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MRI Study of the ACL in Children and Adolescents

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A B S T R A C T

Reconstruction of the ACL (anterior cruciate ligament) requires precise anatomical placement of the tendon graft. Anatomic variations may increase/decrease risk of the ACL rupture. Twenty-eight children with clinical, MRI and arthroscopic verified ACL ruptures were compared with match case control group. MRI was done one to 12 months after trauma. The thresholds values for identifying the ACL rupture were set; ACL angle <45°, Blumensat angle >0°, and the PCL angle <115°. RESULTS: There was no significant difference of tibial attachment for the ACL and measured parameters of the femur. The ACL angle (p<0.001), the Blumensat angle (p=0.001), and the PCL angle (p<0.001) were significantly different. Each of the patients in group with a torn ACL had at least one parameter positive. DISCUSSION: ACL angle, Blumensat angle and PCL angle might help to diagnose ruptured ACL. Pediatric patients with the ruptured ACL show no difference in notch width or the tibial roof inclination angle as compared with pediatric patients without ACL rupture.

Key words: *anterior cruciate ligament rupture, magnetic resonance imaging, children, pediatric, Blumensat angle, PCL angle, ACL angle*

Introduction

Several studies have shown that non-operative treatment of ruptured anterior cruciate ligament (ACL) in skeletally immature patients results with a poor outcome[1,2]. In recent years growing proportion of younger patients with ACL rupture has undergone surgery while the results in conservatively treated children and adolescents are not satisfactory. Remaining instability of the knee with pain, recurrent injuries, meniscus tears and osteochondral defects is the major concern. This is in particular for the young athletes who want to return to the previous level of the sport activities. On the other side it is unclear whether surgical ACL reconstruction in children would harm the physis. Transphyseal drilling for the placement of a tendon graft could result in postoperative discrepancies of the extremity lengths or in axis deviations in some of the patients[3]. Other studies prove the operative technique in children to be safe[4,5].

Reconstruction of the ACL requires precise anatomical placement of the tendon graft. Therefore many surgeons study the anatomy of the ACL insertions in adults, tibial insertion and position of the femoral canal. Availability of the young patients with ruptured ACL is limited; therefore the studies with large number of pediatric patients are rare. There are few anatomical studies of ruptured ACL in children as well as the few studies that show dynamic change of anatomical landmarks over the years in a growing individual. In order to understand better the anatomy of the children's knee we compared the MRI findings in the injured children with a ruptured ACL and MRI images of the non-injured children. We investigated if there are anatomical predispositions for the ACL injury and we reevaluated the threshold criteria of the ACL angle, the Blumensat angle, and the PCL angle for the diagnosis of the ACL rupture in children.

Materials and Methods

A database of the 470 children who had undergone arthroscopic surgery was examined. Group of 56 children (age 7–18, mean 16.4) was reviewed. Group of 28 children

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with clinical, MRI and arthroscopic verified ACL ruptures was compared with match case control group (regarding age, sex and side of the injury) of 28 patients without lesion of the ACL. Two patients with fractures of the tibia eminencies were excluded from the study (found within the control group). MRI was done one to 12 months after trauma. Patients were in a supine position with the knees extended and externally rotated 15°.

All the measurements were done on MRI hard copies. Images with the ACL and PCL best visibility as well as the images where the slice in frontal plain with the notch highest and widest was selected. A surgeon who was blinded for the clinical findings and the diagnosis did measurements randomly. Patients were once more randomized and another surgeon also blinded for the diagnosis repeated measurements. Metric measurements (done with a micrometer) were converted into ratios and percentage.

Regarding tibia, we measured anterior-posterior dimension (sagittal diameter) of the tibia, distance from the anterior edge of the tibia to the anterior fibers of the ACL, and anterior-posterior dimension of the tibial insertion of the ACL. Posterior limit of the ACL and ACL center point were calculated. We also measured the intercondylar fossa roof inclination angle[22]. Regarding the ACL, we measured the ACL angle; – angle between the straight line drawn at the anterior margin of the ACL and the medial tibial plateau[6]; – and the Blumensat angle; – angle between the Blumensat line (line parallel to the roof of the intercondylar notch) and the line along the anterior margin of the ACL[7], (Figure 1).

We evaluated the PCL angle as well; defined as the point of the intersection between lines drawn trough proximal and distal proportions of the posterior cruciate angle[7].

Regarding femur, we measured its width and width of the notch (Figure 2).

Statistical analysis was done using Microsoft Excel and SPSS. The results are shown as median (min-max) or $\overline{X}$±SD. Groups were compared using Student's t-test. P value of less than 0.05 was considered statistically significant.

Fig. 1. Blumensat angle.

Fig. 2. Intercondylar width.

Results

There were no significant differences of the tibial attachment of the ACL between two compared groups of patients as shown in Table 1.

There were statistically significant differences of the ACL angle, the Blumensat angle, and the PCL angle between two compared groups of patients as shown in Table 2.

Mellado et al. set the threshold values for identifying the ACL rupture as ACL angle <45°, the Blumensat angle >0°, and the PCL angle <115°[9]. In our study patients with the ACL rupture had always at least one parameter positive; in 21 patient (2 measurements for each patient were performed) all three parameters were positive for the ACL rupture, in 6 patients two parameters, and in one case only one parameter was positive (ACL angle). In

TABLE 1
TIBIAL ATTACHMENT OF THE ANTERIOR CRUCIATE LIGAMENT

	Patients with torn ACL	Patients with intact ACL	p
ACL anterior limit (%)	27.2 (19.2–46.2) 28±7.4	27.9 (12.5–34.8) 26.7±5.6	0.56
ACL center (%)	41.1 (31.7–61.5) 42.1±8.4	40.7 (25–47.8) 39.7±6.1	0.341
ACL posterior limit (%)	54.4 (41–76.9) 55.4±10.5	55.4 (37.5–62) 53.4±8.2	0.512
ACL insertion (%)	27.2 (17.9–44) 27.5±6.5	27 (13.3–39.3) 26.7±7	0.725

TABLE 2
THE ORIENTATION OF THE ACL

	Patients with torn ACL	Patients with intact ACL	p
ACL angle°	31 (22–44)	50 (30–62)	<0.001
	31.5±10.8	47.5±15.8	
Blumensat angle°	6 (–1–73)	–2 (–9–0)	0.001
	11.6±16.1	–2.5±2.9	
PCL angle°	107 (90–127)	134 (112–140)	<0.001
	106.8±25.5	134.2±33	
Roof inclination angle°	34 (12–42)	32 (20–53)	0.706
	32.5±10.1	33.5±11.2	

TABLE 3
PARAMETERS OF THE FEMUR

	Patients with torn ACL	Patients with intact ACL	p
Notch Width Index	22.6 (18.3–31.4)	21.4 (13.3–32.6)	0.191
	23.4±3	21.6±4.8	
Lateral Condylus	41.1 (39.7–43.9)	42 (34.9–47.6)	0.088
(% of the femur width)	38.5±11.7	42.2±9.7	
Medial Condylus	36.4 (30.4–47.4)	35.4 (28.6–44.4)	0.823
(% of the femur width)	36.4±8.5	36.1±4.6	
Centre of the Notch	52.6 (40.2–54.9)	53.3 (48.9–62.9)	0.127
(% of the femur width)	0.51±0.32	53.5±3.6	

control group, 17 patients with intact ACL had all three parameters positive, 5 patients were with two parameters positive, 2 patients had one parameter positive (in both cases PCL angle was more then 115°), and in two cases we had negative parameters for intact ACL.

There were no significant differences in measured parameters of the femur comparing the two groups of patients as shown in Table 3.

Discussion

Precise graft placement is one of the crucial steps in order to perform successful ACL reconstruction[10]. Surgeon should respect course and orientation of the ACL and its relation to the roof of the intercondylar fossa in order to avoid the loss of knee extension. Improper positioning of the ACL could result in its structural changes of the transplant as well[11,12].

Some authors suggest techniques without drilling the femoral tunnel or centrally placed femoral canal[13]. However, these reconstruction techniques result in asymmetric graft. Earlier study performed at our department showed importance of the knee positioning when securing anatomically non-ideally placed graft. Securing the non-ideally positioned graft taut in extension (with the knee in flexion) resulted in over constrained knee in extension, while securing the graft with knee in extension resulted with the knee laxity in flexion. In extension of the over constrained knee the ACL substitute holds the femur anterior. In under constrained knee in flexion tibia has tendency to subluxate anterior[14].

In other study of the patients referred to our institution because of persistent knee instability and pain after the ACL reconstruction the most common error was femoral placement of the graft anterior to the anatomical insertion of the ACL. There was a significant correlation of the femoral placement of the graft in the sagittal plane and clinical results. The IKDC score declined with increasing distance of the graft from the most isometric bundle of the ACL in the anteroposterior direction[15].

Relative anterior placement of the graft to the anatomical insertion of the ACL into the femur results in over constrained knee in flexion. Placement posterior or distal to the anatomical attachment results in excessive tightening of the graft when the knee is extended[15].

Although previous studies of the tibial attachment of the ACL in children showed similar proportions as that of in adolescents found by Shea et al.[16], in our study the center point and the posterior point of the ACL are something more anterior as in the study of adults by Staubli et al.[17]. This is in contradiction with a relatively posterior placement of the tibial canal suggested by the other authors in order to avoid the roof impingement. The anterior limit is at the same distance from the anterior border of the tibia as in adults. Difference in anterior and posterior margins of the tibial attachment of the ACL in children in our study as compared to adults would propose center point of the tibial attachment for the orientation. The center point might be closer to the exact anatomic position and would also provide more posterior position to avoid the impingement.

We were not able to find any difference in the examined groups regarding the ACL attachment to the tibia, the roof inclination angle, and size of the condylus or NWI as proposed by Souryal et al.[8]. The roof inclination angle did vary from patient to patient from min 12° in one patient with torn ACL to 53° in one patient without ACL rupture. Individual variations of the roof inclination angle and the ACL tibial attachment position and area may suggest preoperative planning and selective approach for the each patient selected for the ACL reconstruction. One of the methods for measuring the femur has already been published[15]. The authors constructed ACL ruler for determining the femoral ACL graft positioning on radiographs.

For the statistics we used only the ratios because we are not sure if the exact measurements on the MRI hard copies are possible. Our study shows that width of the tibial attachment of the ACL in the knee extension does not differ to the width of the ACL attachment to tibia in adults[17].

The remains of the ACL in the patients with the rupture sometimes appear differently when changed with edema and hemorrhage. It would lead to conclusion that measurement of the orientation of the ruptured ACL is insecure. When comparing results of our study with the threshold values of Mellado et al. we actually discovered that there are more failures to recognize the intact ACL as to recognize the rupture (Table 2, 9). If we sat the threshold level for the ACL at 41° instead at 45° than we would also always have within the group with intact ACL (the control group) at least one positive parameter without having more negatives in the other group. Threshold levels for the Blumensat angle 0° and 115° for the PCL angle were the most discriminative for our groups of patients as well. No matter how we changed the threshold levels we couldn't manage to have always at least two positive parameters for the each patient.

Staubli and Rausching measured tibial attachment of the ACL in the extended knee position using 10 fresh cadavers' knees. Several other studies were done with cadavers' knees[18,19]. Our study was done using MRI hard copies. There is always some distance between each section and only some of the images were selected for the measurements. It is possible that we failed to choose the most representative image for the each patient.

Not all of the knees in the control group could be regarded as a radiological normal. Although without the torn ACL some of the patients in the control group have had contusions, meniscus lesions or other knee injuries. The problem is of course that MRI is not being done to young and healthy individuals. Instead of chronological age it might be better to use maturity studies of Tanner[20,21] or skeletal age[22]. We plan to do another anatomical study in which we will divide the patients in the subgroups regarding age and maturity. This would hopefully show us the dynamics of the changes in a growing individual. We would try to find out if and how the anatomical landmarks alter over the age.

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MRI SUDIJA PREDNJE UKRIŽENE SVEZE U DJECE I ADOLESCENATA

SAŽETAK

Rekonstrukcija prednje ukrižene sveze (ACL) zahtijeva precizan anatomski smještaj presatka tetive. Anatomske varijacije mogu povećati ili smanjiti rizik rupture ACL. Dvadeset i osam djece s klinički, MRI i artroskopski verificiranom rupturom ACI je uspoređeno s odgovarajućom kontrolnom skupinom. MRI je učinjen 12 mjeseci nakon ozljede. Postavljene su granične vrijednosti za identificiranje rupture ACL: kut ACL $<45°$, Blumensatov kut $>0°$, te kut PCL $<115°$. Signifikantne razlike tibijalnog hvatišta ACL i mjerenih parametara na femuru nisu ustanovljene. Kut ACL ($p < 0{,}001$), Blumensatov kut ($p=0{,}001$), i kut PCL ($p<0{,}001$) su bili značajno različiti. Kod svakog je pojedinog pacijenta u skupini s rupturirnim ACL barem jedan promatrani parametar bio pozitivan. Kut ACL, Blumensatov kut te kut PCL mogu pomoći pri postavljanju dijagnoze rupture ACL. Kod pedijatrijskih pacijenata s rupturom ACL u usporedbi s pacijentima bez rupture ACL nema razlike u širini interkondilarnog usjeka ili u nagibu gornje pokrovne plohe tibije.