LITHUANIAN SPORTS UNIVERSITY

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EARLY DIAGNOSTICS OF SKELETAL MUSCLE AND TENDON CHRONIC DAMAGE RISK FOR CHILDREN AND ADOLESCENTS ENGAGED IN SPORT

Summary of the Doctoral Dissertation

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SPORTUOJANČIŲ VAIKŲ IR PAAUGLIŲ GRIAUČIŲ RAUMENŲ IR SAUSGYSLIŲ LĖTINIŲ PAŽEIDIMŲ RIZIKOS ANKSTYVA DIAGNOSTIKA

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CONTENT

INTRODUCTION

Sport and physical activity strengthen muscles, cardiovascular system, reduce overweight, and improve mood and performance (Haskell et al., 2007). Regular physical exercises are beneficial for the cognitive function and increase self-confidence. However, with the growing competiveness in sport, children, adolescents and young participants are under increasing psychological pressure to win, and for this reason physical training is often too intense, frequent and highly specialized and this may lead to health problems due to traumatic injuries (Ladenhauf, Graziano, & Marx, 2013).

It is assumed that a single bout of physical exercise has little effect on the tendons and muscles (Ladenhauf et al., 2013). However, in practice the exercises applied are not single-bout, but permanent, and very often another exercise is performed when the body does not fully recover after the previous one. Permanent overload, biomechanically incorrectly performed exercises and physical activity in condition of chronic fatigue may change the material properties of the joints, such as the knee joint that they become more prone to injuries and associated pain (Helland et al., 2013). More than half arm and leg injuries occur not in physical contact with opponents. They are more related to imbalance of muscle strength and the range of motion, motor control and muscle activation disorders, changes in tendon mechanical and morphological characteristics (Gagnier, Morgenstern, & Chess, 2013; Ladenhauf et al., 2013).

Children playing baseball may be vulnerable to injuries as the ball is thrown by one side body muscles (Escamilla, Fleisig, Zheng, Barrentine, & Andrews, 2001). Such asymmetric exercise can cause functional imbalance, which in the long term results in the appearance of side-to-side differences in individual muscle groups, tendons and ligaments (Byram et al., 2010). Previous studies have shown an increase in glenohumeral external rotation and a decrease in the internal rotation range of motion (ROM) for the throwing shoulder compared with the opposite side (Borsa, Dover, Wilk, & Reinold, 2006; Byram et al., 2010; Donatelli et al., 2000; Wilk et al., 2009). Structural and functional side-to-side differences of muscles and tendons are more common in the adult population (Byram et al., 2010; Chen, Lin, Chen, Lin, & Nosaka, 2011; Noffal, 2003). Yet the arm range of motion and strength side-to-side differences were established for players during their puberty and growth (Harada et al., 2010; Hurd et al., 2011; Levine et al., 2006;

Trakis et al., 2008). It remains unclear at what age there may be the greatest risk of injury, when side-to-side differences occur practicing sport which involves asymmetric exercise and what is the relationship between side-to-side differences and the risk of injury. Since the connective tissue in boys at the onset of puberty can be particularly sensitive to intense eccentric exercise (Harada et al., 2010), we hypothesized that regular baseball playing, which often aggravates joints and muscles on one side, can create asymmetry of individual muscle groups, tendons and ligaments in young (11-12 years old) athletes, which makes them more prone to injury compared to those non-trained.

Adolescents are especially vulnerable to injuries because of the occurrence of many structural, hormonal, biomechanical and functional body changes during puberty (Adirim & Cheng, 2003; Cassas & Cassettari-Wayhs, 2006; Frisch, Croisier, Urhausen, Seil, & Theisen, 2009). Approximately one-third of adolescent injuries are associated with knee soft tissue damage (Foss, Myer, Magnussen, & Hewett, 2014). Previous studies have shown that up to 54% of adolescent athletes experience some form of knee pain annually (Calmbach & Hutchens, 2003; Fagan & Delahunt, 2008; Louw, Manilall, & Grimmer, 2008). In basketball, the incidence of non-contact knee joint injuries in adolescents is higher than in other sports (Belechri, Petridou, Kedikoglou, & Trichopoulos, 2001; Caine, Maffulli, & Caine, 2008). This can be attributed to the fact that during a basketball game there are rapid and frequent sprints and stops, direction changes and jumps (Cumps, Verhagen, & Meeusen, 2007; Drakos, Domb, Starkey, Callahan, & Allen, 2010). Such activities place particularly high stresses on the knee and the muscle-tendon unit (Cassas & Cassettari-Wayhs, 2006). This causes pain in the most overloaded structures, so research into athletes' muscles and tendons, adapted to basketball exercise, can reveal differences (compared to non-trained adolescents) and provide new predictive indicators of injuries. We hypothesized that adolescent basketball players who experienced knee pain would have worse balance in muscle strength, activation and coordination, lower range of motion and more common tendon lesions than those basketball players who did not have pain and adolescents who were not engaged in sport.

Biomechanical and clinical studies support the claim that the position of the upper part of the body can affect mechanical properties of femur and tibia, patella and hip joints (Reiman, Bolgla, & Lorenz, 2009). Malfunction of the hips, pelvis and trunk movement control puts more stress on the knee joint, which can result in the incidence of injury (Cibulka & Threlkeld-Watkins, 2005; Powers, 2010). During the jumps, side torso movements, excessive hip adduction and internal rotation can cause the knee joint centre to move medially relative to the foot fixed on the ground (Hollman et al., 2009). The inward movement of the knee joint results in an increase in the dynamic knee valgus and increases the risk of numerous knee injuries (Hewett et al., 2005), including patellofemoral joint dysfunction (Blackburn & Padua, 2009). The effect on tendon size and mechanical properties of irregular loading of the patellar tendon related to an increase in dynamic knee *valgus* or Q-angle is not known. However, studies describe alterations in the elastic properties of patellar tendon with tendinopathy. The tendon can be more elastic (Helland et al., 2013) or elasticity does not change (Couppé et al., 2013; Kongsgaard et al., 2010), but the tendon is less stiff. This can be related to increasing patellar tendon thickness, patellar tendon pain and functional deficit (De Zordo et al., 2009, 2010; Ooi et al., 2016). As such pain and decrease in functional strength in the tendons could mean an end to the athletic career of an athlete, it is important to identify how global posture, lower limb joint alignment, and movements of the hip, pelvis, and trunk may change knee loading, tendon morphology, and mechanical properties. Therefore, we hypothesized that for basketball players who feel the knee pain due to differences in kinematic and kinetic parameters the knee loading will be higher and will affect the mechanical properties of the patellar tendon.

Research aim was to establish the expression of primary indicators of skeletal muscle and tendon chronic damage in children and adolescents at increased risk and untrained children and adolescents.

Research objectives

1. Compare side-to-side differences in morphological and functional indicators for children adapted to physical exercise with pain in the dominant upper limb and those free of pain.
2. Compare side-to-side differences in morphological and functional indicators for adolescents adapted to physical exercise with and without knee pain and untrained adolescents.
3. Compare kinematic and kinetic indicators as well as patellar tendon mechanical properties for adolescents adapted to physical exercise with and without knee pain.

Theoretical and practical significance of research. Coaches, sports medical professionals and physical therapists should pay attention to the fact that pain in 11–12-year-old baseball players is neither associated with muscle contraction strength, range of motion nor side-to-side morphological differences. Knee pain in adolescent basketball players is associated with greater height, lower lumbar and pelvic stability, and often accompanied by morphological knee pathologies in which the risk of developing knee pain increases more than 8 times. Besides, leg stiffness, *valgus* knee motion, and Q-angle are associated with hypertrophic soft patella tendon and idiopathic knee pain in adolescent basketball players. In the early diagnosis of the risk of injury, it is particularly important to use the ultrasound methods because morphological changes can occur even in the absence of persistent pain.

1. RESEARCH METHODS AND ORGANIZATION

1.1. Participants

The experiments were carried out in accordance with the principles of human experimentation ethics set out in the Declaration of Helsinki. Participants were familiarized with research aims, methods and procedures. Written informed consent was obtained from parents or foster parents. Research protocol was discussed and approved by Kaunas Regional Biomedical Research Ethics Committee (protocol No. 64/2013). The numbers and characteristics of research participants involved in each study are given in Table 1.

Table 1. *Number, age, body height, body weight, training experience of participants (mean and SD)*

Study	Group	Training experience (years)	Number of participants (n)	Age (years)	Body height (cm)	Body weight (kg)
I	With pain (symptomatic)	4.5 ± 0.8	14	11.6 ± 0.6	158.5 ± 6.3	54.1 ± 11.9
	Control	–	16	11.8 ± 0.7	158.0 ± 7.1	55.1 ± 10.6
II	With pain (symptomatic)	6.3 ± 1.6	29	14.5 ± 0.6	179.1 ± 8.4	65.4 ± 10.6
	Without pain (asymptomatic)	6.3 ± 1.4	30	14.0 ± 0.6	174.1 ± 10.6	61.4 ± 13.2
	Control	–	29	14.2 ± 0.7	172.2 ± 9.0	63.4 ± 15.1
III	With pain (symptomatic)	6.5 ± 1.4	10	15.2 ± 0.6	179.3 ± 8.4	64.2 ± 9.7
	Without pain (asymptomatic)	6.5 ± 1.2	10	14.6 ± 0.8	177.3 ± 8.0	63.6 ± 9.0

Study I. The participants of this study were 14 male baseball players who 1) participated 4 or more years in baseball activities and 2) experienced moderate intensity pain during at least two training sessions in the last month. Baseball players were recruited from the local baseball league during the off-season preparation phase (November-December). We used a modified questionnaire by Trakis et al. (2008) to determine whether a participant could be included in the study or should be excluded. For the control group physically active boys (n = 16) were recruited from local high schools from the same grades and of similar mass and height as the baseball players. Boys in the control group attended physical education classes 2 times a week, but they did not participate in any sports training.

Study II. Research participants were 88 adolescents who were divided into three groups (**Table 1**) using a modified KOOS questionnaire (Roos & Lohmander, 2003). The first group (*n* = 29) included adolescent basketball players who 1) had participated in basketball activities for 5 or more years; 2) experienced anterior knee joint pain during at least two training sessions in the last month. The second group (*n* = 30) included basketball players who 1) had participated in basketball activities for 5 or more years; 2) had not experienced anterior knee joint pain in the last month. Basketball players were recruited from the local basketball league at the end of the season (in July-August). The third group consisted of 29 healthy physically active adolescents from Kaunas city secondary schools. They were of the same age as basketball players. The control group participants did not play any sport.

Study III. Research participants were 20 adolescents who were divided into two groups (**Table 1**) using a modified KOOS questionnaire. The first group (*n* = 10) included adolescent basketball players who had complained of knee pain in the past six months. The second group (*n* = 10) included adolescent basketball players who had not complained of knee pain in the past six months. All adolescents participating in the studies had played basketball for 5 or more years. Basketball players were recruited from Kaunas city basketball league at the end of the season (in July-August).

1.2. Research methods

Anthropometric measurements. Participants' body height was measured using a height rod. Their body weight was measured using the scales *Tanita Body Composition Analyzer TBF – 300* (Japan).

Dynamometry. An isokinetic dynamometer was used for skeletal muscle strength testing (*Biodex Medical System 3 PRO*, certified by ISO 9001 EN 46001). Arm muscle concentric-isokinetic and eccentric peak torque was tested during shoulder internal and external rotation, shoulder and elbow flexion and extension. Testing shoulder extensor and flexor muscles, the subjects arm was stretched up, the shoulder joint was positioned at 0°. Strength was tested through 90° of the ROM, between the angles of 90° and 180° (0º – arm resting against the side).

Shoulder joint internal and external rotation peak torque was assessed with the subject's arm positioned with the shoulder abducted at 90° and turned to the side (Zanca, Oliveira, Saccol, & Mattiello-Rosa, 2011). Strength was tested through 90° of the ROM, between 0° of internal rotation and 90° of external rotation.

Elbow flexions and extensions were then performed. The subject's arm was at shoulder height stretched forward, the joint - at 90°, the forearm was supinated, holding the lever arm of the dynamometer. Strength was tested through 110°of the ROM, between 0° and 110° (0º – elbow fully extended).

Isometric MVC torque of the knee extensor and flexor muscles were measured at a 90° knee joint (0° – full knee extension). Concentric-isokinetic peak torque of the knee extensor and flexor muscles were measured performing 3 trials at angular velocities of 60°/s, 240°/s and 450°/s. Eccentric peak torque of the knee extensor and flexor muscles was measured performing 3 trials at angular velocities of 60°/s and 240°/s. These measurements were taken through 85° of the ROM, i.e. between 20° and 105° (0º – leg fully extended).

Testing proprioception. Proprioception was assessed using an isokinetic dynamometer. First we registered knee flexion and extension MVC, then we established the value of 20% MVC. For the accuracy of values of the generated force, during the testing, the subjects performed repeated isometric knee flexion and extension (10 trials with 1-s intervals) in an attempt to match the required 20% MVC. Proprioception was established calculating the absolute error size (AE) of knee extensor and flexor muscle repeated isometric contraction torque applying the formula (Magill, 2007; Schmidt & Lee, 2005):

$$\text{AE} = \sum |x_i - T| / n,$$

where x_i is the torque generated during trial (N·m); T – the target torque, i.e. the required torque t; n – the number or trials. Aiming at comparing the data between different subjects, we calculated also the absolute error (AE) size as a percentage of MVC:

$$\text{AE (\%)} = \text{AE}*100/(20\% \text{ MVC}).$$

Goniometry. Measurements of leg and arm range of motion (ROM) were performed using static passive stretching till the feeling of discomfort (Sauer, Potter, Weisshaar, Ploeg, & Thelen, 2007). Measurements were taken using a standard goniometer. Internal and external rotations of the upper arm (Reinold et al., 2008) as well as the ROM of elbow flexion and extension were measured. We also performed knee extension (“*90–90”* test; Russell & Bandy, 2004), *Prone Knee Bend test* (Dutton, 2004), *Straight Leg Test* (Neto, Jacobsohn, Carita, & Oliveira, 2014), *Internal and External Hip Rotation* (Byrd, 2005) and *Slump test* (Davis, Anderson, Carson, Elkins, & Stuckey, 2008).

Assessment of Movement Stability. Assessing the qualitative stability of movements, we performed the *Active Straight Leg Rise Test* (Mens, Vleeming, Snijders, Koes, & Stam, 2001), *Single Leg Squat Test* (Bailey, Selfe, & Richards, 2011), *Single Leg Hoop Test* and *Foam Roller Supine Test.*

Ultrasonography. Ultrasonography of the shoulder and elbow regions was performed (Harada et al., 2006) using an ultrasound device (*GE Logiq 7, Wuppertal*, Germany) with a 7–12 MHz linear probe. We measured the thickness of the subscapular muscle tendon, supraspinatus muscle attachment tendon, humeral capitulum, and lateral elbow ligament, and we performed a stress test aiming at assessing the inner elbow and upper arm distance. Patella tendon measurements were performed using an ultrasound device (*Esaote MyLab 50 XVision*, Italy) with a 7–12 MHz linear probe. With the subject in a supine position and the knee bent at 90° angle, we measured the cross-sectional area, thickness and circumference of the patella.

Electromyography (EMG). A 16 channel MP 150 (*Biopac Systems*, Inc., USA) was synchronized with a dynamometer and used to register electrical activity of rectus femoris muscle and biceps femoris muscle while performing isometric, concentric and eccentric knee flexion and extension strength tests. EMG signals were recorded with a frequency of 1,000 Hz and analysed using computer Acknowledge software (*Acknowledge, Biopac System*, CA, USA). EMG signals were filtered using analogue high-pass (10 Hz) and low-pass (500 Hz) filters and assessed using the root mean square (RMS) of the EMG signal.

Measurements of the morphological and mechanical parameters of tendons. During the third study, we registered the length and cross-sectional area image of the patella tendon using an ultrasonography device (*LS128 CEXT-1Z, Telemed*, Vilnius, Lithuania) with a linear 5–10 MHz probe. Tendon length and cross-sectional area were measured using image analysis computer software (*ImageJ, National Institute of Health*, Austin, TE, USA).

Aiming at evaluating patella tendon mechanical properties (elasticity and stiffness), the knee extension torque was increased to 80% MVC within 2 s. simultaneously registering patella tendon elongation using ultrasonography (LS128 CEXT-1Z, Telemed) and the biceps femoris muscle EMG using *Biopac* system (*MP150WSW, Biopac Systems*) (Maganaris, 2003).

Kinematic parameters of vertical jump. The movement registration system consisted of two 100 Hz cameras *Basler A602fc* (resolution 656 × 490 pixels), connected via *FireWire* (IEEE-1394) with a personal computer (*Dell Computer Corporation*, Round Rock, TX) and video recording software *Templo* (*Contemplas*, Kempten, Germany). Analysis of jumping technique was performed using the SIMI movement analysis software (*Simi Reality Motion Systems GmbH*, Unterschleissheim, Germany).

Kinetic parameters of vertical jump. Kinetic variables of vertical jumps were measured at the frequency of 200 Hz, using a 50 × 50 cm portable force plate (*Kistler*, Switzerland, Slimline System 9286) with software (*Qualisys Track Manager v 2.10*; *Qualisys*, Gotenbergas, Švedija). Variables were assessed in the eccentric, concentric and landing phases.

Assessment of knee joint function. A modified KOOS questionnaire (*Knee Injury Osteoarthritis Outcome Score*) was used to assess the subjective opinions of experienced knee pain and its frequency (Roos & Lohmander, 2003). During the research we used a subscale which included 9 items.

1.3. Research organization

Research was carried out at Lithuanian Sports University, Institute of Sport Science and Innovations. Research participants were tested under the same conditions, i.e. at the same time of day, at the temperature of 21–22°C. The subjects were not allowed to exercise for at least one day before the tests. They were trained to carry out tests.

1.3.1. Study I

On arrival at the laboratory on the first day of testing, each subject subjectively evaluated the level and the frequency of pain in the arm joints in points using a modified Trakis et al. (2008) questionnaire. After the anthropometric measurements, the subjects' arm joint range of motion was measured using a goniometer. Then the warming-up was carried out, which consisted of 5 arm ergometer rotation for minutes and stretching exercises for 3-5 minutes. Then the subjects were seated in a dynamometer chair, where their arm muscle torque was recorded in the following order: 1) shoulder joint extensor and flexor muscle concentric-isokinetic and eccentric peak torque; 2) elbow joint extensor and flexor muscle concentric-isokinetic and eccentric peak torque; 3) shoulder joint muscle internal and external rotation concentric-isokinetic and eccentric peak torque. On the second day of testing, ultrasonic measurements of arm joints were taken. Research protocol is given in **Figure 1.**

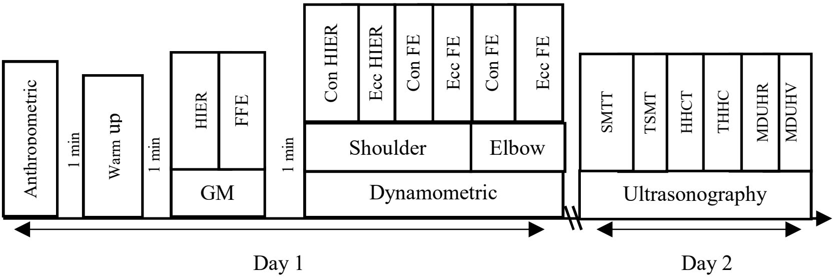

Figure 1. *Protocol of Study I*

Note. GM – goniometric measurements; HIER – humeral internal and external rotation; FFE – forearm flexion and extension; Con – concentric; Ecc – eccentric; FE – flexion and extension; SMTT – subscapular muscle tendon thickness; TSMT – thickness of supraspinatus muscle tendon; HHCT - humeral head cartilage thickness; THHC – thickness of the head of the humerus cartilage; MDUHR – medial distance of ulna and humerus at rest; MDUHV – medial distance of ulna and humerus during *valgus* force test.

1.3.2. Study II

On arrival at the laboratory on the first test day of the second study, the subject had subjective assessment of the knee pain level and frequency in points using a modified KOOS questionnaire. After taking the anthropometric measurements, the subjects' ROM of legs were measured using a goniometer. Then the legs were assessed applying qualitative movement stability tests. Then the warming-up was carried out, which was a 10 min exercise on a veloergometer (50 W, frequency 70 times/min), after which the surface EMG electrodes were attached. Then the subjects were seated in a dynamometer chair, where their leg quadriceps and hamstrings muscles peak torque simultaneously with EMG, was recorded in the following order: 1) in the isometric mode; 2) 20% of MVC; 3) in the concentric mode; 4) in the eccentric mode. On the second day of testing, knee ultrasonic measurements were carried out. Research protocol is given in **Figure 2**.

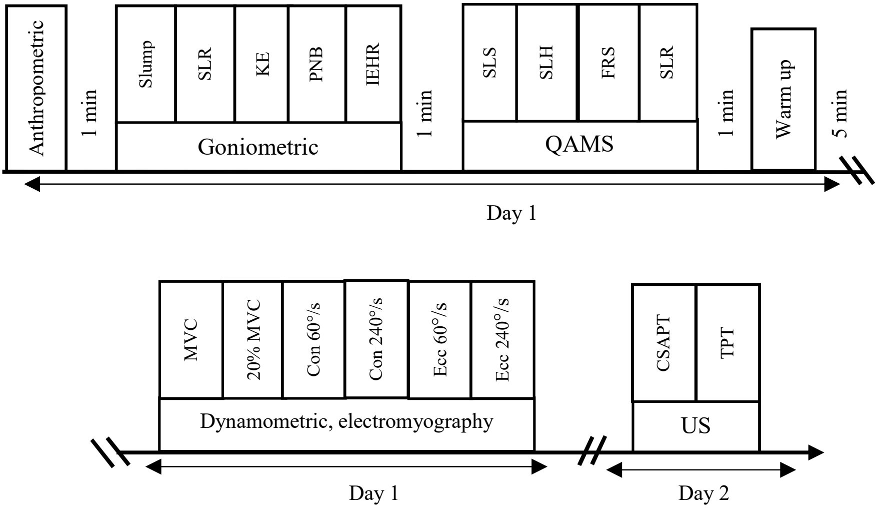

Figure 2. *Protocol of Study II*

Note. Slump – Slump Test; SLR – Straight Leg Rise Test; KE – Knee Extension Test; PNB – Prone Knee Bend Test; IEHR – Internal and External Hip Rotation; QAMS – Qualitative Assessment of Movement Stability; SLS – Single Leg Squat Test; SLH – Single Leg Hoop Test; FRS – Foam Roller Supine Test; SLR – Straight Leg Rise Test; MVC – maximal voluntary contraction force; Con – concentric muscle contraction; Ecc – eccentric muscle contraction; US – ultrasonography; CSAPT – cross-sectional area of the patellar tendon; TPT – thickness of the patellar tendon.

1.3.3. Study III

On arrival at the laboratory on the first test day of the third study, the subject had subjective assessment of the knee pain level and frequency in points using a modified KOOS questionnaire. After taking the anthropometric measurements, the warming-up was carried out, which was a 10 min exercise on a veloergometer, (50 W, frequency 70 times/min). Surface EMG electrodes were attached on the subjects' biceps femoris muscle. Then the subject was seated in the *Biodex* chair, where his isometric knee extensor and flexor muscle MVC was registered simultaneously with EMG. Patella length and cross-sectional area were examined applying ultrasonography at rest. By means of ultrasonography, 3 isometric knee extensions and 3 passive knee extensions were filmed simultaneously with EMG recording and goniometry as well as dynamometry.

After muscle function testing and patellar tendon ultrasonography, the subjects performed 3 vertical jumps on the contact force plate. At the same time kinematic parameters of the jumps were recorded using the *Contemplas Templo* system. After completing the jumps, 2 video cameras recorded sagittal and frontal planes of the standing position. Research protocol is given in **Figure 3**.

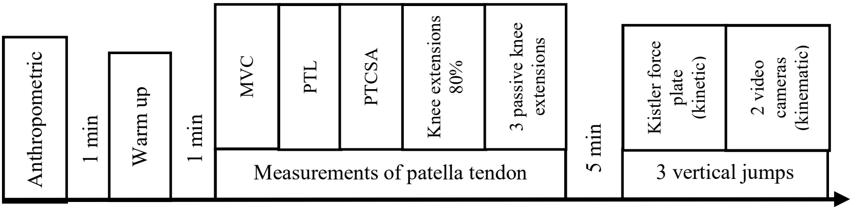

Figure 3. *Protocol of Study III*

Note. MVC – isometric maximal voluntary contraction; PT – patella tendon; PTCSA – patella tendon cross section area.

1.4. Mathematical statistics

Statistical analysis was used to provide means and standard deviations (SD) of the data described. Shapiro-Wilk test was used to determine whether the data obtained were normally distributed. During the research, the effect the side of the body (dominant vs. non-dominant) and the group (players vs. the controls) was compared using a two-factor analysis of variance (ANOVA). In case of the group effect, *Tukey Post-hoc Test* was carried out to establish the differences between different groups. Nonparametric *Wilcoxon* test was used to evaluate the difference of movement stability test results. Aiming at calculating the odds ratio, the subjects were divided into low (rated by 3 and 4 points), and high (rated by 1 and 2 points) stability groups. The relationship between knee pain and the movement stability (low/high), or morphological changes (ultrasonography – positive/negative) was described by the Four-field 2 x 2 contingency table, the statistical evaluation accuracy was set up at 95% confidence interval (CI). During the third study, Student *t* test was used to compare the differences between the groups with a normal distribution of variables, and Wilcoxon W test – when the groups could not be assumed to be normally distributed. Analysis of the difference between Q-angle and knee *valgus* angle was performed using the nonparametric Wilcoxon signed-rank criterion 2 for related samples. Confidence interval was determined using the *Monte Carlo* method. In all cases, the difference was considered significant when $p < 0.05$. Calculations are performed using *IBM SPSS v. 20* software (IBM, Armonk, NJ).

2. RESEARCH RESULTS

2.1. Bilateral differences in morphological and functional parameters for children adapted to physical exercise and suffering from pain in the dominant arm, and children not engaged in sport

2.1.1. Arm muscle contraction torque

Arm muscle contraction peak torque of the dominant and non-dominant arms in the groups of baseball players and the controls was not significantly different performing the internal and external shoulder rotation in the concentric and eccentric mode ($p > 0.05$, **Table 2**). However, the eccentric shoulder external rotation peak torque was higher in the control group comparing the results to those of baseball players (20.1%; $p < 0.05$). Accordingly, the ratio of the eccentric external rotation and concentric internal rotation was higher in the control group in comparison to that of the baseball players (17.9%, $p < 0.05$).

In addition, muscle strength in the dominant and non-dominant arms in subjects did not differ in the elbow and shoulder flexion and extension regardless of the mode of performance and the group of subjects ($p > 0.05$).

Table 2. *Comparison of peak torques between the baseball players and the control group for the dominant and non-dominant arms.*

Test	Baseball players		Control group	
	Dominant	Nondominant	Dominant	Nondominant
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Shoulder				
Concentric				
Internal rotation (N·m)	31.7 ± 8.0	28.4 ± 7.6	32.5 ± 6.81	29.5 ± 6.8
External rotation (N·m)	18.7 ± 3.8	18.0 ± 3.5	22.4 ± 4.1	21.8 ± 4.9
Eccentric				
Internal rotation (N·m)	37.8 ± 9.4	34.1 ± 5.0	39.9 ± 5.3	39.4 ± 7.5
External rotation (N·m)*	16.8 ± 5.6	15.3 ± 3.8	19.9 ± 3.8	20.3 ± 6.6
Ratio				
IRecc / IRcon	1.23 ± 0.26	1.20 ± 0.24	1.31 ± 0.15	1.37 ± 0.19
ERecc / IRcon*	0.55 ± 0.05	0.55 ± 0.04	0.64 ± 0.01	0.70 ± 0.03
ERcon / IRcon	0.65 ± 0.04	0.71 ± 0.04	0.70 ± 0.01	0.74 ± 0.03
Shoulder				
Concentric				
Flexion (N·m)	35.4 ± 12.4	32.9 ± 12.2	35.2 ± 9.4	33.0 ± 7.9
Extension (N·m)	44.4 ± 7.8	42.6 ± 10.8	46.9 ± 9.1	44.8 ± 10.2
Ratio				
Flexion / Extension	0.79 ± 0.04	0.77 ± 0.06	0.78 ± 0.04	0.77 ± 0.03
Elbow				
Concentric				
Flexion (N·m)	19.5 ± 5.5	17.7 ± 4.4	19.8 ± 4.0	18.8 ± 3.6
Extension (N·m)	27.3 ± 5.6	26.7 ± 7.7	27.9 ± 8.2	26.3 ± 7.9
Ratio				
Flexion / Extension	0.71 ± 0.02	0.67 ± 0.03	0.73 ± 0.03	0.75 ± 0.04

Note. ER – external rotation; IR – internal rotation; ecc – eccentric; con – concentric; * – $p < .05$, for group effect.

2.1.2. Range of motion

There were no differences in the range of motion between the dominant and non-dominant arms in both groups ($p > 0.05$; **Table 3**). Shoulder joint internal rotation ROM was significantly lower in baseball players compared to that of the controls (5.6%; $p < 0.05$), though external rotation ROM did not differ between the two groups ($p > 0.05$). Elbow flexion and extension range of motion was not different between the two groups ($p > 0.05$).

Table 3. *Comparison of the range of motion (deg) between the baseball players and the control group for the dominant and non-dominant arms*

Motion	Baseball players		Control group	
	Dominant	Nondominant	Dominant	Nondominant
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Shoulder				
Internal rotation*	71.9 ± 10	76.3 ± 10.6	79.9 ± 7.8	77.1 ± 7.7
External rotation	87.9 ± 9.7	88.4 ± 10.8	89.6 ± 10.2	88.8 ± 7.4
Total motion	159.7 ± 15.9	164.7 ± 18.0	169.5 ± 1.,0	166.0 ± 12.8
Elbow				
Extension	5.4 ± 2.4	4.6 ± 1.3	5.7 ± 2.9	5.8 ± 4.4
Flexion	149.4 ± 5.4	151.9 ± 8.0	152.8 ± 5.7	152.5 ± 5.2
Total motion	154.7 ± 6.5	156.5 ± 8.4	158.5 ± 7.4	158.4 ± 7.7

Note. * – $p < .05$, for group effect.

2.1.3. Morphological parameters

Morphological parameters of the dominant and non-dominant arms measured by ultrasonography, revealed no significant differences in both the players and the controls ($p > 0.05$; **Table 4**). However, baseball players' supraspinatum muscle tendon was 0.07 cm thicker, compared that of the control group (12.2%, $p < 0.05$). Articular thickness of the humeral capitulum and ulnar collateral ligament thickness were greater in baseball players compared with the control group (respectively 22.2%, 15.4%, $p < 0.05$). Medial ulnohumeral distance with no *valgus* stress was greater in baseball players (17.9%, $p < 0.05$), but in case of *valgus* stress applied the difference between the groups was not.

There were two cases in which the two ossification centers in the medial epicondylitis were seen in the dominant baseball players' arm, and one case – in subjects of the control group. One of the ossification centers was established in subjects of both groups in the non-dominant arm, besides, medial epicondylitis of both arms were established for three subjects in the control group.

Table 4. *Comparison of ultrasonography measures (cm) between baseball players and the control group for the dominant and non-dominant arms*

Parameter	Baseball players		Control group	
	Dominant	Nondominant	Dominant	Nondominant
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Subscapular tendon thickness	0.52 ± 0.06	0.52 ± 0.06	0.48 ± 0.09	0.49 ± 0.09
Supraspinatus tendon thickness *	0.58 ± 0.09	0.56 ± 0.07	0.50 ± 0.07	0.50 ± 0.07
Articular cartilage thickness of the humeral head *	0.18 ± 0.05	0.18 ± 0.05	0.14 ± 0.03	0.14 ± 0.03
Ulnar collateral ligament thickness *	0.34 ± 0.05	0.31 ± 0.03	0.28 ± 0.03	0.27 ± 0.03
Articular thickness of the humeral capitulum	0.22 ± 0.05	0.22 ± 0.04	0.19 ± 0.04	0.20 ± 0.04
Valgus stress test:				
Medial ulnohumeral distance with no *valgus* stress *	0.14 ± 0.03	0.14 ± 0.02	0.11 ± 0.03	0.12 ± 0.03
Medial ulnohumeral distance with applied *valgus* stress	0.20 ± 0.06	0.18 ± 0.04	0.17 ± 0.05	0.18 ± 0.03

Note. * – $p < .05$, for group effect.

2.2. Bilateral differences in morphological and functional parameters for children adapted to physical exercise and suffering from pain in the leg, not suffering from pain, and children not engaged in sport

2.2.1. Pain intensity, frequency and description of subjects

Asymptomatic players did not complain of any pain, but symptomatic players' pain intensity and frequency was assessed by 1.5 ± 0.7 points 10.7 ± 5.7 days per month. Prevalence of pain in the dominant and non-dominant leg was not significantly different (8 – in the dominant leg, 8 – in the non-dominant leg, 13 – in both legs). Symptomatic players were taller than asymptomatic subjects and controls, respectively 5.0 and 6.9 cm ($p < .05$ in both cases), and the body weight did not differ in all groups.

2.2.2. Leg muscle contraction torque and co-activation

Indicators of knee extensors muscles isometric MVC, concentric muscle contraction peak torque at the speed of 60°/s and eccentric muscle contraction peak torque at the speed of 60°/s were higher for the dominant leg as compared to the non-dominant one ($p < .05$, **Table 5**).

The subjects in the symptomatic and asymptomatic groups generated higher muscle contraction peak torque rates compared to the control group by performing concentric contraction during the leg extension and flexion at the speed of 60°/s, and the eccentric contraction during leg flexion at the speed 60°/s ($p < .05$, **Table 5**).

Besides, symptomatic players achieved higher muscle contraction torque indicators during knee flexion isometric contractions (18.2%), and knee extension concentric contractions (11%) as well as leg flexion (11.3%) at the speed of 240°/s and extension (12.7%), flexion (17%) at the speed of 60 and 240°/s (15.6 and 14.3%) during the eccentric contraction, compared to players in the control group ($p <.05$; **Table 5**). Symptomatic players also achieved higher indicators of quadriceps isometric contraction torque (10.1%) and eccentric extension torque (12.1%) at the speed of 60°/s compared to asymptomatic players ($p = .044$, **Table 5**).

During muscle flexion eccentric contraction at the speed of 60°/s, lower significance of co-activation was in the dominant leg (17.5%, $p < .05$) compared to the non-dominant one. No significant differences in co-activation between the dominant and non-dominant legs performing concentric and isometric muscle contractions were established (**Table 5**).

During isometric flexion of the leg (22.8%) and eccentric contractions at the speed of 60°/s (20.6%), co-activation of symptomatic players was lower than that of the controls, and co-activation in asymptomatic players was lower during concentric leg flexion at the speed of 60°/s (31.9%) and 240°/s (19.6%) compared to that of controls ($p < .05$, **Table 5**).

Significant differences in co-activation between symptomatic and asymptomatic groups were observed only in eccentric contractions during leg flexion at the speed of 60°/s (17.8% lower in the symptomatic group). Co-activation was always lower in leg flexion compared to leg extension ($p < .05$).

Table 5. *Comparison of peak torques and co-activation for the dominant and non-dominant leg of symptomatic (S) and asymptomatic (A) basketball players and controls (C)*

	Symptomatic		Asymptomatic		Control		Side effect	Group effect
	Dominant	Nondominant	Dominant	Nondominant	Dominant	Nondominant		
Isometric								
MVC extension CoAc	175 ± 29 (11.7 ± 4.7)	162 ± 34 (15.7 ± 8.5)	159 ± 48 (15.4 ± 7.4)	144 ± 38 (14.9 ± 7.4)	160 ± 42 (17.5 ± 7.4)	149 ± 35 (18.0 ± 8.5)	D > ND; $p < 0.05$ $p > 0,05$	S > A; $p = .044$ S < C; $p = .012$
MVC flexion CoAc	87.8 ± 21.2 (8.0 ± 3.7)	78.0 ± 17.6 (7.3 ± 3.9)	78.6 ± 25,5 (8.1 ± 3.9)	70.6 ± 23.1 (7.8 ± 4.0)	71.2 ± 17.3 (7.9 ± 3.4)	64.4 ± 20,8 (7.7 ± 3.5)	D > ND; $p < 0.05$ $p > 0.05$	S > C; $p < .001$ $p > .05$
Concentric								
60°/s extension CoAc	154 ± 29 (14.0 ± 5.9)	147 ± 35 (14.9 ± 7.6)	145 ± 42 (17.0 ± 9.1)	135 ± 33 (16.6 ± 6.5)	130 ± 34 (16.9 ± 7.0)	125 ± 33 (18.3 ± 8.0)	D > ND; $p < 0.05$ $p > 0.05$	S,A > C; $p = .041$ $p > .05$
60°/s flexion CoAc	108 ± 26 (7.9 ± 5.6)	102 ± 23 (8.2 ± 4.2)	103 ± 29 (6.6 ± 2.9)	93 ± 25 (6.2 ± 2.4)	91 ± 26 (9.9 ± 3.8)	83 ± 19 (8.9 ± 4.2)	D > ND; $p < 0.05$ $p > 0.05$	S,A > C; $p = .048$ A < C; $p < .001$
240°/s extension CoAc	95.9 ± 16.3 (18.3 ± 7.6)	91.6 ± 19.7 (17.0 ± 9.0)	86.9 ± 22.8 (17.4 ± 7.4)	86.0 ± 21.4 (19.3 ± 6.9)	83.7 ± 23.1 (1.,2 ± 7.9)	83.3 ± 21.4 (18.6 ± 7.4)	$p > 0.05$ $p > 0.05$	S > K; $p = .025$ $p > .05$
240°/s flexion CoAc	79.4 ± 18.8 (10.0 ± 4.3)	75,8 ± 14.6 (10.3 ± 5.9)	75.4 ± 20.6 (9.0 ± 3.5)	71.4 ± 17.5 (8.0 ± 4.0)	71.0 ± 21.6 (11.4 ± 3.2)	66.5 ± 17.1 (9.7 ± 4.6)	$p > 0.05$ $p > 0.05$	S > C; $p < .001$ A < C; $p = .043$
Eccentric								
60°/s extension CoAc	199 ± 39 (14.7 ± 6.4)	194 ± 40 (18.0 ± 7.2)	190 ± 60 (17.8 ± 9.9)	179 ± 50 (22.0 ± 11.9)	173 ± 43 (18.9 ± 7.0)	170 ± 42 (22.3 ± 9.1)	$p > 0.05$ D < ND; $p < 0.05$	S > C; $p = .017$ S < A,C; $p < .05$
60°/s flexion CoAc	136 ± 34 (8.0 ± 4.8)	129 ± 35 (9.5 ± 5.7)	124 ± 42 (10.1 ± 6.6)	109 ± 32 (7.5 ± 4.3)	115 ± 34 (10.3 ± 5.1)	105 ± 29 (9.2 ± 4.3)	D < ND; $p < 0.05$ $p > 0.05$	S > A,C; $p = .041$ $p > .05$
240°/s extension CoAc	143 ± 44 (17.1 ± 7.2)	159 ± 46 (15.6 ± 8.4)	132 ± 59 (21.2 ± 8.7)	126 ± 54 (17.3 ± 9.2)	133 ± 57 (16.5 ± 8.9)	122 ± 56 (21.0 ± 12.2)	$p > 0.05$ $p > 0.05$	S > C; $p = .048$ $p > .05$
240°/s flexion CoAc	130 ± 37 (13.3 ± 7.2)	122 ± 42 (12.6 ± 5.8)	118 ± 40 (17.8 ± 8.3)	106 ± 37 (16.5 ± 8.4)	112 ± 26 (15.4 ± 8.5)	104 ± 29 (14.6 ± 12.2)	$p > 0.05$ $p > 0.05$	S > C; $p = .046$ $p > .05$

Note. Values are presented as mean ± SD; peak torque is given in N m; co-activation in percent; MVC – maximal voluntary contraction; CoAc – co-activation; D – dominant leg, ND – non-dominant leg.

2.2.3. Range of motion

Significant difference in the range of motion (ROM) has not been established in any group of subjects according to the laterality of the body (**Figure 6**). Range of motion of symptomatic of players was higher than that in the control group during knee joint during extension in the Slump test (p = .020; 18.7%), but lower during hip external rotation (18.8%, p < .001) and knee fend with subjects lying prone (6.3%, p < .001). Also in the asymptomatic group of players who felt knee pain hip external rotation was (15.7%, p < .05) compared to that of the control group.

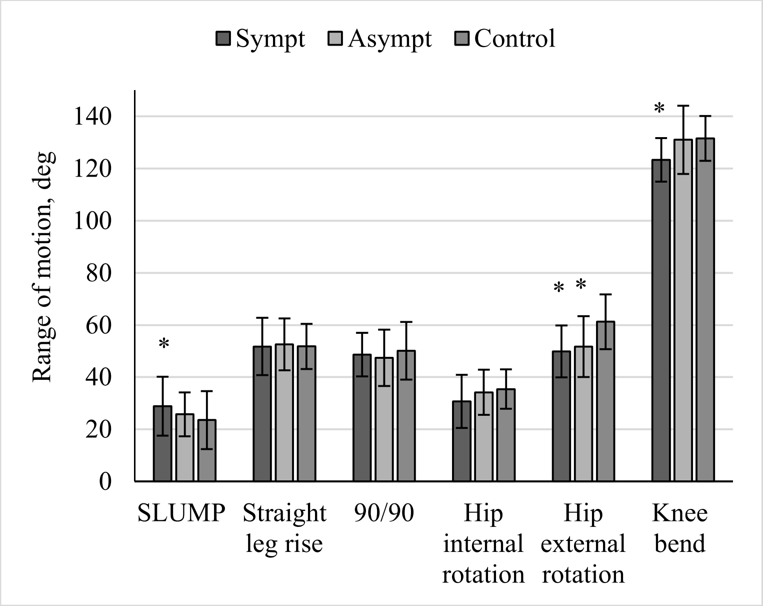

Figure 6. *Comparison of the range of motion for basketball players in symptomatic and asymptomatic groups and controls*

Note. * – p < .05 compared to the control group; the data are presented as mean ± SD.

2.2.4. Movement stability

Visual examination revealed that the control group subjects had higher points single leg squats and active straight leg raise test compared to basketball players ($p < .05$, **Figure 7**). Movement stability points in the symptomatic and asymptomatic groups of basketball players did not differ significantly. The summary of results for athletes engaged and not engaged in sport showed that active straight leg raise test was the highest knee pain prediction factor indicating a little more than twice higher risk of pain (95% CI 1.1 to 4.2, $p < .05$). All stability test results were associated with an increased risk of knee pain by 1.5 times (95% CI 1.2 to 2.1, $p < .05$).

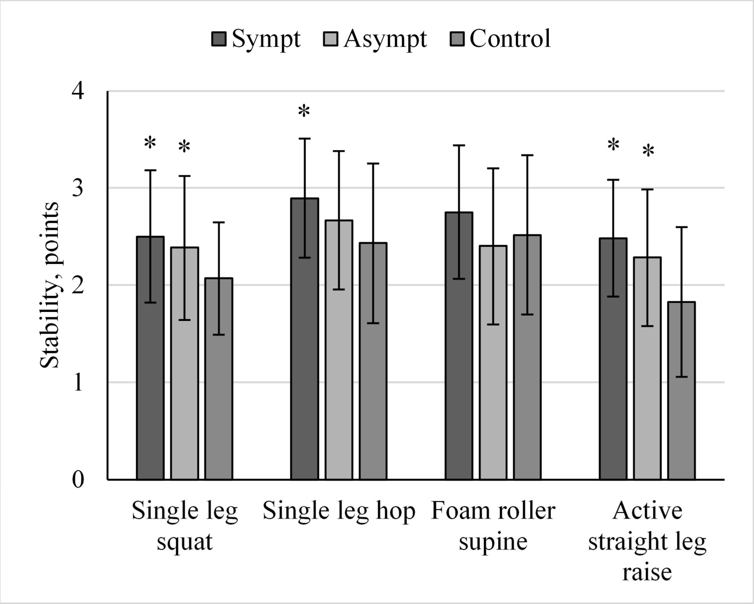

Figure 7. *Qualitative comparison of movement stability assessment for basketball players in symptomatic and asymptomatic groups and controls*

Note. * – $p < 0.05$ compared to the control group; the data are presented as mean ± SD.

2.2.5. Proprioception

During leg extension at 20% MVC, the absolute error between the groups did not differ ($p > .05$), but during leg flexion it was lower in the symptomatic group of players than in the control group (dominant – 28.5%, non-dominant – 30%, $p < .05$, **Figure 8**).

During leg extension, the absolute error was lower in the dominant than the non-dominant leg ($p < .001$).

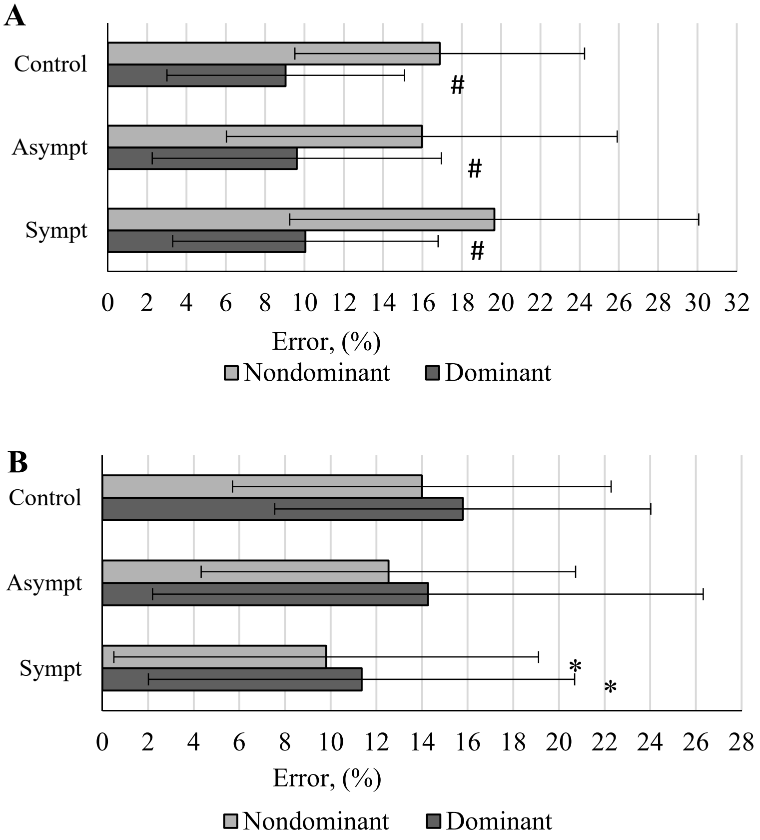

Figure 8. *Relative comparison of the absolute error values for basketball players in symptomatic and asymptomatic groups and controls performing isometric muscle contractions at 20% MVC with the dominant and non-dominant leg*

Note. A – leg extension; B – leg flexion; * – $p < .05$ compared to the control group; # – $p < 0.001$ comparing the performance with the dominant and non-dominant leg; the data are presented as mean ± SD.

2.2.6. Morphological parameters

Knee joints of 176 adolescents were examined, among them 44 knee joints were painful and pathology was established in 26 of them. The most common diagnosis was Osgood-Shlatter disease (50.0%), muscle semimembranosus bursitis (19.2%), patellar division into two halves (lat. *patella bipartida*, 15.4%), patellar tendon tendinitis (15.4%). Morphological changes were associated with 8.6 fold increased risk of knee pain (95% CI 3.7 to 19.5, $p < .001$). Patellar tendon cross-sectional area and thickness did not differ between the groups.

2.3. Differences in kinematic and kinetic parameters as well as mechanical properties of the patellar tendon for adolescents adapted to physical exercise, suffering and not suffering from pain

2.3.1. Morphological and mechanical properties of tendon

Patellar tendon length and cross-sectional area did not differ significantly between basketball players who suffered (symptomatic) and did not suffer (asymptomatic) from knee pain (**Table 6**). However, in the symptomatic group, cross-sectional area of the upper part of the tendon was significantly bigger than that of the middle part (p = .006, CI 0.004 to 0.008), and the lower part ($p = .039$, CI 0.034 to 0.044), and in the asymptomatic group, the cross-sectional area of the upper part of the tendon was significantly bigger than that of the middle part ($p = .004$, CI 0.002 to 0.005).

***Table 6**. Patellar tendon length and cross-sectional area (CSA) in the symptomatic and asymptomatic groups*

Parameters	Symptomatic group	Asymptomatic group	*p* value
Length (cm)	5.22 ± 0.45	5.00 ± 0.45	.322
CSA in the proximal part (mm^2)	92.65 ± 14.60	89.00 ± 9.75	.530
CSA in the middle part (mm^2)	88.33 ± 12.05*	86.23 ± 8.93$^{\#}$	.530
CSA in the distal part (mm^2)	87.64 ± 11.45*	86.88 ± 7.33	.484
Mean CSA (mm^2)	89.54 ± 12.51	87.37 ± 8.45	.530

Note. *p* – value comparing symptomatic and asymptomatic groups; * – $p < .05$ compared to CSA in the proximal part in the symptomatic group; # – $p < .05$ compared to CSA in the proximal part in the asymptomatic group

Absolute tendon stiffness and Young's modulus absolute were significantly lower in the symptomatic group as compared to the asymptomatic group **(Table 7).** Tendon stress did not differ between the groups, but in both groups the upper part tendon stress was significantly lower than the one in the middle part (in the symptomatic group $p = .006$, CI 0.004 to .008; in the asymptomatic group $p = .015$, CI 0.011 to 0.018). In addition, in the symptomatic group there was a higher tendency to tendon stress in the lower part compared with the upper part ($p = .081$, CI 0.074 to 0.088).

Table 7. *Patellar tendon mechanical properties in symptomatic and asymptomatic groups of subjects*

Parameters	Symptomatic group	Asymptomatic group	*p* value
Peak force (N)	4242.89 ± 915.95	4264.20 ± 769.83	1.000
Stiffness, absolute (kN/mm)	2.14 ± 0.41	2.89 ± 0.64	.013
Stress proximal tendon (Mpa)	46.64 ± 11.57	48.78 ± 12.11	.597
Stress middle tendon (Mpa)	48.56 ± 11.10	50.24 ± 12.03	.650
Stress distal tendon (Mpa)	48.87 ± 10.49	49.58 ± 11.06	.821
Strain (%)	7.48 ± 1.75	7.12 ± 1.47	.705
Elongation (mm)	3.92 ± 1.03	3.57 ± 0.85	.450
Young's modulus absolute (Gpa)	1.26 ± 0.25	1.68 ± 0.49	.034

Note. p – value comparing symptomatic and asymptomatic groups the data are presented as mean ± SD.

2.3.2. Kinematic parameters of vertical jump

There was no difference of Q-angle in the frontal plane and knee *valgus* angle between the healthy and painful legs in symptomatic subjects as well as right and left legs in asymptomatic subjects. Regardless of the side of the body Q-angle value was significantly lower in symptomatic patients (CI from 0.040 to 0.050, **Table 8**). Knee *valgus* angle did not differ between the groups. The ratio of pelvis width and femoral length was significantly lower in symptomatic subjects ($t = -2.321$, $p = .032$).

***Table 8.** Kinematic parameters of patellar tendon jump in the frontal plane in symptomatic and asymptomatic groups of subjects*

Parameters	Symptomatic group	Asymptomatic group	*p* value
Pelvis width (m)	0.24 ± 0.02	0.25 ± 0.01	.602
Femoral length (m)	0.50 ± 0.02	0.49 ± 0.02	.714
Pelvis width/femoral length, %	48.77 ± 3.2	51.65 ± 2.38	.032[a]
Q-angle (degrees)	8.44 ± 3.57	10.61 ± 3.94	.045[b]
Valgus angle (degrees)	–2.97 ± 2.84	–4.25 ± 2.74	.956

Note. p value comparing in symptomatic and asymptomatic groups; data are presented as mean ± SD; [a] Mann–Whitney *U* test; [b] Wilcoxon *W* test.

Maximum knee *varus* and *valgus* angles in the phases of vertical jump squats and landing for symptomatic and asymptomatic subjects are presented in **Figure 10**. Maximum *varus* angles in symptomatic subjects were significantly lower (9.56 ± 9.32°) compared to those in asymptomatic group of subjects (17.43 ± 13.15°) in the squat phase (t = -2.186, p = .035), but did not differ in the landing phase (respectively 8.99 ± 9.55° and 9.28 ± 9.38°). Maximum *valgus* angle in squat and landing phases did not differ for subjects in symptomatic and asymptomatic groups.

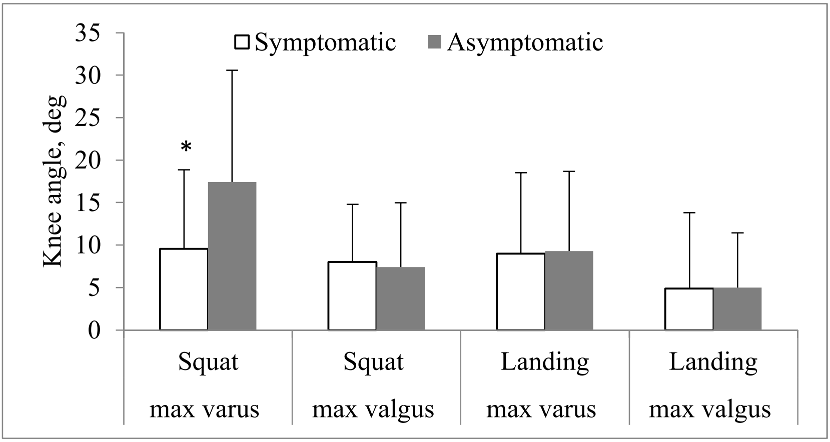

***Figure 10.** Maximal knee varus and valgus angles (the average of both legs and SD in the frontal plane in the phases of squat and landing*

Note. * – *t* test $p < .05$ comparing symptomatic and asymptomatic groups.

Changes in the distance between the knees in the frontal plane in the phases of squats and landing phases for symptomatic and asymptomatic subjects are given in **Figure 11**. In the squat phase, symptomatic players' knees moved inward more compared to asymptomatic players (3.67 ± 3.67 cm, max. 9.76 cm, and 0.35 ± 0.73 cm, max. 1.9 cm) (*p* = .039; CI 0.034 to 0.044), and this group had a higher tendency of knee movement inwards (3.78 ± 3.61 cm, max. 8.40 cm, and 1.16 ± 2.01 cm, max. 4.42 cm) during the landing phase (*p* = .057; CI 0.051 to 0.062).

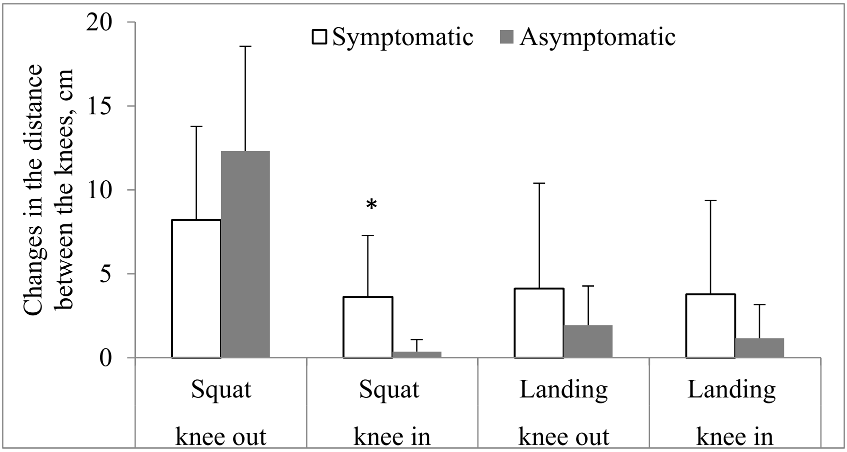

Figure 11. *Changes in the distance between the knees of the right and the left legs in the frontal plane during the squat and landing phases of vertical jump*

Note. * – Mann–Whitney *U* test, *p* < .05 (CI 0.034 – 0.044) comparing value comparing in symptomatic and asymptomatic groups.

2.3.3. Kinetic parameters of vertical jump

Kinetic parameters of vertical jump are given in **Table 9**. The value of leg stiffness in the squat phase was significantly higher in the asymptomatic group (*p* = 0.015, CI 0.013 to 0.016). The tendency of lower leg stiffness was observed in the eccentric phase and higher peak power in the concentric phase in symptomatic subjects compared to the asymptomatic group (*p* = .055, CI 0.049 to 0.061 and *p* = .055, CI 0.043 to 0.054).

Table 9. *Kinetic parameters of vertical jump in symptomatic and asymptomatic subjects*

Parameters	Symptomatic group	Asymptomatic group	*p* value
Peak force in the eccentric phase / body weight	1.09 ± 0.27	1.11 ± 0.18	.671
Peak force in the concentric phase / body weight	1.41 ± 0.15	1.32 ± 0.11	.400
Peak force in the landing phase / body weight	4.33 ± 1.81	4.88 ± 1.82	.759
Eccentric force growth rate (BW/s)	6.57 ± 3.40	6.37 ± 1.53	.671
Peak power of concentric phase / body weight	5.49 ± 0.58	5.09 ± 0.26	.055
Average leg stiffness during landing (N/m/kg)	290.07 ± 185.16	322.07 ± 153.68	.015
Average leg stiffness in the eccentric phase (N/m/kg)	68.41 ± 19.55	77.25 ± 9.52	.055

Note. p value comparing in symptomatic and asymptomatic groups; data are presented as mean ± SD.

CONCLUSIONS

1. Side-to-side changes of shoulder and elbow structure and function in 11–12-year-old baseball players are not related to pain occurring during throws, but a small shoulder joint eccentric external rotation torque and decreased internal rotation range of motion may have an effect on the occurrence of pain.
2. Side-to-side differences of the knee joint structure and function in14–15-year-old male basketball players are not related to early diagnosed knee pain. Pain is more prevalent in taller players and those with smaller pelvic movement stability. In addition, pain is often accompanied by the knee morphological pathology in which the risk of developing knee pain increases more than 8 times.
3. Q-angle, knee *valgus* movement and leg stiffness are related to increased and less stiff patellar tendon and early diagnosed idiopathic knee pain in 14–15-year-old basketball players. When intramuscular coordination is lower, pain is felt more often.

SANTRAUKA

Sportas ir fizinė veikla stiprina raumenų, širdies ir kraujagyslių sistemų darbą, mažina antsvorį, gerina nuotaiką ir darbingumą (Haskell et al., 2007). Reguliarūs fiziniai pratimai yra naudingi pažintinei funkcijai ir didina pasitikėjimą savimi. Vis dėlto, augant konkurencingumui, sportuojantys vaikai ir paaugliai patiria didelį spaudimą laimėti, taigi fizinės pratybos intensyvėja, dažnėja ir tampa labiau specializuotos. Padidėjęs ir / ar nesubalansuotas fizinis krūvis sukelia sveikatos sutrikimų dėl patiriamų traumų (Ladenhauf, Graziano, & Marx, 2013).

Manoma, kad vienkartiniai fiziniai krūviai mažai veikia sausgysles ir raumenis (Ladenhauf et al., 2013). Visgi praktikoje taikomi ne pavieniai, bet nuolatiniai fiziniai krūviai ir labai dažnai kitas krūvis atliekamas ne visiškai atsigavus po prieš tai buvusio. Nuolatinė perkrova, biomechaniškai klaidingai atliekami pratimai ir fizinis krūvis esant nuovargiui gali formuoti lėtinius klinikinius sausgyslių pakitimus (Helland et al., 2013). Daugiau nei pusė patiriamų rankų ar kojų traumų įvyksta ne fizinio kontakto su varžovais metu. Tai labiau susiję su raumenų jėgos, judesių amplitudės disbalansu, judesių valdymo ir raumenų aktyvavimo sutrikimais, sausgyslių mechaninių ir morfologinių savybių pokyčiais (Gagnier, Morgenstern, & Chess, 2013; Ladenhauf et al., 2013).

Vaikai, žaidžiantys beisbolą, gali būti jautrūs pažeidimui, nes kamuoliukas metamas dalyvaujant vienos kūno pusės raumenims (Escamilla, Fleisig, Zheng, Barrentine, & Andrews, 2001). Toks asimetrinis pratimas gali sukelti funkcinį disbalansą, kuris per ilgesnį laiką lemia atskirų raumenų grupių, sausgyslių ir raiščių dvipusių skirtumų atsiradimą (Byram et al., 2010). Ankstesnių tyrimų metu nustatyta didesnė kamuoliuką metančios rankos žastikaulio išorinės rotacijos judesio amplitudė ir mažesnė vidinės rotacijos judesio amplitudė, lyginant su priešingos pusės peties sąnariu (Borsa, Dover, Wilk, & Reinold, 2006; Byram et al., 2010; Donatelli et al., 2000; Wilk et al., 2009). Raumenų ir sausgyslių struktūriniai bei funkciniai dvipusiai skirtumai dažnesni suaugusiųjų populiacijoje (Byram et al., 2010; Chen, Lin, Chen, Lin, & Nosaka, 2011; Noffal, 2003). Visgi rankų judesio amplitudės ir jėgos dvipusiai skirtumai buvo nustatyti augimo ir brendimo metu (Harada et al., 2010; Hurd et al., 2011; Levine et al., 2006; Trakis et al., 2008). Lieka neaišku, kokiu amžiaus tarpsniu galima didžiausia traumų rizika, kada pasireiškia dvipusiai skirtumai

kultivuojant asimetrinės apkrovos sportą ir koks dvipusių skirtumų ryšys su traumų rizika. Kadangi berniukų brendimo pradžioje jungiamasis audinys yra ypač jautrus intensyviems ekscentriniams krūviams (Harada et al., 2010), kėlėme hipotezę, kad reguliariai žaidžiant beisbolą, kurio metu dažnai apkraunami vienos pusės sąnariai ir raumenys, jaunesniojo amžiaus sportininkams gali vystytis atskirų raumenų grupių, sausgyslių ir raiščių asimetrija, kuri gali lemti didesnę traumų riziką, lyginant su nesitreniruojančiais vaikais.

Paaugliai ypač jautrūs pažeidimui, nes brendimo laikotarpiu vyksta daug struktūrinių, hormoninių, biomechaninių ir funkcinių organizmo pokyčių (Adirim & Cheng, 2003; Cassas & Cassettari-Wayhs, 2006; Frisch, Croisier, Urhausen, Seil, & Theisen, 2009). Maždaug trečdalis paauglių traumų susijusios su kelio sąnario minkštųjų audinių pažeidimais (Foss, Myer, Magnussen, & Hewett, 2014). Anksčiau atliktų tyrimų duomenimis, kasmet net iki 54% paauglių sportininkų patiria kelio sąnario skausmą (Calmbach & Hutchens, 2003; Fagan & Delahunt, 2008; Louw, Manilall, & Grimmer, 2008). Žaidžiant krepšinį, paauglių nekontaktinio kelio sąnario traumų skaičius yra didesnis negu kitų sportininkų (Belechri, Petridou, Kedikoglou, & Trichopoulos, 2001; Caine, Maffulli, & Caine, 2008). Traumos dažnesnės tarp krepšininkų, nes žaidžiant dažnai sustojama, keičiama kryptis, pašokama (Cumps, Verhagen, & Meeusen, 2007; Drakos, Domb, Starkey, Callahan, & Allen, 2010). Dėl tokios veiklos ypač didelė apkrova tenka kelio sąnario audiniams, raumens ir sausgyslės kompleksui (Cassas & Cassettari-Wayhs, 2006). Tai sukelia labiausiai apkraunamų struktūrų skausmą, todėl krepšinio fiziniams krūviams adaptuotų sportininkų raumenų ir sausgyslių tyrimai gali parodyti skirtumus (lyginant su nesportuojančiais paaugliais) ir išryškinti naujus traumų prognozavimo rodiklius. Kėlėme hipotezę, kad paauglių krepšininkų, kurie jaučia kelio sąnario skausmus, bus blogesnis raumenų jėgos balansas, aktyvacija ir koordinacija, mažesnė judesių amplitudė ir dažnesni sausgyslių pažaidos požymiai nei krepšininkų, nejaučiančių skausmo, ir nesportuojančiųjų.

Biomechaninių ir klinikinių tyrimų rezultatai patvirtina teiginį, kad viršutinės kūno dalies padėtis gali turėti įtakos šlaunikaulio ir blauzdikaulio, kelio girnelės ir šlaunikaulio sąnarių mechaninėms savybėms (Reiman, Bolgla, & Lorenz, 2009). Sutrikus klubų, dubens ir liemens judesių valdymui, labiau apkraunamas kelio sąnarys, ir tai gali lemti traumos atsiradimą (Cibulka & Threlkeld-Watkins, 2005; Powers, 2010). Atliekant šuolius, liemens šoniniai judesiai, per didelis šlaunų pritraukimas bei vidinė rotacija gali padidinti kelių suglaudimą pėdų atžvilgiu (Hollman et al., 2009). Kelių suglaudimas didina kelio sąnario *valgus* kampą ir kelio sąnario traumų riziką (Hewett et al., 2005), kelio girnelės ir šlaunikaulio sąnario disfunkciją (Blackburn & Padua, 2009). Kelio girnelės sausgyslės dinaminės apkrovos poveikis, įskaitant kelio *valgus* ar Q-kampo pasikeitimus, sausgyslės dydžiui ir mechaninėms savybėms nėra žinomas. Esant tendinopatijai, sausgyslė gali būti elastingesnė (Helland et al., 2013) arba elastingumas nesikeičia (Couppé et al., 2013; Kongsgaard et al., 2010), tačiau sausgyslė būna ne tokia standi. Tai gali būti susiję su padidėjusiu girnelės sausgyslės storiu ir girnelės skausmu, funkciniu nepakankamumu (De Zordo et al., 2009, 2010; Ooi et al., 2016). Kadangi skausmas ir funkcinės jėgos sumažėjimas gali reikšti sportininko karjeros pabaigą, svarbu įvertinti, kaip kūno laikysena, klubų, dubens bei liemens judesiai gali keisti kelio sąnario apkrovą, sausgyslės morfologiją ir mechanines savybes. Todėl kėlėme hipotezę, kad krepšinio žaidėjų, kurie jaučia kelio sąnario skausmus, dėl kinematinių ir kinetinių rodiklių skirtumo kelio sąnario apkrova bus didesnė ir turės įtakos girnelės sausgyslės mechaninėms savybėms.

Tyrimo tikslas – išsiaiškinti griaučių raumenų ir sausgyslių lėtinių pažeidimų pirminių rodiklių raišką padidintos rizikos, nesportuojančių vaikų ir paauglių grupėse.

Tyrimo uždaviniai

1. Palyginti fiziniams krūviams adaptuotų vaikų, jaučiančių dominuojančios rankos skausmą, ir jo nejaučiančių dvipusius morfologinių ir funkcinių rodiklių skirtumus.
2. Palyginti fiziniams krūviams adaptuotų paauglių, jaučiančių kelio skausmą, jo nejaučiančių ir nesportuojančių paauglių dvipusius morfologinių ir funkcinių rodiklių skirtumus.
3. Palyginti fiziniams krūviams adaptuotų paauglių, jaučiančių kelio skausmą, ir jo nejaučiančių kinematinius bei kinetinius rodiklius, girnelės sausgyslės mechanines savybes.

Teorinė ir praktinė tyrimo reikšmė. Treneriai, sporto medikai ir kineziterapeutai turėtų atkreipti dėmesį į tai, kad 11–12 metų beisbolininkų skausmas nėra susijęs su raumenų susitraukimo jėgos, judesių amplitudės ir morfologiniais dvipusiais skirtumais. Paauglių krepšininkų kelio sąnario skausmas susijęs su aukštesniu ūgiu, mažesniu juosmens ir dubens stabilumu, o skausmą dažnai lydi kelio sąnario morfologinės patologijos, kurioms esant rizika atsirasti skausmui kelio sąnaryje padidėja daugiau nei 8 kartus. Be to, paauglių krepšininkų kelio Q-kampas, *valgus* kelio judesys ir kojos standumas yra susiję su paauglių krepšininkų padidėjusia, mažiau standžia girnelės sausgysle ir idiopatiniu kelio skausmu. Anksti diagnozuojant traumų riziką, ypač svarbu naudoti ultragarso metodiką, nes morfologiniai pokyčiai gali atsirasti dar nesant nuolatiniam skausmui.

IŠVADOS

1. 11–12 m. beisbolo žaidėjų peties ir alkūnės struktūros bei funkcijos dvipusiai skirtumai neturi sąsajų su metimo metu atsirandančiu skausmu, tačiau mažas peties sąnario ekscentrinės išorinės rotacijos jėgos momentas ir sumažėjusi vidinės rotacijos amplitudė gali turėti įtakos skausmo atsiradimui.
2. 14–15 m. berniukų krepšinio žaidėjų kelio sąnario struktūros bei funkcijos dvipusiai skirtumai neturi sąsajų su anksti diagnozuotu kelio skausmu. Skausmas būdingesnis aukštesnio ūgio ir mažesnio dubens judesių stabilumo žaidėjams. Be to, skausmą dažnai lydi kelio sąnario morfologinės patologijos, kurioms esant rizika atsirasti kelio sąnario skausmui padidėja daugiau nei 8 kartus.
3. Q-kampas, *valgus* kelio judesys ir kojos standumas yra susiję su 14–15 m. krepšinio žaidėjų padidėjusia, mažiau standžia girnelės sausgysle ir idiopatiniu anksti diagnozuotu kelio skausmu. Kai tarpraumeninė koordinacija yra mažesnė, skausmas jaučiamas dažniau.

PUBLICATIONS

The thesis is based on the following articles:

1. Mickevičius, M., Rutkauskas, S., Sipavičienė, S., Skurvydas, A., Jürimäe, J., Degens, H., & Kamandulis, S. (2016). Absence of Bilateral Differences in Child Baseball Players with Throwing-related Pain. *International Journal of Sports Medicine*, 37(12), 952–957. doi: 10.1055/s-0042-106297
2. Satkunskienė, D., Mickevičius, M., Snieckus, A., Kamandulis, S. (2017). Leg Stiffness, Valgus Knee Motion, and Q-Angle Are Associated with Hypertrophic Soft Patella Tendon and Idiopathic Knee Pain in Adolescent Basketball Players. *The Journal of Sports Medicine and Physical Fitness,* 57(7-8), 1003–1013. doi: 10.23736/S0022-4707.17.06911-0
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Other publications:

1. Rutkauskas, Saulius; Čekanauskas, Emilis; Valaikaitė, Raimonda; Kamandulis, Sigitas; Mickevičius, Mantas; Skurvydas, Albertas. The Ultrasonographic measurements of shoulder and elbow joint cartilage thickness in young baseball players // 2nd Baltic Paediatric Congress and 20th Estonian Paediatric Congress : 30 May-1 June 2013, Pärnu, Estonia / Keynote speakers: Jochen H.H. Ehrich, Valdis Folkmanis, Tari Haahtela, et al.; Estonian Paediatric Society. Pärnu: Estonian Paediatric Society, 2013, p. 84.
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