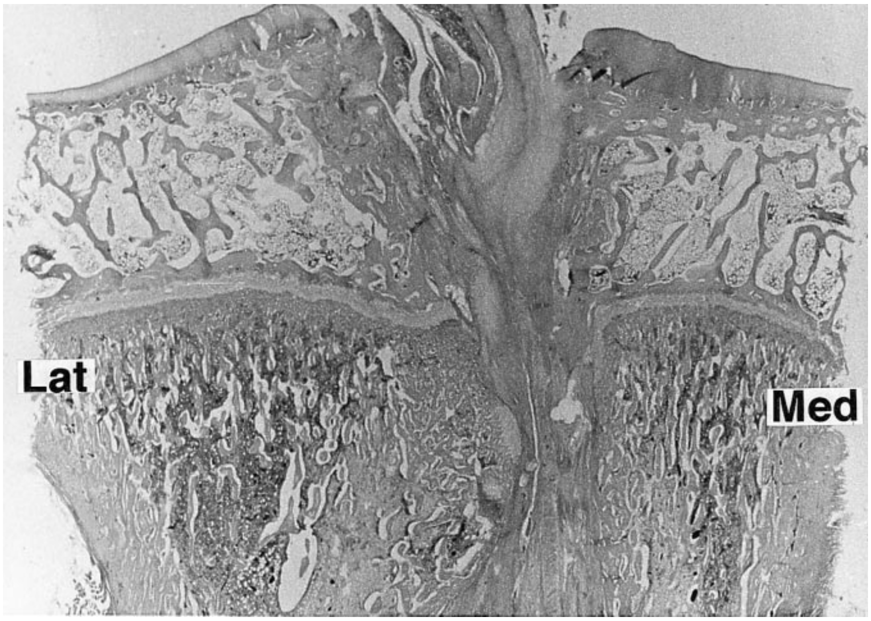

Fig. 2. Photomicrograph of proximal tibia from a rabbit in the iliotibial band (ITB) group with a successfully reconstructed anterior cruciate ligament (ACL), 8 weeks after surgery. Note that the growth plate is divided into two parts by the connective tissue from the grafted ITB. The lateral (*lat*) zone of the epiphyseal plate is thicker than the medial (*med*) zone. No bony bridge formation is seen

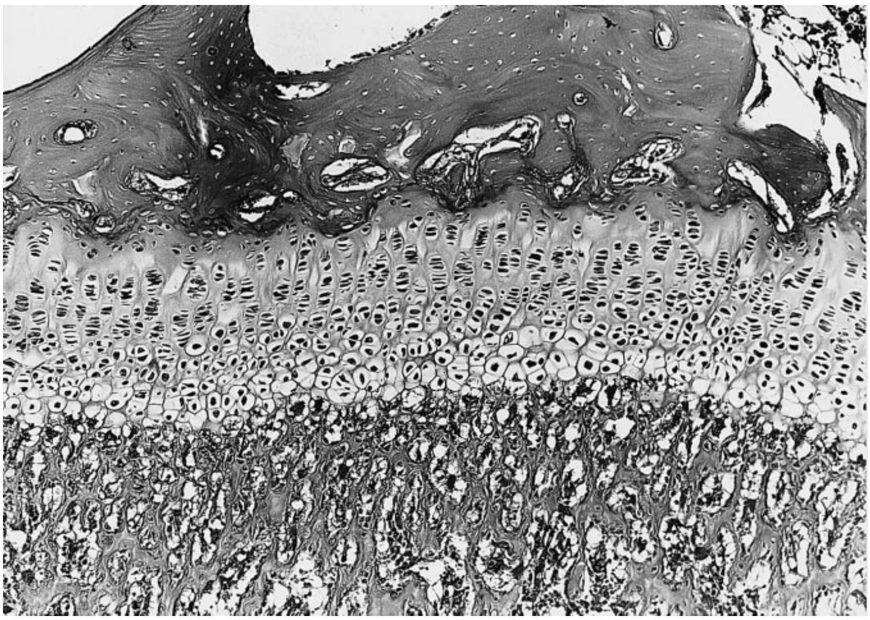

Fig. 3. High-power view of Fig. 1 (lateral). The growth plate appears normal. ×100

with joint deformity. Siffert[19] evaluated experimental epiphysiodesis in young rabbits, in a study in which stainless steel staples were inserted across the physis. He noted the same lack of parallelism of cartilage columns we found in this study, and that transepiphyseal stapling exerted a pressure effect resulting in joint deformity. Hall-Craggs and Lawrence[8] have also described epiphysiodesis in young rabbits in which they used metal staples in the proximal tibial epiphyseal plate, which also caused joint deformity. Therefore, we believe the growth plates of the rabbits in our study were subjected to increased pressure from the ACL reconstruction, resulting in growth deformity.

Generally, it is thought to be harmful to damage the epiphyseal plates.[14,22] Even minor damage may alter a

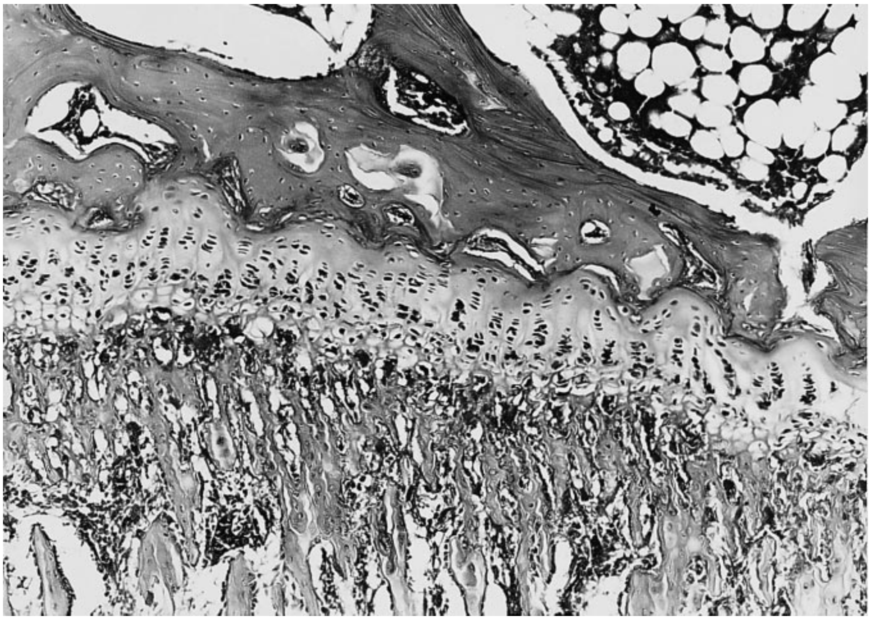

Fig. 4. High-power view of Fig. 1 (medial). The cell column of the epiphyseal plate is compressed. The thinner cartilage columns show lack of parallelism, and condensation of the subepiphyseal bone can be seen. ×100

Fig. 5. Photomicrograph of proximal tibia from a rabbit in the patellar tendon bone group with a successfully reconstructed ACL, 8 weeks after surgery. The proximal tibial growth plate is divided into two parts by the grafted ligament. The lateral (*lat*) zone of the epiphyseal plate is thicker than the medial (*med*) zone

growing joint. This is the reason for the reluctance to reconstruct the ACL in knees with an open physis. However, in Nordentoft's study, the bones of immature rabbits grew normally after a 3-mm drill hole was employed, and no growth disturbances were noted after epiphysiolysis. Johnson[9] reported experimental transepiphyseal damage in young rabbits, observing that damaged to an epiphyseal plate caused by drilling did not lead to joint abnormalities and that drilling did not impair its continuing normal growth. Key and Ford[12] obtained similar results. Campbell et al.[4] reported the effects of transepiphyseal damage in young dogs, showing that transepiphyseal damage from drill holes did not cause bone growth retardation. These studies demonstrate that drilling of the epiphyseal plate per se is not harmful, and that only a transepiphyseal connection between the epiphysis and metaphysis hampers normal bone growth. This is in agreement with our findings in the PTB group in rabbits with successfully reconstructed ACLs. We did not find any bony bridges. Bony bridges may produce growth disturbances, but the joint deformity observed in animals in the ITB and PTB groups with successfully reconstructed ACLs was not caused by the formation of bony bridges. Animals with successfully reconstructed ACLs in both the ITB and PTB groups showed the same pathologic findings in the medial and lateral epiphyses. Therefore, we conclude that deformity and growth disturbances were due to a pressure effect, that is, tenoepiphysiodesis, caused by the successfully reconstructed ACLs connecting the distal femoral metaphysis and the proximal tibial metaphysis.

Most of the reconstructed ACLs in our study failed during the growth period, and all rabbits with successfully reconstructed ACLs showed shortening and deformity of the tibias. Accordingly, suggest that particular care must be taken when ACL reconstruction is performed in young patients with open physes.

Conclusion

We reconstructed ACLs in immature rabbits using autogenous materials. In 10 of 56 rabbits reconstruction was successful, but all 10 showed postoperative tibial shortening and tibial deformity.

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