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Isokinetic evaluation of knee joint flexor and extensor muscles after tibial eminence fractures

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The aim of the study was to evaluate the knee joint function in adolescent patients following operative treatment – fixation via arthroscopic or open surgery (arthrotomy), due to tibial eminence fractures. 28 patients, aged from 7 to 16 years, treated operatively between 1994–2009 in four orthopeadic centres underwent evaluation. Evaluation was performed 12–180 months following surgery. Patients were divided into two groups depending on the operative treatment received. Group A consisted of 14 patients who underwent arthroscopic reduction and stabilization. Group B consisted of 14 patients who were treated by open reduction (artrothomy) and stabilization. The results of clinical and radiological examinations and isokinetic tests used in the evaluation declared that operative treatment due to tibial eminence fracture, regardless of surgical method used, does not significantly disrupt knee joint function resulting in a slight weakening of knee joint extensor muscle strength.

Key words: *tibial eminence fracture; surgical treatment; isokinetic evaluation*

1. Introduction

Tibial eminence fractures are characterised by the detachment of the cartilage and bone of the intercondylar eminence together with the tibial end of the anterior cruciate ligament. The fracture usually runs along the intercondylar eminence, sometimes up to the medial tibial joint surface [1].

Tibial eminence fractures mainly occur in older children (aged 10–14 years) and occasionally in 8–10 year-olds [1], [2], but this fracture type has not been recorded in children below the age of 7 [3]. It is estimated that it forms less than 1% of fractures in children, type II fractures (according to the Meyer and McKeever classification scale) are the most common up to the age of 10, over the age of 10 type III fractures are more frequent [4]–[6].

Treatment of the fracture depends on the degree of trauma. In type I fractures according to the Meyers and McKeever classification scale, the treatment of choice is immobilization of the leg in a cast for a period of 6 weeks [3], [7]. In type II fractures on the Meyers and McKeever scale, surgical treatment of other intra-articular structures is indicated as arthroscopic investigations have revealed concurrent additional damage in 54% of fractures of all types [8]. Surgical treatment is indicated for Meyers and McKeever type III fractures [1], [6]. In such cases arthroscopic methods are most commonly applied to stabilise the displaced bony fragment of the tibial eminence. Methods described so far: absorbable surgical suture of the fragment – placing stitches in a u-shape through the eminence, fixation with a cannulated screw, fixation with a wire knot, stabilisation using absorbable elements, fixation with Kirschner wire and open repositioning without internal stabilisation followed by immobilisation with the knee joint in full extension [3], [5], [9], [10]. Published data does not permit an unambiguous surgery due to the larger area of incision and higher degree of tissue trauma.

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In accordance with the definition of the degree to which knee joint function returns in patients who suffered avulsion detachment of the intercondylar eminence in childhood, it may be assumed that open repositioning via arthrotomy, in addition to the primary trauma, can result in poorer joint function than in arthroscopic. With the above assumptions, the aim of the study was to evaluate function and any eventual disturbances in the knee joint structure in children treated operatively due to avulsion fracture of the tibial insertion of the anterior cruciate ligament.

2. Materials and methods

Patient recruitment was carried out across four pediatric orthopedics centres. The inclusion criteria were as follows: patient age – under 16 years at the time of trauma; a minimum 12-month post-operative observation period; degree of trauma – Meyers and McKeever classification scale type III fractures; treatment method – patient underwent operative treatment. Due to the low frequency of avulsion fractures of the tibial eminence and the strict inclusion criteria for patients in the study group, the retrospective analysis of records followed by treatment – fixation via arthrotomy or arthroscopic surgery. Exclusion criteria were: further trauma to the operated leg, which could affect the results achieved and systemic disease which could disrupt ability to perform the tests.

28 individuals fulfilled the above-mentioned inclusion criteria for the study. Analysis of the records for all 28 evaluated study participants did not reveal any rules regarding fixation of the tibial eminence fracture by arthrotomy or arthroscopy either within one centre or across the centres as a whole.

Table 1. Age and time elapsed following trauma in patients treated via open or arthroscopic surgery

	N	Median	Range (Min–Max)	
Open and arthroscopic surgery groups				
Age (yrs)	28	12.0	7.0	16.0
Time elapsed post trauma (months)	28	43.0	12.0	180.0
Arthroscopic surgery group (A)				
Age (years)	14	11.5	7.0	14.0
Time elapsed post trauma (months)	14	30.0	12.0	180.0
Open surgery group (B)				
Age (yrs)	14	12.0	8.0	16.0
Time elapsed post trauma (months)	14	61.0	12.0	168.0

The study participants were divided into two groups according to treatment: group A comprised 14 patients who underwent arthroscopic fixation, whereas the 14 patients in group B were treated by fixation through arthrotomy. Patient age and time elapsed following trauma are summarized in Table 1.

The study material included 20 boys (71.4%) and 8 girls (28.6%). Trauma mechanism was dominated by cycling accidents – 15 individuals (53.6%), traffic accidents accounted for 8 study participants (28.6%) 4 (14.2%) were involved in skiing accidents and 1 (3.6%) suffered trauma due to a fall from a height. The study was approved by the Bioethics Committee of Poznan University of Medical Sciences (approval number 291/07).

Clinical and radiologic examination – methodology

The methodology of objective analysis was based on general principles of orthopedic examination. Range of motion and joint stability were evaluated and radiologic measurement of the patella-femur distance performed as clinical manifestations of the condition of the patient's knee joint.

Methods of examination and evaluation of range of motion

Range of active motion was measured using a goniometer and a comparison then made between the operated and healthy knee joints.

Methods of examination and evaluation of anteroposterior stability of the knee

Anteroposterior stability was assessed using the Rolimeter 50A (Aircast Summit NJ US) arthrometer which measured the translation of the tibia in relation to the femur using the Lachman test. The result was recorded in millimeters as the difference between the operated and healthy leg. Measurement error was 2 mm.

Methods of radiologic investigation and evaluation

Patellofemoral narrowing was measured between the joint surface of the patella and the anterior edge of the femur condyles on a side view X-ray of the knee joint flexed at 45°. Where no narrowing was detected this was recorded as no change. Minimal changes including small osteophytes, small sclerotic changes, flattening of femoral condyles were recorded as mild narrowing. Medium narrowing included similar changes together with narrowing of the joint space between 2–4 mm. Severe change is when the joint space is narrowed to less than 2 mm. Measurement error was 2 mm.

Methods of isokinetic evaluation of the knee flexor and extensor muscles

Isokinetic evaluation of the knee flexor and extensor muscles in patients following surgical treatment was performed on the "Biodex 3" (Biodex Shirley U.S.) platform for isokinetic examination. Before each test the chair and the dynamometer with the appropriate attachment were positioned according to manufacturer's guidelines (Biodex System 3 – Application Manual) and adjusted for each individual study participant [11]. Measurements were taken at the following angular velocities; low: 60°/s, medium: 180°/s and 240°/s and high: 300°/s.

The following muscle velocity-torque parameters were evaluated: peak value of maximum knee extensor and flexor torque at 60°/s velocity; peak value of maximum knee extensor and flexor torque in relation to body mass at 60°/s velocity; coefficient of variation for knee extensor and flexor muscles at 60°/s and 240°/s velocity; mean knee extensor/flexor torque; total work of knee extensors and flexor during the test at 240°/s velocity; percentage relation flexor-extensor torque.

Statistical methods

The description of quantitative variables collected in the tests performed consists of arithmetic median and minimum/maximum values in a group. These variables do not exhibit normal distribution therefore differences between the results of both groups and between the results of operated and healthy joints were verified using the Mann–Whitney test. Results of a p value lower or equal to 0.05 were deemed statistically significant. As a bilateral analysis a comparison of the operated legs in both groups was evaluated; unilateral analysis was the comparison of identical muscle groups in both legs. Spearman's rank correlation coefficient was used for calculating correlations between quantitative variables. Calculations were made using Statistica (StatSoft) software.

3. Results

Evaluation of anteroposterior translation (Lachman test)

The Lachman test showed that the leg with trauma exhibited anteroposterior laxity of 2 mm in comparison to the healthy leg in 1 patient from the group treated by arthroscopic surgery. In the arthrotomy group increased anteroposterior translation in the operated joint as compared to the healthy knee was observed in 8 patients.

Evaluation of the range of motion

In the evaluation of extension deficit in the arthroscopic surgery group, one patient showed limited extension of 20 degrees; in the arthrotomy group no incidence of restricted extension was found.

In the evaluation of flexion deficit 5 patients from the arthroscopy group exhibited restricted flexion of 20 degrees. In the open surgery group 1 patient had restricted flexion of 40 degrees.

Evaluation of patellofemoral narrowing

In the arthroscopy group 4 patients were found to have narrowing of the patellofemoral joint (0–2 mm), in the remaining patients the minimum distance was 4–5 mm. 3 patients in the open surgery group exhibited patellofemoral narrowing of 0–2 mm and in the remaining patients the minimum distance was found to be 4–5 mm.

Clinical assessment revealed a statistically significant difference between both study groups in regard to the Lachmann test only ($p = 0.024$). Anteroposterior insufficiency was lower in the arthroscopy group than in the open surgery group, however the difference in the results did not exceed the 2 mm measurement error. The comparison of the remaining parameters did not indicate any statistically significant differences in the results of both groups.

Isokinetic test results

Isokinetic tests were used in the bilateral analysis – a comparison of the same muscle groups of the operated leg from both patient groups. The results of the test in absolute values are presented in Tables 2–5.

The statistical evaluation consisted of two types of analysis: Bilateral analysis – the results of the isokinetic tests comparing the operated legs in both groups did not reveal any significant differences; apart from the parameter for mean torque of extensors ($p = 0.050$), which revealed the advantage of patients who underwent fixation of the fracture by open surgery (Table 4).

Unilateral analysis – in the second stage of the study, identical muscle groups on both legs were compared in relation to the operated/healthy leg for all patients studied. The parameter for mean torque of knee extensors was not included in the analysis due to statistically significant differences between both groups. The analysis revealed statistically significant

Table 2. Isokinetic test results – arthroscopic fixation

	Median	Range (Min–Max)	
Peak maximum torque value – extensors at 60°/s	94.8	30.8	183.5
Peak maximum torque value – flexors at 60°/s	53.6	20.9	108.4
Peak maximum torque value of knee extensors, in relation to body mass, at 60°/s	176.0	114.4	282.7
Peak maximum torque value of knee extensors and flexors, in relation to body mass, at 60°/s	99.1	53.0	157.1
Coefficient of variation for extensors at 60°/s	7.6	0.6	22.1
Coefficient of variation for flexors at 60°/s	13.1	1.6	72.0
Mean torque of knee extensors	60.3	18.5	117.3
Mean torque of knee flexors	32.0	8.0	74.7
Extensor torque in relation to flexor torque (percent)	57.0	28.3	79.1
Coefficient of variation for extensors at 240°/s	13.8	0.6	19.9
Coefficient of variation for flexors at 240°/s	17.7	4.4	31.6
Total work of knee extensors during the test, at 240°/s	1726.9	407.0	3525.0
Total work of knee extensors during the test, at 240°/s	969.5	276.0	2161.0

Table 3. Isokinetic test results – arthrotomic fixation

	Median	Range (Min–Max)	
Peak maximum torque value of extensors at 60°/s	131.6	66.2	221.0
Peak maximum torque value of flexors at 60°/s	72.7	33.9	118.3
Peak maximum torque value of knee extensors, in relation to body mass, at 60°/s	201.2	134.6	306.1
Peak maximum torque value of knee extensors and flexors, in relation to body mass, at 60°/s	109.5	75.4	163.9
Coefficient of variation for extensors at 60°/s	7.4	3.2	16.6
Coefficient of variation for flexors at 60°/s	9.7	1,2	22,8
Mean torque/force of knee extensors	87.0	43.3	137.8
Mean torque/force of knee flexors	48.1	19.1	82.5
Percentage relation of flexors to extensors	54.7	46.4	77.5
Coefficient of variation for extensors at 240°/s	13.1	2.5	24.6
Coefficient of variation for flexors at 240°/s	16.3	4.0	31.6
Total work of knee extensors during the test at 240°/s	2445.1	1205.9	3936.9
Total work of knee flexors during the test at 240°/s	1185.0	101.0	2606.0

Table 4. Levels of significance of differences between the two study groups – results of isokinetic tests on the operated leg

	p value
Peak maximum torque value – extensors at 60°/s	0.094
Peak maximum torque value – flexors at 60°/s	0.085
Peak maximum torque value of knee joint extensors, in relation to body mass, at 60°/s	0.164
Peak maximum torque value of knee joint extensors and flexors, in relation to body mass, at 60°/s	0.376
Coefficient of variation for extensor muscles at 60°/s	0.667
Coefficient of variation for flexor muscles at 60°/s	0.839
Mean torque of knee joint extensors	0.050*
Mean torque of knee joint flexors	0.069
Percentage relation of torque of flexors to extensors	0.352
Coefficient of variation for extensor muscles at 240°/s	0.910
Coefficient of variation for flexor muscles at 240°/s	0.667
Total work of knee joint extensors during the test, at 240°/s	0.085
Total work of knee joint flexors during the test, at 240°/s	0.352

Note * $p < 0.05$.

Table 5. Levels of significance for differences between both groups regarding relative value of isokinetic test on the operated/healthy leg results

	p value
Peak maximum torque value – extensors at 60°/s	0.052
Peak maximum torque value – flexors at 60°/s	0.688
Peak maximum torque value of knee extensors, in relation to body mass, at 60°/s	0.004*
Peak maximum torque value of knee extensors and flexors, in relation to body mass, at 60°/s	0.533
Coefficient of variation for extensor muscles at 60°/s	0.954
Coefficient of variation for flexor muscles at 60°/s	0.652
Mean force of knee joint flexors	0.768
Percentage relation of torque of flexors to extensors	0.002*
Coefficient of variation for extensor muscles at 240°/s	0.502
Coefficient of variation for flexor muscles at 240°/s	0.896
Total work of knee joint extensors during the test, at 240°/s	0.456
Total work of knee joint flexors during the test, at 240°/s	0.700
Peak maximum torque value – extensors at 60°/s	0.664
Peak maximum torque value – flexors at 60°/s	0.163

Note * $p < 0.05$.

Table 6. Spearman's rank correlation coefficients for isokinetic test results in regard to time elapsed post trauma

Isokinetic test results in regard to time elapsed post trauma (months)	Spearman's rank correlation coefficient	*p* value
Peak maximum torque value of extensors at 60°/s	0.467	0.012*
Peak maximum torque value of flexors at 60°/s	0.411	0.030*
Peak maxium torque value of knee extensors, in relation to body mass, at 60°/s	0.241	0.217
Peak maxium torque value of knee extensors and flexors, in relation to body mass, at 60°/s	0.197	0.315
Coefficient of variation for extensors at 60°/s	–0.168	0.393
Coefficient of variation for flexors at 60°/s	–0.087	0.660
Mean torque /force of knee extensors	0.497	0.007*
Mean torque /force of knee flexors	0.413	0.029*
Percentage relation of flexors to extensors	–0.022	0.910
Coefficient of variation for extensors at 240°/s	–0.300	0.121
Coefficient of variation for flexors at 240°/s	0.131	0.506
Total work of knee extensors during the test at 240°/s	0.473	0.011*
Total work of knee flexors during the test at 240°/s	0.409	0.031*

Note * $p < 0.05$.

differences between healthy and operated legs in regard to maximum force of knee extensors in relation to weight ($p = 0.004$), and percentage relation to torque of knee flexors compared to extensors ($p = 0.002$). These results point to the weakening of extensor muscle parameters (Table 5).

Spearman's Coefficient of rank correlation for isokinetic test results in regard to time elapsed post trauma

Correlation for isokinetic test results in regard to time elapsed post trauma were evaluated as well. The results are summarized in Table 6.

4. Discussion

Tibial eminence fractures are a relatively rare intra-articular fracture, the long-term consequences of which may be of significance for later functioning of the knee joint. The most important factor of the trauma mechanism is torque during large flexion or extension in the knee joint together with accompanying internal rotation of the tibia or valgus of the lower leg with concurrent external rotation in relation to the thigh.

The Meyers and McKeever classification is the scale most commonly used to assess extent of trauma [6]. On the basis of X-rays the authors identified three degrees of damage: I – minimal displacement of fractured fragment with slightly elevated anterior portion; II – anterior third to half elevated; III – complete displacement of eminence [6]

Discussion of surgical treatment and post-operative rehabilitation of such fractures occurs on a number of levels. The first issue is of course the selection of surgical access, and in recent years non-invasive arthroscopy to the knee joint, where trauma of tissue surrounding the joint is less than in arthronomy, has been advocated. Also to be considered is the method of fixation used to stabilize the fracture, characterized by high primary/initial strength. In this context, the work of Bong et al. [34], who performed 14 experimental intercondylar eminence fractures on knee joints taken from cadavers should be mentionned. The fractures were classified as Meyers and McKeever type III and fixation using fiberwire was primarily stronger than cannulated screw. This data indicates the neccessity of further research into optimal fracture fixation. In the context of this study post-operative treatment should also be considered. In this age group in particular, difficulties arise regarding consistency of strength and stamina training as well as problems verifying time dedicated to rehabilitation. The many years of experience of the second author in pediatric-orthopeadics indicate that the patient group evaluated here was most probably characterized by a high level of physical activity and, as is typical of this age group, a lack of consistency in performing post-treatment exercises. Difficulties encountered in post-operative rehabilitation connected with patient age can be furthered by the weak response to extensor muscle strength training as described by Staniszewski et al. [13].

According to data currently available, there are no published equivalents of isokinetic testing performed on teenage patients treated operatively for avulsion tibial detachment of the anterior cruciate ligament.

Published research does exist into adult patients following anterior cruciate ligament trauma and arthroplasty of the knee joint [14]. Following the study of hip joint muscle in 29 healthy male patients aged 6–8, Burnett et al. [15] claimed that isokinetic tests can be performed on children.

The results of the isokinetic test were analysed in regard to bilateral relation – the comparison of the same leg following operative treatment in both patient groups and also unilateral comparison of identical extensor and flexor muscle groups of both legs in relation to the healthy/operated leg for the entire patient group studied.

In the comparison of the bilateral results we did not find any stastically significant differences between patients treated with either method, apart from the mean torque of knee extensors in the group which underwent open surgery, which in our opinion may be due to the longer period of time elapsed in the arthrotomic surgery group together with the accompanying longer regeneration period rather than the influence of arthotomy or arthroscopy on torque of knee extensors.

Unilateral analysis indicated statistically significant differences between healthy and operated legs regarding maximium extensor torque in relation to body weight and percentage relation of knee joint flexor to extensor strength. These results suggest the deterioration of these parameters for the extensor muscles which indicates that the operated leg, in the rehabilitation plans currently applied, does not return to the level of functioning of the healthy limb.

Analysis of available publications revealed discrepancies in attempts to explain the mechanism of restriction in antagonist knee joint muscle mobility [16]. Some authors consider the main cause is damage to the mechanoreceptors around the anterior cruciate ligement. Krauspe et al. [17] with the aid of monoclonal antibodies, claimed that a three-year-old child has a maximum of 17 mechanoreceptors around the anterior cruciate ligament. The overall number of mechanoreceptors decreases with age and after trauma, and it is currently believed that their regeneration does not take place [17]. In the region of the nearest tibial end of the anterior cruciate ligament different types of mechanoreceptors have been identified: free nerve endings, Ruffini bodies, Golgi bodies and Pacini bodies. Ruffini receptors are activated during ligament extension and Pacini bodies during ligament compression. Golgi bodies are activated along the border areas due to their high stimulation threshold. Free nerve endings are the most common – apart from the mechanoreceptor function they are also responsible for nociceptive sensation [16]. Other authors play down the role of the mechanoreceptors around the anterior cruciate ligament highlighting their low number and the lack of experimentally confirmed impact of anterior cruciate ligament mechanoreceptors on the muscles surrounding the knee joint.

Matthews [18] claims that the intra-articular mechanoreceptors probably signal movement, but do not influence the sense of stability. He highlights the main role of the mechanorecpetors found in the region of the knee joint muscle fibres in the proprioreception [18]. Other authors: Abbott et al. [19], Gardner et al. [20], have proposed the existence of a ligament-muscle reflex between the anterior cruciate ligament and the hamstrings. This reflex is thought to be due to the direct activation of the antagonist muscle motorneurons in order to oppose any damage to intra-articular structures. However, experiments on animal did not unequivocally prove activation of flexor muscles via tibial translation [21]. The theory described by McNaira et al. [22] emphasised the effect of mechanoreceptors on muscle stiffness, but this has yet to be confirmed. Many published studies of patients following anterior cruciate ligament trauma have found disturbances in muscle torque in the quadriceps and concurrent restrictions on electrical activity of the muscle. Elmqvist et al. [23] claimed that these changes are brought about by a fall in stimulation of the central quadricep as the result of a less afferent impulse from the damaged anterior cruciate ligament. This reflex is probably an adaptive defensive reaction to the risk of overextension of the anterior cruciate ligament being repeated.

Study limitations

The retrospective nature of this study is a limitation which leads to difficulties in the evaluation of rehabilitation time post-trauma as well as the commitment of young patients to this process. A further restriction is the relatively small number of patients analyzed though this reflects the low incidence rate of this trauma. However, the material evaluated in this study is similar to the numbers of patients evaluated in international literature, e.g., Tsan-Wen et al. [24], evaluated a group of 26 patients (children and adults), Louis et al. [25] studied 17 patients and Matthews and Geissler 6 patients [10].

In conclusion, operative treatment of tibial eminence fracture, regardless of surgical method used, does not significantly disrupt knee joint function resulting in a slight weakening of knee joint extensor muscle strength.

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