LITHUANIAN UNIVERSITY OF HEALTH SCIENCES

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COMPARISON OF ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION USING HAMSTRING OR QUADRICEPS TENDON GRAFTS IN PAEDIATRIC PATIENTS

Doctoral Dissertation
Medical and Health Sciences,
Medicine (M 001)

Kaunas, 2025

Dissertation has been prepared at the Department of Pediatric Surgery of the Faculty of Medicine of the Lithuanian University of Health Sciences during the period of 2020–2024.

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Dissertation will be defended at the open session of the Medical Research Council of the Lithuanian University of Health Sciences on the 29th of August 2025 at 10 AM in 4004 Auditorium of the Department of Pediatrics of the Hospital of the Lithuanian University of Health Sciences, Kauno klinikos.
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Daktaro disertacija
Medicinos ir sveikatos mokslai,
medicina (M 001)

Kaunas, 2025

Disertacija rengta 2020–2024 metais Lietuvos sveikatos mokslų universiteto Medicinos fakulteto Vaikų chirurgijos klinikoje.

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Disertacija bus ginama viešajame Medicinos mokslo krypties tarybos posėdyje 2025 m. rugpjūčio 29 d. 10 val. Lietuvos sveikatos mokslų universiteto Kauno klinikų Vaikų ligų klinikos 4004 auditorijoje.
Disertacijos gynimo vietos adresas: Eivenių g. 2, LT-50161 Kaunas, Lietuva.

CONTENTS

ABBREVIATIONS

ACL	–	anterior cruciate ligament
ACL-RSI	–	ACL-Return to Sport after Injury scale
ACLR	–	anterior cruciate ligament reconstruction
ALL	–	anterolateral ligament
ATT	–	anterior tibial translation
BMI	–	body mass index
BPTB	–	bone-patellar tendon-bone (graft)
COVID-19	–	Coronavirus Disease 2019
GNRB	–	Genourob knee arthrometer
GDPR	–	General Data Protection Regulation
H/Q ratio	–	hamstring to quadriceps strength ratio
HT	–	hamstring tendon (autograft)
ICF	–	informed consent form
IKDC	–	International Knee Documentation Committee
ITB	–	iliotibial band
LET	–	lateral extra-articular tenodesis
MRI	–	magnetic resonance imaging
PROs	–	patient-reported outcomes
QT	–	quadriceps tendon (autograft)
RT	–	rectus tendon
TQ/BW	–	peak torque to body weight ratio

INTRODUCTION

One of the most common and debilitating knee injuries is an anterior cruciate ligament (ACL) tear, which requires a prolonged recovery period and poses a significant physical, psychological, and economic burden. This injury is particularly devastating for athletes, as it often leads to an extended pause in their careers [1–3].

ACL tears are a growing health concern, particularly among children and adolescent patients. Over the last few decades, the prevalence of ACL tears and ACL reconstruction (ACLR) surgeries has considerably risen in paediatric population [4–6]. In fact, the incidence in paediatric population is increasing at a higher rate than in adults [7].

Possible reasons for the higher ACL injury rate might include heightened competitive athletic activity, single-sport specialization at an earlier age, and year-round competitive play. Intense training stresses the joints and adjacent structures, including ACL. Focusing on one sport rather than multiple sports can lead to repetitive strain on certain muscles and joints reducing the overall musculoskeletal strength balance that might lead to injury. In addition, unlike the seasonal training that was common in the past, currently, young athletes now train throughout the year, reducing rest and recovery time, which may elevate the risk of overuse injuries [8,9]. Furthermore, increased awareness that ACL ruptures can occur in paediatric population, along with more widespread use of advanced medical imaging, may also influence the rising rate of ACL rupture diagnoses [10].

During the COVID-19 pandemic, ACL surgeries temporarily decreased by about 30 % due to delayed elective procedures and reduced sports activity. However, they returned to pre-pandemic levels after restrictions were lifted, and ACL injuries have since risen in amateur soccer players [11,12].

ACL is one of the four main ligaments stabilizing the knee joint by preventing the tibia from sliding forward relative to the femur. It also contributes to the prevention of excessive knee extension, as well as knee varus, valgus movements, and tibial rotation. Additionally, a healthy ACL protects the menisci from shearing forces that occur during dynamic, high-intensity athletic manoeuvres [10].

ACL injuries are frequently observed in high-impact sports involving sudden changes of movement such as sharp turns, twists, rotations, jumping, and landing [13]. They are particularly prevalent in team sports like football, basketball, volleyball, handball, and other similar activities [14]. ACL injury may not only result from a single instance of joint overload but rather from the cumulative effect of ligament fatigue failure caused by sub-maximal, repeated stresses over time [15].

The risk for ACL tear varies by sex and age but, in general, female athletes are more prone to ACL injuries in most age groups compared to males. However, males exhibit a higher incidence in prepubescent years, while post-pubertal females face an increased risk due to hormonal, anatomical, and biomechanical factors [16–19].

Traditionally, ACL injuries in paediatric and adolescent populations were treated conservatively with non-operative treatment by physical activity modification, physical therapy, and specialized bracing until the individual reached skeletal maturity. However, recent data reveals that delaying the surgical treatment for young athletes might be too risky resulting in secondary injuries to adjacent structures, such as the menisci and collateral ligaments [13,20], as well as chronic knee instability and inability to return to sports [21]. Thus, early operative treatment is now preferred to prevent meniscal or ligament damage and ensure better long-term outcomes [20,22].

The most common complication in this population is graft rupture, occurring in up to 25 % of cases, which often leads to revision surgeries. As the primary ACLR rate increases in skeletally immature patients, the rate of revision ACLR is also on the rise. Additionally, studies have shown that primary ACLR procedures in paediatric patients result in higher revision rates compared to adults [20,23].

ACLR surgeries in paediatric patients raise specific challenges as opposed to adults. The risks related to skeletal immaturity need to be taken into consideration and minimized as much as possible, such as avoiding growth plate disturbances and consequent limb malalignment. To address these concerns, different physeal-sparing surgical techniques have been described in the literature [20,24], including all-epiphyseal, extraphyseal, transphyseal approaches, or a hybrid/combination techniques [25]. Additionally, evaluating the patient's skeletal age, pubertal status, and remaining growth potential is crucial for selecting the safest surgical techniques and graft options [13]. However, graft failure or contralateral knee injury may occur even after successful ACLR. Therefore, further research and clear guidelines for optimal graft type selection in paediatric patients are still needed [26].

The selection of an ACLR graft should be carefully tailored to the patient prior to surgery. Key factors influencing graft choice are the patient's age, sex, bone maturity, activity level, personal goals, hamstring-to-quadriceps strength (H/Q) ratio, and unique anatomical characteristics. Equally important is the decision regarding the type of graft—whether autograft or allograft. Additionally, the graft harvesting site is crucial and may include the hamstring tendon (HT), iliotibial band (ITB), quadriceps tendon (QT), or bone-patellar tendon-bone (BPTB) [25,27]. As allografts are associated with a two- to threefold higher re-rupture rate, this option is typically avoided, especially in the paediatric population who already face a higher graft rupture risk due to their age and activity level [25]. For this reason, autografts are the more typical choice for paediatric cohorts, though each graft type presents its own set of benefits and limitations [20].

Autografts with bone plugs usually cause subsequent complications at the harvesting site, such as anterior knee pain, and a heightened risk of patellar fractures. Therefore, they may not be the safest option for skeletally immature patients. Due to these reasons, soft tissue autografts may be preferred [28]. The HT autograft is the most used graft for ACLR in paediatric patients worldwide, particularly outside of North America. While the BPTB autograft is the second most frequently used graft globally, it is significantly more common in the United States compared to other regions [20,25,29]. Recently, QT autograft has gained popularity due to its relative thickness and high load-to-failure strength, which contributes to a lower graft rupture rate [20]. It has been shown that QT soft tissue autograft has several advantages over HT autografts, including larger more consistent graft dimensions and better preservation of hamstring strength post-surgery [28]. Aitchison *et al*. have demonstrated that QT autografts achieve better graft maturation, synovialization, and structural integrity than HT autografts 12 months postoperatively [30]. However, the gap remains in understanding the benefits of QT autograft over HT autograft in skeletally immature patient populations [20]. Only a few studies have used arthrometric side-to-side assessments to compare the QT autograft with a patellar bone block to the HT autograft [31,32]. Furthermore, no studies have specifically focused on the all-soft-tissue QT autograft [33].

Despite the advancements in the paediatric ACLR field, a lack of a unified approach remains when treating ACL injuries in skeletally immature patients. In addition, there remains a lack of consensus about the optimal surgical techniques and graft choices, particularly when comparing HT and QT autografts. This study aims to address these gaps by comparing the outcomes of HT and all-soft-tissue QT autografts in skeletally immature patients.

The study hypothesis is that hamstring-sparing and QT grafting will lead to improved functional outcomes, greater postoperative satisfaction, and a reduced risk of re-injury. Specifically, the all-soft-tissue QT autograft will provide knee stability comparable to that of the HT autograft, and we believe that our findings can contribute to the broader acceptance and application of the QT autograft in clinical practice.

The aim of the study

The aim of this study was to compare the outcomes of ACLR in children using either HT or all-soft-tissue QT grafts.

Objectives

1. To evaluate knee joint stability after ACLR by comparing postoperative results using HT or QT grafts (with the Genourob arthrometer).
2. To assess thigh muscle strength after ACLR, employing two different surgical treatment approaches (using the Biodex isokinetic system).
3. To compare knee joint function recovery and rehabilitation efficiency after ACLR, applying two different surgical treatment approaches.
4. To identify predictors of psychological readiness to return to sport (ACL-RSI).

Novelty and relevance of the study

QT autografts have been increasingly gaining popularity in the scientific literature and are often referred to as "the graft of the future" [34,35]. A recently published 12-year Google trends analysis has also revealed a growing public interest in QT autografts over other types of grafts [36]. Many studies have compared HT autografts to QT autografts in adults, but the evidence for paediatric populations is limited. Only a few studies have directly compared QT autografts with other traditional options, such as HT or BPTB autografts, in skeletally immature patients [35], highlighting a research gap in paediatric ACLR.

Currently, there is no unified approach for treating ACL injuries in skeletally immature patients, with ongoing debates for growth plate preservation, appropriate surgical timing, and graft selection. Thorolfsson *et al*. found that adolescents had twice the revision rate of young adults after ACLR with HT autograft [37], which might suggest that HT graft is not the most optimal graft type for skeletally immature, and there is a need for more optimal graft selection. In addition, very few studies compared the QT autograft with a patellar bone block to the HT autograft by using arthrometric side-to-side comparison [31,38], and none of them examined the all-soft-tissue QT autograft. This is a significant gap, as QT all-soft-tissue autografts may be preferred over those with bone plugs due to lower donor-site morbidity and reduced anterior knee pain, patellar fractures, and complications in adolescents with open physes [28].

Our study is one of the first to comprehensively examine the all-soft-tissue QT autograft in the paediatric population and compare it with HT autograft, by integrating multiple measurement parameters. While many studies focus on graft survival and knee stability post-surgery, only a few evaluate thigh muscle strength and functional recovery in paediatric ACLR patients. The current study integrates multiple outcome measures, including knee joint stability (evaluated by comparing postoperative results with Genourob arthrometer), muscle strength (measured with the Biodex isokinetic system), and functional recovery, providing a holistic view of the features and potential benefits of QT grafts over HT grafts.

Moreover, our study might provide timely and valuable data in the post-pandemic context, as there has been a noticeable increase in sport traumas, especially among amateur athletes [12]. Since the steep rise of ACL ruptures is occurring in paediatric population [4,6,39], our findings could directly impact clinical decision-making by providing surgeons with evidence-based insights on whether all-soft-tissue QT autografts offer superior outcomes compared to HT autografts. Given the high revision rates associated with HT autografts in younger patients, this study could contribute to the optimized graft selection and rehabilitation protocols, potentially reducing graft failure rates and improving long-term knee function among paediatric patients.

1. LITERATURE REVIEW

1.1. Epidemiology of ACL injuries

ACL injuries were once thought to be rare in children and adolescents. In the 1980s, the estimated incidence rate of ACL rupture in the paediatric population was only up to 3.4 % [40]. Over time, this previously widely accepted notion that ACL tears are uncommon in skeletally immature individuals has been challenged by the advancements in imaging technology and greater clinical awareness, which resulted in increased ACL injury recognition in young athletes [40]. For example, between 1994 and 2006, the frequency of ACLR in patients under 15 years old in the USA increased by 924 % [41,42]. A more recent study also reported that ACL injuries are becoming more frequent among the adolescent population, particularly among high school athletes [43].

The reasons for this rise are not fully clear and open to debate. Advanced diagnostic tools might have allowed higher detection and identification of more cases, improved surgical techniques might have made ACLR more accessible for skeletally immature patients, or that there has been a genuine increase in ACL injury rates among paediatric populations [40].

Although there is no comprehensive global epidemiological data, findings from several studies in various countries support the notion of a rising trend in ACL injuries and ACLR surgeries worldwide.

A descriptive epidemiology study conducted in New York State by Dodwell *et al*. estimated the yearly ACLR rate between the years 1990–2009. The researchers found that ACLR rate per 100,000 population between ages 3 to 20 years has increased from 17.6 in 1990 to 50.9 in 2009, with peak age for ACLR being 17 years old, at a rate of 176.7. As only ACLR rates was evaluated, authors concluded that ACL tears are likely undiagnosed or treated non-surgically, therefore, the rate for ACL injuries is likely higher in paediat-ric individuals [44]. Another more recent study analysed New York popula-tion data for the period between 2009 and 2017. It has been found that paediatric ACLR rates continued to rise until 2014, however, there was a notable decline after 2014. Researchers speculated that the recent decrease in ACLR could be attributed to injury prevention programs or changes in practice management. The study also found differences by sex, in particular, higher revision rates in males, and higher contralateral surgery rate in females [45].

A similar pattern has been observed not only in North America but also in Europe. A study in Norway reported an increasing trend of paediatric ACLR incidence from 2005 to 2021. The rate rose from 18 to 26 per 100,000 population, reflecting a 40 % increase in boys and 55 % increase in girls. Several other trends were also observed in this study – the most common activity causing ACL injury among children under 12 was alpine skiing, while in those over 12 years old, soccer and handball posed the highest risk; surgical approaches have shifted from meniscal resection to meniscal repair and the proportion of the latter has more than doubled; patient-reported outcomes (PROs) indicated that even after ACLR, 30 % reduction in knee function persisted even at long-term follow-up, highlighting a health burden in the young population [39].

A more than two-fold increase in ACL injury frequency was detected in Finland during the period from 1997 to 2014 among 13–17-year-old adolescents of both sexes. The most significant rise occurred in girls within this age group. Researchers propose that increased participation in competitive sports and improved imaging techniques during the study period contributed to the rise in ACL injuries and suggest implementing preventive measures in athletic teams [6].

Epidemiological data in Victoria, Australia from 10-year period from 2005 to 2015 revealed an increase of overall annual rate of ACL injuries among children aged 5 to 14 years by 147.8 %. The vast majority of these injuries occurred in 10–14-year-olds. Over 80 % of the hospitalizations involved ACLR surgeries. More than half ACL tears occurred while performing sports, and ball sports caused female injuries more often than in males [40]. Another Australian study evaluated demographic features of ACLR for the period of 15 years (July 2000 – June 2015) and identified the annual incidence increase by 43 % and by 74 % among those under 25 years of age. The greatest risk was determined for males aged 20–24 years and females of 15–19 years, and ACLR rate displays the most rapid growth among those aged 5–14 years [46].

In the context of the COVID-19 pandemic, different tendencies were observed. Kiani *et al*. analyzed data from the Paediatric Health Information System database covering the period from January 2016 to June 2021. The increase in number of ACLR procedures performed between 2016-2020 has been identified, following a significant decrease in March 2020. The number of ACLR procedures declined by 30 % during the pandemic, probably due to delayed or cancelled elective procedures and reduced sports activity. Nevertheless, ACLR numbers returned to pre-pandemic levels following the easing of restrictions [11]. In the study conducted by Memmel *et al*., it was identified that the lack of training in German soccer during the lockdown significantly contributed to increased ACL injury rate in amateur soccer players, while no differences were reported in professional and semi-professional soccer. In addition, ACL injury mechanism post-COVID was similar to pre-COVID, mainly as non-contact injury mechanism [12].

A recent global bibliometric analysis of paediatric ACLR research identified key trends, such as return to sport, re-rupture rates, and functional recovery post-surgery. These focal points highlight growing concerns about the long-term outcomes for this population [47].

In summary, ACL injuries, once considered rare in paediatric populations, have significantly increased over the past few decades. This rise of injuries and ACLR surgeries is evident across multiple countries and regions. While advancements in imaging technology and surgical techniques may partly explain this increase, there is also a genuine rise in the frequency of ACL injuries due to growing participation in competitive high-impact sports. Long-term outcomes display a significant health burden for young populations. To address this, cost-effective ACL injury prevention programs are needed, such as those involving neuromuscular training [40].

1.2. Risk factors for ACL injuries

The development of successful ACL injury prevention strategies requires the identification of risk factors, which can be categorized as non-modifiable (age, gender, history of previous injury, anatomical features, and genetic predisposition) and modifiable. Modifiable risk factors include intrinsic factors (body mass index, hormonal status during sports participation, neuromuscular deficits, biomechanical abnormalities) and extrinsic factors (playing surface, environmental conditions, equipment, level of competition, type of sport, training loads and neuromuscular control) [48,49].

Non-modifiable risk factors are mainly biological and cannot be altered. Awareness of these risk factors is important for physicians treating active children and adolescents. The main non-modifiable risk factors for ACL tears in skeletally immature include female sex, generalized joint laxity, knee recurvatum, increased lateral tibial slope, decreased intercondylar notch width, structural lower extremity valgus, limb length discrepancy, genetic predisposition (family history), and history of contralateral knee ACL injury [50]. Younger age is a risk factor for both ipsilateral and contralateral ACL reinjury [51,52]. Furthermore, young athletes with non-modifiable risk factors have a higher risk for reinjury after ACLR [50].

One major group of non-modifiable risk factors includes anatomical and morphological features that increase susceptibility to ACL injury. Pradhan *et al.* compared magnetic resonance imaging scans of ACL-injured and asymptomatic ACL-intact knees in paediatric patients, identifying and linking key tibiofemoral anatomical features, such as lateral tibial slope and femoral notch width, with higher ACL injury risk. Their findings suggest that skeletal growth and maturation play a developmental role in injury predisposition.

For instance, ACL-injured knees had higher lateral tibial slopes and smaller notch widths, making certain anatomical features possible early markers for identifying those more prone to ACL injury [53]. Shaw *et al*. found that the notch width index was significantly smaller in ACL injury group, suggesting that individuals with smaller femoral notches may be at higher risk for ACL injuries [54]. Ongoing research continues to explore additional anatomical differences and their role in injury risk.

As previously mentioned, female sex has been identified as a significant non-modifiable risk factor among most age groups compared to males, including skeletally immature [16,17]. However, the relationship between sex and puberty stage is complex. It was found that prepubescent males (<12 years old) have a two-fold higher risk for ACL tears compared to females [18]. Probable causes for higher ACL rupture susceptibility in pubescent females are due to hormonal, anatomical, and biomechanical factors. Adolescent girls do not exhibit the same muscular growth as boys. In particular, slower hamstring muscle development as opposed to the quadriceps muscle, increased knee valgus during landing, along with estrogen influx might contribute to the higher risk of non-contact ACL injuries in adolescent females [19,49]. Furthermore, sex related differences in bone morphology, with female subjects showing decreased intercondylar notch and tibial eminence volumes, have been identified. This further supports the higher predisposition of females to ACL injuries [54]. While non-modifiable factors establish a baseline risk, targeted interventions may be developed by better understanding modifiable risk factors [55].

Modifiable risk factors are mostly environmental aspects that can be altered. Avoiding or altering them may minimize or eliminate the risk of injury [50,55]. Some of the identified modifiable risk factors for ACL tear include the type of primary sport played, inadequate neuromuscular control in the lower body, abnormal movement patterns, reduced core strength, and returning to sport too soon after injury [51]. As choice of sport and sport specialization is considered extrinsic modifiable risk factors, corresponding intervention strategies might include targeted sport-specific intervention programmes, shifting to a lower risk sport, or reducing the time spent in exposure. Intrinsic risk factors include joint kinematics, ground reaction forces, muscle strength and activation patterns, quadriceps and hamstring strength ratio, and lower extremity asymmetries between dominant and non-dominant. These intrinsic factors can be modified by neuromuscular training, strength conditioning, and movement re-education [56]. Additionally, it has been found that participation in level I sports, characterized by high-intensity activities, such as frequent pivoting, jumping, and sudden changes in direction, along with participation in sport competitions, significantly increased the risk of requiring primary ACLR surgery [57].

ACL injuries may be prevented by addressing the risk factors and incorporating preventive interventions. They can be primary (preventing injuries through education and training programs), secondary (reducing early symptoms and managing injuries), and tertiary (rehabilitation and long-term strategies to prevent re-injury) [48]. Some of the suggested approaches for evaluating and reducing ACL injury risk in children include examination of a whole-body movement patterns, moving from constraint to less constraint tasks, and encouraging multi-sport participation [58].

However, significant knowledge gaps remain, limiting the development of targeted risk reduction strategies [58]. Expanding knowledge of non-modifiable risk factors and identifying new modifiable ones, as well as understanding collective and individual risk factors may enhance future prevention programs [7].

1.3. Non-surgical management of ACL injuries

Historically, conservative management of ACL injuries has been the preferred approach for skeletally immature patients. This preference stemmed largely from concerns about the potential disruption of long bone growth plates. For decades, the non-operative treatment approach was the standard ACL injury treatment strategy in paediatric population [22]. This typically involved a combination of bracing, strengthening exercises, rehabilitation of the quadriceps and hamstrings, as well as counselling, and modifications to physical activity to support recovery and prevent further injury [59–61]. Injury prevention programs have also been advocated for skeletally immature athletes to reduce ACL injury risk [62], but once an ACL injury occurs, the best management strategy remains a topic of debate.

The prevailing concern over the risk of physeal damage, growth disturbances, and angular deformities led to the preference for non-operative management or delayed ACLR until skeletal maturity was reached [63]. Non-operative treatment may still be a valid option for partial ACL injuries with negative pivot shift test, as well as type 1 tibial eminence fracture, and type 2 fractures with minimal displacement, particularly in younger and less active patients without significant instability or signs of progression to a complete tear [64–66]. However, conservative treatment has presented particular challenges in skeletally immature patients. This population is often not fully compliant with activity modifications, rehabilitation, and other non-operative treatment measures. Furthermore, research has demonstrated that non-operative treatment or delayed surgery leads to functional knee instability, which places additional risks for meniscal tears and early degenerative arthritis at such a young age [61,67].

However, the research has shown that non-operative treatment of complete ACL ruptures typically results in poor outcomes. The first report on the outcomes of the conservative treatment in young athletes with open physes was published by McCarroll *et al*., who followed 16 patients treated with rehabilitation, bracing, and counselling on activity modification. After 27 months, 9 of these athletes had not returned to sports due to knee instability, while the remaining 7 who returned to sports reported episodes of knee giving way, even when wearing a brace during athletic activity [68]. In addition, the natural history of ACL ruptures in children and adolescents treated conservatively has shown increased knee instability and functional deterioration, often leading to meniscal and osteochondral damage [34].

A meta-analysis by James *et al*. [21] found that both early and delayed ACLR resulted in satisfactory knee stability, whereas conservative treatment was associated with recurrent knee instability, higher risk for meniscal tears, and significantly lower return to sport rates. However, delayed ACLR (>12 weeks after injury) significantly increased the risk of meniscal injuries and irreparable meniscal tears, suggesting that early surgical intervention may be more preferred.

While early ACLR was historically considered risky due to concerns over growth plate damage, advances in physeal-sparing surgical techniques have changed this perspective. Current evidence suggests that carefully performed ACLR can provide long-term stability and functional recovery without compromising growth. As a result, early surgical intervention is increasingly favored for young athletes with complete ACL tears and high-demand activity levels [20–22].

1.4. Surgical considerations for ACL reconstruction

The rising incidence of ACL injuries in skeletally immature patients presents unique challenges for surgeons. Currently, there is no widely accepted consensus within the medical community regarding the optimal surgical techniques or graft selection for these patients. However, numerous studies have reviewed the existing literature and proposed guidelines to support a personalized, evidence-based approach to treatment [70].

To minimize the risk of iatrogenic growth disturbances, careful consideration must be given to the size, orientation, and drilling speed of bone tunnels. Smaller, vertically aligned tunnels, drilled at slower speeds, are preferred over larger, more oblique tunnels, as they reduce biomechanical disadvantages and potential injury to the growth plates [63,71].

Proper tunnel placement is critical in ACLR to ensure isometric graft placement and restore knee biomechanics and stability. However, this is more complex in paediatric patients due to the presence of open physes. Correct tunnel positioning needs to be adjusted and placed individually based on the remaining growth potential, often assessed through Tanner staging. However, the more objective method is the measurement of skeletal age via an anteroposterior radiograph of the left hand and wrist as described by the Greulich and Pyle atlas [72,73]. Recent advancements have introduced a more accurate method for skeletal age estimation, combining chronological age, sex, and central peak value from knee radiographs. This method has shown promise in predicting 90 % of final height, potentially offering better insight into growth disturbances than the Greulich and Pyle method alone. Accurate skeletal age assessment remains crucial, as it can significantly influence the likelihood of growth disturbances after surgery [24].

In general, it is recommended to perform physeal-sparing ACLR in prepubescent patients with open growth plates and significant growth remaining. For pubescent patients who still have some growth remaining, a physeal-respecting ACLR is more appropriate. In adolescents with minimal or no growth left, a transphyseal ACLR may be considered [73].

ACLR surgical techniques for paediatric population can be classified as extraphyseal, all-epiphyseal, transphyseal or partial-transphyseal, based on how the bone tunnels relate to the growth plates [63]. The choice of technique influences the method used to drill the femoral tunnel, which can be achieved through transtibial, anteromedial portal, or outside-in approaches. The transtibial technique creates a vertical tunnel, typically positioned near the 11 o'clock position on the femoral notch. The anteromedial portal provides reliable access to the femoral footprint, resulting in a more oblique tunnel. The outside-in technique facilitates precise anatomic tunnel placement and is also used for drilling all-epiphyseal femoral tunnels in skeletally immature patients [74]. It was estimated that up to 88 % of failed ACLRs are due to non-anatomical graft placement, predominantly resulting from the transtibial drilling technique, which restricts precise positioning of the femoral tunnel [75].

It is advised that surgery should not be delayed beyond 3 months to minimize the risk of chondral and meniscal pathology. Additionally, to avoid potential growth disturbances, no more than 7 % of the physis should be violated during the procedure [41]. Most surgeons recommend delaying ACLR in paediatric patients until knee range of motion improves (flexion greater than 120°) and a positive pivot shift test is present, unless there is a tibial eminence fracture or a bucket-handle meniscus injury, in which case surgery may be necessary sooner [66].

Recent advancements in surgical planning, such as finite element modeling, have shown promise in simulating knee biomechanics and predicting outcomes following ACLR. This could potentially help refine surgical techniques, especially in skeletally immature patients, by minimizing risks of overconstraint and ensuring optimal graft placement while preserving growth [70]. With a variety of surgical techniques and considerations available, selecting the most appropriate approach depends on patient-specific factors, including skeletal maturity and remaining growth potential. The following sections will examine these techniques in greater detail, outlining their indications, advantages, and potential complications.

1.4.1. Physeal-sparing techniques

1.4.1.1. Extraphyseal techniques

The original MacIntosh procedure, first described in 1976, was an extra-articular technique used for ACLR in adults [66,76]. Later, Micheli *et al.* [77] and Kocher *et al.* [78] modified this procedure to make it suitable for younger patients with open growth plates. Their modifications combined both extra-articular and intra-articular components, using the ITB as a graft, while sparing the growth plates. The modifications appear to have good outcomes, as there were no implied disturbances of growth and a graft failure rate of 4.5 %. Similarly encouraging results were reported by Willimon *et al.* in 2015 [79], further endorsing the technique in paediatric ACLR.

The extra-articular and intra-articular reconstructions are nonanatomic techniques that do not involve drilling tunnels. The ITB, released proximally but attached at Gerdy's tubercle, is routed posteriorly around the lateral femoral condyle and positioned within the knee in an "over-the-top" alignment. In the extra-articular method, it is secured to the periosteum of the lateral femoral condyle. In the intra-articular method, the graft follows the path of the ACL through the intercondylar notch, passes under the intermeniscal ligament, and is secured to the anteromedial tibial metaphysis. The graft is also sutured to the periosteum of the distal lateral femoral condyle and the intermuscular septum, providing additional stability [63,73].

Even though the technique is non-anatomic, it closely mimics the function of an intact ACL. Biomechanical testing has indicated that it restores the native knee stability, and clinical studies have shown it to have a low rate of revisions. Due to its proven safety, this physeal-sparing ACLR using ITB is preferred for prepubescent skeletally immature patients with considerable growth remaining [73,76,79].

While extraphyseal techniques have shown favourable results, they also have certain limitations. Nonanatomic graft positioning on the femur raises concerns regarding graft isometry and its control of rotation. Some studies also indicate a higher incidence of angular deformities in over-the-top reconstructions compared with all-epiphyseal techniques [80]. Although over-the-top procedures in prepubescent children yield good short-term results, long-term follow-up shows a 25 % re-rupture rate in adulthood [81] suggesting these techniques may not provide an ideal long-term solution for this patient group.

1.4.1.2. All-epiphyseal techniques

All-epiphyseal ACLR is a physeal-sparing technique that avoids injury to the growth plate by confining bone tunnels to the distal femoral epiphysis and proximal tibial epiphysis. This method fully respects the physis while utilizing the anatomic femoral and tibial ACL attachments, making it an anatomic reconstruction. More anatomic graft placement enhances knee kinematics and rotational stability than more vertical graft placement of transphyseal techniques. Precise tunnel placement is crucial and often relies on fluoroscopic guidance to drill tunnels parallel to the physis, which can be technically difficult due to the limited epiphyseal space [63,73,82].

A common variation, described by Anderson, employs outside-in drilling to create transepiphyseal tunnels. This technique uses hamstring autografts secured with suspensory cortical fixation on the femoral side and with a suture post on the tibial side [82]. Anderson's study reported favourable outcomes, including excellent knee function (mean IKDC score of 96 ± 4.4 points), restored knee stability with a mean KT-1000 difference of 1.5 ± 1.1 mm, and no cases of clinically significant leg length discrepancy over a 4.1-year follow-up period [83]. Despite its benefits in preserving growth potential, challenges such as short or shallow tibial tunnels and technical complexity remain key considerations when making a choice for this technique regarding paediatric patients [73,83].

Lawrence *et al*. [84] introduced an all-epiphyseal ACLR method for prepubescent skeletally immature patients. This technique uses intraoperative computed tomography scanning to position the femoral and tibial tunnels. The femoral tunnel is drilled in the epiphysis of the lateral femoral condyle, and the tibial tunnel is drilled from inside-out, extending to the tibial physis. The graft is fixed with retrograde interference screws on both the femoral and tibial sides. They tested the technique on three boys, aged 10–12 (Tanner Stage 1), with a minimum of 1 year follow-up. The study outcomes were preserved knee stability, full range of motion, and symmetric strength, with no signs of growth disturbance, and successful return to sports with the help of a custom ACL brace.

The Cordasco–Green "all-epiphyseal, all-inside" technique is based on the approach outlined by Lawrence *et al*. The main additions are cortical button fixation on both the femoral and tibial sides, which preserve the advantages of avoiding bone tunnels that cross the growth plates and eliminating the need for sutures to tension the graft across the physis. Additionally, it avoids screw fixation in the softer epiphyseal bone, where there is limited data on biomechanical pullout strength. The technique involves inside-out drilling to form epiphyseal sockets in the femur and tibia, leaving bone bridges intact, and uses suspensory fixation to secure a hamstring or other graft types [85,86].

In a study published in 2018, Pennock *et al*. modified the all-epiphyseal technique for skeletally immature patients. They opposed the fixation proposed by Anderson *et al*. by using suspensory fixation on the tibia and interference screw for femoral graft fixation. This approach avoids any fixation or suturing across the growth plate, ensuring that all fixation devices are placed in the epiphysis without inadvertently restricting the growth plate. The technique also prioritizes anatomic accuracy, positioning both femoral and tibial tunnels directly at the center of the ACL footprint. Compared to traditional methods that rely on post-fixation or suture attachment to the periosteum, this modification may offer more stable combination of interference screw and suspensory fixation [87].

The transepiphyseal technique is the variation of the all-epiphyseal approach, aiming to create anatomic ACLR by preserving the growth plate [88]. Femoral and tibial tunnels are drilled through the epiphysis with limited crossing into the physis, taking measures to minimize physeal damage [89]. This technique is beneficial for patients who are approaching skeletal maturity or for those who may not have enough epiphyseal space to create all-epiphyseal tunnels [90]. It restores native knee kinematics and stability, with favourable outcomes in knee function and minimal growth disturbance [88]. However, as with all-epiphyseal techniques, it has similar risk of growth plate violation, and long-term follow-up is necessary to assess potential complications or re-rupture rates [89].

Recent technological advancements hold great promise for improving all-epiphyseal ACLR techniques. For instance, robot-assisted surgery enhances the accuracy of femoral and tibial tunnel placement in skeletally immature patients, while also reducing operation time and the need for intraoperative fluoroscopy [91]. Furthermore, 3D intraoperative imaging has demonstrated a significantly increased distance from the proximal tibial physis and decreased distal femoral physis violation during all-epiphyseal ACLR tunnel placement. Surgeons utilizing 3D imaging can better plan tunnel placements, reducing the risk of physis disruption and improving the overall safety and effectiveness of the procedure [92]. These advancements represent promising tools for refining surgical techniques and minimizing complications in paediatric ACLR.

1.4.2. Non-physeal sparing techniques

1.4.2.1. Transphyseal and partial transphyseal ACL reconstruction

The majority of ACL tears in skeletally immature occur in adolescents who have less than 1 year of growth remaining. In these cases, traditional transphyseal reconstructions, similar to those used in adults, can be performed with minimal risk of growth disturbances [76].

In conventional adult ACLR, the tunnels typically pass through both the tibial and femoral growth plates. When graft fixation involves crossing both the distal femoral and proximal tibial physes, the approach is known as transphyseal. If only the tibial physis is crossed and femoral fixation remains within the epiphysis, the technique is described as partial-transphyseal. The rationale for the partial-transphyseal technique is to reduce growth disturbances by avoiding damage to the distal femoral physis, which is more prone to injury due to its eccentric position. This technique crosses only the proximal tibial physis, where the central graft tunnels are less likely to impact growth. Additionally, the tibial physis closes earlier and more centrally than the femoral physis, further decreasing the risk of growth-related complications [63].

Fauno *et al*. [93] examined the outcomes of transphyseal ACLR in 39 children with open physes and conducted follow-up assessments after an average of 68 months. Their study revealed that 24 % of the children experienced minor limb length discrepancies by the time they reached skeletal maturity. The study by Hui *et al*. [94] evaluated outcomes of all-arthroscopic transphyseal ACLR in 16 prepubescent patients (Tanner stages 1 and 2) with a minimum 2-year follow-up. The study found excellent clinical results, with a mean IKDC score of 96 and stable knees in all patients. Most patients had negative Lachman and pivot-shift tests, and they were all able to get back to strenuous activities. Importantly, no limb malalignment or growth disturbances were observed. Although transphyseal ACLR is often debated for younger patients with many years of growth remaining, several studies have reported favorable outcomes, with only rare cases of growth disturbances [95–98]. A meta-analysis of 10 studies found that both all-epiphyseal and transphyseal ACLR techniques can produce good clinical outcomes with minimal impact on growth in Tanner stage II and III patients, though more research is needed for Tanner stage I patients [99].

Transphyseal technique in skeletally mature or nearly mature adolescents allows greater flexibility in graft choice (either soft tissue graft or a graft with bone plugs) and fixation, as there is no longer a concern about growth plate damage. This approach mirrors the technique used for ACLR in adults [73]. With careful planning and patient selection, a transphyseal technique offers a safe and effective treatment for most skeletally immature patients [76].

1.4.3. Anterolateral augmentation procedures

Anterolateral augmentation procedures have recently gained renewed interest as a supplementary technique for ACLR in high-risk patients, such as children, adolescents, and athletes, who face higher graft re-rupture rates compared to adults [100]. Younger patients, in particular, tend to resume high-impact activities earlier after surgery, increasing their risk of ACL re-rupture. Notably, athletes under the age of 25 have a reported secondary ACL injury rate of 23 % [26]. These procedures include lateral extra-articular tenodesis (LET) and anterolateral ligament reconstruction (ALLR) [101]. The anterolateral ligament (ALL) is an extra-articular structure that serves as a secondary stabilizer to rotational knee stability, and its reconstruction aims to enhance stability in ACL-deficient knees [102].

Common LET techniques include the MacIntosh, Ellison, Lemaire, and Marcacci/Zaffagnini [103]. Growth plate preservation is still important to consider when performing LET [25]. Isolated non-anatomic LET procedures are rarely performed in contemporary practice as they are associated with a high rate of persistent anterior laxity and early degenerative changes in the lateral compartment, thus LET is mostly performed in combination with ACLR [103].

Recent studies indicate that adding LET to ACLR reduces the re-rupture rate and improves pivot shift in high-risk young patients compared to ACLR alone [104–107]. A randomized controlled trial by Getgood *et al*. investigated whether adding LET to single-bundle HT ACLR reduces the risk of graft failure in young, active patients. A total of 618 patients aged 14–25 were randomized to undergo ACLR with or without LET. The study found that ACLR+LET had lower clinical failure rates (25 % vs. 40 %) and graft rupture rates (4 % vs. 11 %) compared to ACLR alone. While patients in the ACLR group reported slightly less pain in the early months post-surgery, there were no long-term differences in PROs or sports activity levels [106]. Another study examining 2-year outcomes of ACLR with a soft tissue QT autograft and LET using the modified Lemaire technique in skeletally immature patients found a significant reduction in retear rates [107]. These results suggest that adding LET significantly improves graft survival and rotational control in high-risk patients. However, further research involving larger cohorts is needed to determine the impact of LET on return to sport and PROs measures [103].

ALLR is another approach in anterolateral augmentation, which has been explored for improving stability in ACL-deficient knees. Generally, the ACL graft is created using a tripled semitendinosus tendon combined with a single-strand gracilis tendon, and the excess gracilis length is used to create the ALL graft. The ALL portion exits the femoral tunnel at its anatomic footprint on the lateral femoral cortex. It is then routed deep to the ITB, passed through a tibial tunnel, and redirected proximally back to the femur. Finally, the ALL graft is fixed in full extension. Combined ACLR and ALLR is associated with reduction of graft failure and improved return to sport rates when compared to ACLR only [108].

In the study conducted by Trentacosta *et al.*, in order to assess biomechanical stability in skeletally immature patients, two physeal-sparing ACLR techniques (ITB ACLR and all-epiphyseal ACLR with ALLR) were compared. Using cadaveric legs, the study found both techniques reduced anterior tibial translation (ATT) but did not fully restore it except in full extension. ITB ACLR demonstrated better rotational stability without over-restricting knee movement, while all-epiphyseal ACLR, with or without ALLR, improved rotational stability at lower flexion angles but was not as consistent [109]. Compared to LET, ALLR has been studied less extensively, with fewer large-scale studies and clinical trials assessing its long-term outcomes and safety [110].

Despite its potential benefits, concerns remain about ALLR effects on knee stability and healing in younger patients. It has been found that ALL injuries heal slower and there is a higher rotational laxity in adolescents than in adults after ACLR. This may contribute to higher rate of secondary ACL injury in younger patients [111]. Additionally, evidence remains limited regarding the effects of ALLR on growth and potential for overconstraint in skeletally immature patients [101].

Surgeon practices regarding additional anterolateral procedures vary. A recent survey found that 56 % of paediatric sports surgeons sometimes perform ALLR or LET in primary ACLR and 79 % in revisions. However, concerns about the lack of solid evidence supporting these techniques remain [112]. It is still debated whether LET or ALLR is superior and better option. A recent study found that both LET and ALLR are associated with reduced quadriceps strength at 6 to 9 months post-ACLR. This indicates the need for focused rehabilitation targeting knee extension strength to counteract these effects. However, no direct comparison between LET and ALLR has been done [113]. Another study showed no significant differences in complication rates between hybrid ACLR + ALLR and hybrid ACLR + LET, highlighting the need for further research to determine the optimal anterolateral augmentation technique in skeletally immature patients [114,115].

1.5. Graft types and selection for ACL reconstruction

1.5.1. Autografts versus allografts

Irrespective of the selected surgical technique, graft choice remains one of the most crucial factors determining the potential for complications, patient recovery, and overall procedure success. Autograft tissue is widely considered the golden standard for ACLR in young patients. The Multicenter Orthopaedic Outcomes Network (MOON) prospective longitudinal cohort study reported that the highest percentage of graft failure rate was in 10–19 years age group, and this rate was 4 times higher when allograft was used compared to autograft [116].

Allografts, harvested from hamstring, patella, quadriceps, Achilles, or tibialis anterior and posterior, may still be used in certain cases, such as when autograft options are limited or in revision surgeries [117]. Allograft failure rates are much higher in young patients, though re-tear rates decrease with age normalizing around 40 years [118]. Since allografts are often considered biomechanically inferior to autografts, efforts to enhance their strength include using grafts from younger donors, using central third patellar tendon or looped soft tissue grafts, avoiding excessive irradiation, and maximizing the graft's cross-sectional area [119]. Despite the potential advantage of reduced donor-site morbidity and faster rehabilitation, studies revealed a tendency for higher allograft failure rates among skeletally immature patients [120,121]. Moreover, synthetic grafts are discouraged in paediatric patients due to the risk of possible growth arrest [122]. Therefore, autografts remain the primary and safest choice for ACLR in the skeletally immature population.

1.5.2. Common autograft types in paediatric ACL reconstruction

The most common grafts for ACLR in the paediatric population are BPTB autograft, HT autograft, QT autograft, ITB, and various soft-tissue allografts. Among these, HT autografts are the most widely utilized worldwide, and BPTB remaining the second most used choice [29,66]. Geographically, however, the surgeon preferences for graft type selection differ. It has been estimated that allografts are more commonly used in USA, where autografts remain prevalent, but the frequency of allograft selection is much higher as opposed to European countries (39.9 % vs. <1 %) [123]. In addition, BPTB grafts are more prevalent in North America compared to the rest of the world, while HT autograft is the main and primary choice in European and other regions [124].

1.5.2.1. Iliotibial band (ITB) autograft

ITB autografts are primarily used in prepubescent patients (Tanner stage I or II, corresponding to ≤12 years old for males and ≤11 years old for females) in extraphyseal techniques such as over-the-top and over-the-front ACLR procedures, allowing avoidance of bone tunnel drilling and enabling a combined intraarticular and extraarticular ligamentous reconstruction [25,125]. ITB autograft is a favorable option for ACLR in prepubescent patients due to the physeal sparing properties, including very low growth disturbance and minimal donor site morbidity, contributing to improved post-operative limb symmetry and kinematics. However, thigh asymmetry is still quite frequently observed [25,126,127]. In pubescent adolescents and adults, ITB is less commonly used due to its lower tensile strength and suboptimal biomechanical properties for patients with higher functional demands. Therefore, other graft types, including HT, BPTB, and QT autografts, are typically preferred in these cases.

1.5.2.2. Bone-Patellar Tendon-Bone (BPTB) autograft

BPTB autografts have several advantages, including structural and biomechanical similarity to the native ACL and a secure bone-to-bone healing process. They are also relatively easy to harvest with minimal dissection [117,128]. Despite these benefits, their use in young athletes is limited due to the risk for recurvatum deformity at the tibial apophysis and physeal arrest at lateral femur. Recent improvements in suspensory fixation devices have made this option more appealing for skeletally immature patients [63,129].

However, the main drawback of BPTB autografts is donor site morbidity, which is widely documented in the literature. Reported complications include patellar fracture, patellar tendon rupture, anterior knee pain, kneeling pain, and extension lag [117,128]. Anterior knee pain and kneeling pain are the most common morbidities, with 52 % of patients reporting anterior knee pain and 65 % reporting kneeling pain at a 2-year follow-up. In comparison, HT autograft recipients reported significantly lower rates (17 % and 35 % after 2 years, respectively). Extension lag followed a similar pattern after 3 years. These differences tend to level out long-term with no significant differences observed between BPTB and HT autografts at 15-year follow-up [130]. In the knee, the highest concentration of afferent nerve fibers type IVa are located in the patellar ligament, the retinacula, and the pes anserinus, especially in synovial tissues and fat pad [131]. Since BPTB grafts involve structures like the patellar ligament, which contain a high concentration of free nerve endings, damage to these areas can cause anterior knee pain [128]. As a result, many surgeons prefer alternative soft tissue graft types, such as HT autografts [128].

1.5.2.3. Hamstring tendon (HT) autograft

Currently, HT autograft is the most common graft option selected by surgeons worldwide [29]. The main advantages of HT grafts include lower donor site morbidity at the harvesting site, smaller incision resulting in better cosmetic appearance of the wound afterward, significantly less anterior knee pain and kneeling pain [132]. However, HT autograft has been questioned for use in younger athletes due to the potential for undersizing in small patients, tunnel widening, and higher failure rates compared with BPTB autografts in young patients [29,133]. Several randomized controlled trials showed a higher incidence of femoral and tibial tunnel widening in patients treated with an HT autograft [134–136]. Tunnel widening after ACLR appears to depend on the fixation technique used [137]. In addition, harvesting HT causes electromechanical delay of the knee flexor muscles [138], and HT autografts are associated with increased ATT due to reduced hamstring strength [139]. There is a tendency for higher revision rates with HT autografts compared to BPTB grafts [140–142]. In terms of subjective patient satisfaction outcomes, multiple studies have shown no significant differences in IKDC and Lysholm scores or PROs between HT and BPTB autografts [143–146].

To reduce graft failure risk, hamstring grafts with a diameter of 8.5 mm or larger are preferred, often requiring folding and bundling to increase thickness [147]. In some cases, hamstrings may yield a smaller graft, which can increase the risk of retear. Allograft augmentation may be used to address the graft size deficiency, but augmentation may not eliminate the risk or it may even increase the possibility of graft failure [148]. Usually, 4-stranded semitendinosus graft or a 6-8 stranded semitendinosus/gracilis graft is used for young ACLR patients. The use of single tendon is preferred in order to enhance deep flexion strength, internal rotation strength, and act as a medial dynamic stabilizer [25]. The addition of more strands shortens the overall graft length, therefore, proper graft placement within bone tunnels is essential. Drilling techniques and fixation methods can help manage it, though assessing intra-articular length accurately can be difficult due to anatomical variations. Factors, such as age and femoral condylar depth and width, can help estimate ACL size for paediatric patients and determine final graft dimensions and configuration for ACLR [147].

1.5.2.4. Quadriceps tendon (QT) autograft

QT is becoming a more common choice for primary and revision ACLR in skeletally immature patients. It can be harvested as all-soft-tissue graft with substantial tissue volume, which means consistent graft sizes without the risk for undersizing, preservation of quadriceps strength, and eliminating the need for allograft augmentation [35,149]. In terms of graft reliability, properties such as size may predict the possibility of ACL retear. It was shown that HT autograft diameter of less than 8 mm increases the likelihood of retear [150–152]. Baghdadi *et al.* found that preoperative magnetic resonance imaging (MRI) sagittal thickness >6.7 mm highly predicts a final QT graft size of ≥8 mm, which occurred in 82 % of paediatric patient cases. They concluded that QT autograft is a reliable graft for paediatric ACLR [148].

Other potential advantages include lower graft rupture rates and better functional outcomes [20]. Additionally, since QT grafts can be harvested without bone plugs, unlike BPTB grafts, they are associated with less kneeling pain and donor site morbidity, and lower risk of growth disturbances [25]. In paediatric patients, QT autografts have demonstrated the potential of restoring preinjury knee stability, improved postoperative function and fewer complications, and favourable return to sport rates [153]. Biomechanically QT autograft was shown to be superior to BPTB autograft in terms of load to failure, strain at failure, and Young's modulus of elasticity [35].

Nevertheless, certain risks associated with the use of QT grafts exist. Patellar fractures have been observed during the harvest of QT-patellar bone grafts in adults and the risk may be elevated in paediatric patients due to their smaller patellar size [149]. Also, QT harvesting has been reported to cause initial extensor weakness [154]; however, full extensor function can be restored with appropriate physical therapy [31]. Extensor weakness can be explained by the separation between the rectus tendon (RT) and the QT complex, which increases the risk of RT retraction and QT weakness after harvest procedure. Careful suturing of the proximal QT harvest site may prevent early or delayed RT retraction leading to significant QT weakness [149]. In addition, a higher rate for post-operative arthrofibrosis after paediatric ACLR with QT graft has been reported [155,156].

However, information about the use of all-soft-tissue QT in young and active patients is scarce and data on this graft is relatively short-term, requiring further investigation [25,27].

1.5.3. Comparison of HT and QT autografts

Research directly comparing QT and HT autografts in children and adolescents is limited. Most studies focus on the adult population or HT and

BPTB grafts in skeletally immature patients, making the optimal graft choice for paediatric ACLR a debatable question.

A tendency towards higher failure rates is observed in HT autografts [157,158]. Even though high school athletes have a relatively low ACL reinjury risk, the likelihood for retear is higher in patients who underwent ACLR with HT autograft as opposed to other graft types [43]. Pennock *et al*. [159] found that the QT yielded bigger grafts compared to HT and the graft failure rate was lower in skeletally immature patients who underwent transphyseal ACLR with QT autograft than in those with HT autograft (4 % and 21 %, respectively). Both graft options provided similar favourable short-term outcomes, high rates of return to sport and low rates of physeal complications. Runer *et al*. [160] reported 2.7 times greater chance of graft rupture in patients receiving HT autograft than QT autograft. Rangasamy *et al*. in their meta-analysis reported graft rupture incidence of 12.4 % for HT autografts and 3.5 % for QT autografts [20]. The larger QT graft size and intact hamstrings during harvesting procedure with preserved hamstring function may determine lower rupture rates in QT group [160].

In terms of functional outcomes, QT grafts may be superior to HT grafts by enabling better knee flexion strength recovery [32,161], and by reducing ATT after ACLR [162]. Since the ACL resists ATT, hamstring weakness may be detrimental to the reconstruction stability [149]. Kay *et al*. presented evidence that QT grafts in adolescent athletes had significantly higher deficits in quadriceps strength but lower deficits in hamstring strength compared to HT group, resulting in better H:Q ratios in QT patients 6 months after surgery [28]. Fischer *et al*. found a higher H:Q isokinetic strength ratio in patients with QT graft after ACLR, which may have a protective effect during the early months of graft maturation [154]. Since the quadriceps act as ACL antagonists, a combination of strong hamstrings and slightly weaker quadriceps may help protect the ACL graft against anteriorly directed force vectors [163]. The graft maturation is an important post-operative aspect as it determines the individual rehabilitation protocol. It has been shown that a better graft maturity is reached when using QT autograft as opposed to HT autograft by magnetic resonance imaging [38].

Postoperative pain and complications also differ between the graft types. According to Buescu *et al*., all-soft-tissue QT autograft resulted in lower pain levels and analgesic consumption in patients aged 16–50 years old during the first 48 hours post-operatively compared to HT autograft. Supplementary analgesic drug usage was 38 % higher in the HT group [164]. In contrast, QT autograft may cause initial extensor deficit, arthrofibrosis, and longer recovery time after surgery [66]. Additionally, another well-known ACLR complication is bone tunnel widening. In the study by Gotlin *et al*., the least radiographic tunnel widening was detected in QT soft tissue autograft group compared with HT autograft and allograft after ACLR performed with suspensory fixation on both femoral and tibial tunnels [165].

Most studies indicate that PROs are not influenced by graft choice [162]. In contrast, Cavaignac *et al*. reported that the functional outcomes, particularly, the residual laxity and PROs, were equal or better in QT group than HT group after 3.6-year follow-up [166]. However, within the past decade there has been a significant decline in the inclusion of this outcome measure within published ACL studies. It is suggested that continued attention should be paid to the reporting of patient satisfaction after ACLR and toward determining a consensus on the method for reporting this measure [167].

QT autografts showcase promising outcomes with lower graft rupture rates and better functionality compared to the commonly used HT autografts in skeletally immature patients [20]. The majority of studies published to this day are mainly observational, level III-IV evidence, and have relatively short-term follow-up, highlighting the need for higher level evidence, multicentric studies with long-term follow-up that would compare QT and HT autografts in order to determine the optimal graft choice for paediatric ACLR [168].

2. METHODS

2.1. Study design

This randomized prospective study was conducted in Lithuanian University of Health Sciences (LUHS) Kaunas Clinics Department of Pediatric Orthopaedics. A total of 68 eligible patients (37 male, 31 female) from 12 to 17 years old were enrolled in this study. All procedures were conducted in accordance with the Declaration of Helsinki and were approved by the Kaunas Regional Biomedical Research Ethics Committee (protocol code BE-2-103).

The recruitment and allocation process, including exclusions and final sample sizes per group, is illustrated in Figure 2.1.1.

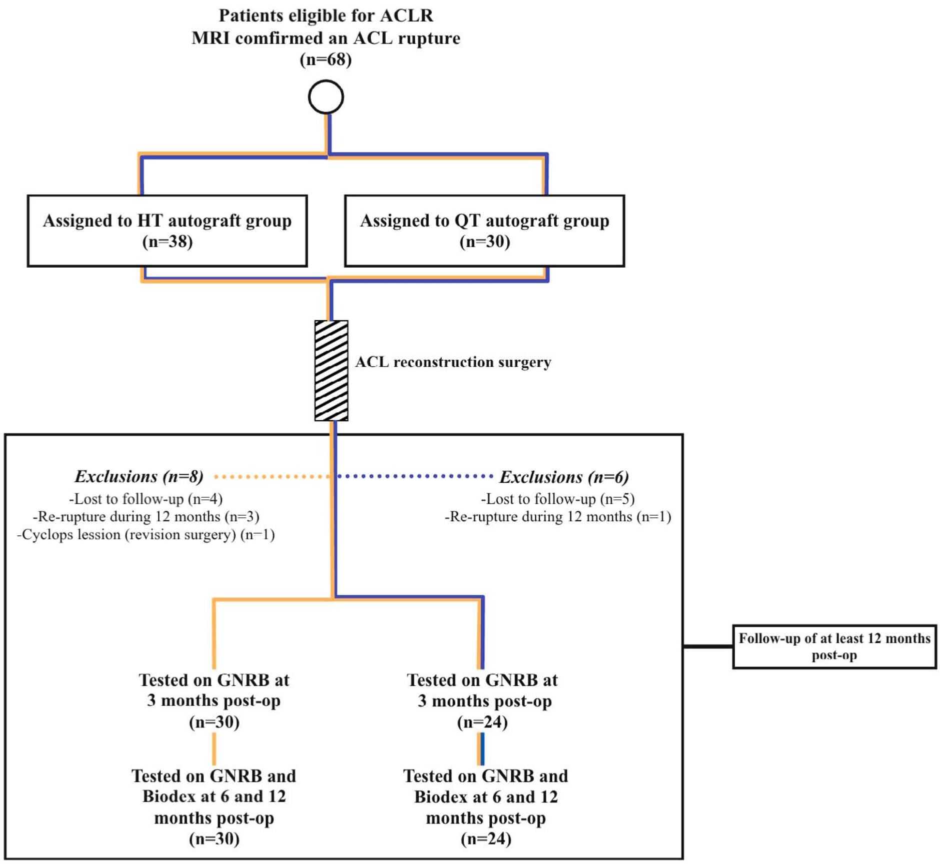


Fig. 2.1.1. *Study flowchart illustrating the patient recruitment, group allocation, follow-up, and inclusion in the final analysis process over the 12-month study period*

2.2. Patient selection

Before inclusion, all patients and/or their parents were informed about the study, provided written informed consent, and were then randomized to receive either the HT or QT autograft, using the closed envelope method. To confirm a physically active lifestyle, patients completed the Tegner activity score questionnaire. Eligibility was based on MRI-confirmed complete ACL rupture, requiring primary ACLR. Concomitant meniscal lesions were permitted, but other bone or ligamentous knee injuries were excluded. The specific inclusion and exclusion criteria used for patient selection are summarized in Table 2.2.1.

Table 2.2.1. *Inclusion and exclusion criteria*

Inclusion criteria	Exclusion criteria
Age between 12 to 17 years Cognitively capable individuals MRI-confirmed complete ACL tear Primary ACLR Signed informed consent Undergoing treatment at LSMU Kaunas Clinics	Concomitant bone or ligamentous injuries (except meniscal lesions) History of prior ACLR Absence of signed informed consent

Demographic and anthropometric data of the patients, including age, sex, height, weight, and BMI, were collected preoperatively. BMI Z-scores were calculated by adjusting reference data according to age and sex to obtain a standardized measure of relative weight status in adolescent patients.

2.3. Surgical procedure

A total of 68 patients underwent ACLR, with 38 receiving HT and 30 QT grafts. All surgeries were performed by a single orthopaedic surgeon using a standard trans-epiphyseal drilling technique.

A 4 mm-diameter full femoral tunnel was drilled alongside a 2-to-2.5 cm deep femoral socket, adapted to each patient's graft size. Based on the graft diameter, the full tibial tunnel was also created. Both HT and QT autografts were fixed in the knee joint using cortical suspensory devices on the femur and tibia (TightRope RT and ABS TightRope, Arthrex (Naples, FL, USA)). Representative HT and QT autografts from the study cohort are displayed in Figure 2.3.1.

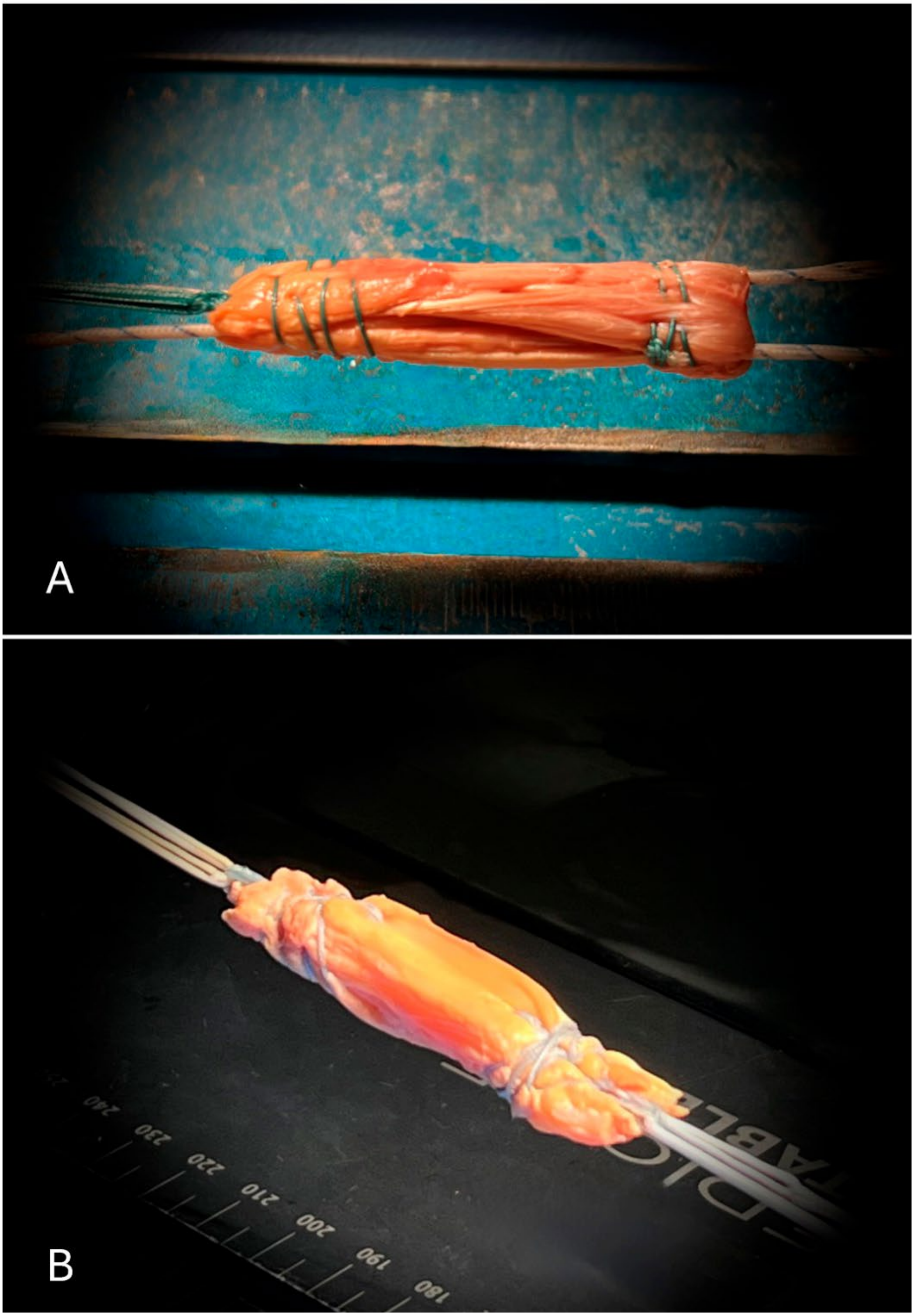


Fig. 2.3.1. *Representative autografts used in ACLR*

(A) HT autograft prepared in a quadrupled configuration (eight-strand graft).
(B) All-soft-tissue QT autograft from the study cohort during preparation.

HT autografts were harvested through a 3-to-4 cm anteromedial incision over the pes anserinus. Both the semitendinosus and gracilis tendons were used to obtain an 8-strand graft, measuring 7 cm in length and from 8 to 11.5 mm in diameter.

QT all-soft-tissue autografts were obtained from the distal anterior thigh through a 3-to-4 cm incision using a 10 mm-width blade. The donor site was closed with a running locking suture. QT grafts varied in size, ranging from 6.5 to 8 cm in length and 8.5 to 11 mm in diameter.

Representative intraoperative images of QT and HT graft harvesting and fixation are shown in Figure 2.3.2.

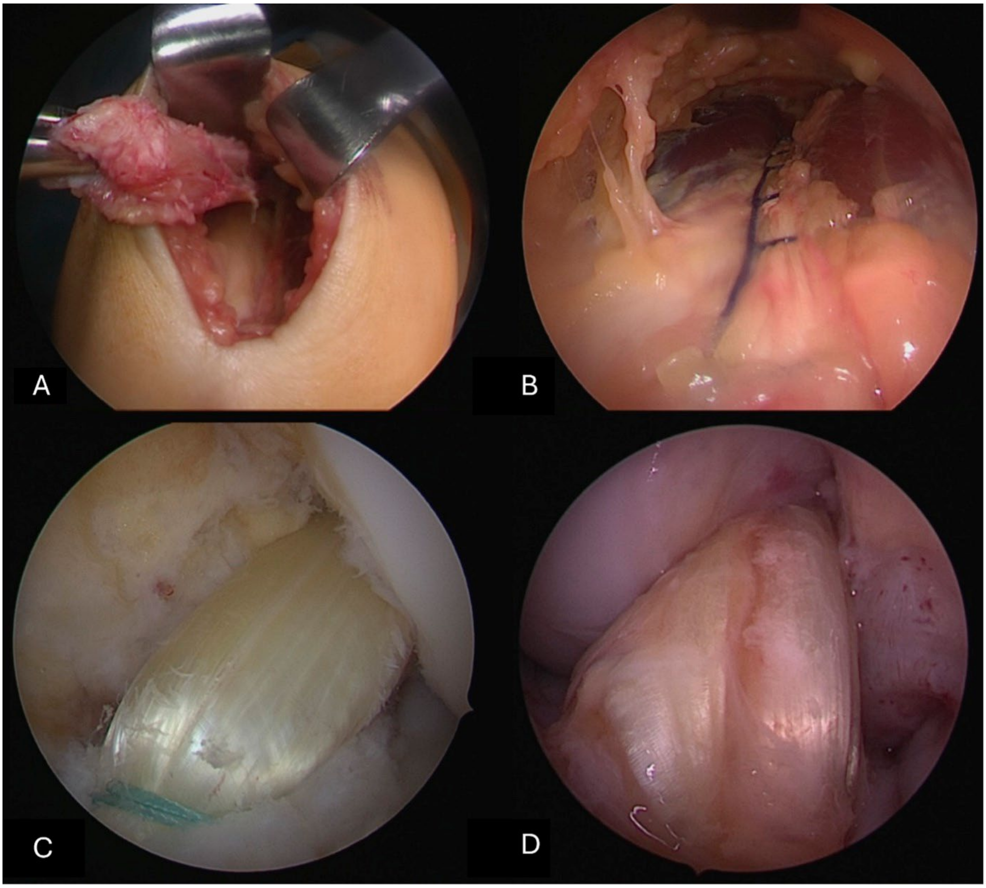


Fig. 2.3.2. *Arthroscopic images illustrating graft harvesting and fixation*

(A) QT graft harvesting; (B) quadriceps tendon defect closed; (C) QT graft fixed in the knee joint; (D) HT graft fixed in the knee joint.

The decision regarding meniscal repair and the graft diameter measurement was made intraoperatively. To ensure adequate positioning of the implants, post-operative X-rays were obtained after each ACLR (Figure 2.3.3). Radiographs were also used to assess the correct placement of the femoral and tibial buttons and confirm the reconstruction quality.

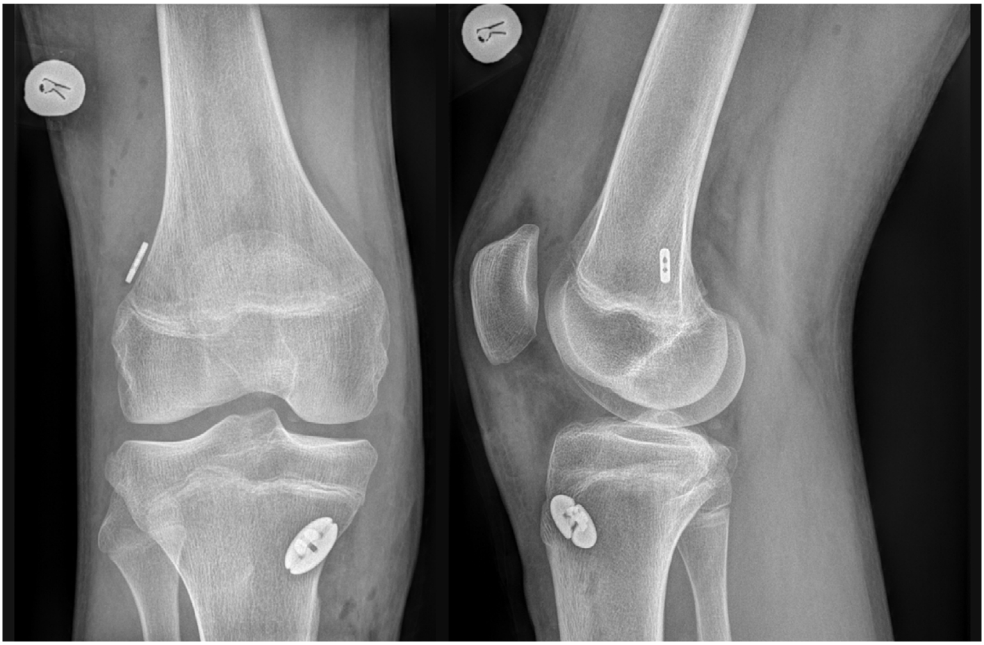


Fig. 2.3.3. *Post-operative X-ray confirming the position of the implants*

2.4. Post-operative rehabilitation protocol

The rehabilitation protocol was tailored individually based on injury complexity and the surgical treatment method and was divided into two distinct stages.

The first stage started after immobilization with a hinged knee brace locked in full extension and focused on protection, swelling control, and the gradual restoration of range of motion. Early weight-bearing to prevent kinesiophobia and muscle weakening was allowed in cases of isolated ACLR or ACLR with meniscal resection, while those who underwent meniscal repair remained non-weight-bearing for 4 weeks. Progressive weight load continued until full weight-bear at 6 weeks to support meniscal healing. The patients started knee flexion exercises at the 2nd week post-operatively with a gradual flexion angle increase of 10–20 degrees every 3–4 days over 6 weeks. They were encouraged to perform daily full passive knee extension, as well as swelling control via cryotherapy and leg elevation. All patients received a 4-week home-based exercise program for improving knee mobility and increasing lower extremity strength before starting the supervised recovery in the rehabilitation centers.

The second stage of rehabilitation started 6 weeks post-operatively and focused on functional recovery and strength development. The GNRB results and overall knee condition determined the subsequent prescribed exercise regimen. If the ATT at 3 months after surgery had normal values of ACL laxity, the operated knee was mobile and not swollen, then muscle strengthening with weight training along with stability and balance exercises was recommended. If laxity remained >1.5 mm, and the operated knee was swollen and limited mobility persisted, the recommendation was to continue the supervised rehabilitation process or to continue cryotherapy, mobility, and muscle-strengthening exercises. Muscle strength testing with electromechanical dynamometer (Biodex) was performed only after 6 months, once deemed safe.

Return to sport was not advised earlier than 6 months after the ACLR and was permitted only if GNRB results showed normal ACL laxity. Return was structured in three phases: return to participation, return to training, and return to play.

2.5. Assessment of side-to-side anterior tibial translation

Postoperative knee stability and ACL autograft maturation were evaluated using the computer-assisted Genourob®, (Laval, France (GNRB)) knee arthrometer. The GNRB is a computer-assisted system which is widely considered the gold standard for objectively evaluating ATT and ACL graft maturation [169].

Testing was conducted with participants in the supine position, with the knee flexed to 20° in a molded support, replicating the typical Lachman test position, as recommended by the manufacturer [170]. Also, a patellar pad for patella immobilization was placed to enable isolated tibial translation [171]. To ensure consistent positioning, the calf was secured with the device's belt.

Each participant underwent bilateral testing, starting with the non-injured leg. At 3 months, a standardized anterior force of 134 N was applied to minimize strain on the healing graft. At 6 and 12 months, additional forces of 150 N and 200 N were also used to evaluate knee laxity and graft behaviour under progressive loading to gain insight about dynamic knee stability.

Side-to-side differences in laxity were measured in millimetres, comparing the operated and the uninjured knees. In addition, displacement curve slopes were recorded as a secondary measure to evaluate the dynamic knee stability, which may provide prognostic insight for ACL graft failure. A side-to-side difference of ≤1.5 mm at 134 N was selected as a threshold for acceptable postoperative knee stability. This threshold, or even lower and more strict values, has been reported for its sensitivity and specificity in evaluating ACL graft integrity [170,172].

Representative GNRB protocol outputs illustrating both preoperative and postoperative measurements are presented in Appendix Figures 2a and 2b.

2.6. Isokinetic strength testing with Biodex

Isokinetic strength testing of the knee flexor and extensor muscles was conducted in collaboration with the Lithuanian Sports University at their scientific laboratory. Participants were instructed to abstain from exercise for 24 hours and to fast for at least 2 hours before testing. Basic anthropometric measurements were collected for each participant.

The testing session began with a 10-minute warm-up on a Monark stationary exercise bike (Varberg, Sweden) at 60-70 reps per minute, 70 W intensity, and a target heart rate between 110 to 130 beats per minute. The ambient room temperature was maintained at 23°C with 77 % humidity. A 5-minute break followed the warm-up period before proceeding to the strength test.

During the rest period, participants were positioned on the Biodex Medical System 4 isokinetic dynamometer (Shirley, NY, USA), securing the chest, waist, and thigh with fixation straps. The lower leg was attached to the dynamometer lever arm proximally to the malleoli. The dynamometer's rotation axis was visually aligned with the femoral axis. The range of motion of the tested leg was measured, and gravitational correction was applied by weighing the leg-foot segment at approximately 60±5° of knee flexion [173].

To familiarize the participants with the procedure, they performed 4 submaximal trials at 25 %, 50 %, 75 %, and 100 % of perceived effort through the set range of motion. During the test, participants performed 3 maximal-effort contractions at a velocity of 60°/s, with a 1-minute rest between each trial. Verbal encouragement for participants was given to ensure maximal performance. The uninjured leg was tested first, and the operated leg afterwards.

The testing was conducted at 6 and 12 months postoperatively. A sample output of the Biodex protocol is provided in Appendix Figure 1.

An H/Q ratio of ≥50 % was considered an acceptable target for muscle balance after ACLR, based on normative data from isokinetic testing in athletes [174].

2.7. Patient-reported outcome measures

Patient-reported outcomes were assessed before ACLR surgery and at 12 months postoperatively, during the final Biodex measurement session, using validated questionnaires: the 2000 IKDC Subjective Knee Evaluation Form, the Lysholm Knee Scoring Scale, and the ACL-RSI (ACL-Return to Sport After Injury) scale [175–177]. Lithuanian translations of these questionnaires were used and are included in Appendix Figures 6–8.

An ACL-RSI score of ≥70 was used as the threshold for psychological readiness to return to sport, based on the findings reported by Langford *et al*. [178], who found that athletes who successfully resumed competitive sport 12 months postoperatively had ACL-RSI scores around this threshold. The importance of ACL-RSI as a predictive tool is further supported by Ardern *et al*. [179], who identified it as the only psychological measure significantly associated with successful return to preinjury sport level.

2.8. Statistical analysis

Data analysis was performed using IBM SPSS Statistics version 29.0 software. Qualitative nominal data are presented using frequencies and relative frequencies (in percent). Quantitative data are presented using mean (with standard deviation) and median (with minimum and maximum values). Because of the small samples or the absence of normality in the data (which was tested by using the Shapiro–Wilk test), the quantitative data in two independent samples were compared by using the non-parametric Mann–Whitney test. Qualitative nominal data were compared by using the Chi-square test.

Data is presented using descriptive statistics (median, minimum, maximum). The Mann-Whitney U test was used to compare data between methods, and the Wilcoxon test was used to compare data between related sample data.

Differences were considered statistically significant if $p < 0.05$.

One of our study's most important variables was arthrometric side-to-side ATT in millimeters, comparing the HT autograft group with the QT autograft group. Since it is a quantitative variable, for the minimum sample size, we used the following formula [180]:

$$n = \frac{\left(s_1^2 + s_2^2\right) \cdot \left(z_{q1} + z_{q2}\right)^2}{\Delta^2}$$

To get standard deviations (s in the formula) for the groups, we took data from 15 patients in our pilot study. The standard deviation we got in the HT group was 1.41 mm, and in the QT – 0.64 mm. To determine the difference of 1 mm between the HT and QT autografts after ACLR in the GNRB test (Δ in formula), we calculated the minimum sample size of 19 in each of the groups, when z_{q1} =1 .96 and z_{q2} = 0.842 with chosen significance level $\alpha = 0.05$ and power of statistical test $1–\beta = 0.8$.

3. RESULTS

3.1. Sample characteristics

A total of 68 patients were enrolled in this study. However, 14 participants were lost to follow-up for various reasons, and 54 participants (24 in QT group and 30 in HT group), aged between 13 and 17 years, completed all stages of the study.

The sample characteristics are summarized in Table 3.1.1. No statistically significant differences were observed between the groups in terms of age, sex distribution, height, weight, BMI Z-score, meniscus injury status, or graft diameter (all $p > 0.05$). This indicates that the groups were comparable at baseline and suitable for postoperative outcome comparison.

Table 3.1.1. *Demographic and surgical patient characteristics*

	QT (n = 24)	HT (n = 30)	Test statistic	*p* value
Age in years median (min–max)	15.5 (13–17)	15 (14–17)	$\lvert Z \rvert = 1.306$	0.192
Sex (male/female)	9/15	18/12	$\chi^2 = 1.875$	0.171
Height in cm median (min–max)	173.5 (158–182)	177.5 (160–197)	$\lvert Z \rvert = 0.157$	0.875
Weight in kg median (min–max)	65 (53–85)	66.5 (49–93)	$\lvert Z \rvert = 0.471$	0.638
BMI Z-score median (min–max)	0.14 (–1.39–1.78)	0.43 (–0.66–1.64)	$\lvert Z \rvert = 1.255$	0.209
Meniscus (repaired / repair not required)	12/12	15/15	$\chi^2 = 0$	1
Graft diameter in mm median (min–max)	10 (9–11)	10.25 (9–11.5)	$\lvert Z \rvert = 0.736$	0.462

QT – quadriceps tendon autograft group; HT – hamstring tendon autograft group; BMI – body mass index; $\lvert Z \rvert$: absolute standardized Mann–Whitney test statistic, χ^2: chi-square test statistic.

3.2. GNRB-assessed knee stability over time in QT and HT groups

Part of the early findings related to knee stability following ACLR were previously published by the author [33]. This PhD thesis presents extended results, including additional patient data and 12-month postoperative measurements, providing a more comprehensive evaluation over time.

Within-group analysis of ATT over time is presented separately for the QT group (Table 3.2.1) and the HT group (Table 3.2.2). GNRB testing at 150 N and 200 N forces was applied only at 6 and 12 months postoperatively due to insufficient graft maturation at 3 months. The Friedman test was used for comparisons across three timepoints, and the Wilcoxon signed-rank test was applied for pairwise comparisons.

Table 3.2.1. *GNRB measurements of knee stability at 3, 6, and 12 months postoperatively in the QT group*

QT (n = 24)					
	3 months post-surgery	**6 months post-surgery**	**12 months post-surgery**	**Test statistic**	***p* value**
Curve slope median (min–max)	2.7 (0.6–18.2)	5 (0–12.9)	4.95 (1.7–8.3)	$\chi^2 = 5.25$	0.072
ATT with 134 N force in mm median (min–max)	0.4 (0.1–1.6)	0.8 (0.1–3.2) *	1.1 (0.3–1.7) *	$\chi^2 = 12.194$	**0.002**
ATT with 150 N force in mm median (min–max)	–	1.05 (0.3–3.0)	1.15 (0.3–1.8)	|Z| = 0.774	0.439
ATT with 200 N force in mm median (min–max)	–	1.15 (0.2–3.2)	0.850 (0.4–1.7)	|Z| = 1.848	0.065

QT – quadriceps tendon autograft group; ATT – anterior tibial translation; N – Newtons; mm – millimetres; χ^2 – chi-square statistic from the Friedman test; |Z|: absolute standardized Wilcoxon signed-rank test statistic.
* p < 0.05 compared with baseline (3 months post-surgery). Pairwise comparisons using the Wilcoxon signed-rank test with Bonferroni correction revealed a significant difference between baseline and 6 months (|Z| = 2.598; *p* = 0.028), and between baseline and 12 months (|Z| = 3.248; *p* = 0.003), but not between 6 and 12 months (|Z| = 0.650; *p* = 1). The significance threshold was adjusted to $p < 0.017$.

Table 3.2.2. *GNRB measurements of knee stability at 3, 6, and 12 months postoperatively in the HT group*

HT (n = 30)					
	3 months post-surgery	**6 months post-surgery**	**12 months post-surgery**	**Test statistic**	***p* value**
Curve slope median (min–max)	4.45 (0–12.4)	3.6 (0.6–14.8)	4.75 (2.9–14.1)	$\chi^2 = 4.2$	0.122
ATT with 134 N force in mm median (min–max)	1.5 (0–3.7)	1.3 (0.1–5.3)	1.75 (0.3–2.3)	$\chi^2 = 0.462$	0.794
ATT with 150 N force in mm median (min–max)	–	1.2 (0.1–5.1)	1.7 (0.4–2.5)	|Z| = 0.371	0.711
ATT with 200 N force in mm median (min–max)	–	1.1 (0.1–5.1)	1.6 (0.3–2.5)	|Z| = 0.742	0.458

HT – hamstrings tendon autograft group; ATT – anterior tibial translation; N – Newtons; mm – millimetres; χ^2 – chi-square statistic from the Friedman test; |Z|: absolute standardized Wilcoxon signed-rank test statistic.

In the QT group, the Friedman test revealed a statistically significant difference across the three timepoints (χ^2 (2) = 12.194, p = 0.002). Pairwise comparisons showed that anterior translation increased significantly from 3 to 6 months (|Z| = 2.598; p = 0.028), and from 3 to 12 months postoperatively (|Z| = 3.248; p = 0.003), but not between 6 and 12 months (|Z| = 0.650; p = 1). In contrast, in the HT group, no statistically significant changes were observed over time (p > 0.05).

3.3. Knee stability comparison between QT and HT autograft groups

The outcomes of GNRB-assessed knee stability evaluation in both QT and HT autograft groups over time are displayed in Figure 3.3.1. ATT was consistently lower in the QT group compared to the HT group at all measured timepoints. Statistically significant differences were found in ATT at 3 months with 134 N force (p = 0.001), and at 12 months under 134 N (p = 0.008), 150 N (p = 0.023), and 200 N (p = 0.008) forces. These findings suggest better anterior stability in the QT group, particularly at 3 and 12 months postoperatively.

No statistically significant differences were found between groups in curve slope values at any time point (all p > 0.05), and no significant ATT differences were observed at 6 months under any force level.

The complete measurements are provided and can be found in Appendix Table 1.

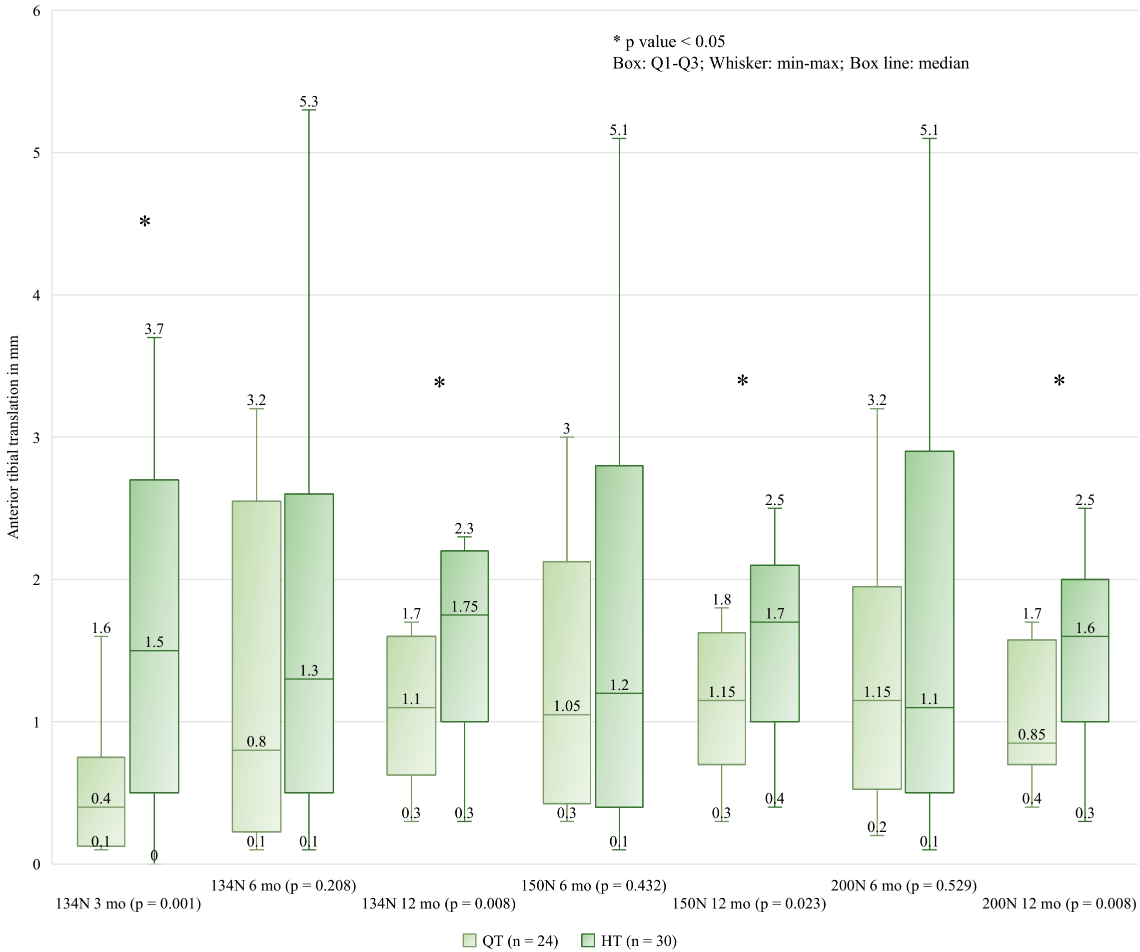


Fig. 3.3.1.*. GNRB measurements of knee stability at 3, 6, and 12 months postoperatively, comparing results between the QT and the HT groups*

3.4. Sex-based knee stability comparison within QT and HT groups

In the QT group (Table 3.4.1), a statistically significant difference in curve slope was observed between males and females at both 3 months (U = 9.000, $p < 0.001$) and 12 months (U = 27.000, $p = 0.017$), with higher values in females at 3 months and higher values in males at 12 months. No significant difference was observed at 6 months ($p = 0.191$).

Table 3.4.1. *GNRB measurements of knee stability in males and females at 3, 6, and 12 months postoperatively in the QT group*

QT				
	Males (n = 9)	**Females (n = 15)**	**Test statistic**	***p* value**
Curve slope 3 months median (min–max)	1.8 (0.6–2.4)	3.5 (2.1–18.2)	U = 9.000	**<0.001***
Curve slope 6 months median (min–max)	5.3 (4.7–7.1)	2.4 (0–12.9)	U = 45.000	0.191
Curve slope 12 months median (min–max)	8.1 (4.5–8.3)	4.6 (1.7–7.6)	U = 27.000	**0.017***
ATT 3 months with 134 N force in mm median (min–max)	0.5 (0.1–0.6)	0.3 (0.1–1.6)	U = 58.500	0.623
ATT 6 months with 134 N force in mm median (min–max)	0.5 (0.2–3.0)	1.1 (0.1–3.2)	U = 63.000	0.860
ATT 12 months with 134 N force in mm median (min–max)	1.6 (0.8–1.7)	0.7 (0.3–1.6)	U = 22.500	**0.006***
ATT 6 months with 150 N force in mm median (min–max)	1 (0.4–3.0)	1.1 (0.3–2.4)	U = 63.000	0.860
ATT 12 months with 150 N force in mm median (min–max)	1.4 (1.1–1.7)	0.7 (0.3–1.8)	U = 36.000	0.062
ATT 6 months with 200 N force in mm median (min–max)	1.2 (0.5–3.2)	1.1 (0.2–2.1)	U = 54.000	0.478
ATT 12 months with 200 N force in mm median (min–max)	0.9 (0.8–1.7)	0.7 (0.4–1.7)	U = 40.500	0.111

QT – quadriceps tendon autograft group; ATT – anterior tibial translation; N – Newtons; mm – millimetres; U – Mann-Whitney test statistic; * – statistically significant difference ($p < 0.05$).

For ATT under 134 N, 150 N, and 200 N force, no statistically significant differences between sexes were found at 3 or 6 months. However, at 12 months, ATT under 134 N was significantly greater in males (U = 22.500, $p = 0.006$). All other comparisons did not reach statistical significance.

In the HT group (Table 3.4.2), curve slope values were significantly different between males and females at all timepoints: 3 months (U = 40.500, $p = 0.003$), 6 months (U = 54.000, $p = 0.021$), and 12 months (U = 49.500, $p = 0.012$), with males showing higher slope values at 3 and 12 months, and lower at 6 months.

Table 3.4.2. *GNRB measurements of knee stability in males and females at 3, 6, and 12 months postoperatively in the HT group*

HT				
	Males (n = 18)	**Females (n = 12)**	**Test statistic**	***p* value**
Curve slope 3 months median (min–max)	7.05 (0.6–12.4)	1.15 (0–6.6)	U = 40.500	**0.003***
Curve slope 6 months median (min–max)	2.3 (0.6–13.1)	4.2 (3.5–14.8)	U = 54.000	**0.021***
Curve slope 12 months median (min–max)	5.05 (4.2–14.1)	3.95 (2.9–7.1)	U = 49.500	**0.012***
ATT 3 months with 134 N force in mm median (min–max)	2.65 (1.3–3.7)	0.35 (0–0.8)	U = 0.0	**<0.001***
ATT 6 months with 134 N force in mm median (min–max)	2 (0.5–5.3)	0.4 (0.1–3.2)	U = 49.500	**0.012***
ATT 12 months with 134 N force in mm median (min–max)	1.75 (0.5–2.2)	1.65 (0.3–2.3)	U = 94.500	0.592
ATT 6 months with 150 N force in mm median (min–max)	2 (0.9–5.1)	0.4 (0.1–3.4)	U = 45.000	**0.006***
ATT 12 months with 150 N force in mm median (min–max)	1.7 (0.6–2.5)	1.5 (0.4–2.3)	U = 90.000	0.489
ATT 6 months with 200 N force in mm median (min–max)	1.85 (0.8–5.1)	0.5 (0.1–3.6)	U = 45.000	**0.006***
ATT 12 months with 200 N force in mm median (min–max)	1.65 (0.5–2.5)	1.4 (0.3–2.4)	U = 81.000	0.283

HT – quadriceps tendon autograft group; ATT – anterior tibial translation; N – Newtons; mm – millimetres; U – Mann-Whitney test statistic; * – statistically significant difference ($p < 0.05$).

For ATT, males demonstrated significantly greater values at 3 months (U = 0.0, $p < 0.001$) and 6 months (U = 49.500, $p = 0.012$) under 134 N.

Similar significant differences favoring males were observed under 150 N at 6 months (U = 45.000, $p = 0.006$) and 200 N at 6 months (U = 45.000, $p = 0.006$). No statistically significant differences were found at 12 months under any force level.

3.5. Graft-based knee stability comparison in males and females

For potential sex-related differences in different graft group, knee stability outcomes were compared separately for males (Table 3.5.1) and females (Table 3.5.2) across HT and QT autograft groups at 3, 6, and 12 months postoperatively with different forces applied.

Table 3.5.1. *GNRB measurements of knee stability at 3, 6, and 12 months postoperatively in males between the HT and QT groups*

Males				
	HT (n = 18)	**QT (n = 9)**	**Test statistic**	***p* value**
Curve slope 3 months median (min–max)	7.05 (0.6–12.4)	1.8 (0.6–2.4)	U = 27.000	**0.004***
Curve slope 6 months median (min–max)	2.3 (0.6–13.1)	5.3 (4.7–7.1)	U = 54.000	0.176
Curve slope 12 months median (min–max)	5.05 (4.2–14.1)	8.1 (4.5–8.3)	U = 63.000	0.400
ATT 3 months with 134 N force in mm median (min–max)	2.65 (1.3–3.7)	0.5 (0.1–0.6)	U = 0.0	**<0.001***
ATT 6 months with 134 N force in mm median (min–max)	2 (0.5–5.3)	0.5 (0.2–3.0)	U = 49.500	0.112
ATT 12 months with 134 N force in mm median (min–max)	1.75 (0.5–2.2)	1.6 (0.8–1.7)	U = 49.500	0.112
ATT 6 months with 150 N force in mm median (min–max)	2 (0.9–5.1)	1 (0.4–3)	U = 63.000	0.377
ATT 12 months with 150 N force in mm median (min–max)	1.7 (0.6–2.5)	1.4 (1.1–1.7)	U = 58.500	0.264
ATT 6 months with 200 N force in mm median (min–max)	1.85 (0.8–5.1)	1.2 (0.5–3.2)	U = 63.000	0.400
ATT 12 months with 200 N force in mm median (min–max)	1.65 (0.5–2.5)	0.9 (0.8–1.7)	U = 45.000	0.074

QT – quadriceps tendon autograft group; HT – quadriceps tendon autograft group; ATT – anterior tibial translation; N – Newtons; mm – millimetres; U – Mann-Whitney test statistic; * – statistically significant difference ($p < 0.05$).

Table 3.5.2. *GNRB measurements of knee stability at 3, 6, and 12 months postoperatively in females between the HT and QT groups*

Females				
	HT (n = 12)	**QT (n = 15)**	**Test statistic**	***p* value**
Curve slope 3 months median (min–max)	1.15 (0–6.6)	3.5 (2.1–18.2)	U = 36.000	**0.008***
Curve slope 6 months median (min–max)	4.2 (3.5–14.8)	2.4 (0–12.9)	U = 54.000	0.82
Curve slope 12 months median (min–max)	3.95 (2.9–7.1)	4.6 (1.7–7.6)	U = 81.000	0.717
ATT 3 months with 134 N force in mm median (min–max)	0.35 (0–0.8)	0.3 (0.1–1.6)	U = 72.000	0.406
ATT 6 months with 134 N force in mm median (min–max)	0.4 (0.1–3.2)	1.1 (0.1–3.2)	U = 76.500	0.530
ATT 12 months with 134 N force in mm median (min–max)	1.65 (0.3–2.3)	0.7 (0.3–1.6)	U = 58.500	0.131
ATT 6 months with 150 N force in mm median (min–max)	0.4 (0.1–3.4)	1.1 (0.3–2.4)	U = 63.000	0.199
ATT 12 months with 150 N force in mm median (min–max)	1.5 (0.4–2.3)	0.7 (0.3–1.8)	U = 54.000	0.082
ATT 6 months with 200 N force in mm median (min–max)	0.5 (0.1–3.6)	1.1 (0.2–2.1)	U = 63.000	0.199
ATT 12 months with 200 N force in mm median (min–max)	1.4 (0.3–2.4)	0.7 (0.4–1.7)	U = 63.000	0.199

QT – quadriceps tendon autograft group; HT – quadriceps tendon autograft group; ATT – anterior tibial translation; N – Newtons; mm – millimetres; U – Mann-Whitney test statistic; * – statistically significant difference ($p < 0.05$).

At 3 months postoperatively, curve slope and ATT with 134 N force were significantly lower in the QT male group compared to the HT male group ($p = 0.004$ and $p < 0.001$, respectively). No other significant differences were detected at 6 and 12 months (all $p > 0.05$).

At 3 months, curve slope for females was significantly higher in the QT group compared to the HT group ($p = 0.008$). No significant differences were found in ATT or curve slope at 6 and 12 months (all $p > 0.05$).

3.6. Overall knee stability comparison by sex

Overall knee stability between males and females, regardless of graft type, is represented in Figure 3.6.1.

When combining both QT and HT groups, statistically significant differences in curve slope were found at 12 months ($|Z| = 3.356$, $p < 0.001$), with males having higher values. No significant differences were observed at 3 or 6 months.

For ATT under 134 N, males showed significantly greater values at 3 months ($|Z| = 3.984$, $p < 0.001$) and 6 months ($|Z| = 2.035$, $p = 0.042$). No significant difference was found at 12 months ($p = 0.072$).

Under 150 N, males demonstrated significantly higher anterior translation at 6 months ($p = 0.006$) and 12 months ($p = 0.035$). Under 200 N, a significant difference was also present at 6 months ($p = 0.006$), while no significant difference was found at 12 months ($p = 0.061$).

The complete measurements are provided and can be found in Appendix Table 2.

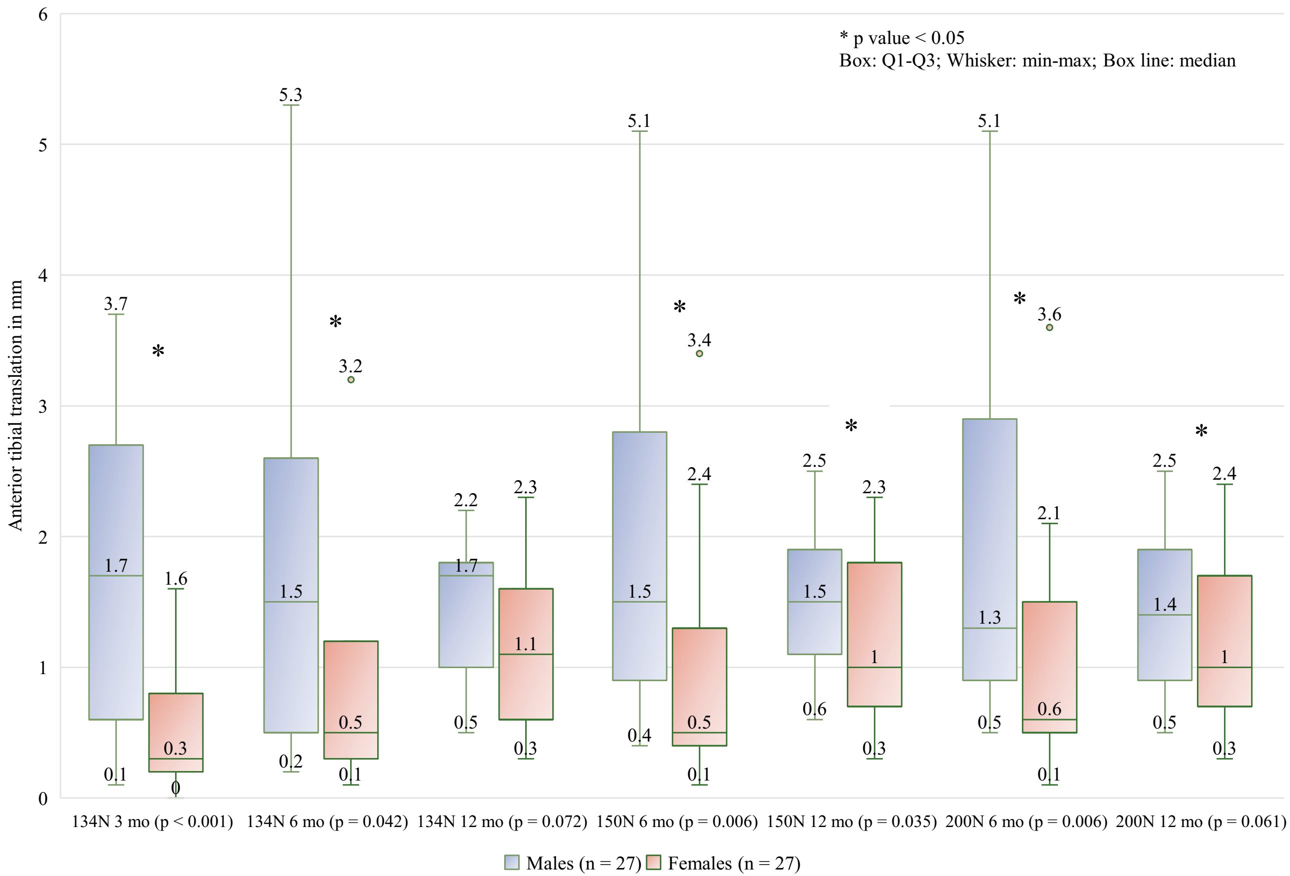


Fig. 3.6.1. *GNRB-assessed knee stability in males and females at 3, 6, and 12 months postoperatively, regardless of graft type*

χ^2 test determined that there is a significant difference in proportions with good outcome of ATT (GNRB) at 134 N after 12 months between males and females (in males 33.3 % (9/27), in females 66.7 % (18/27); χ^2 test statistic = 4.741, $p = 0.029$). Odds of good outcome for ATT in females compared to males were 4 times higher (95 % CI 1.29–12.40).

3.7. Isokinetic strength comparison between involved and uninvolved legs in QT and HT groups

Results comparing the operated and uninvolved legs within each autograft group are presented in Tables 3.7.1 and 3.7.2.

Table 3.7.1. *Comparison of Biodex results between the involved and uninvolved leg (QT group) at 6 and 12 Months postoperatively*

	QT (n = 24)		Test statistic	*p* value
	6 months post-surgery			
	Involved	**Uninvolved**		
Extensors peak TQ/BW in % median (min–max)	121.45 (90.6–211.3)	175.4 (111–287.4)	|Z| = 3.434	**<0.001***
Flexors peak TQ/BW in % median (min–max)	84.35 (42–122.3)	84.35 (36.7–140.7)	|Z| = 0.773	0.455
H/Q ratio median (min–max)	56.1 (31.3–109)	49.6 (20.7–70.9)	|Z| = 3.177	**<0.001***
	12 months post-surgery			
	Involved	**Uninvolved**		
Extensors peak TQ/BW in % median (min–max)	208.55 (113.1–241.6)	252.4 (179.8–324.6)	|Z| = 0.869	**<0.001***
Flexors peak TQ/BW in % median (min–max)	115.3 (73.5–155)	116 (82.1–173.9)	|Z| = 2.146	**0.031***
H/Q ratio median (min–max)	57.2 (40.9–105.8)	50.65 (35.1–58.4)	|Z| = 2.661	**0.006***
	Change (12–6 months)			
	Involved	**Uninvolved**		
Extensors peak TQ/BW in % median (min–max)	44 (–4.5–131.9)	53.5 (–20–133.3)	|Z| = 0.429	0.668
Flexors peak TQ/BW in % median (min–max)	24.3 (–24.6–85)	23.2 (0.3–99.9)	|Z| = 1.202	0.229
H/Q ratio median (min–max)	4.85 (–26.1–32.7)	3.3 (–36.1–12.5)	|Z| = 2.232	**0.026***

QT – quadriceps tendon autograft group; TQ/BW – peak torque to body weight ratio; H/Q ratio – hamstring to quadriceps strength ratio; |Z|: absolute standardized Wilcoxon signed-rank test statistic; * – statistically significant difference ($p < 0.05$).

Table 3.7.2. *Comparison of Biodex results between the involved and uninvolved leg (HT group) at 6 and 12 Months postoperatively*

	HT (n = 30)		**Test statistic**	***p* value**
	6 months post-surgery			
	Involved	**Uninvolved**		
Extensors peak TQ/BW in % median (min–max)	156.9 (96.1–279.2)	232.1 (164.1–316.7)	|Z| = 4.478	**<0.001***
Flexors peak TQ/BW in % median (min–max)	75.2 (34.2–126.8)	102.8 (26.5–157.5)	|Z| = 4.355	**<0.001***
H/Q ratio median (min–max)	43.75 (35.6–63.8)	47.2 (16.2– 50.3)	|Z| = 1.390	0.165
	12 months post-surgery			
	Involved	**Uninvolved**		
Extensors peak TQ/BW in % median (min–max)	250.8 (129.5–338.8)	293 (178.5–342.2)	|Z| = 3.490	**<0.001***
Flexors peak TQ/BW in % median (min–max)	91.25 (68–138.4)	128.95 (78–169.3)	|Z| = 4.787	**<0.001***
H/Q ratio median (min–max)	40.9 (32.8–51.5)	48.4 (33.6–54.8)	|Z| = 3.366	**<0.001***
	Change (12–6 months)			
	Involved	**Uninvolved**		
Extensors peak TQ/BW in % median (min–max)	53.5 (21.2–208.6)	36.5 (–15.9–132.8)	|Z| = 2.934	**0.003***
Flexors peak TQ/BW in % median (min–max)	22.35 (–30–71)	16.15 (–48.2–67.9)	|Z| = 0.154	0.877
H/Q ratio median (min–max)	5.5 (–10.7–13.7)	–2.15 (–17.4–7.1)	|Z| = 4.108	**<0.001***

HT – hamstring tendon autograft group; TQ/BW – peak torque to body weight ratio; H/Q ratio – hamstring to quadriceps strength ratio; |Z|: absolute standardized Wilcoxon signed-rank test statistic; * – statistically significant difference ($p < 0.05$).

In the QT group (Table 3.7.1), extensor strength was significantly lower in the operated leg compared to the uninvolved leg at both 6 months ($p < 0.001$) and 12 months ($p < 0.001$). Flexor strength did not differ significantly at 6 months ($p = 0.455$) but became significantly lower in the involved leg at 12 months ($p = 0.031$). The H/Q ratio was significantly higher in the operated leg at both timepoints ($p < 0.001$ at 6 months; $p = 0.006$ at 12 months).

For the QT group, no statistically significant differences between the involved and uninvolved leg were observed, neither for the change of extension force (Wilcoxon test $|Z| = 0.429$, $p = 0.668$) nor the flexion force (Wilcoxon test $|Z| = 1.202$, $p = 0.229$). However, the change in H/Q ratio between the involved and uninvolved leg was statistically significant (Wilcoxon test

$|Z| = 2.232$, $p = 0.026$), showing a higher change for the operated leg as opposed to the uninvolved leg.

In the HT group (Table 3.7.2), the involved leg showed significantly lower extensor and flexor strength compared to the uninvolved leg at both 6 and 12 months (all $p < 0.001$). The H/Q ratio did not differ significantly at 6 months ($p = 0.165$) but was significantly lower in the operated leg at 12 months ($p < 0.001$).

For the HT group, the change of extension strength from 6 to 12 months was statistically significant (Wilcoxon test $|Z| = 2.934$, $p = 0.003$), showing more pronounced strength in the operated leg. In addition, the difference in change of H/Q ratio was statistically significant as well (Wilcoxon test $|Z| = 4.108$, $p < 0.001$), indicating higher changes in the involved leg compared to the uninvolved leg. The difference in change of flexion force was not statistically significant between the involved and uninvolved legs (Wilcoxon test $|Z| = 0.154$, $p = 0.877$).

3.8. Isokinetic strength comparison between QT and HT autograft groups

Isokinetic strength testing results obtained using the Biodex system at 6 and 12 months postoperatively are represented in Figure 3.8.1.

At 6 months post-surgery, the QT group demonstrated significantly lower extensor strength compared to the HT group ($p = 0.019$), while flexor strength did not differ significantly ($p = 0.638$). The H/Q ratio was significantly higher in the QT group than in the HT group ($p = 0.019$).

At 12 months post-surgery, the QT group continued to show significantly lower extensor strength ($p < 0.001$) and a significantly higher H/Q ratio ($p < 0.001$) compared to the HT group. Flexor strength again did not differ significantly between the groups ($p = 0.117$).

In order to assess recovery progression over time, changes in extensor and flexor strength, as well as the H/Q ratio, were calculated by subtracting 6-month values from 12-month values in the involved leg. No statistically significant differences in these changes were observed between the QT and HT groups for extensor strength ($|Z| = 1.413$, $p = 0.158$), flexor strength ($|Z| = 0.784$, $p = 0.433$), or H/Q ratio ($|Z| = 0.314$, $p = 0.754$). The detailed isokinetic strength data including the changes over time are summarized in Appendix Table 3.

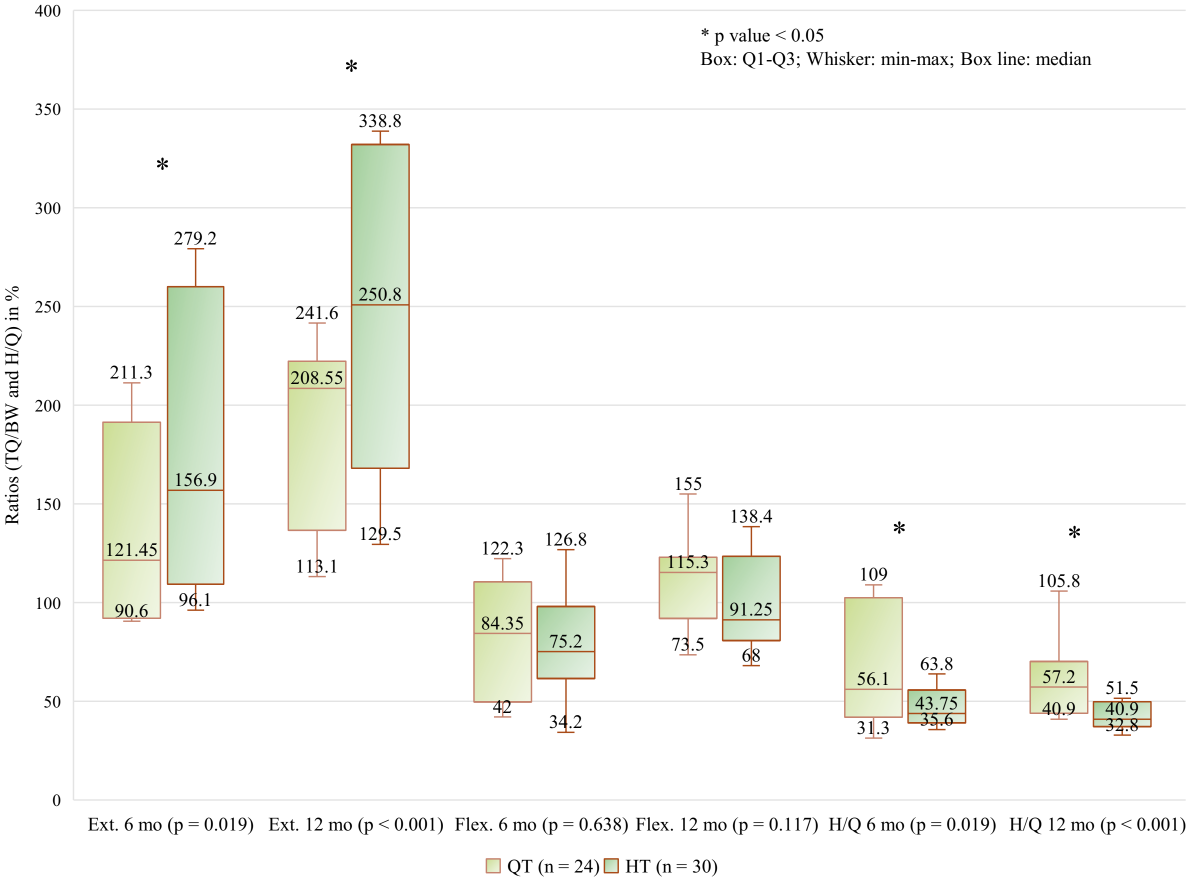


Fig. 3.8.1. *Comparison of Biodex (Isokinetic Dynamometer) results between the QT and HT groups at 6 and 12 months postoperatively*

χ^2 test determined that there is a significant difference in proportions with the acceptable ratio between the HT and the QT groups (in the HT group 20.0 % (6/30), in the QT group 62.5 % (15/24); χ^2 test statistic = 8.424, $p = 0.004$). Odds of acceptable H/Q ratio in the QT group compared to the HT group were 6.67 times higher (95 % CI 1.97–22.53).

3.9. Sex-based isokinetic strength comparison within QT and HT groups

No statistically significant differences were detected in the QT autograft group between males and females in extensor or flexor strength, change values, or H/Q ratio at 6 or 12 months (all $p > 0.05$).

Table 3.9.1. *Comparison of isokinetic strength outcomes between males and females at 6 and 12 months postoperatively using the Biodex dynamometer (QT group)*

QT				
	Males (n = 9)	**Females (n = 15)**	**Test statistic**	***p* value**
Extensors peak TQ/BW in % 6 months median (min–max)	134.4 (92–211.3)	114 (90.6–210.4)	U = 45.000	0.211
Extensors peak TQ/BW in % 12 months median (min–max)	210.3 (206.8–223.9)	157.7 (113.1–241.6)	U = 45.000	0.211
Change of extensors peak TQ/BW in % median (min–max)	75.9 (–4.5–131.9)	22.5 (6.7–112.7)	U = 54.000	0.478
Flexors peak TQ/BW in % 6 months median (min–max)	70 (42–114.3)	98.7 (45.8–122.3)	U = 54.000	0.478
Flexors peak TQ/BW in % 12 months median (min–max)	120.7 (89.7–155)	111 (73.5–123.7)	U = 45.000	0.211
Change of flexors peak TQ/BW in % median (min–max)	78.7 (–24.6–85)	20.9 (1.4–37.6)	U = 45.000	0.211
H/Q ratio 6 months median (min–max)	54.1 (31.3–100.4)	58.1 (40.1–109)	U = 45.000	0.211
H/Q ratio 12 months median (min–max)	57.4 (43.4–69.2)	57 (40.9–105.8)	U = 63.000	0.860
Change of H/Q ratio median (min–max)	–10.7 (–31.2–26.1)	–3.2 (–32.7–5.6)	U = 63.000	0.860

QT – quadriceps tendon autograft group; TQ/BW – peak torque to body weight ratio; H/Q ratio – hamstring to quadriceps strength ratio; U – Mann-Whitney test statistic.

In the HT autograft group, males had significantly higher extensor strength at 12 months after ACLR surgery (p = 0.024), higher change in extensor strength (p = 0.002), and lower H/Q ratio (p = 0.002) as opposed to females. Other comparisons showed no significant differences (all p > 0.05).

Table 3.9.2. *Comparison of isokinetic strength outcomes between males and females at 6 and 12 months postoperatively using the Biodex dynamometer (HT group)*

HT				
	Males (n = 18)	**Females (n = 12)**	**Test statistic**	***p* value**
Extensors peak TQ/BW in % 6 months median (min–max)	166.65 (96.1–279.2)	156.9 (106.9–260)	U = 99.000	0.753
Extensors peak TQ/BW in % 12 months median (min–max)	292.8 (156.7–338.8)	208.05 (129.5–287.9)	U = 54.000	**0.024***
Change of extensors peak TQ/BW in % median (min–max)	63.3 (47.4–208.6)	25.25 (21.2–81.1)	U = 36.000	**0.002***
Flexors peak TQ/BW in % 6 months median (min–max)	75.2 (34.2–126.8)	80.6 (57.2–98)	U = 99.000	0.753
Flexors peak TQ/BW in % 12 months median (min–max)	108.85 (74.5–138.4)	85.85 (68–117.7)	U = 63.000	0.064
Change of flexors peak TQ/BW in % median (min–max)	20.6 (–3.4–71)	22.35 (–30–26.3)	U = 81.000	0.283
H/Q ratio 6 months median (min–max)	43.75 (35.6–62.9)	47.35 (37.7–63.8)	U = 99.000	0.753
H/Q ratio 12 months median (min–max)	38.3 (32.8–51.5)	48.6 (41.0–50.1)	U = 36.000	**0.002***
Change of H/Q ratio median (min–max)	–5.9 (–11.4–1.5)	–2.45 (–13.7–10.7)	U = 81.000	0.283

HT – hamstring tendon autograft group; TQ/BW – peak torque to body weight ratio; H/Q ratio – hamstring to quadriceps strength ratio; U – Mann-Whitney test statistic; * – statistically significant difference (p < 0.05).

3.10. Overall isokinetic strength comparison by sex

At 12 months, males demonstrated significantly higher extensor strength (p = 0.002), significantly higher flexor strength (p = 0.024), and a greater change in extensor strength from 6 to 12 months (p = 0.004). Females had a significantly higher H/Q ratio at 12 months ($p = 0.004$). No other statistically significant differences were observed.

Table 3.10.1. *Comparison of overall isokinetic strength outcomes between males and females at 6 and 12 months postoperatively, regardless of graft type*

	Males (n = 27)	**Females (n = 27)**	**Test statistic**	***p* value**
Extensors peak TQ/BW in % 6 months median (min–max)	134.4 (92–279.2)	128.9 (90.6–260)	|Z| = 1.169	0.242
Extensors peak TQ/BW in % 12 months median (min–max)	227 (156.7–338.8)	168 (113.1–287.9)	|Z| = 3.042	**0.002***
Change of extensors peak TQ/BW in % median (min–max)	67 (–4.5–208.6)	22.6 (6.7–112.7)	|Z| = 2.886	**0.004***
Flexors peak TQ/BW in % 6 months median (min–max)	70 (34.2–126.8)	93 (45.8–122.3)	|Z| = 0.078	0.938
Flexors peak TQ/BW in % 12 months median (min–max)	120.7 (74.5–155)	98.8 (68–123.7)	|Z| = 2.261	**0.024***
Change of flexors peak TQ/BW in % median (min–max)	28.6 (–24.6–85)	20.9 (–30–37.6)	|Z| = 1.793	0.073
H/Q ratio 6 months median (min–max)	47.8 (31.3–100.4)	55.7 (37.7–109)	|Z| = 1.793	0.073
H/Q ratio 12 months median (min–max)	40.8 (32.8–69.2)	49.7 (40.9–105.8)	|Z| = 2.886	**0.004***
Change of H/Q ratio median (min–max)	–9 (–31.2–26.1)	–3.2 (–32.7–10.7)	|Z| = 1.013	0.311

TQ/BW – peak torque to body weight ratio; H/Q ratio – hamstring to quadriceps strength ratio; |Z|: absolute standardized Mann–Whitney test statistic; * – statistically significant difference ($p < 0.05$).

3.11. Patient-Reported Outcome Scores (PROs) comparison between autograft groups

At 12 months postoperatively, the HT group had significantly higher IKDC scores ($p = 0.009$), suggesting better perceived knee function. Although Lysholm and ACL-RSI questionnaire outcomes were also higher in the HT group, the differences were not statistically significant.

Table 3.11.1. *IKDC, Lysholm, and ACL-RSI scores at preoperative and 12-month follow-up in QT and HT groups*

	QT (n = 24)	**HT (n = 30)**	**Test statistic**	***p* value**
IKDC (pre-op) median (min–max)	58.05 (35.63–72.41)	60.92 (29.89–77.01)	|Z| = 0.314	0.753
IKDC (12 months post-op) median (min–max)	87.94 (64.36–96.55)	93.13 (85.06–100)	|Z| = 2.599	**0.009***
Change of IKDC median (min–max)	27.75 (21.84–51.73)	37.93 (14.95–62.07)	|Z| = 1.413	0.158
Lysholm (pre-op) median (min–max)	67 (36–100)	75 (35–95)	|Z| = 1.178	0.239
Lysholm (12 months post-op) median (min–max)	95 (66–100)	98 (80–100)	|Z| = 1.487	0.137
Change of Lysholm median (min–max)	26.5 (0–54)	21.5 (0–65)	|Z| = 0.708	0.479
ACL-RSI (12 months post-op) median (min–max)	70.67 (46.67–95.83)	80.82 (55.83–100)	|Z| = 1.570	0.116

QT – quadriceps tendon autograft group; HT – hamstring tendon autograft group; IKDC – International Knee Documentation Committee subjective score; ACL-RSI – ACL-Return to Sport after Injury scale; |Z|: absolute standardized Mann–Whitney test statistic; * – statistically significant difference ($p < 0.05$).

χ^2 test determined that there is a significant difference in proportions with good outcome of ACL-RSI after 12 months between the HT and the QT groups (in the HT group 80.0 % (24/30), in the QT group 50.0 % (12/24); χ^2 test statistic = 4.134, $p = 0.042$). Odds of good outcome for ACL-RSI in the HT group compared to the QT group were 4 times higher (95 % CI 1.21–13.28).

3.12. Multiple linear regression model predicting psychological readiness (ACL-RSI)

The study resulted in a positive ACL-RSI correlation with IKDC score after 12 months (r = 0.455, $p < 0.001$) and a negative correlation with BMI-Z score (r = -0.274, $p = 0.045$).

The multiple regression analysis was used to determine whether the IKDC score after 12 months following ACLR and BMI-Z score could significantly predict ACL-RSI score at 12 months after ACLR. The results of the regression analysis indicated that the determination coefficient $R^2 = 0.372$ and the model had significant predictors for ACL-RSI score (F = 15.114, $p < 0.001$).

VIF coefficients showed no multicollinearity problem between predictors (VIF < 4).

Table 3.12.1. *Multiple linear regression results for ACL-RSI score*

Model	Unstandardized coefficients		Standardized coefficients	t	*p* value
	B	Std. error	Beta		
(Constant)	–25.335	21.612		–1.172	0.247
IKDC 12 months	1.156	0.241	0.557	4.799	< 0.001
BMI-Z	–9.515	2.388	–0.463	–3.984	< 0.001

Both predictors (IKDC score after 12 months and BMI-Z score) were statistically significant. According to standardized beta coefficients, predictors had a similar impact.

The final predictive model was:

ACL-RSI (12 months after ACLR) =
= –25.335 + 1.156 × IKDC 12 months score −9.515 × BMI-Z score.

A multiple regression model could be useful to predict the ACL-RSI score 12 months post-ACLR based on the IKDC score 12 months after ACLR and BMI-Z score. Notably, graft type (HT or QT) was tested in the model but did not reach statistical significance and was therefore excluded, indicating that graft type alone did not independently influence psychological readiness outcomes at 12 months.

4. DISCUSSION

This doctoral thesis aimed to compare the outcomes of ACLR using either HT or QT autografts in paediatric patients by assessing knee joint stability, isokinetic thigh muscle strength recovery, and patient-reported satisfaction. A total of 54 patients (24 in the QT group and 30 in the HT group), aged between 13 and 17 years, completed the study. GNRB-assessed ATT measurements to evaluate knee stability were tested 3-, 6-, and 12-month postoperatively. The findings for each group over time are displayed separately for the QT group (Table 3.2.1) and the HT group (Table 3.2.2). 150 N and 200 N forces were not applied at 3 months postoperatively due to the insufficient graft maturation.

In our previously published study with interim results, we reported the 3- and 6-month data with a partial patient cohort [177]. Early results from this prospective study have shown that the QT autograft has comparable, and in some aspects superior, performance to the HT autograft in adolescent athletes. The first post-surgery side-to-side ATT assessment revealed that the QT autograft had twice the mechanical stability as the HT autograft as early as 3 months following ACLR. The current thesis study includes data from a 12-month postoperative time point from a full set of patient cohorts. This enables a more comprehensive analysis of different graft type performances over time.

Within-group knee stability over time was statistically significant only for the QT group, and no differences were found in the HT group. GNRB-assessed within-group knee stability analysis in the QT group revealed very low initial ATT values 3 months following ACLR, indicating high initial graft stiffness and mechanical stability. These findings reflect the known quadriceps tendon biomechanical properties, such as the greatest modulus and strength of collagen alignment compared to hamstring tendons, which resist elongation under load [181]. In addition, Mizuno *et al*. investigated different tendon types in an 11-year-old boy and found out that the patient in QT had higher percentages of collagen type I, which is considered physically and mechanically strong, while the semitendinosus tendon had more of collagen type III, which is considered weak [182].

Within the QT group, ATT significantly increased between 3 and 6 months, and between 3 and 12 months, but not between 6 and 12 months. The higher laxity between 3 and 6 months may indicate early graft adaptation, probably related to graft biological remodelling, revascularization, and ligamentization by 6 months postoperatively. It may also suggest that the QT grafts reached mechanical maturity quite early, as they plateaued and stabilized 6 months forward with no progressive laxity. The displacement curve slope for the

QT group also slightly increased from 3 to 6 months, further reflecting the reduction in graft stiffness due to undergoing the biological remodelling phase. By 12 months, the curve slope stabilized in the QT group, suggesting that this type of graft had reached mechanical equilibrium.

In contrast, the HT group demonstrated stable anterior translation and displacement curve slope values throughout the 12-month follow-up. The findings suggest that HT autografts provide consistent biomechanical performance with no progressive laxity or instability over time. However, this pattern was not supported with statistical significance as no meaningful changes were observed in either ATT or curve slope between the 3, 6, and 12-month time points in the HT group.

In general, both types of grafts showed positive outcomes, as they remained within the acceptable clinical ranges (Figure 3.3.1, Appendix Table 4). However, certain specific differences between the QT and HT graft groups were observed. The QT group demonstrated lower ATT compared to the HT group at all measured timepoints, but statistical significances were detected only at 3 months under 134 N force and at 12 months under all applied forces (134 N, 150 N, 200 N). These findings show greater QT graft stiffness and better and more sustained overall stability long-term as opposed to HT grafts. No statistically significant differences were observed between the groups at 6 months, suggesting a temporary convergence in their behavior. This could be due to the biological remodelling phase in mid-stage healing, potentially making the grafts perform similarly short term. At 12 months post-ACLR, the significant differences reappeared, and QT grafts significantly outperformed HT grafts in terms of knee stability, expanding our understanding of graft behavior beyond our early postoperative published data. Based on the previously published interim results, we observed early superiority of the QT graft at 3 months, followed by comparable performance between grafts at 6 months. At that time, we anticipated that both grafts would maintain similar outcomes long-term. However, the 12-month data revealed statistically significant differences between the groups, showing that QT autografts may provide superior long-term mechanical stability compared to HT autografts.

Although no statistical significance was found between both graft types in curve slope values at any time point, the observed trend was lower ranges and variability in the QT group. Higher variability in the HT group may indicate greater inter-individual variability in graft performance. This might have clinical significance when selecting graft type and appropriate postoperative rehabilitation. As the QT graft is stiffer and more predictable, a more standardized rehabilitation progression might be suitable, while higher HT group variability suggests a more individualized approach. In addition, QT graft consistency and stiffness show more mechanical robustness, which may be desired and a more appropriate choice for the active adolescent population.

Sex-based comparisons in terms of knee stability from our data differ from those reported in the published literature. Generally, it has been widely reported that the outcomes after ACLR, do not significantly differ by sex, particularly in terms of graft or contralateral ACL rupture risk, postoperative knee laxity, or subjective recovery [183]. In addition, some studies reported postoperative ligamentous laxity to be similar between males and females after ACLR using the HT autografts [184,185]. However, in our study, sex-based statistically significant differences in knee stability following ACLR were detected, particularly in the HT autograft group. At 3 and 6 months post-ACLR, higher ATT values were observed in males in the HT autograft group, indicating early knee laxity in males compared to females. No such differences were found at 12-month follow-up. While some literature reports inferior outcomes in terms of knee laxity in females [186], our results showed higher mechanical stability in females, possibly due to faster graft integration or neuromuscular adaptation. In the QT group, we also identified sex related differences. At 12 months after ACLR, males showed significantly higher knee instability than females. Therefore, males showed less knee stability when using both graft types, but at different time points, indicating early laxity when using HT autograft, and delayed laxity when using QT autograft. We found a significantly higher early laxity at 3 months in males in the HT group than in the QT group, suggesting that males may benefit from QT autograft more based on knee stability outcomes. Also, our findings suggest that while injury risk may differ by sex due to anatomical and hormonal factors, postoperative muscle function and balance may recover at different rates. Our findings may help to develop different rehabilitation strategies based on sex differences, for example, adolescent female patients may benefit from accelerated rehabilitation progressions, while males, particularly when using HT autograft, may benefit from a more gradual and targeted approach.

In addition, we used chi-square tests to study group differences in categorical outcomes, to reveal further clinically relevant distinctions. When evaluating knee stability with GNRB at 134 N after 12 months, a significantly higher proportion of females achieved a good outcome (66.7 % vs. 33.3 %; $p = 0.029$). Females had four times higher odds of achieving good knee stability than males (OR: 4.00; 95 % CI: 1.29–12.40). This supports our earlier interpretation that females exhibit better early recovery and graft integration patterns post-ACLR.

No studies have compared knee laxity outcomes as early as 3 and 6 months postoperatively in adolescents. However, some studies have reported similar patterns at later follow-up points. Cavaignac *et al*. [166] found significantly higher variation in side-to-side laxity in patients who received the HT autograft than in those who received the QT autograft 3 years after ACLR surgery. While our measurements were conducted at earlier time points, particularly at 3, 6, and 12 months, our results showed similar trends, with QT autografts demonstrating superior mechanical stability and less variability over time. At 12 months, the QT graft group remained better at knee stability under all applied forces, suggesting stronger long-term graft resistance to elongation. In contrast, other studies in adult populations, such as Akoto *et al*. [187], reported no significant differences between QT and HT autografts in knee stability at approximately one year postoperatively. Similarly, Kim *et al*. [188] and Lund *et al*. [189] also studied the QT as a possible autograft, although they compared it with the BPTB autograft, and they found no statistically significant side-to-side differences between the grafts, using KT-2000 arthrometers. They concluded that the QT graft has comparable knee stability outcomes but with lower donor site morbidity. Runer *et al*. [190] reported similar outcomes for functional testing, knee laxity and re-rupture rates between QT and HT grafts, but found a higher tendency a higher graft failure in highly active patients treated with the HT autograft. These findings further support the viability of QT autografts for adolescent ACLR.

Meniscal injuries are known as a potential confounding factor in ACLR outcomes, due to distortion of knee biomechanics and impacting ATT. To evaluate this, we grouped patients into two groups based on whether the meniscus required surgical repair or not, indicated as "repaired" and "repair not required" in the sample characteristics table (Table 3.1.1). No statistically significant difference in ATT between these categories was detected, suggesting that concomitant meniscal injury did not distort the comparison of knee stability between the QT and HT grafts.

Assessing knee joint kinematics after ACLR is important, as it directly relates to functional recovery, return to sport readiness, and the risk of graft re-rupture. The general differences between the strength of extensor and flexor mechanisms, represented by peak torque to body weight ratio and H/Q ratio between the graft groups, are shown in Figure 3.8.1 and in Appendix Table 12.

The isokinetic strength measurements obtained by using the Biodex isokinetic dynamometer revealed outcomes that differed from the initial expectations. Despite harvesting the hamstring tendons in the HT autograft group, flexor strength did not significantly differ between the HT and QT groups, even though the hamstrings were preserved in the QT group. These findings suggest that hamstring harvesting may have a less pronounced impact on flexor strength than previously assumed.

On the contrary, extensor strength was significantly lower in the QT group, which is a more expected finding and is probably attributable to quadriceps tendon harvesting. This procedure may directly impair extensor strength by compromising the biomechanical function of the quadriceps muscle in knee extension. This strength deficit persisted at both 6- and 12-month timepoints post-surgery.

Interpretation of the H/Q ratio results is more complex. At first glance, the QT group demonstrated a more favorable ratio, which is closer to the commonly accepted threshold of ≥60, commonly associated with reduced risk of graft re-rupture. However, the wide variability (min–max range) in this group suggests that the ratio may indicate a high morbidity of the quadriceps muscle due to the harvesting procedure, leading to a falsely elevated H/Q ratio rather than actual muscle balance superiority.

In addition, the data suggest that a 12-month follow-up period may not be sufficient for strength normalization between the groups. Flexion, extension, and their ratio results persisted at one year postoperatively.

For further analysis, the isokinetic strength was compared in the same autograft group between operated and healthy legs, as displayed in Tables 3.7.1, 3.7.2. The results further support the reasoning that quadriceps' morbidity improves the H/Q ratio in the QT group. Reduced quadriceps strength was observed at both 6- and 12-months in the operated leg, thus, the ratio of agonists/antagonists in the involved leg was higher and closer to the target of 60 percent. Additionally, at 6 months post-ACLR, the flexor strength between both involved and uninvolved legs did not differ, probably due to the positive impact of hamstrings preservation on the posterior muscle group.

In the HT group, even though the HT was the selected autograft type, the operated leg demonstrated a statistically significant reduction in quadriceps strength at both 6 and 12 months postoperatively. This might suggest that both the initial injury and the surgical procedure may significantly affect quadriceps strength. Regarding the flexor strength evaluation in the HT group, the findings were more predictable and straightforward, as the operated leg demonstrated weaker flexors at 6- and 12-months post-surgery due to harvested hamstring tendons. Thus, no compensation in extensor strength was observed, and both muscle groups were weaker in the involved legs in the HT group. The H/Q ratio in the HT group remained higher in the uninvolved leg over time, which is expected in the unoperated leg. However, the persistent muscular imbalance in the operated leg after 12 months highlights the remaining reinjury risk in this graft type group.

Our sex-based isokinetic strength data showed that males had significantly higher extensor strength at 12 months postoperatively, particularly in the HT group, as well as a greater improvement in extensor strength from 6 to 12 months. This trend was also observed in the total cohort, regardless of graft type. In contrast, females exhibited significantly higher H/Q ratios at

12 months. Although female sex is widely recognized as a non-modifiable risk factor for ACL injuries, in particular during adolescence, due to certain hormonal, anatomical, and biomechanical factors [16–19], our data did not show inferior isokinetic strength recovery in females. In fact, females exhibited a more balanced H/Q ratio at 12 months, indicating better muscle balance by relatively stronger hamstrings or slower quadriceps recovery. Thus, even though female sex is known as a possible higher ACL injury risk factor, it may be also associated with faster and more balanced recovery. In the QT group, no statistically significant sex differences were found in isokinetic strength outcomes, suggesting that this graft type affects males and females similarly. Both sexes demonstrated similar and consistent extensor strength deficits, which aligns with the presumption that quadriceps tendon harvesting itself may weaken extensors. Therefore, based on our findings, the HT graft may be a more suitable option for adolescent females, while the QT graft may be a more neutral option in terms of sex-based differences. In addition, our sex-based isokinetic strength results support the need for sex-specific targeted rehabilitation approaches.

A significantly higher proportion of patients in the QT group achieved an acceptable H/Q ratio at 12 months postoperatively compared to the HT group (62.5 % vs. 20.0 %; $p = 0.004$). The odds of reaching an acceptable H/Q ratio were 6.67 times higher in the QT group. These findings further reinforce the idea that the QT graft may facilitate better muscle balance around the knee joint, even if the improved H/Q ratio may reflect relative quadriceps weakness.

There is limited research and no clear consensus on comparing QT and HT autografts on functional outcomes, failure rates, and patient satisfaction for paediatric ACLR [191]. Fischer *et al*. compared post-ACLR isokinetic quadriceps and hamstring muscle strength in patients who received either HT or QT autografts, finding no significant differences between groups. They reported that age was not a confounding factor [192].

The graft harvest site typically determines the predictable functional outcome pattern. Biomechanical principles suggest a general anticipation that postoperative peak knee flexion torque would be lower in HT autograft recipients, while peak knee extension torque would be reduced in the QT group due to graft harvest location [193]. Harvesting the quadriceps tendon has been associated with poorer functional outcomes, such as persistent knee extensor weakness [194–197], and lower patient satisfaction after ACLR [198]. Our results challenge these notions as hamstring harvesting did not cause significant morbidity in the HT group in our study. Also, quadriceps weakness that was found in our study is in accordance with previously mentioned research; on the contrary, a recent study published by Giusti *et* *al*. [199] reported that all-soft-tissue QT autograft showed superior donor-site morbidity outcomes compared to the HT autograft. However, their study was retrospective and based on the use of questionnaires rather than actual muscle strength measurements. Although QT grafts often produce an almost ideal H/Q ratio after ACLR, which is considered to have a connection with lower re-rupture rates, this balance may be misleading. The improved ratio is probably caused by iatrogenic injury to the quadriceps muscle rather than preserved or enhanced hamstring strength. This imbalance may also contribute to decreased patient satisfaction postoperatively.

A higher H/Q ratio in the QT group indicates strong hamstrings relative to the quadriceps, which is generally considered an indicator of better muscle balance around the knee joint and is associated with a reduced risk of recurrent ACL injury [192]. Martin-Alguacil *et al*. support this from a different perspective in their randomized clinical trial with young soccer players, suggesting that flexion strength deficits in the HT group and the subsequent H/Q imbalance increase the graft rupture risk in these patients [196]. However, H/Q ratio alone may not predict graft re-rupture risk, as indicated in recent literature, that it is not an independent risk factor and should be interpreted in combination with other functional and clinical parameters [200].

Several studies support the use of the QT graft as a viable option for ACLR, despite some evidence of reported short-term quadriceps weakness. In their similarly designed short-term study, Hughes *et al*. evaluated functional outcomes using Biodex after ACLR with QT, HT, and BPTB, showing more favorable strength outcomes [194]. While the strength of quadriceps muscles was reduced in the QT group at 5 to 8 months, the weakness resolved by 9 to 15 months, and no significant difference was observed between the graft groups. The study highlighted the importance of targeted rehabilitation programs focusing on quadriceps strengthening to overcome the residual quadriceps weakness. De Petrillo *et al*. concluded that the QT, HT, and BPTB autografts cause specific short-term muscle strength deficits after ACLR surgery in paediatric patients that should be considered along with other patient-specific factors, such as sex and age or skeletal maturity, and adequate rehabilitation protocols can help mitigate those muscle strength deficits [191]. In the retrospective study conducted by Kay *et al*. [201], similar findings to ours were reported: adolescents who underwent ACLR with a QT autograft exhibited greater deficits in quadriceps strength, while those with an HT autograft demonstrated reduced flexion strength. In addition to greater extensor weakness, patients in the QT group had stronger flexors than those in the HT group, which led to improved H/Q ratio; also, no influence on hop performance was found between the groups. Interestingly, Horteur *et al*. [202] reported that even though QT harvesting is generally thought to harm quadriceps functional outcomes, they did not observe any significant quadriceps weakness post-ACLR.

We hypothesize that one of the primary reasons for such a high residual quadriceps weakness is that all patients endured the same rehabilitation program, no matter what type of autograft was used. Setuain *et al*. evaluated the effectiveness of objective-care versus usual-care rehabilitation programs following ACLR. They found that patients in the objective-care program group achieved superior peak torque values in both flexion and extension as opposed to the usual-care group [203]. In addition, Solie *et al*. also concluded that rehabilitation should not be universally applied and needs to be adapted specifically for each individual situation [204]. Leung *et al*. reported similar ideas and suggestions for targeted ongoing rehabilitation [205].

Clinical milestones postoperatively may differ based on the graft type used; therefore, rehabilitation protocols should be tailored accordingly and consider the graft type chosen for ACLR surgery. In cases where the QT or BPTB grafts are used, rehabilitation should take into account the risk for surgically induced tendinopathy. Early-stage protocols should promote regular muscle contractions to support tissue healing. Specific rehabilitation programs should extend beyond 2-3 months post-operatively, and the flexion-extension mechanism should be continuously evaluated and appropriately addressed throughout the rehabilitation process. Preoperative knee flexion and extension torque evaluation and prescription of a prehabilitation protocol can also improve postoperative strength deficits and favor a balanced H/Q ratio to prevent graft re-rupture [191,196].

Additionally, recent evidence suggests no difference between the unsupervised and the supervised programs for laxity, subjective function, functional outcomes, strength, or atrophy in early rehabilitation after ACLR. Also, the duration of the rehabilitation did not significantly affect knee laxity or subjective function [206]. However, objective laxity measurements can guide decision-making during the rehabilitation process. For instance, a side-to-side difference within acceptable limits ($\leq$1.5 mm) at 3 months post-op could allow physiotherapists to adjust the home-based exercise programs, focusing more on limb strength symmetry and delaying the running-based exercises. At 6 months post-ACLR, if laxity measures within the acceptable range, progression towards sport-specific tasks and return-to-sport activities may be considered.

Patient satisfaction is a key indicator to determine how successful the surgical intervention was [167]. In the final stage of our study, we evaluated patient-reported outcomes between both autograft groups at 12-month follow-up after the surgery. All three questionnaire results (IKDC, Lysholm, and ACL-RSI) were lower in the QT group; only the IKDC score was statistically significant. These findings might be better understood in the context of our isokinetic muscle strength data. The H/Q ratio was better in the operated leg in the QT group than in the uninvolved leg, which seemed counterintuitive. It may be due to a significant quadriceps morbidity effect caused by tendon harvesting rather than enhanced hamstring performance. Residual quadriceps weakness might explain the apparently optimal H/Q ratio and lower subjective satisfaction outcomes in the QT group.

In addition to lower IKDC, Lysholm, and ACL-RSI scores in the QT group, our multiple linear regression model assessed how functional knee outcomes (IKDC score) and BMI-Z score predict psychological readiness (ACL-RSI) at 12 months postoperatively. The model was statistically significant (R^2= 0.372, p<0.001), with both predictors contributing independently. More specifically, higher IKDC scores were significantly associated with greater psychological readiness ($p < 0.001$), while higher BMI-Z scores were linked to reduced ACL-RSI outcomes ($p < 0.001$). This could explain how residual quadriceps weakness in the QT group may have indirectly lowered psychological readiness and patient satisfaction by contributing to lower IKDC scores. Additionally, factors related to higher BMI may have further influenced recovery perception, particularly in adolescents with higher body weight. Our findings are in alignment with previous research. For example, Gauthier *et al*. [207] found that ACL-RSI was significantly better in lower BMI patients. Webster *et al*. [208] reported that IKDC subjective knee score was more strongly associated with ACL-RSI than physical function (measured as hop-test limb symmetry). Lentz *et al*. [209] concluded that lower IKDC scores correlated with lower return to sports due to fear of reinjury and lack of confidence. Our chi-square test analysis revealed that a significantly higher proportion of HT patients had a favorable ACL-RSI score at 12 months compared to the QT group (80 % and 50 %, respectively). The odds of a good ACL-RSI outcome were 4 times higher in the HT group. This was possibly due to better subjective knee function recovery, which is also supported by the IKDC results.

Unfortunately, only a limited number of studies evaluate patient satisfaction after ACLR, particularly after reconstruction with the QT autograft [167,191]. Gorschewsky *et al*. utilized Lysholm and IKDC scores (although as functional) to evaluate BPTB and QT with bone block and found that patients who received the BPTB autograft were more likely to have a normal score than those who received the QT with bone block autograft [210]. For the evaluation of patient satisfaction, they created a grading scale, which was a different approach from our study. Researchers concluded that very good results were more frequent in the BPTB group. However, direct comparison of their study with ours is challenging, as they compared the QT with bone block to the BPTB graft, while we compared the all-soft tissue QT autograft with the HT autograft. To date, we were unable to find studies that would compare patient satisfaction between the QT and HT autografts exclusively.

Dadoo *et al*. reported that out of 80 % of QT autograft with bone block receiving adolescent athletes, who successfully returned to sports at a mean time of 9.7 months postoperatively, 85 % of them returned to the same or higher activity level [211]. The rate of return to sports post-ACLR was similar to previously reported rates among adolescent athletes who underwent ACLR with QT and other autografts, ranging from 60 % to 100 % [211–214]. In addition, Dadoo *et al*. found that patients who received QT autograft achieved a significant increase from pre- to postoperative IKDC scores (37.5 vs 88.5; $p<0.001$) [211]. These findings provide strong support for using the QT autograft in ACLR.

The QT autograft is the least investigated and rarely used for ACLR, but its use is expected to increase [215]. Some studies have investigated QT autografts with a patellar bone block [31,188,216,217]. Additionally, in the meta-analysis published in 2019 by Mouarbes *et al*. [218], only five articles were identified that compared the HT and QT autografts for ACLR, and in all of them, the QT autograft was harvested with a patellar bone block. Thus, comparative studies investigating all-soft-tissue QT autografts remain especially limited. Crum *et al*. [219], in their systematic review, compared only 181 patients who received all-soft-tissue QT autografts (5 studies) with 1534 patients who received patellar bone QT autografts (20 studies). Despite the limited data on the all-soft-tissue QT autograft use for ACLR, the available results are promising, such as no reported difference in graft rupture between all-soft-tissue QT and patellar-bone-block QT autografts [219], great functional outcomes at short and intermediate follow-up [220], and decreased donor site morbidity [221]. Our study contributes to this underexplored research area involving mainly two poorly studied fields: the all-soft-tissue QT autograft and its use in young and active patients [191,215]. This makes our findings of current significance and clinically relevant for paediatric orthopaedic practice regarding graft selection and rehabilitation strategies.

Based on the reviewed studies and our findings, the QT autograft seems to be a viable and promising option for ACLR in adolescent patients. Further studies should focus on the biological or mechanical properties that may influence the QT graft performance. Tenocytes are the predominant cells in tendons and ligaments, participating in important processes such as donor site healing, collagen production, regeneration after graft harvesting, and graft ligamentization. Higher density of tenocytes and collagen in the QT than in other graft sources may be the reason for promoting better knee functional outcomes after QT harvesting [222,223]. In addition, using QT autograft spares the hamstrings, which are important for rotational, translational, and varus/valgus stability of the knee. Hamstring loss after their harvesting significantly compromises knee kinematics and stability before regeneration occurs [224].

The present study had some limitations that need to be considered when interpreting the results. First, a relatively small sample size may limit the statistical power. The sample size was reduced after patient drop-out during the follow-up process and due to the ongoing nature of the research. In addition, for some patients the instrumented laxity testing was too early postoperatively, which may have distorted group representation at certain time points. Another limitation is the lack of preoperative isokinetic strength data, which limits the comprehensive evaluation of the recovery timeline. Our study follow-up was only up to 12 months postoperatively, which limits the ability to draw long-term conclusions. Lastly, the examiners conducting the follow-up assessments were not blinded to the graft type, possibly introducing an assessment bias.

In future studies, researchers should consider including larger patient cohorts and apply different rehabilitation protocols that would be graft specific. Furthermore, extended patient follow-ups beyond 12-month timeline should be applied to better capture the resolution of persistent quadriceps weakness that is often associated with QT autografts.

Despite these limitations, the study's strengths include its prospective design, standardized surgical technique performed by a single experienced orthopaedic surgeon, and homogenous comparison groups for QT and HT autografts. Over a two-year period, we invited all adolescent patients with a primary ACL tear who were presented to the Hospital of Lithuanian University of Health Sciences Kaunas Clinics to participate in our study. Therefore, we believe our study population is representative, as all eligible patients had an opportunity to be included in the study. The high physical activity level among participants illustrates the type of patient who is at risk for ACL injury. Even though, the minimum sample size was achieved, larger patient cohorts could reveal more statistically significant differences.

Overall, our study is the first to objectively evaluate graft performance specifically in adolescent patients after ACLR. Notably, the study's patient cohort consisted of only physically active adolescents (median preoperative Tegner score of 8 [3–10; 7.49]), and 89.71 % of them ruptured the ACL while participating in sports activities. A single orthopaedic surgeon performed all surgeries, and one experienced senior physiotherapist conducted all knee laxity assessments. Lastly, the use of the all-soft-tissue QT autograft makes the data of our study novel and clinically relevant due to the scarcity of research of this type of graft in the paediatric population.

CONCLUSIONS

1. Both QT and HT graft types provided acceptable postoperative ATT outcomes at 12 months, but the QT autograft showed faster and greater stability with less variability. Males exhibited more knee instability than females after ACLR, particularly early laxity in the HT group and delayed in the QT group, while females achieved faster and more stable outcomes regardless of graft type.
2. QT group showed significantly lower extensor strength up to 12 months. Flexor strength was unaffected by HT harvesting. Males had stronger extensors, while females exhibited a more favorable H/Q ratio, suggesting sex-specific recovery patterns.
3. Lower subjective satisfaction in the QT group was detected at 12 months post-ACLR, with the IKDC score being the only statistically significant measure. Additionally, patients with HT grafts had 4 times higher odds of achieving a favorable ACL-RSI outcome.
4. Multiple regression analysis revealed that subjective knee function (IKDC) and BMI-Z score were independent predictors of psychological readiness (ACL-RSI) at 12 months post-ACLR. Graft type had no independent predictive effect.

PRACTICAL RECOMMENDATIONS

The quadriceps tendon (QT) autograft as a reliable choice for primary ACL reconstruction (ACLR) in adolescents, showing outcomes comparable to, and in some aspects better than, hamstring tendon (HT) autografts.

Our findings support the need for tailored rehabilitation approaches: accelerated for females, more gradual for males, individualized for HT graft recipients with variable recovery, and standardized for QT graft recipients due to more predictable recovery.

Finally, psychological readiness is a crucial yet often overlooked factor, especially in adolescents facing both physical recovery and external pressures. Enhancing body composition and functional outcomes may help support a confident return to pre-injury activity levels.

SUMMARY IN LITHUANIAN

ĮVADAS

Viena dažniausių ir labiausiai funkciją apribojančių kelio traumų yra priekinio kryžminio raiščio (PKR) plyšimas, reikalaujanti ilgo sveikimo laikotarpio ir sukelianti reikšmingą fizinę, psichologinę ir ekonominę naštą. Ši trauma yra ypač sudėtinga sportininkams, nes dažnai lemia ilgas pertraukas jų karjeroje [1–3].

PKR plyšimai yra auganti sveikatos problema, vis dažniau nustatoma vaikams ir paaugliams. Per pastaruosius kelis dešimtmečius PKR plyšimų ir PKR rekonstrukcijų (PKRR) skaičius vaikų populiacijoje reikšmingai išaugo [4–6], o jų dažnis vaikų populiacijoje auga sparčiau nei suaugusiųjų [7].

Galimos didesnio PKR traumų dažnio priežastys gali būti padidėjęs sportinis aktyvumas, ankstyva vienos sporto šakos specializacija ir ištisus metus trunkantis varžybinis sportas be sezoninių pertraukų. Intensyvus treniravimasis apkrauna sąnarius ir greta esančias struktūras, įskaitant ir PKR. Vienos sporto šakos pasirinkimas vietoje kelių gali lemti pasikartojantį tam tikrų raumenų ir sąnarių krūvį, mažinantį bendrą raumenų ir kaulų sistemos jėgos pusiausvyrą ir tokiu būdu galimai sukeliantį traumos pavojų. Taip pat, skirtingai nuo anksčiau paplitusio sezoninio treniruočių pobūdžio, šiuolaikiniai jauni sportininkai treniruojasi ištisus metus, o tai mažina poilsio ir atsistatymo laiką ir gali padidinti perkrovos traumų riziką [8, 9]. Be to, didėjantis sveikatos priežiūros specialistų informuotumas apie tai, kad PKR plyšimai gali pasitaikyti ir vaikų amžiaus grupėje, kartu su plačiau taikomais pažangiais medicininiais vaizdinimo metodais taip pat gali lemti geresnę PKR pažeidimų diagnostiką [10].

COVID-19 pandemijos metu PKR operacijų skaičius laikinai sumažėjo maždaug 30 proc. dėl atidėtų planinių operacijų ir sumažėjusios fizinės veiklos. Tačiau panaikinus apribojimus, operacijų skaičius grįžo į priešpandeminį lygį, o PKR traumų dažnis nuo tada išaugo tarp mėgėjų futbolininkų [11, 12].

PKR yra vienas iš keturių pagrindinių kelio sąnarį stabilizuojančių raiščių – jis apsaugo nuo blauzdikaulio slydimo į priekį šlaunikaulio atžvilgiu. Taip pat jis padeda išvengti per didelio kelio tiesimo, varus (pritraukimo), valgus (atitraukimo) judesių bei blauzdikaulio rotacijos. Be to, sveikas PKR saugo meniskus nuo šlyties jėgų, kurios atsiranda atliekant dinamiškus, intensyvius sportinius judesius [10].

PKR traumos dažnai pasitaiko intensyviose sporto šakose, kurioms būdingi staigūs judesio pokyčiai, pavyzdžiui, staigūs krypties keitimai, sukimaisi, šuoliai ir nusileidimai [13]. Jos ypač dažnos komandinėse sporto šakose, tokiose kaip futbolas, krepšinis, tinklinis, rankinis ir kitose panašiose sportinėse veiklose [14]. PKR trauma gali įvykti ne tik dėl vienkartinio sąnario perkrovimo, bet ir dėl laipsniško raiščio nuovargio, kurį sukelia per laiką pasikartojančios, submaksimalios apkrovos [15].

PKR plyšimo rizika priklauso nuo lyties ir amžiaus, tačiau apskritai moterys yra labiau linkusios į šias traumas daugumoje amžiaus grupių, lyginant su vyrais. Vis dėlto berniukai dažniau patiria PKR traumas prieš lytinį brendimą, o po brendimo rizika labiau išauga merginoms dėl hormoninių, anatominių ir biomechaninių veiksnių [16–19].

Tradiciškai PKR traumos vaikų ir paauglių populiacijoje buvo gydomos konservatyviai - koreguojant fizinį aktyvumą, taikant kineziterapiją ir specialius įtvarus iki pacientas pasiekdavo kaulinį subrendimą. Vis dėlto naujausi duomenys rodo, kad chirurginio gydymo atidėjimas jauniems sportininkams gali būti pernelyg rizikingas ir lemiantis antrines gretimų struktūrų, tokių kaip meniskai ir kolateraliniai raiščiai, traumas [13, 20], taip pat lėtinį kelio sąnario nestabilumą ir reikšmingą sportinės veiklos apribojimą [21]. Todėl šiuo metu pirmenybė teikiama ankstyvam chirurginiam gydymui, siekiant apsaugoti meniskus ar raiščius nuo pažeidimų ir užtikrinti geresnius ilgalaikius rezultatus [20, 22].

Dažniausia komplikacija šioje pacientų grupėje yra transplantato plyšimas, pasitaikantis iki 25 proc. atvejų ir dažnai reikalaujantis pakartotinių rekonstrukcinių operacijų. Didėjant pirminių PKRR skaičiui dar kaulinės brandos nepasiekusiems pacientams, auga ir pakartotinių rekonstrukcijų skaičius. Be to, tyrimai rodo, kad po vaikams atliekamos pirminės PKRR nustatomas didesnis pakartotinių operacijų dažnis nei suaugusiesiems [20, 23].

PKRR, atliekamos vaikystėje ir paauglystėje, kelia specifinius iššūkius lyginant su suaugusiaisiais. Būtina atsižvelgti į nepakankamą kaulinę brandą ir kiek įmanoma sumažinti su tuo susijusias rizikas, tokias kaip augimo zonų pažeidimai ir galimi galūnių ašies sutrikimai. Siekiant šių rizikų išvengti, literatūroje aprašyti įvairūs augimo zonas tausojantys chirurginiai metodai [20, 24], įskaitant visiškai epifizinį, ekstrafizinį, transfizinį ar mišrų (kombinuotą) metodą [25]. Taip pat, siekiant parinkti saugiausią chirurginę metodiką bei transplantato tipą, itin svarbu įvertinti paciento kaulinį amžių, brendimo stadiją ir likusį augimo potencialą [13]. Visgi net ir sėkmingai atlikus PKRR, transplantatas gali plyšti ar įvykti priešingos kojos trauma. Todėl vis dar reikalingi tolesni tyrimai ir aiškios gairės dėl optimalaus transplantato tipo parinkimo vaikų populiacijoje [26].

PKRR transplantato parinkimas turėtų būti nuodugniai apgalvotas kiekvienam pacientui dar prieš operaciją. Pagrindiniai veiksniai, darantys įtaką transplantato parinkimui, yra paciento amžius, lytis, kaulinė branda, fizinio aktyvumo lygis, asmeniniai tikslai, šlaunies lenkiamųjų ir tiesiamųjų raumenų jėgos santykis (angl. *hamstring-to-quadriceps ratio* – H/Q ratio) bei individualūs anatominiai ypatumai.

Ne mažiau svarbus ir transplantato kilmės klausimas - autologinis ar alogeninis. Taip pat svarbi ir transplantato donorinė vieta: tai gali būti šlaunies lenkiamųjų raumenų sausgyslės (ŠLRS), iliotibialinis traktas (ITT), šlaunies keturgalvio raumens sausgyslės (ŠKRS) ar girnelės sausgyslė su kaulo fragmentais (angl. *bone-patellar tendon-bone* – BPTB) [25, 27]. Kadangi alogeniniai transplantatai siejami su 2–3 kartus didesne pakartotinio plyšimo rizika, juos naudoti vengiama, ypač vaikų populiacijoje, kuri dėl amžiaus ir didelio fizinio aktyvumo jau ir taip patiria didesnę transplantato plyšimo riziką [25]. Dėl šios priežasties vaikams dažniausiai naudojami autotransplantatai, nors kiekvienas transplantato tipas turi savų privalumų ir trūkumų [20].

Autotransplantatai su kaulo fragmentais dažnai sukelia komplikacijų transplantato paėmimo vietoje, pavyzdžiui, priekinį kelio skausmą ir padidėjusią girnelės lūžių riziką. Todėl jie gali būti ne pats saugiausias pasirinkimas kaulinės brandos nepasiekusiems pacientams. Dėl šių priežasčių pirmenybė dažnai teikiama vien minkštųjų audinių (sausgyslė be kaulinio fragmento) autotransplantatams [28]. ŠLRS autotransplantatas yra dažniausiai naudojamas PKRR transplantatas vaikų amžiaus pacientams visame pasaulyje, ypač už Šiaurės Amerikos ribų. Tuo tarpu BPTB autotransplantatas yra antras pagal dažnumą pasaulyje, tačiau žymiai dažniau naudojamas Jungtinėse Amerikos Valstijose nei kitose šalyse [20, 25, 29]. Pastaruoju metu ŠKRS autotransplantatas vis labiau populiarėja dėl savo santykinio storio ir didelio atsparumo plyšimui esant apkrovai, kas prisideda prie mažesnio transplantato plyšimo dažnio [20]. Tyrimai parodė, kad ŠKRS vien minkštųjų audinių autotransplantatai turi kelis pranašumus prieš ŠLRS, įskaitant didesnius ir pastovesnius transplantato matmenis bei geresnį šlaunies lenkiamųjų raumenų jėgos išsaugojimą po operacijos [28]. Aitchison ir kt. nustatė, kad ŠKRS transplantatai po 12 mėnesių pasižymėjo geresne transplantato branda, sinovializacija ir struktūriniu vientisumu nei ŠLRS transplantatai [30]. Vis dėlto dar trūksta žinių apie ŠKRS transplantatų pranašumus prieš ŠLRS transplantatus kaulinės brandos nepasiekusių pacientų grupėje [20]. Tik keli tyrimai naudojo artrometrinį abiejų kelių lyginamąjį vertinimą (angl. *side-to-side*) lyginant ŠKRS transplantatus su girnelės kauliniu fragmentu su ŠLRS transplantatais [31, 32]. Be to, iki šiol nebuvo atlikta nė vieno tyrimo, kuris būtų konkrečiai nagrinėjęs vien minkštųjų audinių (sausgyslė be girnelės kaulinio fragmento) ŠKRS autotransplantatus [33].

Nepaisant pažangos vaikų PKRR srityje, vis dar trūksta vieningo požiūrio gydant kaulinės brandos nepasiekusių pacientų PKR traumas. Taip pat nėra sutarimo dėl optimalios chirurginės technikos ir transplantato parinkimo, ypač lyginant ŠLRS ir ŠKRS autotransplantatus. Šiuo tyrimu siekiame užpildyti šias spragas, lyginant ŠLRS ir vien minkštųjų audinių ŠKRS autotransplantatų rezultatus šioje pacientų populiacijoje.

Šiame tyrime keliama hipotezė, kad tausojant šlaunies lenkiamųjų raumenų sausgysles ir naudojant ŠKRS transplantatus, bus pasiekti geresni funkciniai rezultatai, palankesnis pacientų subjektyvus gijimo vertinimas po operacijos ir mažesnė pakartotinių traumų rizika. Tikimasi, kad vien minkštųjų audinių ŠKRS autotransplantatas užtikrins kelio sąnario stabilumą, panašų į ŠLRS transplantatą, o tyrimo rezultatai prisidės prie platesnio šio transplantato pritaikymo klinikinėje praktikoje.

Tyrimo tikslas

Šio tyrimo tikslas buvo palyginti PKRR rezultatus vaikų amžiuje naudojant ŠLRS arba vien minkštųjų audinių (be kaulinio fragmento) ŠKRS transplantatą.

Tyrimo uždaviniai

1. Įvertinti pooperacinius kelio sąnario stabilumo, išmatuoto Genourob artrometru, rezultatus po PKRR, kai naudojami ŠLRS arba ŠKRS transplantatai.
2. Įvertinti šlaunies raumenų jėgą po PKRR naudojant Biodex izokinetinę sistemą, kai taikomos dvi skirtingos chirurginio gydymo metodikos.
3. Palyginti kelio sąnario funkcijos atsistatymą ir reabilitacijos efektyvumą po PKRR, taikant dvi skirtingas operacinio gydymo metodikas.
4. Nustatyti psichologinio pasirengimo grįžti į sportą (PKR-GST) prognozinius veiksnius.

Tyrimo naujumas ir praktinė reikšmė

ŠKRS autotransplantatai vis dažniau minimi mokslinėje literatūroje ir neretai vadinami „ateities transplantatu“ [34, 35]. Naujausia 12 metų „Google Trends“ analizė taip pat parodė augantį visuomenės susidomėjimą ŠKRS autotransplantatais, lyginant su kitais transplantatų tipais [36]. Nors daug tyrimų lygino ŠLRS ir ŠKRS autotransplantatus suaugusiųjų populiacijoje, duomenų apie vaikų amžiaus grupę vis dar trūksta. Vos keli tyrimai tiesiogiai lygino ŠKRS autotransplantatus su kitais įprastai naudojamais variantais, tokiais kaip ŠLRS ar BPTB autotransplantatais kaulinės brandos nepasiekusių pacientų grupėje [35], pabrėžiant tyrimų trūkumą vaikų PKRR srityje.

Šiuo metu vis dar nėra vieningo požiūrio į PKR traumų gydymą kaulinės brandos nepasiekusiems pacientams – vis dar vyksta diskusijos dėl augimo zonų išsaugojimo, tinkamiausio operacijos laiko ir transplantato parinkimo.

Thorolfsson ir kt. nustatė, kad paaugliams, kuriems buvo atlikta PKRR naudojant ŠLRS autotransplantatą, revizinių operacijų dažnis buvo dvigubai didesnis nei jauniems suaugusiesiems [37]. Tai gali reikšti, kad ŠLRS transplantatas nėra optimaliausias pasirinkimas pacientams, kurių augimas dar nepasibaigęs, ir būtina ieškoti tinkamesnių variantų. Be to, tik labai nedaug tyrimų lygino ŠKRS transplantatą su girnelės kauliniu fragmentu ir ŠLRS transplantatą, naudodami artrometrinį *side-to-side* vertinimą [31, 38] ir nė viename iš jų nebuvo tirti vien minkštųjų audinių ŠKRS autotransplantatai. Tai reikšminga spraga, nes šie minkštųjų audinių ŠKRS autotransplantatai gali būti pranašesni už transplantatus su kaulo fragmentais dėl mažesnės komplikacijų rizikos donorinėje vietoje, retesnio priekinio kelio skausmo, girnelės lūžių ir kitų komplikacijų paaugliams [28].

Šis mūsų tyrimas yra vienas pirmųjų, išsamiai nagrinėjantis vien minkštųjų audinių ŠKRS autotransplantatą vaikų populiacijoje ir lyginantis jį su ŠLRS autotransplantatu, integruojant kelis vertinimo parametrus. Nors dauguma ankstesnių tyrimų daugiausia dėmesio skyrė transplantato patvarumui bei kelio sąnario stabilumui po operacijos, tik nedaugelis jų vertino šlaunies raumenų jėgą ir funkcinį atsistatymą vaikams po PKRR. Šiame tyrime buvo integruoti keli baigčių vertinimo rodikliai, įskaitant kelio sąnario stabilumą (vertintą Genourob artrometru), raumenų jėgą (matuotą Biodex izokinetine sistema) ir pacientų subjektyvų savijautos vertinimą po PKRR (vertintą pagal pacientų pateiktų klausimynų rezultatus), taip pateikiant visapusišką ŠKRS ir ŠLRS transplantatų savybių ir galimos naudos vaizdą.

Be to, šis tyrimas gali suteikti savalaikių ir vertingų duomenų popandeminiame kontekste, nes pastaruoju metu pastebimai padaugėjo sportinių traumų, ypač tarp sportininkų mėgėjų [12]. Kadangi vaikų populiacijoje stebimas staigus PKR plyšimų augimas [4, 6, 39], mūsų tyrimo rezultatai gali tiesiogiai paveikti sprendimų priėmimą klinikinėje praktikoje, suteikiant chirurgams įrodymais pagrįstų įžvalgų apie tai, ar vien minkštųjų audinių ŠKRS autotransplantatai gali užtikrinti geresnį gydymo poveikį nei ŠLRS. Atsižvelgiant į didelį ŠLRS autotransplantatų revizijų skaičių jaunesnių pacientų grupėje, šis tyrimas gali prisidėti prie optimalesnio transplantato parinkimo ir veiksmingesnių reabilitacijos protokolų taikymo, galinčių sumažinti transplantatų plyšimo riziką bei pagerinti ilgalaikę kelio sąnario funkciją vaikų populiacijoje.

METODAI

Tyrimo dizainas

Šis atsitiktinių imčių prospektyvinis tyrimas buvo atliktas Lietuvos sveikatos mokslų universiteto (LSMU) Kauno klinikų Vaikų ortopedijos skyriuje. Į tyrimą buvo įtraukti 68 pacientai (37 vaikinai ir 31 mergina), kurių amžius – nuo 12 iki 17 metų. Visi tyrimo protokolai atitiko Helsinkio deklaracijos principus ir buvo patvirtinti Kauno regioninio biomedicininių tyrimų etikos komiteto (protokolo Nr. BE-2-103).

Pacientų atranka

Prieš įtraukiant į tyrimą, visi pacientai ir/ar jų tėvai buvo informuoti apie tyrimą ir pasirašė informuoto asmens sutikimą, po kurio atsitiktinės atrankos būdu buvo paskirstyti gauti ŠLRS arba ŠKRS autotransplantatą, naudojant uždarų vokų metodą (angl. *closed envelope method*). Siekiant patvirtinti fiziškai aktyvų gyvenimo būdą, pacientai pildė Tegner fizinio aktyvumo skalės klausimyną. Tinkamumas dalyvauti tyrime buvo nustatytas remiantis MRT patvirtintu visišku PKR plyšimu, kuriam reikalinga pirminė PKRR. Buvo leidžiami kartu esantys menisko pažeidimai, tačiau kiti kauliniai ar kelio raiščių pažeidimai buvo atmetimo kriterijus. Tiksli įtraukimo ir atmetimo kriterijų apžvalga pateikta 1 lentelėje.

Prieš operaciją buvo surinkti pacientų demografiniai ir antropometriniai duomenys: amžius, lytis, ūgis, svoris ir KMI. KMI-Z reikšmės buvo apskaičiuotos koreguojant referencinius duomenis pagal amžių ir lytį, siekiant gauti standartizuotą reliatyvų paauglių svorio įvertinimą.

1 lentelė. *Įtraukimo ir atmetimo kriterijai*

Įtraukimo kriterijai	Atmetimo kriterijai
Amžius nuo 12 iki 17 metų Kognityviai pajėgūs asmenys MRT patvirtintas visiškas PKR plyšimas Pirminė PKRR Pasirašytas informuoto asmens sutikimas Gydymas LSMU Kauno klinikose	Kiti gretutiniai kauliniai ar raiščių sužalojimai (išskyrus menisko pažeidimus) Anksčiau atlikta PKRR Nepasirašytas informuoto asmens sutikimas

Chirurginė procedūra

Iš viso PKRR buvo atlikta 68 pacientams – 38 pacientams buvo naudoti ŠLRS, o 30 – ŠKRS autotransplantatai. Visas operacijas atliko vienas chirurgas ortopedas traumatologas, taikydamas standartinę transepifizinę tunelių gręžimo techniką.

ŠLRS autotransplantatai buvo paimti per 3–4 cm anteromedialinį pjūvį virš *pes anserinus* srities. Tiek pusgyslinio (lot. *musculus semitendinosus*), tiek grakščiojo raumenų (lot. *musculus gracilis*) sausgyslės buvo panaudotos 8 gijų transplantatui gauti, kurio ilgis siekė 7 cm, o skersmuo svyravo nuo 8 iki 11,5 mm.

Vien minkštųjų audinių ŠKRS autotransplantatai buvo paimti iš priekinės distalinės šlaunies srities per 3–4 cm pjūvį, naudojant skalpelį su 10 mm pločio ašmenimis. Donorinė vieta buvo užsiūta ištisinę siūle. ŠKRS transplantatų ilgis svyravo nuo 6,5 iki 8 cm, o skersmuo – nuo 8,5 iki 11 mm.

Sprendimas dėl menisko siuvimo bei transplantato skersmens nustatymo buvo priimamas chirurginės procedūros metu. Po kiekvienos PKRR operacijos buvo atlikta rentgenograma, siekiant užtikrinti tikslią implantų (endosagų) poziciją.

Pooperacinės reabilitacijos protokolas

Reabilitacijos protokolas buvo individualiai pritaikytas atsižvelgiant į traumos sudėtingumą ir taikytą chirurginio gydymo metodą, ir buvo suskirstytas į du etapus.

Pirmasis etapas prasidėjo po imobilizacijos kelio sąnario įtvaru, fiksuotu pilnai ištiestoje padėtyje. Šio etapo tikslai buvo apsauga, tinimo kontrolė ir laipsniškas judesių amplitudės atkūrimas. Ankstyvas krūvio taikymas, siekiant išvengti kineziofobijos ir raumenų silpnėjimo, buvo leidžiamas pacientams, kuriems atlikta izoliuota PKRR arba PKR kartu su menisko rezekcija. Tuo tarpu pacientams, kuriems buvo atliktas menisko siuvimas, buvo neleidžiama remtis koja 4 savaites. Progresyvus krūvio didinimas buvo tęsiamas iki visiško apkrovos leidimo 6-tą savaitę, siekiant užtikrinti menisko gijimą. Antrą savaitę po operacijos pacientai pradėjo kelio lenkimo pratimus, kas 3–4 dienas didindami lenkimo kampą 10–20 laipsnių per 6 savaites. Taip pat buvo skatinama kasdien atlikti pasyvų visišką kelio tiesimą ir taikyti tinimo mažinimo priemones – šaldymą bei kojos pakėlimą. Visiems pacientams buvo paskirta 4 savaičių trukmės namų pratimų programa, skirta kelio judrumui gerinti ir apatinių galūnių raumenų jėgai stiprinti prieš pradedant prižiūrimą reabilitaciją reabilitacijos centruose.

Antrasis reabilitacijos etapas prasidėjo po 6 savaičių ir buvo orientuotas į funkcinį atsistatymą bei jėgos vystymą. Tolimesnę pratimų programą nulėmė GNRB tyrimo rezultatai ir bendra kelio būklė. Jei po 3 mėnesių priekinio blauzdikaulio poslinkio (PBP) rodikliai buvo normos ribose, o operuotas kelias buvo judrus ir nepatinęs, buvo rekomenduojami raumenų stiprinimo pratimai su svoriais bei stabilumo ir pusiausvyros lavinimo pratimai. Jei PBP išliko >1,5 mm, ir kelio patinimas ir judėjimo apribojimai tęsėsi, buvo rekomenduota tęsti reabilitaciją su priežiūra arba toliau taikyti šaldymą, mobilumo ir raumenų stiprinimo pratimus. Raumenų jėga buvo vertinama tik po 6 mėnesių naudojant elektromechaninį dinamometrą (Biodex), kai tai buvo laikoma saugu dėl transplantato subrendimo.

Grįžimas į sportą nebuvo rekomenduojamas anksčiau nei po 6 mėnesių po PKRR ir buvo leidžiamas tik tuo atveju, jei GNRB tyrimo duomenys rodė normalią PKR paslankumo būklę. Grįžimas į sportą buvo struktūruotas trimis etapais: grįžimas į dalyvavimą veikloje, grįžimas į treniruotes ir galiausiai - grįžimas į varžybas.

Priekinio blauzdikaulio poslinkio *side-to-side* vertinimas

Pooperacinis kelio sąnario stabilumas ir PKR autotransplantato brendimas buvo vertinami naudojant kompiuterizuotą „Genourob®" (Laval, Prancūzija) artrometrą (GNRB). GNRB laikomas „aukso standartu" objektyviai vertinant PBP ir PKR transplantato brandą [164].

Tyrimai buvo atliekami pacientams gulint ant nugaros, kai kelio sąnarys sulenktas 20°, naudojant specialią formuotą atramą – taip imituojant Lachmano testo padėtį, kaip rekomenduoja gamintojas [165]. Be to, buvo naudojamas girnelės fiksatorius, siekiant ją imobilizuoti ir užtikrinti izoliuotą blauzdikaulio poslinkį [166]. Blauzda buvo pritvirtinta prietaiso diržu, kad būtų išlaikyta pastovi padėtis.

Kiekvienam dalyviui buvo atliktas abiejų kelių testavimas, pradedant nuo neoperuotos kojos. Praėjus 3 mėnesiams po operacijos, buvo taikoma standartinė 134 N priekinė jėga, siekiant sumažinti apkrovą gyjančiam transplantatui. Po 6 ir 12 mėnesių taip pat buvo naudojamos didesnės – 150 N ir 200 N – jėgos, siekiant įvertinti kelio sąnario laisvumą ir transplantato elgseną progresuojančios apkrovos sąlygomis ir taip gauti daugiau informacijos apie dinaminį kelio stabilumą.

Poslinkio skirtumas buvo matuotas milimetrais, lyginant operuotą ir sveiką kojas. Be to, kaip antrinis parametras buvo registruojami poslinkio kreivės nuolydžiai, leidžiantys įvertinti dinaminį kelio stabilumą, kuris gali turėti prognostinę reikšmę PKR transplantato pakartotinio plyšimo rizikai. Siektinu pooperacinio stabilumo kriterijumi buvo laikomas poslinkio skirtumas iki 1,5 mm esant 134 N apkrovai. Ši slenkstinė riba (ar dar griežtesnė) laikoma jautriu ir specifišku rodikliu PKR transplantato vientisumui vertinti [165, 167].

Izokinetinės jėgos testavimas su „Biodex“

Šlaunies lenkiamųjų ir tiesiamųjų raumenų izokinetinis jėgos testavimas buvo atliktas bendradarbiaujant su Lietuvos sporto universitetu jų mokslinėje laboratorijoje. Dalyviams buvo nurodyta 24 valandas iki testavimo nesportuoti ir bent 2 valandas nevalgyti. Buvo surinkti pagrindiniai antropometriniai duomenys kiekvienam dalyviui.

Testavimo sesija prasidėjo 10 minučių apšilimu su stacionariu treniruokliu „Monark“ (Varberg, Švedija), važiuojant 60–70 pedalų apsisukimų per minutę greičiu, 70 W intensyvumu ir palaikant širdies ritmą tarp 110–130 dūžių per minutę. Patalpos temperatūra buvo palaikoma ties 23 °C, o drėgmė – 77 proc. Po apšilimo sekė 5 minučių pertrauka prieš jėgos testą.

Poilsio metu dalyviai buvo pozicionuojami „Biodex Medical System 4“ izokinetiniame dinamometre (Shirley, NY, JAV), užfiksuojant krūtinę, liemenį ir šlaunį specialiais diržais. Blauzda buvo pritvirtinta prie dinamometro svirties ties kulkšnių viršumi. Dinamometro sukimosi ašis buvo vizualiai sulygiuota su šlaunikaulio ašimi. Buvo išmatuotas tiriamosios kojos judesių amplitudės intervalas, o gravitacinė korekcija atlikta pasveriant blauzdos-pėdos segmentą esant maždaug 60±5° kelio lenkimui [168].

Kad dalyviai susipažintų su procedūra, jie atliko 4 ne maksimalaus pajėgumo bandymus - atitinkamai 25 proc., 50 proc., 75 proc. ir 100 proc. pastangų, per visą judesio amplitudę. Pagrindinio testavimo metu dalyviai atliko 3 maksimalių pastangų reikalaujančius judesius 60°/s kampiniu greičiu, tarp kiekvieno bandymo darant 1 minutės pertrauką. Siekiant užtikrinti maksimalų įsitraukimą, buvo taikomas žodinis paskatinimas. Pirmiausia buvo tiriama neoperuota koja, o po to – operuota.

Testavimas buvo atliktas praėjus 6 ir 12 mėnesių po operacijos. H/Q santykis ≥50 proc. buvo laikomas priimtinu raumenų pusiausvyros rodikliu po PKRR, remiantis sportininkų izokinetinio testavimo norminiais duomenimis [169].

Pacientų pateiktų klausimynų rezultatų vertinimas

Pacientų pateikti klausimynų rezultatai buvo vertinami prieš PKRR operaciją ir praėjus 12 mėnesių po jos, galutinės „Biodex“ jėgos matavimo sesijos metu, naudojant validuotas lietuviškas klausimynų versijas: IKDC 2000 subjektyvų kelio sąnario įvertinimo klausimyną, Lysholm kelio funkcijos vertinimo skalę ir PKR-GST (grįžimo į sportą po traumos) skalę [170–172].

PKR-GST balas ≥70 buvo naudojamas kaip psichologinio pasirengimo grįžti į sportą slenkstis, remiantis Langford ir kt. [173] išvadomis, kurios parodė, kad sportininkai, sėkmingai grįžę į varžybinį sportą praėjus 12 mėnesių po PKRR, dažniausiai turėjo apie 70 balų PKR-GST rezultatą. PKR-GST, kaip prognostinio įrankio, svarbą papildomai patvirtina ir Ardern ir kt. tyrimas [174], kuriame ši skalė įvardinta kaip vienintelis psichologinis matmuo, statistiškai reikšmingai susijęs su sėkmingu grįžimu į ankstesnį sporto lygį.

Statistinė analizė

Duomenų analizė buvo atlikta naudojant „IBM SPSS Statistics" 29.0 versijos programinę įrangą. Kokybiniai nominalieji duomenys pateikiami dažniais ir santykiniais dažniais (procentais). Kiekybiniai duomenys pateikiami kaip vidurkis (su standartiniu nuokrypiu) bei mediana (su minimaliomis ir maksimaliomis reikšmėmis). Dėl mažos imties arba duomenų normalumo stokos (nustatyto taikant Šapiro-Vilko testą), kiekybinių duomenų palyginimui tarp dviejų nepriklausomų imčių buvo taikytas neparametrinis Mann-Whitney testas. Kokybiniai nominalieji duomenys buvo lyginami naudojant chi kvadrato testą.

Duomenys pateikiami aprašomosios statistikos būdu (mediana, minimumas, maksimumas). Skirtumams tarp metodų buvo taikytas Mann-Whitney U testas, o susijusių imčių palyginimui - Vilkoksono testas. Skirtumai buvo laikomi statistiškai reikšmingais, kai $p < 0,05$.

Vienas svarbiausių mūsų tyrimo kintamųjų buvo artrometriškai nustatytas PBP *side-to-side* skirtumas milimetrais, lyginant ŠLRS ir ŠKRS autotransplantatų grupes. Kadangi tai yra kiekybinis kintamasis, minimaliam imties dydžiui apskaičiuoti buvo naudota ši formulė [175]:

$$n = \frac{\left(s_1^2 + s_2^2\right)\cdot\left(z_{q1} + z_{q2}\right)^2}{\Delta^2}$$

Norint nustatyti standartinius nuokrypius (s formulėje) abiejose grupėse, buvo panaudoti duomenys iš 15 pacientų pilotiniame tyrime. Gauti standartiniai nuokrypiai buvo: ŠLRS grupėje – 1,41 mm, ŠKRS grupėje – 0,64 mm. Norint nustatyti 1 mm skirtumą tarp ŠLRS ir ŠKRS transplantatų po PKRR, pagal GNRB tyrimo duomenis (Δ formulėje), buvo apskaičiuotas minimalus imties dydis – po 19 pacientų kiekvienoje grupėje, kai $z_{q1} = 1,96$,$z_{q2} = 0,842$, reikšmingumo lygis $\alpha = 0,05$ ir statistinės galios kriterijus $1–\beta = 0,8$.

REZULTATAI

Tiriamųjų charakteristikos

Iš viso į tyrimą buvo įtraukti 68 pacientai. Tačiau dėl įvairių priežasčių 14 dalyvių nutraukė dalyvavimą tyrime, todėl visus tyrimo etapus užbaigė ir į duomenų analizę buvo įtraukti 54 dalyviai (24 ŠKRS grupėje ir 30 ŠLRS grupėje), kurių amžius buvo nuo 13 iki 17 metų.

Tiriamųjų charakteristikos pateiktos 2 lentelėje. Tarp grupių nenustatyta statistiškai reikšmingų skirtumų pagal amžių, lyties pasiskirstymą, ūgį, svorį, KMI z reikšmę, menisko pažeidimo būklę ar transplantato skersmenį (visais atvejais p > 0,05). Tai rodo, kad grupės buvo panašios pradinėje būklėje ir tinkamos pooperacinių rezultatų palyginimui.

2 lentelė. *Pacientų demografinės ir klinikinės (chirurginės) charakteristikos*

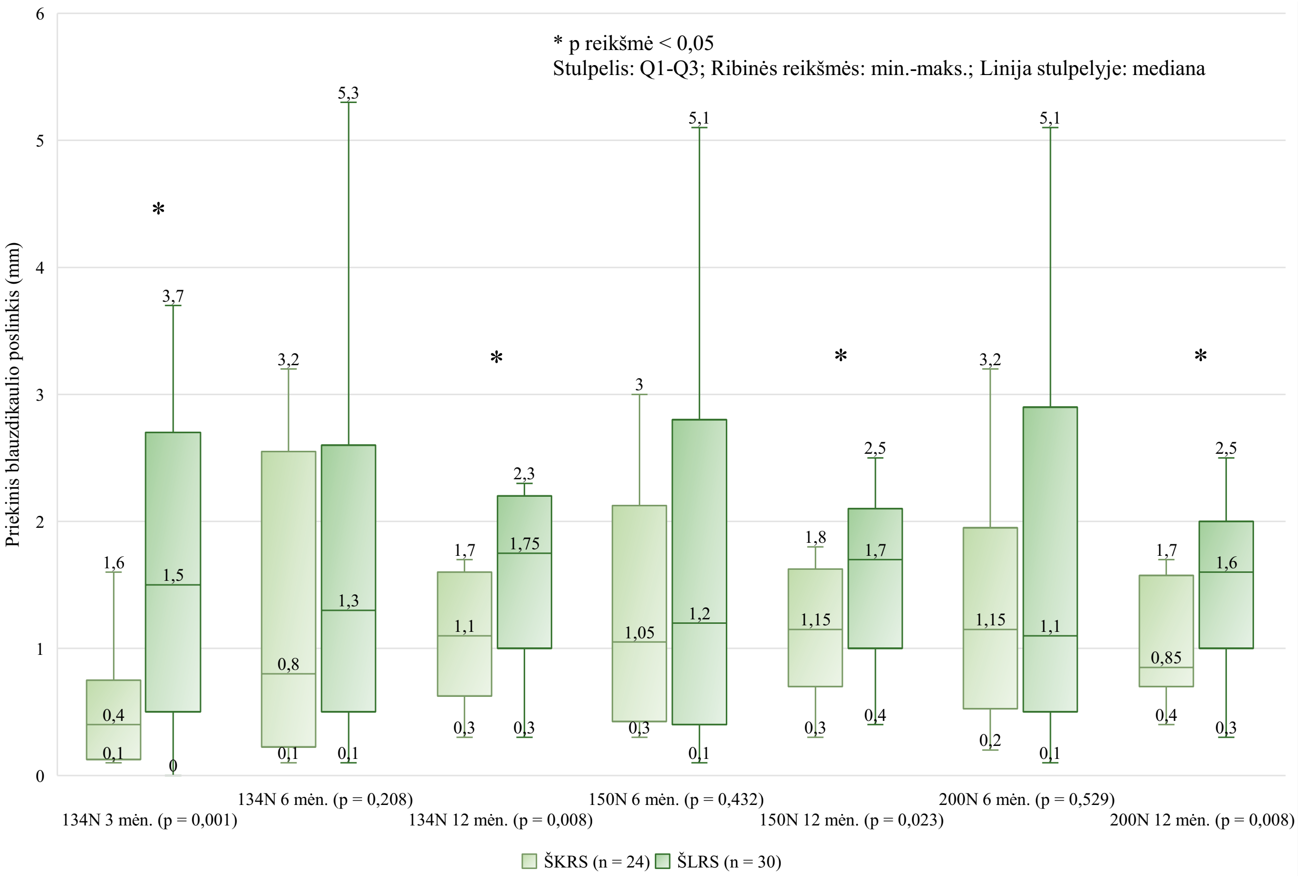
	ŠKRS (n = 24)	**ŠLRS (n = 30)**	**Kriterijaus statistika**	***p* reikšmė**
Amžius metais mediana (min.–maks.)	15,5 (13–17)	15 (14–17)	|Z| = 1,306	0,192
Lytis (vaikinai/merginos)	9/15	18/12	χ^2 = 1,875	0,171
Ūgis, cm mediana (min.–maks.)	173,5 (158–182)	177,5 (160–197)	|Z| = 0,157	0,875
Svoris, kg mediana (min.–maks.)	65 (53–85)	66,5 (49–93)	|Z| = 0,471	0,638
KMI z reikšmė mediana (min.–maks.)	0,14 (–1,39–1,78)	0,43 (–0,66–1,64)	|Z| = 1,255	0,209
Meniskai (siūti/nesiūti)	12/12	15/15	χ^2 = 0	1
Transplantato skersmuo, mm mediana (min.–maks.)	10 (9–11)	10,25 (9–11,5)	|Z| = 0,736	0,462

ŠKRS – šlaunies keturgalvio raumens sausgyslės autotransplantato grupė; ŠLRS – šlaunies lenkiamųjų raumenų sausgyslių autotransplantato grupė; KMI – kūno masės indeksas; |Z| – absoliutinė standartizuoto Mann–Whitney kriterijaus statistika; χ^2 – chi kvadrato kriterijaus statistika.

Kelio sąnario stabilumo palyginimas tarp ŠKRS ir ŠLRS autotransplantatų grupių

Kelio sąnario stabilumo, įvertinto GNRB prietaisu, rezultatai ŠKRS ir ŠLRS autotransplantatų grupėse skirtingais pooperaciniais laikotarpiais pavaizduoti 1 paveiksle. PBP visais matavimo laikotarpiais buvo nuosekliai mažesnis ŠKRS grupėje lyginant su ŠLRS grupe. Statistiškai reikšmingi PBP skirtumai nustatyti po 3 mėnesių taikant 134 N jėgą (*p* = 0,001) ir po 12 mėnesių, taikant 134 N (*p* = 0,008), 150 N (p = 0,023) ir 200 N (*p* = 0,008) jėgas. Šie rezultatai rodo geresnį priekinį kelio sąnario stabilumą ŠKRS grupėje, ypač praėjus 3 ir 12 mėnesių po operacijos.

Statistiškai reikšmingų skirtumų tarp grupių kreivės nuolydžio verčių nė vienu vertinimo laikotarpiu nenustatyta (visais atvejais *p* > 0,05). Taip pat nebuvo rasta reikšmingų PBP skirtumų praėjus 6 mėnesiams, taikant bet kokio stiprumo jėgą.



1 pav. *GNRB artrometru išmatuotas kelio sąnario stabilumas praėjus 3, 6 ir 12 mėnesių po operacijos lyginant ŠKRS ir ŠLRS grupių rezultatus*

Vaikinų ir merginų kelio sąnario stabilumo pagal transplantato tipą palyginimas

Vertinant galimus su lytimi susijusius skirtumus skirtingose transplantatų grupėse, kelio sąnario stabilumo rezultatai buvo lyginami atskirai vaikinams (3 lentelė) ir merginoms (4 lentelė) tarp ŠLRS ir ŠKRS autotransplantatų grupių praėjus 3, 6 ir 12 mėnesių po operacijos, taikant skirtingo stiprumo jėgas.

3 lentelė. *Vaikinų kelio sąnario stabilumo (GNRB) vertinimo rezultatai praėjus 3, 6 ir 12 mėnesių po operacijos ŠLRS ir ŠKRS grupėse*

Vaikinai				
	ŠLRS (n = 18)	**ŠKRS (n = 9)**	**Kriterijaus statistika**	***p* reikšmė**
Kreivės nuolydis, 3 mėn. mediana (min.–maks.)	7,05 (0,6–12,4)	1,8 (0,6–2,4)	U = 27,000	**0,004***
Kreivės nuolydis, 6 mėn. mediana (min.–maks.)	2,3 (0,6–13,1)	5,3 (4,7–7,1)	U = 54,000	0,176
Kreivės nuolydis, 12 mėn. mediana (min.–maks.)	5,05 (4,2–14,1)	8,1 (4,5–8,3)	U = 63,000	0,400
PBP 3 mėn., 134 N, mm mediana (min.–maks.)	2,65 (1,3–3,7)	0,5 (0,1–0,6)	U = 0,0	**<0,001***
PBP 6 mėn., 134 N, mm mediana (min.–maks.)	2 (0,5–5,3)	0,5 (0,2–3,0)	U = 49,500	0,112
PBP 12 mėn., 134 N, mm mediana (min.–maks.)	1,75 (0,5–2,2)	1,6 (0,8–1,7)	U = 49,500	0,112
PBP 6 mėn., 150 N, mm mediana (min.–maks.)	2 (0,9–5,1)	1 (0,4–3)	U = 63,000	0,377
PBP 12 mėn., 150 N, mm mediana (min.–maks.)	1,7 (0,6–2,5)	1,4 (1,1–1,7)	U = 58,500	0,264
PBP 6 mėn., 200 N, mm mediana (min.–maks.)	1,85 (0,8–5,1)	1,2 (0,5–3,2)	U = 63,000	0,400
PBP 12 mėn., 200 N, mm mediana (min.–maks.)	1,65 (0,5–2,5)	0,9 (0,8–1,7)	U = 45,000	0,074

ŠKRS – šlaunies keturgalvio raumens sausgyslės autotransplantato grupė; ŠLRS – šlaunies lenkiamųjų raumenų sausgyslių autotransplantato grupė; N – niutonai; mm – milimetrai; U – Mann–Whitney kriterijaus statistika; * – statistiškai reikšmingas skirtumas ($p < 0,05$).

4 lentelė. *Merginų kelio sąnario stabilumo (GNRB) vertinimo rezultatai praėjus 3, 6 ir 12 mėnesių po operacijos ŠLRS ir ŠKRS grupėse*

Merginos				
	ŠLRS (n = 12)	**ŠKRS (n = 15)**	**Kriterijaus statistika**	***p* reikšmė**
Kreivės nuolydis, 3 mėn. mediana (min.–maks.)	1,15 (0–6,6)	3,5 (2,1–18,2)	U = 36,000	**0,008***
Kreivės nuolydis, 6 mėn. mediana (min.–maks.)	4,2 (3,5–14,8)	2,4 (0–12,9)	U = 54,000	0,82
Kreivės nuolydis, 12 mėn. mediana (min.–maks.)	3,95 (2,9–7,1)	4,6 (1,7–7,6)	U = 81,000	0,717
PBP 3 mėn., 134 N, mm mediana (min.–maks.)	0,35 (0–0,8)	0,3 (0,1–1,6)	U = 72,000	0,406
PBP 6 mėn., 134 N, mm mediana (min.–maks.)	0,4 (0,1–3,2)	1,1 (0,1–3,2)	U = 76,500	0,530
PBP 12 mėn., 134 N, mm mediana (min.–maks.)	1,65 (0,3–2,3)	0,7 (0,3–1,6)	U = 58,500	0,131
PBP 6 mėn., 150 N, mm mediana (min.–maks.)	0,4 (0,1–3,4)	1,1 (0,3–2,4)	U = 63,000	0,199
PBP 12 mėn., 150 N, mm mediana (min.–maks.)	1,5 (0,4–2,3)	0,7 (0,3–1,8)	U = 54,000	0,082
PBP 6 mėn., 200 N, mm mediana (min.–maks.)	0,5 (0,1–3,6)	1,1 (0,2–2,1)	U = 63,000	0,199
PBP 12 mėn., 200 N, mm mediana (min.–maks.)	1,4 (0,3–2,4)	0,7 (0,4–1,7)	U = 63,000	0,199

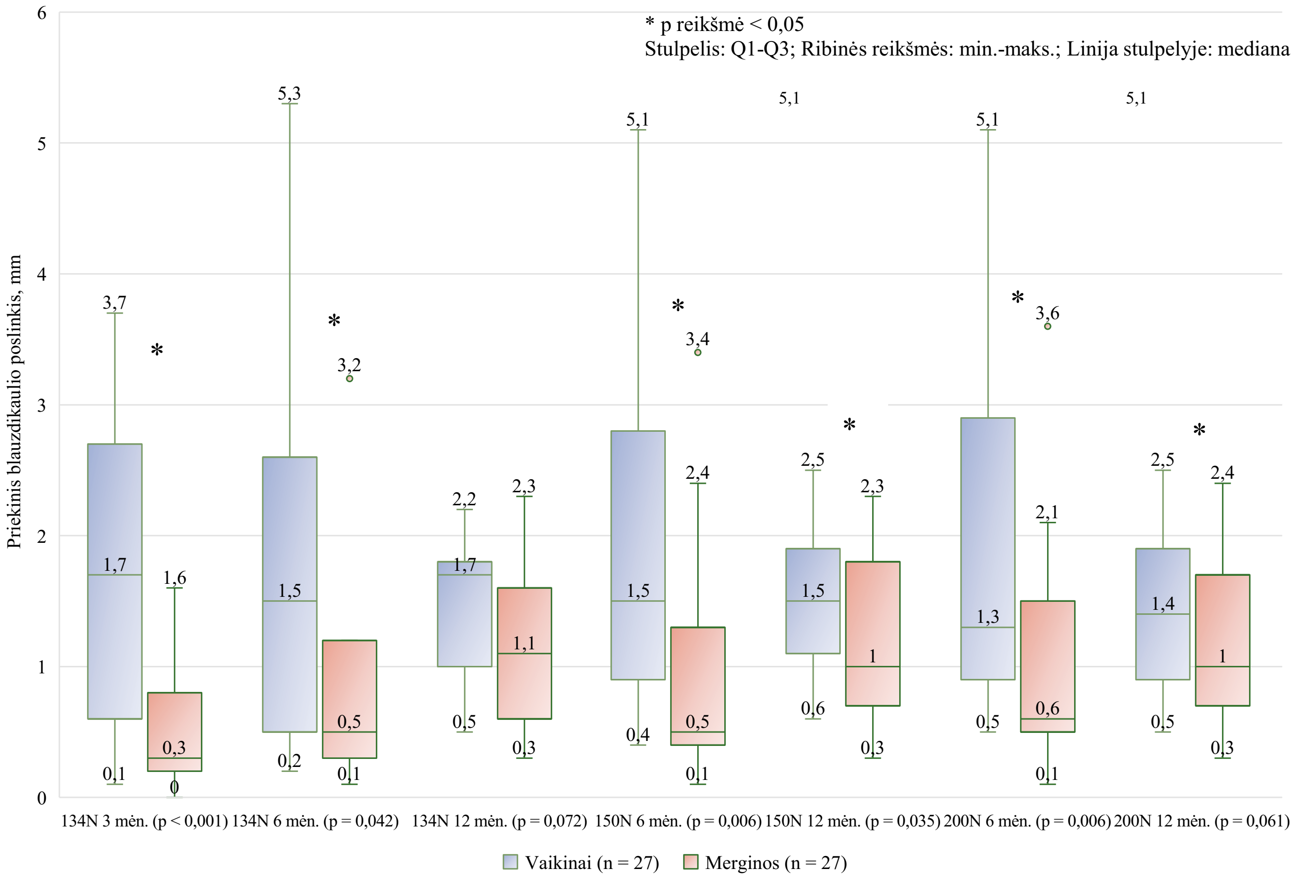
ŠKRS – šlaunies keturgalvio raumens sausgyslės autotransplantato grupė; ŠLRS – šlaunies lenkiamųjų raumenų sausgyslių autotransplantato grupė; N – niutonai; mm – milimetrai; U – Mann–Whitney kriterijaus statistika; * – statistiškai reikšmingas skirtumas ($p < 0,05$).

Po 3 mėnesių kreivės nuolydis ir PBP taikant 134 N jėgą buvo reikšmingai mažesni ŠKRS vaikinų grupėje, palyginti su ŠLRS vaikinų grupe (atitinkamai $p = 0,004$ ir $p < 0,001$). Kitais laikotarpiais – po 6 ir 12 mėnesių – reikšmingų skirtumų nenustatyta (visais atvejais $p > 0,05$).

Tuo tarpu merginoms po 3 mėnesių kreivės nuolydis buvo reikšmingai didesnis ŠKRS grupėje lyginant su ŠLRS grupe ($p = 0,008$). PBP ir kreivės nuolydžio reikšmingų skirtumų po 6 ir 12 mėnesių nenustatyta (visais atvejais $p > 0,05$).

Bendras kelio sąnario stabilumo palyginimas pagal lytį

Bendras kelio sąnario stabilumas tarp vaikinų ir merginų, neatsižvelgiant į naudotą transplantato tipą, pateiktas 2 paveiksle.



2 pav. *GNRB artrometru įvertintas kelio sąnario stabilumas vaikinams ir merginoms praėjus 3, 6 ir 12 mėnesių po operacijos, nepaisant transplantato tipo*

Apjungus ŠKRS ir ŠLRS grupes, statistiškai reikšmingi skirtumai pagal kreivės nuolydį buvo nustatyti po 12 mėnesių ($|Z| = 3,356$, $p < 0,001$), didesnes reikšmes fiksuojant vaikinams. Reikšmingų skirtumų po 3 ir 6 mėnesių nenustatyta.

PBP reikšmės taikant 134 N jėgą buvo statistiškai reikšmingai didesnės vaikinams po 3 mėnesių ($|Z| = 3,984$, $p < 0,001$) ir po 6 mėnesių ($|Z| = 2,035$, $p = 0,042$). Po 12 mėnesių reikšmingo skirtumo nenustatyta ($p = 0,072$).

Taikant 150 N jėgą, vaikinams taip pat nustatytas reikšmingai didesnis priekinis poslinkis po 6 mėnesių ($p = 0,006$) ir po 12 mėnesių ($p = 0,035$). Taikant 200 N jėgą, reikšmingas skirtumas išliko po 6 mėnesių ($p = 0,006$), tačiau po 12 mėnesių reikšmingo skirtumo nenustatyta ($p = 0,061$).

χ^2 kriterijaus analizė parodė, kad po 12 mėnesių, taikant 134 N jėgą, buvo nustatytas statistiškai reikšmingas skirtumas tarp lyčių pagal PBP gerų rezultatų proporcijas – vaikinų grupėje geri rezultatai nustatyti 33,3 proc. atvejų (9 iš 27), o merginų – 66,7 proc. atvejų (18 iš 27); $\chi^2 = 4,741$, $p = 0,029$. Tikimybė merginoms pasiekti gerą PBP rezultatą buvo 4 kartus didesnė nei vaikinams (95 proc. PI 1,29–12,40).

Izokinetinės jėgos palyginimas tarp operuotos ir sveikos kojos ŠKRS ir ŠLRS grupėse

Operuotos ir sveikos kojos palyginimo rezultatai kiekvienoje autotransplantatų grupėje pateikti 5 ir 6 lentelėse.

ŠKRS grupėje (5 lentelė) tiesiamųjų raumenų jėga operuotoje kojoje buvo reikšmingai mažesnė nei sveikoje tiek po 6 mėnesių ($p < 0,001$), tiek po 12 mėnesių ($p < 0,001$). Lenkiamųjų raumenų jėga po 6 mėnesių reikšmingai nesiskyrė ($p = 0,455$), tačiau po 12 mėnesių buvo reikšmingai mažesnė operuotoje kojoje ($p = 0,031$). H/Q santykis operuotoje kojoje buvo reikšmingai didesnis tiek po 6 mėnesių ($p < 0,001$), tiek po 12 mėnesių ($p = 0,006$).

ŠKRS grupėje reikšmingų skirtumų tarp operuotos ir sveikos kojos pokyčių nebuvo nustatyta nei tiesiamųjų raumenų jėgai (Vilkoksono testas $|Z| = 0,429$, $p = 0,668$), nei lenkiamųjų raumenų jėgai ($|Z| = 1,202$, $p = 0,229$). Vis dėlto H/Q santykio pokytis tarp operuotos ir sveikos kojų buvo statistiškai reikšmingas ($|Z| = 2,232$, $p = 0,026$), rodančio didesnį pokytį operuotoje kojoje.

5 lentelė. *Biodex rezultatų palyginimas tarp operuotos ir sveikos kojų ŠKRS grupėje po 6 ir 12 mėn.*

	ŠKRS (n = 24)		**Kriterijaus statistika**	**p reikšmė**
	6 mėn. po operacijos			
	Operuota koja	**Sveika koja**		
Tiesiamųjų raumenų jėgos momento ir kūno masės santykis (%) mediana (min.–maks.)	121,45 (90,6–211,3)	175,4 (111–287,4)	|Z| = 3,434	**<0,001***
Lenkiamųjų raumenų jėgos momento ir kūno masės santykis (%) mediana (min.–maks.)	84,35 (42–122,3)	84,35 (36,7–140,7)	|Z| = 0,773	0,455
H/Q santykis mediana (min.–maks.)	56,1 (31,3–109)	49,6 (20,7–70,9)	|Z| = 3,177	**<0,001***
	12 mėn. po operacijos			
	Operuota koja	**Sveika koja**		
Tiesiamųjų raumenų jėgos momento ir kūno masės santykis (%) mediana (min.–maks.)	208,55 (113,1–241,6)	252,4 (179,8–324,6)	|Z| = 0,869	**<0,001***
Lenkiamųjų raumenų jėgos momento ir kūno masės santykis (%) mediana (min.–maks.)	115,3 (73,5–155)	116 (82,1–173,9)	|Z| = 2,146	**0,031***
H/Q santykis mediana (min.–maks.)	57,2 (40,9–105,8)	50,65 (35,1–58,4)	|Z| = 2,661	**0,006***
	Pokytis (12–6 mėn.)			
	Operuota koja	**Sveika koja**		
Tiesiamųjų raumenų jėgos momento ir kūno masės santykis (%) mediana (min.–maks.)	44 (–4,5–131,9)	53,5 (–20–133,3)	|Z| = 0,429	0,668
Lenkiamųjų raumenų jėgos momento ir kūno masės santykis (%) mediana (min.–maks.)	24,3 (–24,6–85)	23,2 (0,3–99,9)	|Z| = 1,202	0,229
H/Q santykis mediana (min.–maks.)	4,85 (–26,1–32,7)	3,3 (–36,1–12,5)	|Z| = 2,232	**0,026***

ŠKRS – šlaunies keturgalvio raumens sausgyslės autotransplantatų grupė; H/Q santykis – lenkiamųjų ir tiesiamųjų raumenų jėgos momento santykis; |Z|: standartizuota Vilkoksono porinių imčių rangų testo statistika; * – statistiškai reikšmingas skirtumas ($p < 0,05$).

6 lentelė. *Biodex rezultatų palyginimas tarp operuotos ir sveikos kojų ŠLRS grupėje po 6 ir 12 mėn.*

	ŠLRS (n=30)		**Kriterijaus statistika**	***p* reikšmė**
	6 mėn. po operacijos			
	Operuota koja	**Sveika koja**		
Tiesiamųjų raumenų jėgos momento ir kūno masės santykis (%) mediana (min.–maks.)	156,9 (96,1–279,2)	232,1 (164,1–316,7)	|Z| = 4,478	**<0,001***
Lenkiamųjų raumenų jėgos momento ir kūno masės santykis (%) mediana (min.–maks.)	75,2 (34,2–126,8)	102,8 (26,5–157,5)	|Z| = 4,355	**<0,001***
H/Q santykis mediana (min.–maks.)	43,75 (35,6–63,8)	47,2 (16,2– 50,3)	|Z| = 1,390	0,165
	12 mėn. po operacijos			
	Operuota koja	**Sveika koja**		
Tiesiamųjų raumenų jėgos momento ir kūno masės santykis (%) mediana (min.–maks.)	250,8 (129,5–338,8)	293 (178,5–342,2)	|Z| = 3,490	**<0,001***
Lenkiamųjų raumenų jėgos momento ir kūno masės santykis (%) mediana (min.–maks.)	91,25 (68–138,4)	128,95 (78–169,3)	|Z| = 4,787	**<0,001***
H/Q santykis mediana (min.–maks.)	40,9 (32,8–51,5)	48,4 (33,6–54,8)	|Z| = 3,366	**<0,001***
	Pokytis (12–6 mėn.)			
	Operuota koja	**Sveika koja**		
Tiesiamųjų raumenų jėgos momento ir kūno masės santykis (%) mediana (min.–maks.)	53,5 (21,2–208,6)	36,5 (–15,9–132,8)	|Z| = 2,934	**0,003***
Lenkiamųjų raumenų jėgos momento ir kūno masės santykis (%) mediana (min.–maks.)	22,35 (–30–71)	16,15 (–48,2–67,9)	|Z| = 0,154	0,877
H/Q santykis mediana (min.–maks.)	5,5 (–10,7–13,7)	–2,15 (–17,4–7,1)	|Z| = 4,108	**<0,001***

ŠLRS – šlaunies lenkiamųjų raumenų sausgyslių autotransplantatų grupė; H/Q santykis – lenkiamųjų ir tiesiamųjų raumenų jėgos momento santykis; |Z|: standartizuota Vilkoksono porinių imčių rangų testo statistika; * – statistiškai reikšmingas skirtumas ($p < 0,05$).

ŠLRS grupėje (6 lentelė) operuotoje kojoje tiesiamųjų ir lenkiamųjų raumenų jėga buvo reikšmingai mažesnė nei sveikoje tiek po 6, tiek po

12 mėnesių (visais atvejais $p < 0{,}001$). H/Q santykis po 6 mėnesių reikšmingai nesiskyrė ($p = 0{,}165$), tačiau po 12 mėnesių buvo reikšmingai mažesnis operuotoje kojoje ($p < 0{,}001$).

ŠLRS grupėje tiesiamųjų raumenų jėgos pokytis tarp 6 ir 12 mėnesių buvo statistiškai reikšmingas (Vilkoksono testas $|Z| = 2{,}934$, $p = 0{,}003$), rodančio labiau išreikštą stiprumą operuotoje kojoje. Taip pat reikšmingas buvo ir H/Q santykio pokyčio skirtumas tarp operuotos ir sveikos kojų ($|Z| = 4{,}108$, $p < 0{,}001$), rodantis didesnį pokytį operuotoje kojoje. Tuo tarpu lenkiamųjų raumenų jėgos pokyčio skirtumas tarp operuotos ir sveikos kojų nebuvo statistiškai reikšmingas ($|Z| = 0{,}154$, $p = 0{,}877$).

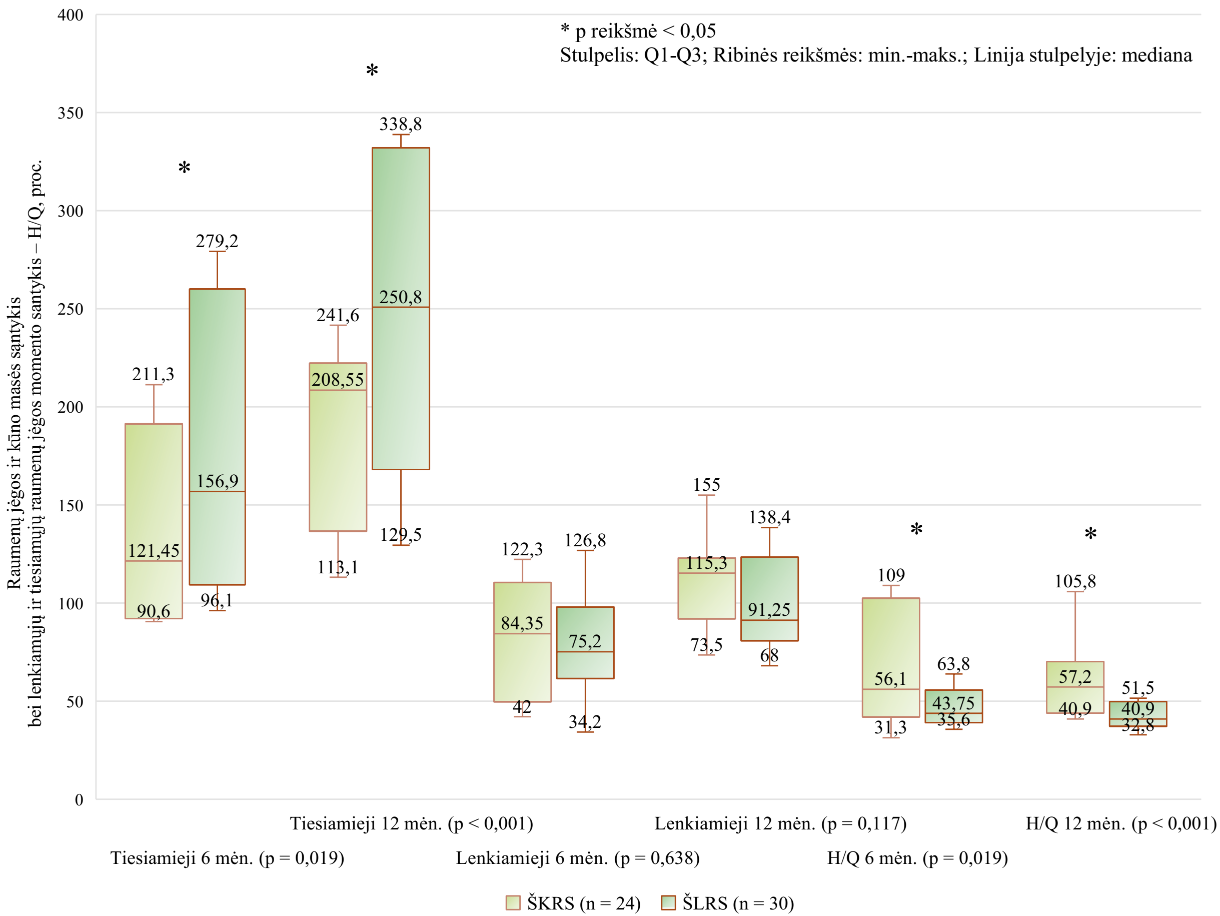
Izokinetinės raumenų jėgos palyginimas tarp ŠKRS ir ŠLRS autotransplantatų grupių

Izokinetinės raumenų jėgos testavimo rezultatai, gauti naudojant „Biodex“ sistemą po 6 ir 12 mėnesių po operacijos bei pateikti 3 paveiksle.

Praėjus 6 mėnesiams po operacijos, ŠKRS grupėje buvo nustatyta statistiškai reikšmingai mažesnė tiesiamųjų raumenų jėga, palyginti su ŠLRS grupe ($p = 0{,}019$), tuo tarpu lenkiamųjų raumenų jėga tarp grupių statistiškai reikšmingai nesiskyrė ($p = 0{,}638$). H/Q santykis buvo statistiškai reikšmingai didesnis ŠKRS grupėje nei ŠLRS grupėje ($p = 0{,}019$).

Praėjus 12 mėnesių po operacijos, ŠKRS grupėje tiesiamųjų raumenų jėga ir toliau buvo statistiškai reikšmingai mažesnė ($p < 0{,}001$), o H/Q santykis – reikšmingai didesnis ($p < 0{,}001$), palyginti su ŠLRS grupe. Lenkimo jėga tarp grupių vėl statistiškai reikšmingai nesiskyrė ($p = 0{,}117$).

Siekiant įvertinti funkcinio atsistatymo dinamiką tarp 6 ir 12 mėnesių, buvo apskaičiuoti tiesiamųjų ir lenkiamųjų raumenų jėgos bei H/Q santykio pokyčiai: operuotos kojos 6 mėnesių vertės buvo atimtos iš 12 mėnesių verčių. Tarp ŠKRS ir ŠLRS grupių šie pokyčiai statistiškai reikšmingai nesiskyrė nei pagal tiesiamųjų raumenų jėgą ($|Z| = 1{,}413$, $p = 0{,}158$), nei pagal lenkiamųjų raumenų jėgą ($|Z| = 0{,}784$, $p = 0{,}433$), nei pagal H/Q santykį ($|Z| = 0{,}314$, $p = 0{,}754$).



3 pav. *Biodex (izokinetinio dinamometro) rezultatų palyginimas tarp ŠKRS ir ŠLRS grupių po 6 ir 12 mėnesių po operacijos*

χ^2 kriterijaus analizė parodė, kad tarp ŠLRS ir ŠKRS grupių nustatytas statistiškai reikšmingas skirtumas pagal pacientų, kuriems pasiektas priimtinas H/Q santykis, proporcijas – ŠLRS grupėje priimtinas santykis nustatytas 20,0 proc. atvejų (6 iš 30), o ŠKRS grupėje – 62,5 proc. atvejų (15 iš 24); $\chi^2 = 8{,}424$, $p = 0{,}004$. Tikimybė pasiekti priimtiną H/Q santykį ŠKRS grupėje buvo 6,67 karto didesnė nei ŠLRS grupėje (95 proc. pasikliautinasis intervalas: 1,97–22,53).

Bendras izokinetinės raumenų jėgos palyginimas tarp lyčių

Praėjus 12 mėnesių po operacijos, vaikinams buvo nustatyta statistiškai reikšmingai didesnė tiesiamųjų raumenų jėga (p = 0,002), reikšmingai didesnė lenkiamųjų raumenų jėga (p = 0,024) bei didesnis tiesiamųjų raumenų jėgos pokytis nuo 6 iki 12 mėnesių (p = 0,004). Tuo tarpu merginų grupėje 12 mėnesių laikotarpiu buvo nustatytas statistiškai reikšmingai didesnis H/Q santykis (p = 0,004). Kitų statistiškai reikšmingų skirtumų nenustatyta.

7 lentelė. *Bendrų izokinetinės raumenų jėgos rezultatų palyginimas tarp vaikinų ir merginų po 6 ir 12 mėnesių po operacijos, nepaisant naudoto transplantato tipo*

	Vaikinai (n = 27)	**Merginos (n = 27)**	**Kriterijaus statistika**	***p* reikšmė**
Tiesiamųjų raumenų jėgos momento ir kūno masės santykis (%), 6 mėn. mediana (min.–maks.)	134,4 (92–279,2)	128,9 (90,6–260)	|Z| = 1,169	0,242
Tiesiamųjų raumenų jėgos momento ir kūno masės santykis (%), 12 mėn. mediana (min.–maks.)	227 (156,7–338,8)	168 (113,1–287,9)	|Z| = 3,042	**0,002***
Tiesiamųjų raumenų jėgos momento ir kūno masės santykio (%) pokytis mediana (min.–maks.)	67 (–4,5–208,6)	22,6 (6,7–112,7)	|Z| = 2,886	**0,004***
Lenkiamųjų raumenų jėgos momento ir kūno masės santykis (%), 6 mėn. mediana (min.–maks.)	70 (34,2–126,8)	93 (45,8–122,3)	|Z| = 0,078	0,938
Lenkiamųjų raumenų jėgos momento ir kūno masės santykis (%), 12 mėn. mediana (min.–maks.)	120,7 (74,5–155)	98,8 (68–123,7)	|Z| = 2,261	**0,024***
Lenkiamųjų raumenų jėgos momento ir kūno masės santykio (%) pokytis mediana (min.–maks.)	28,6 (–24,6–85)	20,9 (–30–37,6)	|Z| = 1,793	0,073

7 lentelės tęsinys

	Vaikinai (n = 27)	**Merginos (n = 27)**	**Kriterijaus statistika**	***p* reikšmė**
H/Q santykis, 6 mėn. mediana (min.–maks.)	47,8 (31,3–100,4)	55,7 (37,7–109)	|Z| = 1,793	0,073
H/Q santykis, 12 mėn. mediana (min.–maks.)	40,8 (32,8–69,2)	49,7 (40,9–105,8)	|Z| = 2,886	**0,004***
H/Q santykio pokytis mediana (min.–maks.)	–9 (–31,2–26,1)	–3,2 (–32,7–10,7)	|Z| = 1,013	0,311

H/Q santykis – lenkiamųjų ir tiesiamųjų šlaunies raumenų jėgos santykis; |Z| – absoliuti standartizuota Mann–Whitney testo statistika; * – statistiškai reikšmingas skirtumas ($p < 0,05$).

Pacientų pateiktų klausimynų rezultatų palyginimas tarp autotransplantatų grupių

Praėjus 12 mėnesių po operacijos, ŠLRS grupėje buvo nustatyti statistiškai reikšmingai aukštesni IKDC balai ($p = 0,009$), rodantys geriau vertinamą kelio sąnario funkciją. Nors Lysholm ir PKR-GST klausimynų rezultatai taip pat buvo aukštesni ŠLRS grupėje, šie skirtumai nebuvo statistiškai reikšmingi.

8 lentelė. *IKDC, Lysholm ir PKR-GST balai prieš operaciją ir po 12 mėnesių ŠKRS ir ŠLRS grupėse*

	ŠKRS (n = 24)	**ŠLRS (n = 30)**	**Kriterijaus statistika**	***p* reikšmė**
IKDC (prieš operaciją) mediana (min.–maks.)	58,05 (35,63–72,41)	60,92 (29,89–77,01)	|Z| = 0,314	0,753
IKDC (po 12 mėn.) mediana (min.–maks.)	87,94 (64,36–96,55)	93,13 (85,06–100)	|Z| = 2,599	**0,009***
IKDC balo pokytis mediana (min.–maks.)	27,75 (21,84–51,73)	37,93 (14,95–62,07)	|Z| = 1,413	0,158
Lysholm (prieš operaciją) mediana (min.–maks.)	67 (36–100)	75 (35–95)	|Z| = 1,178	0,239
Lysholm (po 12 mėn.) mediana (min.–maks.)	95 (66–100)	98 (80–100)	|Z| = 1,487	0,137
Lysholm balo pokytis mediana (min.–maks.)	26,5 (0–54)	21,5 (0–65)	|Z| = 0,708	0,479
PKR-GST (po 12 mėn.) mediana (min.–maks.)	70,67 (46,67–95,83)	80,82 (55,83–100)	|Z| = 1,570	0,116

ŠKRS – šlaunies keturgalvio raumens sausgyslės autotransplantatų grupė; ŠLRS – šlaunies lenkiamųjų raumenų sausgyslės autotransplantatų grupė; IKDC – klausimyno IKDC 2000 subjektyvaus kelio sąnario ištyrimo balas; PKR-GST – grįžimo į sportą po PKR traumos skalės balas; |Z| – standartizuota Mann–Whitney testo statistika; * – statistiškai reikšmingas skirtumas ($p < 0,05$).

χ^2 kriterijaus analizė parodė, kad po 12 mėnesių tarp ŠLRS ir ŠKRS grupių nustatytas statistiškai reikšmingas skirtumas pagal PKR-GST klausimyno gerų rezultatų proporcijas - ŠLRS grupėje geri rezultatai pasiekti 80,0 proc. atvejų (24 iš 30), o ŠKRS grupėje - 50,0 proc. atvejų (12 iš 24); $\chi^2 = 4{,}134$, $p = 0{,}042$.

Tikimybė pasiekti gerą PKR-GST rezultatą ŠLRS grupėje buvo 4 kartus didesnė nei ŠKRS grupėje (95 proc. pasikliautinasis intervalas: 1,21–13,28).

Daugybinės linijinės regresijos modelis, prognozuojantis psichologinį pasirengimą (PKR-GST)

Tyrimo metu nustatyta teigiama PKR-GST koreliacija su IKDC balu po 12 mėnesių ($r = 0{,}455$, $p < 0{,}001$) ir neigiama koreliacija su KMI z reikšme ($r = –0{,}274$, $p = 0{,}045$). Daugybinė regresijos analizė buvo taikyta siekiant nustatyti, ar IKDC balas 12 mėnesių po PKRR ir KMI z reikšmė gali reikšmingai prognozuoti PKR-GST balą po 12 mėnesių po PKRR. Regresijos analizės rezultatai parodė, kad determinacijos koeficientas $R^2 = 0{,}372$, o modelis turėjo reikšmingus PKR-GST balo prediktorius ($F = 15{,}114$, $p < 0{,}001$). VIF koeficientai parodė, kad tarp prediktorių multikolinearumo problemos nebuvo (VIF < 4).

9 lentelė. *Daugybinės linijinės regresijos rezultatai prognozuojant PKR-GST balą*

Modelis	**Nestandartizuoti koeficientai**		**Standartizuoti koeficientai**	**t**	***p* reikšmė**
	B	**Stand. paklaida**	**Beta**		
(Konstanta)	–25,335	21,612		–1,172	0,247
IKDC po 12 mėn.	1,156	0,241	0,557	4,799	< 0,001
KMI z reikšmė	–9,515	2,388	–0,463	–3,984	< 0,001

Abu prediktoriai (IKDC balas po 12 mėnesių ir KMI z reikšmė) buvo statistiškai reikšmingi.

Pagal standartizuotus beta koeficientus, abiejų prediktorių įtaka buvo panaši.

Galutinė prognozavimo modelio lygtis:

PKR-GST (12 mėnesių po PKRR) =
=–25,335 + 1,156 × IKDC balas (po 12 mėn.) – 9,515 × KMI z reikšmė.

Daugybinės regresijos modelis gali būti naudingas prognozuojant PKR-GST balą praėjus 12 mėnesių po PKRR, remiantis IKDC balu po 12 mėnesių ir KMI z reikšme. Transplantato tipas (ŠLRS arba ŠKRS) nepasiekė statistinio reikšmingumo, todėl į šį modelį nebuvo įtrauktas. Tai rodo, kad transplantato tipas neturėjo nepriklausomos įtakos psichologiniam pasirengimui grįžti į sportą po 12 mėnesių.

IŠVADOS

1. ŠKRS ir ŠLRS transplantatų grupėse pooperaciniai PBP rezultatai po 12 mėn. buvo teigiami, tačiau ŠKRS autotransplantatas užtikrino greitesnį ir didesnį PBP stabilumą bei mažesnę šių rodiklių variaciją. Vaikinams stebimas mažesnis ankstyvas kelio sąnario stabilumas po PKRR ŠLRS grupėje ir uždelstas nestabilumas ŠKRS grupėje. Tuo tarpu merginos pasiekė stabilesnius rezultatus greičiau, nepriklausomai nuo naudoto transplantato tipo.
2. Nors bendri izokinetinės jėgos rodikliai buvo priimtini abiejų transplantato tipų grupėse, ŠKRS grupėje iki 12 mėn. po operacijos nustatyta reikšmingai mažesnė tiesiamųjų raumenų jėga. ŠLRS transplantato paėmimas lenkiamųjų raumenų jėgai reikšmingos įtakos nepadarė. Vaikinai turėjo stipresnius tiesiamuosius raumenis, o merginos – palankesnį H/Q santykį, kas leidžia manyti, jog raumenų atsistatymo eiga gali būti lyčiai specifiška.
3. ŠKRS grupėje 12 mėn. po PKRR nustatytas žemesnis pacientų subjektyvus savijautos vertinimas, iš kurio tik IKDC balas buvo statistiškai reikšmingas. Be to, pacientai, kuriems buvo atlikta ŠLRS transplantacija, turėjo 4 kartus didesnę tikimybę pasiekti palankų PKR-GST rezultatą.
4. Daugybinės regresijos analizė parodė, kad subjektyvi kelio funkcija (IKDC) ir KMI z reikšmė buvo nepriklausomi psichologinio pasirengimo grįžti į sportą (PKR-GST) prediktoriai 12 mėnesių po PKRR. Transplantato tipas neturėjo nepriklausomos prognostinės reikšmės.

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LIST OF SCIENTIFIC PUBLICATIONS

Publications related to the dissertation results:

1. **Rakauskas, R**., Šiupšinskas, L., Streckis, V., Galinskas, L., Jurkonis, R., Tomkevičiūtė, J., Malcius, D., & Čekanauskas, E. (2025). Adolescent ACL Reconstruction Using Quadriceps or Hamstring Tendon Autografts: A Comparative Study of Muscle Strength and Patient-Reported Outcomes. Journal of Clinical Medicine, 14(11), 1-11. https://doi.org/10.3390/jcm14113842 [IF: 3, Q1]
2. **Rakauskas, R**., Šiupšinskas, L., Streckis, V., Balevičiūtė, J., Galinskas, L., Malcius, D., & Čekanauskas, E. (2023). Hamstring vs. All-Soft-Tissue Quadriceps Tendon Autograft for Anterior Cruciate Ligament Reconstruction in Adolescent Athletes: Early Follow-Up Results of a Prospective Study. Applied Sciences. Basel: MDPI, 2023, Vol. 13, No. 11., 1-13. https://doi.org/10.3390/app13116715 [IF: 2.5, Q1]

LIST OF CONFERENCE PRESENTATIONS

Conference presentations related to the dissertation results:

1. Žiaukas, V., Bergelis, T., & **Rakauskas, R**. (2023). Quadriceps Muscle Graft for ACL Reconstruction in Young Athletes: Efficacy and Return to Athletic Performance. International Medical Student Research Conference (IMRC) 2023 "Technology-Enhanced Simulation and the New Frontier of Medical Research": December 9-10, 2023: Abstract Book Editor-in-Chief Wisit Kaewput, 185-185. https://pcm-imrc.com/virtual/downloads/Abstract_Book.pdf
2. **Rakauskas, R**., Šiupšinskas, L., Tomkevičiūtė, J., & Čekanauskas, E. (2022). ACL reconstruction in adolescent athletes. Hamstring vs quadriceps tendon tendon autografts. Early outcomes of a prospective study. Nordic OrthopaedicFederation (NOF) Congress: 7–9 September 2022, Vilnius, Lithuania. Online Abstract Book Editor: Šarūnas Tarasevičius; Abstracts' Reviewers: Emilis Čekanauskas, Rimtautas Gudas, Jaunius Kurtinaitis, Giedrius Kvederas, Aleksas Makulavičius, Arnoldas Sipavičius, Justinas Stučinskas, Valentinas Uvarovas.Nordic OrthopaedicFederation.[Kaunas]:Eventas,2022.ISBN9786099616766, pp. 32–34. https://hdl.handle.net/20.500.12512/116599

APPENDICES

Appendix Table 1. *GNRB measurements of knee stability at 3, 6, and 12 months postoperatively, comparing results between the QT and HT groups*

	QT (n = 24)	**HT (n = 30)**	**Test statistic**	***p* value**
Curve slope 3 months median (min–max)	2.7 (0.6–18.2)	4.5 (0–12.4)	|Z| = 0.079	0.937
Curve slope 6 months median (min–max)	5 (0–12.9)	3.6 (0.6–14.8)	|Z| = 0.236	0.814
Curve slope 12 months median (min–max)	4.95 (1.7–8.3)	4.75 (2.9–14.1)	|Z| = 0.236	0.814
ATT 3 months with 134 N force in mm median (min–max)	0.4 (0.1–1.6)	1.5 (0–3.7)	|Z| = 3.223	**0.001***
ATT 6 months with 134 N force in mm median (min–max)	0.8 (0.1–3.2)	1.3 (0.1–5.3)	|Z| = 1.260	0.208
ATT 12 months with 134 N force in mm median (min–max)	1.1 (0.3–1.7)	1.75 (0.3–2.3)	|Z| = 2.673	**0.008***
ATT 6 months with 150 N force in mm median (min–max)	1.05 (0.3–3.0)	1.2 (0.1–5.1)	|Z| = 0.786	0.432
ATT 12 months with 150 N force in mm median (min–max)	1.15 (0.3–1.8)	1.7 (0.4–2.5)	|Z| = 2.277	**0.023***
ATT 6 months with 200 N force in mm median (min–max)	1.15 (0.2–3.2)	1.1 (0.1–5.1)	|Z| = 0.629	0.529
ATT 12 months with 200 N force in mm median (min–max)	0.85 (0.4–1.7)	1.6 (0.3–2.5)	|Z| = 2.670	**0.008***

QT – quadriceps tendon autograft group; HT – quadriceps tendon autograft group; ATT – anterior tibial translation; N – Newtons; mm – millimetres; |Z|: absolute standardized Mann–Whitney test statistic; * – statistically significant difference ($p < 0.05$).

Appendix Table 2. *GNRB-assessed knee stability in males and females at 3, 6, and 12 months postoperatively, regardless of graft type*

	Males (n = 27)	**Females (n = 27)**	**Test statistic**	***p* value**
Curve slope 3 months median (min–max)	2.4 (0.6–12.4)	3 (0–18.2)	|Z| = 0.705	0.482
Curve slope 6 months median (min–max)	4.7 (0.6–13.1)	3.7 (0–14.8)	|Z| = 0.312	0.755
Curve slope 12 months median (min–max)	5.3 (4.2–14.1)	4.6 (1.7–7.6)	|Z| = 3.356	**<0.001***
ATT 3 months with 134 N force in mm median (min–max)	1.7 (0.1–3.7)	0.3 (0–1.6)	|Z| = 3.984	**<0.001***
ATT 6 months with 134 N force in mm median (min–max)	1.5 (0.2–5.3)	0.5 (0.1–3.2)	|Z| = 2.035	**0.042***
ATT 12 months with 134 N force in mm median (min–max)	1.7 (0.5–2.2)	1.1 (0.3–2.3)	|Z| = 1.797	0.072
ATT 6 months with 150 N force in mm median (min–max)	1.5 (0.4–5.1)	0.5 (0.1–3.4)	|Z| = 2.736	**0.006***
ATT 12 months with 150 N force in mm median (min–max)	1.5 (0.6–2.5)	1 (0.3–2.3)	|Z| = 2.107	**0.035***
ATT 6 months with 200 N force in mm median (min–max)	1.3 (0.5–5.1)	0.6 (0.1–3.6)	|Z| = 2.734	**0.006***
ATT 12 months with 200 N force in mm median (min–max)	1.4 (0.5–2.5)	1 (0.2–2.4)	|Z| = 1.837	0.061

ATT – anterior tibial translation; N – Newtons; mm – millimetres; |Z|: absolute standardized Mann–Whitney test statistic; * – statistically significant difference ($p < 0.05$).

Appendix Table 3. *Comparison of Biodex (Isokinetic Dynamometer) results between the QT and HT groups at 6 and 12 months postoperatively*

	QT (n = 24)	**HT (n = 30)**	**Test statistic**	***p* value**
	6 months post-surgery			
Extensors peak TQ/BW in % median (min–max)	121.45 (90.6–211.3)	156.9 (96.1–279.2)	|Z| = 2.353	**0.019***
Flexors peak TQ/BW in % median (min–max)	84.35 (42–122.3)	75.2 (34.2–126.8)	|Z| = 0.471	0.638
H/Q ratio median (min–max)	56.1 (31.3–109)	43.75 (35.6–63.8)	|Z| = 2.353	**0.019***
	12 months post-surgery			
Extensors peak TQ/BW in % median (min–max)	208.55 (113.1–241.6)	250.8 (129.5–338.8)	|Z| = 3.375	**<0.001***
Flexors peak TQ/BW in % median (min–max)	115.3 (73.5–155)	91.25 (68–138.4)	|Z| = 1.569	0.117
H/Q ratio median (min–max)	57.2 (40.9–105.8)	40.9 (32.8–51.5)	|Z| = 4.238	**<0.001***
	Change (12–6 months)			
Extensors peak TQ/BW in % median (min–max)	44 (–4.5–131.9)	53.5 (21.2–208.6)	|Z| = 1.413	0.158
Flexors peak TQ/BW in % median (min–max)	24.3 (–24.6–85)	22.35 (–30–71)	|Z| = 0.784	0.433
H/Q ratio median (min–max)	–4.85(–32.7–26.1)	–5.5 (–13.7–10.7)	|Z| = 0.314	0.754

QT – quadriceps tendon autograft group; HT – hamstring tendon autograft group; TQ/BW – peak torque to body weight ratio; H/Q ratio – hamstring to quadriceps strength ratio; |Z|: absolute standardized Mann–Whitney test statistic; * – statistically significant difference (p < 0.05).

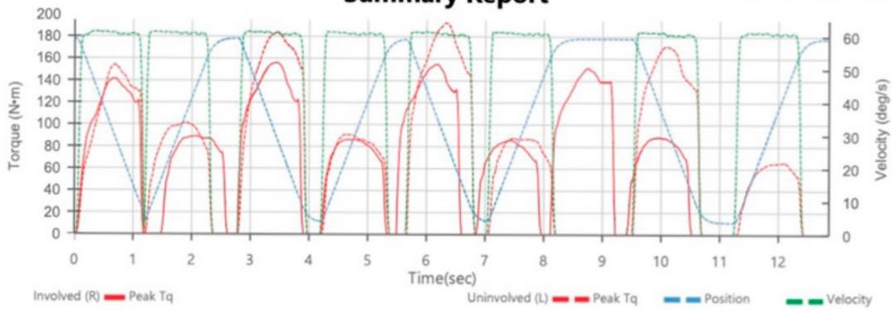
***Appendix Figure 1**. Example of Biodex protocol. All patient-identifying data have been redacted in accordance with GDPR and ethical research standards.*

Patient Name:	[redacted]	**Date:**	2022-11-23	**Joint:**	Knee
Patient ID:		**Time:**	20:37	**Pattern:**	EXT/FLEX
Age:	17	**Involved:**	Right	**Type/Mode:**	BI/ISOK
Weight (kg):	72,0	**GET:**	Right: 22 N•m at 42° Left: 25 N•m at 37°	**Contraction:**	CON/CON
Height (cm):	183			**Sets:**	2
Gender:	Female			**Surgery/Injury Date:**	

Set 1 of 2

Summary Report

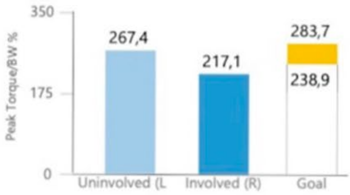
Options: Windowed, Filtered



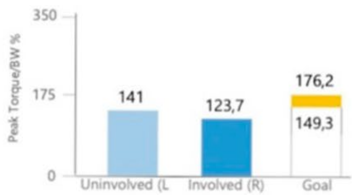
	Extension (60 deg/s)			Flexion (60 deg/s)		
	Uninvolved (L)	Involved (R)	Deficit (%)	Uninvolved (L)	Involved (R)	Deficit (%)
Number of Reps	4	4		4	4	
Peak Torque (N•m)	192,5 (Rep 3)	156,3 (Rep 2)	18,8	101,6 (Rep 1)	89,1 (Rep 1)	12,3
Angle of Peak Torque (deg)	68,0	70,0		79,0	74,0	
Peak Torque/BW (%)	267,4	217,1		141,0	123,7	
Max. Rep Total Work (J)	182,3 (Rep 3)	145,4 (Rep 2)	20,2	96,2 (Rep 1)	86,2 (Rep 1)	10,4
CV (%)	9,5	4,4		17,5	1,8	
Avg. Power (W)	115,5	102,0	11,7	46,3	63,3	-36,7
Total Work (J)	657,2	560,0	14,8	331,1	333,5	-0,7
ROM (deg)	71,9	69,4				
AGON/ANTAG Ratio (%)	52,7	57,0				

1 to 10%: Normal Range 11 to 20%: Rehab Recommended Over 20%: Significant Impairment

Extension (60 deg/s)



Flexion (60 deg/s)



Comments:

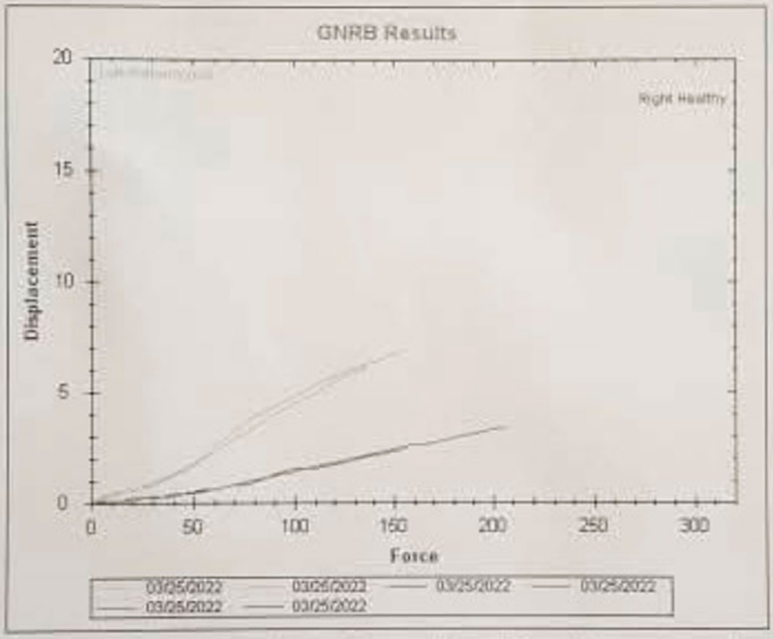
Clinician:

 Software Version: 5.3.00 Page 1 of 2 Printed on 2022-11-23 BIODEX

Appendix Figure 2a. *Genourob protocol example confirming ACL rupture. All patient-identifying data have been redacted in accordance with GDPR and ethical research standards.*

Last Name [redacted]
First Name
Identification Number
Medical Practitioner

Right knee : Healthy
Left knee : Pathological



Date	Knee	State	F. Pat	Dp	134	Slope	Dmax (Fmax)	C
03/25/2022	left	Pathological	70	95	6.2	39.9	6,9 (150)	
03/25/2022	left	Pathological	77	95	6.1	48.9	6,1 (134)	
03/25/2022	right	Healthy	73	95	2.1	19.7	3,4 (200)	
03/25/2022	right	Healthy	72	95	2.1	20	2,4 (150)	
03/25/2022	right	Healthy	73	95	2	20,6	2 (134)	
03/25/2022	right	Healthy	75	95	2	20,6	2 (134)	

Comments :

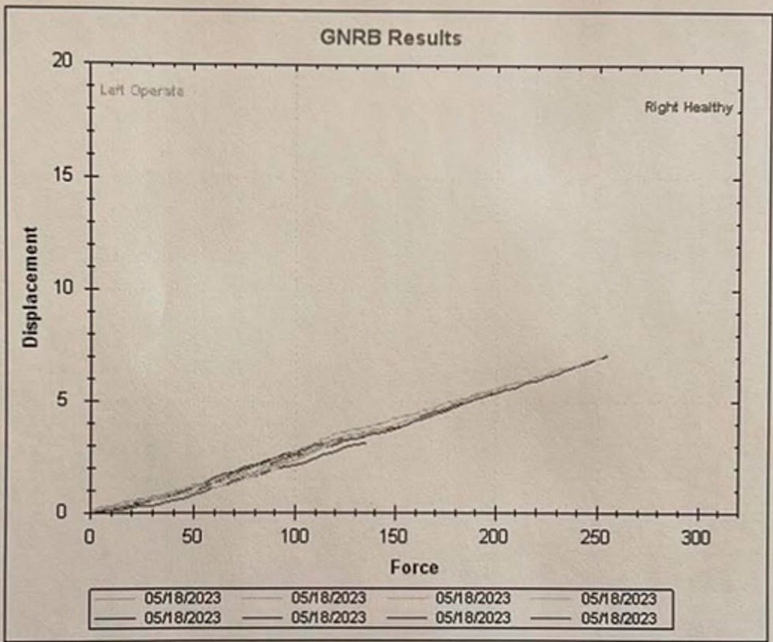
Skirtumas tarp sveikosios ir pažeistosios kojų (Dmax)
(<1 mm - norma; 1 - 3 mm - dalinis; >3 mm - pilnas raiščio plyšimas)
134N - 4,1 mm; 150N - 4,1 mm;
Kreivės nuolydis (ΔP2, 134N): 28,3
Funkcinio kelio sąnario nestabilumo rizika: Didele
>10 - didelė; 5 - 10 - vidutinė; <5 - maža.
IŠVADA: Kairės kojos PKR pilnas plyšimas, nestabilumo rizika - didele

[redacted]

Appendix Figure 2b*. Genourob protocol example showing excellent side-to-side anterior tibial translation after ACLR. All patient-identifying data have been redacted in accordance with GDPR and ethical research standards.*

Last Name
First Name
Identification Number
Medical Practitioner

Right knee : Healthy
Left knee : Operated



Date	Knee	State	F. Pat	Dp	134	Slope	Dmax (Fmax)	C
05/18/2023	left	Operated	63	165	3.8	27,8	7,1 (250)	
05/18/2023	left	Operated	66	165	3.6	29,6	5,6 (200)	
05/18/2023	left	Operated	67	165	3.5	33,6	4,1 (150)	
05/18/2023	left	Operated	70	165	3.6	33,6	3,6 (134)	
05/18/2023	right	Healthy	68	165	3.6	28,8	7 (250)	
05/18/2023	right	Healthy	70	165	3.5	29,2	5,5 (200)	
05/18/2023	right	Healthy	71	165	3.4	28,9	3,9 (150)	
05/18/2023	right	Healthy	74	165	3.1	28,9	3,1 (134)	

Comments :

6 menesiai po kaires kojos PKR rekonstrukcijos
Skirtumas tarp sveikosios ir pažeistosios kojų (Dmax):
(<1,5 mm - norma; 1,5 - 3 mm - dalinis; >3 mm - pilnas raiščio plyšimas)
134N - 0,5 mm; 150N - 0,1 mm; 200N - 0,1 mm; 250N - 0,2 mm
Kreivės nuolydis (ΔP2, 134N): 4,7
Funkcinio kelio sąnario nestabilumo rizika: Maža
>10 - didelė; 5 - 10 - vidutinė; <5 - maža.
IŠVADA: Kairės kojos PKR transplanto funkcija puiki, nestabilumo rizika - maža

Appendix Figure 3. *Ethics Committee Approval (in Lithuanian)*

KAUNO REGIONINIS BIOMEDICININIŲ TYRIMŲ ETIKOS KOMITETAS

Lietuvos sveikatos mokslų universitetas, A. Mickevičiaus g. 9, LT 44307 Kaunas, tel. (+370) 37 32 68 89;el.paštas: kaunorbtek@lsmuni.lt

LEIDIMAS ATLIKTI BIOMEDICININĮ TYRIMĄ

2021-09-01 Nr. BE-2-103

Biomedicininio tyrimo pavadinimas: „Priekinio kryžminio raiščio rekonstrukcijos metodų palyginimas naudojant šlaunies lenkiamųjų raumenų sausgyslių arba šlaunies keturgalvio raumens sausgyslės transplantatą vaikų amžiuje“	
Protokolo Nr.:	**PKRR_OP1**
Data:	**2021-07-22**
Versija:	**1.1**
Asmens informavimo forma:	**Versija: 1.1; data: 2021-07-22**
Pagrindinis tyrėjas: Biomedicininio tyrimo vieta: Įstaigos pavadinimas: Adresas:	**Prof. Emilis Čekanauskas** Lietuvos sveikatos mokslų universiteto ligoninė Kauno klinikos, Vaikų chirurgijos klinika Eivenių g. 2 LT-50161, Kaunas

Išvada:

Kauno regioninio biomedicininių tyrimų etikos komiteto posėdžio, įvykusio **2021 m. rugpjūčio mėn. 30 d.** (protokolo Nr. 2021-BE10-0009) sprendimu pritarta biomedicininio tyrimo vykdymui.

Mokslinio eksperimento vykdytojai įsipareigoja: (1) nedelsiant informuoti Kauno Regioninį biomedicininių Tyrimų Etikos komitetą apie visus nenumatytus atvejus, susijusius su studijos vykdymu, (2) iki sausio 15 dienos – pateikti metinį studijos vykdymo apibendrinimą bei, (3) per mėnesį po studijos užbaigimo, pateikti galutinį pranešimą apie eksperimentą.

Kauno regioninio biomedicininių tyrimų etikos komiteto nariai			
Nr.	Vardas, Pavardė	Veiklos sritis	Dalyvavo posėdyje
1.	Doc. dr. Gintautas Gumbrevičius	Klinikinė farmakologija	Taip
2.	Prof. dr. Kęstutis Petrikonis	Neurologija	Taip
3.	Dr. Saulius Raugelė	Chirurgija	Ne
4.	Dr. Lina Jankauskaitė	Pediatrija	Ne
5.	Prof. dr. Džilda Veličkienė	Endokrinologija	Taip
6.	Doc. dr. Eimantas Peičius	Visuomenės sveikata	Taip
7.	Aušra Degutytė	Visuomenės sveikata	Taip
8.	Dr. Žydrūnė Luneckaitė	Visuomenės sveikata	Taip
9.	Viktorija Bučinskaitė	Teisė	Taip

Kauno regioninis biomedicininių tyrimų etikos komitetas dirba vadovaudamasis etikos principais nustatytais biomedicininių tyrimų Etikos įstatyme, Helsinkio deklaracijoje, vaistų tyrinėjimo Geros klinikinės praktikos taisyklėmis.

Kauno RBTEK pirmininkas

LIETUVOS SVEIKATOS MOKSLŲ UNIVERSITETAS * KAUNO REGIONINIS BIOMEDICININIŲ TYRIMŲ ETIKOS KOMITETAS

Doc. dr. Gintautas Gumbrevičius

Appendix Figure 4. *Informed Consent Form for Participants Aged 12-17 Years (in Lithuanian)*

PATVIRTINTA
Lietuvos bioetikos komiteto
biomedicininių tyrimų ekspertų grupės
2016 m. lapkričio 15 d. sprendimu
PAKEISTA
Lietuvos bioetikos komiteto
biomedicininių tyrimų ekspertų grupės
2020 m. birželio 16 d. sprendimu

Informuoto asmens sutikimo forma, versija Nr. 1.1 , data: 2021-07-22

INFORMUOTO ASMENS SUTIKIMO FORMA

(Vaikams 12-17m.)

Biomedicininio tyrimo pavadinimas: „Priekinio kryžminio raiščio rekonstrukcijos metodų palyginimas naudojant šlaunies lenkiamųjų raumenų sausgyslių arba šlaunies keturgalvio raumens sausgyslės transplantatą vaikų amžiuje“

Protokolo Nr.: PKRR_OP1

Užsakovas: Lietuvos sveikatos mokslų universitetas

Adresas: A. Mickevičiaus g. 9, LT-44307, Kaunas Tel.: (837) 32 72 01
El. paštas: rektoratas@lsmuni.lt

Užsakovo atstovas: Prof. Habil. Dr. Vaiva Lesauskaitė

Atsakingas tyrėjas[1]: Emilis Čekanauskas

Tyrimo centro pavadinimas: Lietuvos sveikatos mokslų universiteto ligoninė Kauno klinikos, Vaikų chirurgijos klinika, Vaikų ortopedijos traumatologijos sektorius

Adresas: Eivenių g. 2, LT – 50161, Kaunas Tel.: (8-37) 32 63 75
El. paštas: vaiku.chirurgijos.klinika@kaunoklinikos.lt

[1] Atsakingas tyrėjas – tyrimo metu konkretų pacientą, pasirašantį Informuoto asmens sutikimo formą, prižiūrėsiantis tyrėjas.

1. Kokia šio dokumento paskirtis?

Šioje formoje pateikiama Jums skirta informacija apie biomedicininį / klinikinį vaistinio preparato tyrimą, aptariamos tyrimo atlikimo priežastys, mokslinio tyrimo procedūros, nauda, rizika, galimi nepatogumai ir kita svarbi informacija. Jei nuspręsite dalyvauti, prašysime Jūsų pasirašyti šią sutikimo formą, kuria sutinkate tyrimo metu vykdyti gydytojo tyrėjo ir tyrimo komandos nurodymus. Pasirašydami šį dokumentą, sutinkate dalyvauti moksliniame tyrime. Neskubėkite ir atidžiai perskaitykite šį dokumentą, jei nesupratote kokio nors žodžio ar teiginio, visus iškilusius klausimus būtinai užduokite tyrimo gydytojui ar kitiems tyrimo komandos nariams. Prieš priimdami sprendimą, galite pasitarti su šeimos nariais, draugais ar savo gydytoju.

2. Kodėl atliekami biomedicininiai tyrimai?

Svarbu suprasti, kad nors biomedicininio tyrimo metu bus atliekami sveikatos patikrinimai ar medicininės procedūros, biomedicininis tyrimas iš esmės skiriasi nuo įprastos (kasdienės) klinikinės praktikos. Įprastos (kasdienės) klinikinės praktikos tikslas yra Jus (t. y. konkretų asmenį, pacientą) išgydyti ir/ar pagerinti Jūsų sveikatos būklę. Pagrindinis biomedicininio (mokslinio) tyrimo tikslas – gauti naujų medicinos mokslo žinių, kurios ateityje padėtų kitų šia liga sergančių pacientų sveikatai. Kitaip tariant, pagrindinis šio tyrimo tikslas nėra tiesioginė nauda Jūsų sveikatai.

3.Kodėl atliekamas šis tyrimas?

Šio tyrimo tikslas – palyginti priekinio kryžminio raiščio rekonstrukcijos (PKRR) rezultatus vaikų amžiuje naudojant šlaunies lenkiamųjų raumenų sausgyslių (ŠLRS) arba šlaunies keturgalvio raumens sausgyslės (ŠKRS) transplantatą. Priekinio kryžminio raiščio plyšimas yra vis dažniau diagnozuojamas fiziškai aktyvių vaikų populiacijoje. Taikant naują gydymo metodiką gydant priekinio kryžminio raiščio (PKR) plyšimus, tikimasi nustatyti pranašesnį PKR rekonstrukcijos metodą vaikams.

4. Kokie asmenys pasirenkami dalyvauti šiame tyrime?

Kviečiame Jus dalyvauti biomedicininiame tyrime, nes Jums yra nustatytas priekinio kryžminio raiščio plyšimas ir yra reikalinga priekinio kryžminio raiščio rekonstrukcija. Pagrindiniai įtraukimo į šį tyrimą kriterijai yra šie:

- 12-17 metų asmenys;
- Patyrę pilną PKR plyšimą, kuomet yra reikalinga priekinio kryžminio raiščio rekonstrukcija;
- Veiksnūs asmenys;
- Sutinka dalyvauti tyrime ir pasirašo Informuto asmens sutikimo formą;

o Gydomi LSMUL Kauno klinikų Vaikų chirurgijos klinikoje, Vaikų ortopedijos traumatologijos sektoriuje;

Prieš sutikdami dalyvauti būtinai pasitarkite su savo tėvais, išsiaiškinkite visą su tyrimu susijusią informaciją ir tik tada apsispręskite ar prisidėkite prie šio tyrimo. Į jūsų nuomonę bus atsižvelgta.

5. Kas atlieka/užsako šį biomedicininį tyrimą?

Šį biomedicininį tyrimą užsako Lietuvos sveikatos mokslų universitetas ir jį atliks Lietuvos sveikatos mokslų universiteto ligoninė Kauno klinikos, Vaikų chirurgijos klinika.

6. Tikimybė patekti į skirtingas tiriamųjų grupes ir dalyvavimo šiose grupėse ypatybės.

Šiame tyrime dalyvaujantys asmenys atsitiktinai (lyg metus monetą) bus suskirstyti į dvi grupes – pirmai grupei bus atliekama priekinio kryžminio raiščio rekonstrukcija naudojant šlaunies lenkiamųjų raumenų sausgyslės transplantatą, antrai - preikinio kryžminio raiščio rekonstrukcija naudojant šlaunies keturgalvio raumens sausgyslės transplantatą. Kiekvienas tyrimo dalyvis turi vienodą galimybę (50 proc.) patekti į vieną iš grupių. Visi kiti tyrimai, kurie bus atliekami Jums, nesiskiria tarp grupių, skiriasi tik transplantato tipas.

7. Kiek truks Jūsų dalyvavimas šiame tyrime?

Bendra tyrimo trukmė –3 metai. Jūs tyrime dalyvausite vienerius metus, t. y. nuo pirmo vizito, kai pasirašysite informuoto asmens sutikimo formą, vizitas truks iki 30 min, turėsite apsilankyti pas gydytoją tyrėją dar 4 kartus, antrojo vizito metu bus atliekama operacija bei užpildomi du klausimynai (Tegner/Lysholm ir IKDC), klausimynų pildymas užtruks apie 15 min, vėliau pas gydytoją reikės atvykti praėjus 3 mėnesiams po operacijos, šis vizitas truks apie 30 minučių, praėjus 6 mėnesiams po operacijos, vizito trukmė: 30-60 minučių , ir paskutinis vizitas praėjus 12 mėnesių po operacijos, vizito trukmė: 30-60 minučių.

8. Kokiose šalyse bus vykdomas šis tyrimas?

Lietuvoje.

9. Kiek tiriamųjų dalyvaus numatyta šiame tyrime?

Tikimasi, kad šiame biomediciniame tyrime dalyvaus 60 tiriamųjų.

10. Ką Jums reikės daryti?

Prašysime, kad Jūs atsakytumėte į keletą tyrimo klausimyno klausimų apie Jūsų kelio sąnario būklę. Klausimyne užrašyta informacija bus anoniminė, remiantis ja nebus įmanoma nustatyti Jūsų tapatybės. Taip pat Jums bus atliekami kelio sąnario stabilumo tyrimai ir atliekamas šlaunies tiesiamųjų ir lenkiamųjų raumenų jėgų santykio matavima. Visų trijų vizitų po operacijos metu bus atliekamas kelio sąnario stabilumo tyrimas, dviejų paskutinių vizitų metu bus atliekami abu tyrimai: kelio sąnario stabilumo ir šlaunies tiesiamųjų ir lenkiamųjų raumenų jėgų santykio matavimo tyrimas. Dviejų paskutinių vizitų metu, prašysime Jūsų užpildyti du gydytojo pateiktus klausimynus, kuriuose klausimai yra apie kelio sąnario būklę. Visi šie tyrimai tokiu pačiu dažniu yra rekomenduojami ir vis dažniau atliekami, Jūsų gydymas nesiskirs nuo įprastinio gydymo.

Atliekant kelio sąnario stabilumo tyrimą Jūs galte patirti nedidelį psichologinį arba fizinį diskomfortą, kuomet yra tikrinamas sąnario stabilumas kontroliuojama aparato jėga. Šlaunies tiesiamųjų ir lenkiamųjų raumenų jėgos tyrimo metu Jūs turėsite naudoti fizinę jėgą atliekant kelio sąnario judesius su aparato keliamu pasipriešinimu. Tyrėjams reikės naudotis Jūsų medicininiais dokumentais (ligos istorija), iš kurių bus renkami duomenys apie Jūsų lytį, amžių, ūgį, svorį, KMI (kūno masės indeksas), informacija apie traumos mechanizmą, traumos data, buvusios kelio sąnario traumos, MRT (magnetinio rezonanso tyrimo) išvada, operacijos metodika (transplantato tipas), transplantato diametras, papildomi pažeidimai (meniskų, kremzlės, kitų kelio raiščių pažeidimai)

11. Ar dalyvavimas biomedicininiame Jums bus naudingas? Kokios naudos galite tikėtis dalyvaudami šiame tyrime?

Dalyvavimas šiame tyrime Jums nebus tiesiogiai naudingas ir visos tyrimo metu atliekamos procedūros yra rekomendacinės, todėl gausite tikslesnį ir išsamesnį būklės ištyrimą.

12. Kokia su dalyvavimu šiame tyrime susijusi rizika ir nepatogumai?

Dalyvaudami šiame tyrime galite patirti keletą nepatogumų, tokių kaip sugaištas laikas atvykstant į pakartotinius vizitus bei pildant gydytojų Jums duotus klausimynus. Taip pat galite jausti nemalonų jausmą gydytojams vykdant kelio sąnario stabilumo bei šlaunies tiesiamųjų ir lenkiamųjų raumenų jėgos tyrimus.

13. Jei atsitiktų kas nors negero? (Informacija apie draudimą)

Jūs turite teisę į žalos sveikatai, patirtos dalyvaujant šiame tyrime, atlyginimą. Žala jums bus atlyginta remiantis Lietuvos Respublikos įstatymais. Su žalos atlyginimo taisyklėmis galite susipažinti tyrimo vietoje, kreipdamiesi į gydytoją tyrėją. Jei manote, kad tyrimo metu patyrėte žalą, taip pat kreipkitės į gydytoją tyrėją.

14. Kokias pasirinkimo galimybes turėsite, jeigu nesutiksite dalyvauti šiame tyrime arba atšauksite sutikimą jame dalyvauti?

Tyrime dalyvaujate savanoriškai, todėl turite teisę atsisakyti, o pradėjęs galite, bet kada iš jo pasitraukti. Jūsų sprendimas atsisakyti dalyvauti ar nutraukti dalyvavimą tyrime nedarys jokios įtakos teikiamai įprastinei sveikatos priežiūrai.

15. Ar galėsite nutraukti dalyvavimą tyrime?

Jei nuspręsite pasitraukti iš tyrimo šiam nepasibaigus, tyrėjas pateiks ir paprašys parašyti laisvos formos atsisakymo prašymą, Jūs turite teisę pasitraukti iš tyrimo nenurodydamas priežasčių ir motyvų. Atsisakymą pasirašys vienas iš tėvų arba kitas teisėtas (Jūsų) atstovas. Jeigu dėl pablogėjusios sveikatos būklės Jūs ar Jūsų tėvai negalėsite spręsti apie tolesnes galimybes dalyvauti tyrime, į Jūsų norus atšaukti sutikimą dalyvauti tyrime bus atsižvelgta, bet teisiškai šį sprendimą priims vienas iš tėvų arba kitas teisėtas atstovas. Norėtume atkreipti dėmesį, kad šio tyrimo rezultatai, t. y. tyrimo dokumentuose iki Jūsų sutikimo dalyvauti biomedicininiame tyrime atšaukimo įrašyti duomenys nebus sunaikinti.

16. Jūsų dalyvavimo tyrime nutraukimo aplinkybės ir kriterijai

Jei nesilaikysite gydytojo tyrėjo nurodymų ar dalyvaujant tyrime smarkiai pablogės Jūsų sveikatos būklė, Jūs daugiau nebegalėsite dalyvauti tyrime.

17. Ar dalyvaudami šiame tyrime patirsite kokių nors išlaidų?

Dalyvaudami tyrime papildomų išlaidų nepatirsite. Dalyvavimas tyrime savanoriškas, atlygis už dalyvavimą nebus mokamas.

18. Ar Jūsų asmens duomenys bus konfidencialūs?

Biomedicininį tyrimą atliekant gauta sveikatos informacija, leidžianti nustatyti asmens tapatybę, bus konfidenciali ir galės būti teikiama tik Lietuvos Respublikos pacientų teisių ir žalos sveikatai atlyginimo įstatymo ir Lietuvos Respublikos asmens duomenų teisinės apsaugos įstatymo nustatyta tvarka. Jei sutiksite dalyvauti tyrime, gydytojas tyrėjas ir tyrimo darbuotojai naudos tyrimui atlikti reikalingus Jūsų asmeninius duomenis. Tyrimo metu bus renkami šie Jūsų asmeniniai duomenys: lytis, amžius, ūgis, svoris, KMI (kūno masės indeksas), informacija apie traumos mechanizmą, traumos data, buvusios kelio sąnario traumos, MRT (magnetinio rezonanso tyrimo) išvada, operacijos metodika (transplantato tipas), transplantato diametras, papildomi pažeidimai (meniskų, kremzlės, kitų kelio raiščių pažeidimai),atsakymai į klausimynuose esančius klausimus. Duomenys bus renkami remiantis Jūsų ir Jūsų tėvų pateikta žodine informacija. Siekiant apsaugoti duomenų konfidencialumą, Jums bus suteiktas specialus kodas.

19. Kas ir kokiu tikslu galės susipažinti su Jūsų asmens duomenimis?

Tyrimo tyrėjai ir tyrimus kontroliuojančios institucijos (tokios kaip, etikos komitetai ir kt.) galės susipažinti su visa šio tyrimo tikslais apie Jus surinkta informacija. Kitiems asmenims bus teikiami tik užkoduoti sveikatos duomenys („Užkoduoti" reiškia, kad dokumentuose bus nurodomas ne Jūsų vardas ir pavardė, o specialus numeris (kodas), kurį susieti su Jūsų asmeniu galės tik gydytojas tyrėjas). Surinktus duomenis tyrimo gydytojai naudos tik šio biomedicininio tyrimo tikslais. Jūs turite teisę sužinoti, kokie duomenys buvo surinkti, taip pat galite reikalauti ištaisyti, sunaikinti ar sustabdyti savo asmens duomenų tvarkymo veiksmus, jei nuspręsite pasitraukti iš tyrimo anksčiau numatyto laiko. Tada tyrėjai apie Jus neberinks naujos informacijos, bet negalės sunaikinti iki tol surinktų duomenų.

Pateikdami asmeninius duomenis apie save turite įvertinti ir su tuo susijusią riziką, kai dėl nenumatytų aplinkybių konfidenciali informacija apie jus gali tapti prieinama tretiesiems asmenims, kuriems nebuvote davęs sutikimo ją duoti. Žinodami visas su duomenų tvarkymu susijusias rizikas biomedicininio tyrimo tyrėjai stengsis užtikrinti tinkamą ir įstatymų nustatyta tvarka atliekamą Jūsų asmens duomenų tvarkymą.

20. Kiek laiko bus saugomi tyrimo metu surinkti duomenys ir kas už tai bus atsakingas?

Visa informacija bus užrašoma specialiai tyrimui sudarytuose elektroniniuose bei popieriniuose dokumentuose ir tyrimo centre saugoma 5 metus pasibaigus tyrimui. Vėliau Jūsų asmens duomenys sunaikins tyrimo centro nustatyta tvarka.

21. Kas įvertino šį biomedicininį /klinikinį vaistinio preparato tyrimą? / Į ką kreiptis, jeigu iškiltų klausimų?

Dėl savo kaip tyrimo dalyvio teisių galite kreiptis į leidimą atlikti šį biomedicininį tyrimą išdavusį Kauno regioninį biomedicininių tyrimų etikos komitetą, Lietuvos Sveikatos mokslų universitetas, Mickevičiaus g. 9, LT-44307, Kaunas, tel. (8-37) 32 68 89, el. paštas: kaunorbtek @lsmuni.lt. Dėl informacijos apie asmens duomenų tvarkymą galite kreiptis į Valstybinę duomenų apsaugos inspekciją (A. Juozapavičiaus g. 6, LT-09310 Vilnius, tel. (8-5) 2127535, el. paštas: ada@ada.lt) arba į Lietuvos Sveikatos mokslų universiteto ligoninės, kauno klinikų duomenų apsaugos pareigūną Tomą Kuzmarską, Tel. +37037326268, El. p. tomas.kuzmarskas@kaunoklinikos.lt.

SUTIKIMAS DALYVAUTIBIOMEDICININIAME TYRIME

(Vaikai 12-17 metų)

Aš perskaičiau šią Informuoto asmens sutikimo formą ir supratau man pateiktą informaciją. Man buvo suteikta galimybė užduoti klausimus ir gavau mane tenkinančius atsakymus.Supratau, kad galiu bet kada pasitraukti iš tyrimo, nenurodydama(s) priežasčių. Supratau, kad asmuo, dėl kurio dalyvavimo biomedicininiame tyrime aš duodu sutikimą, gali bet kada pasitraukti iš tyrimo, nenurodydamas priežasčių.Supratau, kad norėdama(s) atšaukti sutikimą dalyvauti biomedicininiame tyrime, raštu turiu apie tai informuoti tyrėją/kitą jo įgaliotą biomedicininį tyrimą atliekantį asmenį. Patvirtinu, kad turėjau užtektinai laiko apsvarstyti man suteiktą informaciją apie biomedicininį tyrimą. Supratau, kad dalyvavimas šiame tyrime yra savanoriškas. Patvirtinu, kad sutikimą dalyvauti šiame biomedicininiame tyrime duodu laisva valia. Leidžiu naudoti asmens duomenis ta apimtimi ir būdu, kaip nurodyta Informuoto asmens sutikimo formoje.

Patvirtinu, kad gavau Informuoto asmens sutikimo formos egzempliorių, pasirašytą tyrėjo/ kito jo įgalioto biomedicininį tyrimą atliekančio asmens.

Asmuo (ar kitas sutikimą turintis teisę duoti asmuo)

					_:_
vardas	pavardė	atstovavimo pagrindas	parašas	pasirašymo data (m. mėn. d.)	pasirašymo laikas

Patvirtinu, kad suteikiau informaciją apie biomedicininį tyrimą aukščiau nurodytam asmeniui.

Patvirtinu, kad asmeniui (ar kitam sutikimą duoti turinčiam teisę asmeniui) buvo skirta pakankamai laiko apsispręsti dalyvauti biomedicininiame tyrime, atsižvelgiant į biomedicininio tyrimo pobūdį, taip pat įvertinus kitas aplinkybes, galinčias daryti įtaką priimamam sprendimui.

Aš skatinau asmenį (ar kitą sutikimą turintį teisę duoti asmenį) užduoti klausimus ir į juos atsakiau.

Tyrėjas ar kitas jo įgaliotą biomedicininį tyrimą atliekantis asmuo

					_:_
vardas	pavardė	pareigos tyrime	parašas	pasirašymo data (m. mėn. d.)	pasirašymo laikas

Appendix Figure 5. *Informed Consent Form for Parents/Guardians (in Lithuanian)*

PATVIRTINTA
Lietuvos bioetikos komiteto
biomedicininių tyrimų ekspertų grupės
2016 m. lapkričio 15 d. sprendimu
PAKEISTA
Lietuvos bioetikos komiteto
biomedicininių tyrimų ekspertų grupės
2020 m. birželio 16 d. sprendimu

Informuoto asmens sutikimo forma, versija Nr. 1.1, data: 2021-07-22

INFORMUOTO ASMENS SUTIKIMO FORMA

(tėvams/globėjams)

Biomedicininio tyrimo pavadinimas: „Priekinio kryžminio raiščio rekonstrukcijos metodų palyginimas naudojant šlaunies lenkiamųjų raumenų sausgyslių arba šlaunies keturgalvio raumens sausgyslės transplantatą vaikų amžiuje“

Protokolo Nr.: PKRR_OP1

Užsakovas: Lietuvos sveikatos mokslų universitetas

Adresas: A. Mickevičiaus g. 9, LT 44307 Kaunas, Tel.: +370 37 327201, El. paštas: rektoratas@lsmuni.lt

Užsakovo atstovas: prof. habil. Dr. Vaiva Lesauskaitė

Atsakingas tyrėjas[1]: prof. Emilis Čekanauskas

Tyrimo centro pavadinimas: Lietuvos sveikatos mokslų universiteto ligoninėje Kauno klinikų Vaikų chirurgijos klinikoje, Vaikų ortopedijos traumatologijos sektorius.

Adresas: Eivenių g. 2, LT 50161, Kaunas, Tel.: +37037326465, El. paštas: vaiku.chirurgijos.klinika@kaunoklinikos.lt

1. Kokia šio dokumento paskirtis?

Šioje formoje pateikiama Jums skirta informacija apie biomedicininį tyrimą, aptariamos tyrimo atlikimo priežastys, mokslinio tyrimo procedūros, nauda, rizika, galimi nepatogumai ir kita svarbi

[1] Atsakingas tyrėjas – tyrimo metu konkretų pacientą, pasirašantį Informuoto asmens sutikimo formą, prižiūrėsiantis tyrėjas.

informacija. Jei nuspręsite dalyvauti, prašysime Jūsų pasirašyti šią sutikimo formą, kuria sutinkate tyrimo metu vykdyti gydytojo tyrėjo ir tyrimo komandos nurodymus. Pasirašydami šį dokumentą, sutinkate dalyvauti moksliniame tyrime. Neskubėkite ir atidžiai perskaitykite šį dokumentą, jei nesupratote kokio nors žodžio ar teiginio, visus iškilusius klausimus būtinai užduokite tyrimo gydytojui ar kitiems tyrimo komandos nariams. Prieš priimdami sprendimą, galite pasitarti su šeimos nariais, draugais ar savo gydytoju.

2. Kodėl atliekami biomedicininiai tyrimai?

Svarbu suprasti, kad nors biomedicininio tyrimo metu Jūsų vaikui bus atliekamos medicininės procedūros, biomedicininis tyrimas iš esmės skiriasi nuo įprastos (kasdienės) klinikinės praktikos. Įprastos (kasdienės) klinikinės praktikos tikslas yra Jūsų vaiką (t. y. konkretų asmenį, pacientą) išgydyti ir/ar pagerinti Jūsų vaiko sveikatos būklę. Pagrindinis biomedicininio (mokslinio) tyrimo tikslas – gauti naujų medicinos mokslo žinių, kurios ateityje padėtų kitų šia liga sergančių pacientų sveikatai. Kitaip tariant, pagrindinis šio tyrimo tikslas nėra tiesioginė nauda Jūsų vaiko sveikatai.

3.Kodėl atliekamas šis tyrimas?

Šio tyrimo tikslas – Palyginti priekinio kryžminio raiščio rekonstrukcijos (PKRR) rzultatus vaikų amžiuje naudojant šlaunies lenkiamųjų raumenų sausgyslių (ŠLRS) arba šlaunies keturgalvio raumens sausgyslės (ŠKRS) transplantatą.

Priekinio kryžminio raiščio (PKR) plyšimas vis dažniau diagnozuojamas fiziškai aktyvių vaikų populiacijoje. LSMUL KK pirminei PKRR nėra naudojamas ŠKRS transplantatas, todėl taikant šią naują gydymo metodiką gydant PKR plyšimus, tikimasi nustatyti pranašesnį metodą PKRR vaikams.

4. Kokie asmenys pasirenkami dalyvauti šiame tyrime?

Kviečiame Jūsų vaiką dalyvauti biomedicininiame tyrime, nes jam yra nustatytas priekinio kryžminio raiščio plyšimas ir yra reikalinga priekinio kryžminio raiščio rekonstrukcija. Pagrindiniai įtraukimo į šį tyrimą kriterijai yra šie:

- 12-17 metų asmenys
- Patyrę pilną PKR plyšimą, kuomet yra reikalinga priekinio kryžminio raiščio rekonstrukcija
- Veiksnūs asmenys
- Sutinka dalyvauti tyrime ir pasirašo Informuto asmens sutikimo formą
- Gydomi LSMUL Kauno klinikų Vaikų chirurgijos klinikoje, Vaikų ortopedijos traumatologijos sektoriuje

5. Kas atlieka šį biomedicininį tyrimą?

Šį biomedicininį tyrimą atlieka Lietuvos sveikatos mokslų ligoninės Kauno klinikų Vaikų chirurgijos klinika, Vaikų ortopedijos traumatologijos sektorius.

6. Tikimybė patekti į skirtingas tiriamųjų grupes ir dalyvavimo šiose grupėse ypatybės.

Šiame tyrime dalyvaujantys asmenys atsitiktinai (lyg metus monetą) bus suskirstyti į dvi grupes – pirmai bus atliekama priekinio kryžminio raiščio rekonstrukcija naudojant šlaunies lenkiamųjų raumenų sausgyslės transplantatą, antrai - preikinio kryžminio raiščio rekonstrukcija naudojant šlaunies keturgalvio raumens sausgyslės transplantatą. Kiekvienas tyrimo dalyvis turi vienodą galimybę (50 proc.) patekti į vieną iš grupių.

Visi kiti tyrimai, kurie bus atliekami Jūsų vaikui nesiskiria tarp grupių, skiriasi tik transplantato tipas.

7. Kiek truks Jūsų vaiko dalyvavimas šiame tyrime?

Bendra tyrimo trukmė – trys metai.

Jūsų vaikas dalyvaus metus, t. y. nuo pirmo vizito, kai pasirašysite informuoto asmens sutikimo formą, vizitas truks iki 30 minučių, turėsite apsilankyti pas gydytoją tyrėją dar 4 kartus, antrojo vizito metu bus atliekama operacija bei užpildomi du klausimynai Tegner/Lysholm ir IKDC, klausimynų pildymas užtruks apie 15 minučių, vėliau pas gydytoją reikės atvykti po 3 mėn. po operacijos, šis vizitas truks apie 30 minučių, po 6 mėn. po operacijos, vizito trukmė: 30-60 minučių , ir paskutinis vizitas po 12 mėn. po operacijos, vizito trukmė: 30-60 minučių.

8. Kokiose šalyse bus vykdomas šis tyrimas?

Tyrimas bus atliekamas tik Lietuvoje.

9. Kiek tiriamųjų dalyvaus numatyta šiame tyrime?

Tikimasi, kad šiame biomedicininiame tyrime dalyvaus apie 60 žmonių, po 30 kiekvienoje grupėje.

10. Ką Jums reikės daryti?

Prašysime Jūsų vaiko atsakyti į keletą tyrimo klausimyno klausimų apie Jūsų vaiko kelio sąnario būklę. Klausimyne užrašyta informacija bus anoniminė, remiantis ja nebus įmanoma nustatyti Jūsų vaiko tapatybės. Taip pat Jūsų vaikui bus atliekami tyrimai kelio sąnario stabilumo Genourob robotiniu artrometru ir atliekamas šlaunies tiesiamųjų ir lenkiamųjų raumenų jėgų santykio matavimas Biodex izokinetine sistema. Visų trijų vizitų po operacijos metu bus atliekamas kelio sąnario stabilumo Genourob robotiniu artrometru tyrimas, dviejų paskutinių vizitų metu bus atliekami abu tyrimai: kelio sąnario stabilumo Genourob robotiniu artrometru ir atliekamas šlaunies tiesiamųjų ir lenkiamųjų raumenų jėgų santykio matavimas Biodex izokinetine sistema. Dviejų paskutinių vizitų metu, prašysime Jūsų vaiko užpildyti IKDC ir ACL-RSI klausimynus, kuriuose klausimai yra apie kelio sąnario būklę. Visi šie tyrimai tokiu pačiu dažniu yra rekomenduojami ir vis dažniau atliekami, Jūsų vaiko gydymas nesiskirs nuo įprastinio gydymo.

Atliekant procedūrą Genourob robotiniu artrometru Jūsų vaikas gali patirti nedidelį psichologinį arba fizinį diskomfortą, kuomet yra tikrinamas sąnario stabilumas kontroliuojama aparato jėga, Biodex tyrimo metu Jūsų vaikas turės naudoti fizinę jėgą atliekant kelio sąnario judesius su aparato keliamu pasipriešinimu. Tyrėjams reikės naudotis Jūsų vaiko medicininiais dokumentais (ligos istorija), iš kurių bus renkami duomenys apie ankstesnes traumas ir kiti duomenys apie Jūsų vaiką.

11. Ar dalyvavimas biomedicininiame tyrime Jūsų vaikui bus naudingas?

Dalyvavimas tyrime Jūsų vaikui tiesiogiai nebus naudingas. Visos atliekamos procedūros yra rekomendacinės, o Jūsų vaikui jos bus atliekamos, todėl jis gaus geresnį ištyrimą.

12. Kokia su dalyvavimu šiame tyrime susijusi rizika ir nepatogumai?

Atliekant procedūrą Genourob robotiniu artrometru Jūsų vaikas gali patirti nedidelį psichologinį arba fizinį diskomfortą, kuomet yra tikrinamas sąnario stabilumas kontroliuojama aparato jėga, Biodex tyrimo metu Jūsų vaikas turės naudoti fizinę jėgą atliekant kelio sąnario judesius su aparato keliamu pasipriešinimu, tai gali sukelti trumpalaikį fizinį nuovargį, retais atvejais dėl didesnio krūvio gali šiek tiek patinti kelio sąnarys, atsirasti nedidelis raumenų skausmas. Dalyvaudamas šiame tyrime Jūsų vaikas gali patirti ir kitų nepatogumų, tokių kaip sugaištas laikas vykstant į tyrimo vietą ar pildant tyrimo klausimynus.

Dėl nenumatytų aplinkybių konfidenciali informacija gali tapti prieinama tretiesiems asmenims, kuriems ją suteikti nebuvote davęs sutikimo.

Jei dėl nenumatytų aplinkybių (force majore ar nenugalima jėga, trečiųjų asmenų nusikalstamos veikos ir pan.), kurios tyrėjui nėra žinomos ir kurioms įtakos tyrėjas negali daryti, konfidenciali informacija taptų prieinama tretiesiems asmenims, kuriems ją suteikti nebuvote davęs sutikimo, tyrėjas iškarto Jus apie tai informuos. Tačiau tyrėjas visais būdais stengsis užtikrinti, kad Jūsų vaiko asmens duomenys, tvarkomi šio biomedicininio tyrimo tikslu, nebūtų prieinami tretiesiems asmenims, kuriems jos suteikti nebuvote davęs sutikimo ir įgyvendins duomenų saugumo priemones, skirtas apsaugoti asmens duomenis nuo atsitiktinio ar neteisėto atskleidimo, taip pat nuo bet kokio kito neteisėto tvarkymo.

13. Jei atsitiktų kas nors negero? (Informacija apie draudimą)

Šio biomedicininio tyrimo metu bus taikomi tik neintervenciniai tyrimo metodai, kurie nekelia rizikos Jūsų sveikatai, todėl biomedicininis tyrimas nėra apdraustas biomedicininio tyrimo užsakovų ir pagrindinių tyrėjų civilinės atsakomybės draudimu.

Jūs turite teisę į žalos sveikatai ir su tuo susijusios neturtinės žalos, patirtos dalyvaujant šiame tyrime, atlyginimą.

14. Kokias pasirinkimo galimybes turėsite, jeigu nesutiksite, kad Jūsų vaikas dalyvautų šiame tyrime arba atšauksite sutikimą jame dalyvauti?

Tyrime Jūs ir Jūsų vaikas dalyvaujate savanoriškai, todėl turite teisę atsisakyti, o pradėjęs galite bet kada iš jo pasitraukti.

15. Ar galėsite nutraukti dalyvavimą tyrime?

Jei Jūs ar Jūsų vaikas nuspręsite pasitraukti iš tyrimo šiam nepasibaigus, tyrėjas pateiks ir paprašys parašyti laisvos formos atsisakymo prašymą arba užpildyti atsisakymo formą.

Jeigu dėl pablogėjusios sveikatos būklės negalėsite spręsti apie tolesnes galimybes dalyvauti tyrime, į Jūsų norą atšaukti sutikimą dalyvauti tyrime bus atsižvelgta, bet teisiškai šį sprendimą priims sutuoktinis, jeigu jo nėra – vienas iš tėvų, pilnamečių vaikų, globėjas ar rūpintojas.

16. Jūsų vaiko dalyvavimo tyrime nutraukimo aplinkybės ir kriterijai

Jei Jūsų vaikas nesilaikys gydytojo tyrėjo nurodymų ar dalyvaujant tyrime smarkiai pablogės Jūsų vaiko sveikatos būklė, Jūsų vaikas daugiau nebegalėsite dalyvauti tyrime.

Tyrimo gydytojas ar užsakovas turi teisę bet kuriuo metu sustabdyti tyrimą ar Jūsų vaiko dalyvavimą jame. Jūs nebegalėsite dalyvauti tyrime, jei neatvyksite į suplanuotus vizitus ar nesilaikysite kitų tyrėjų nurodymų.

Jeigu Jūsų vaikas nebenori dalyvauti biomedicininiame tyrime, jis turi teisę nutraukti dalyvavimą tyrime, nenurodydamas priežasčių ir motyvų, išskyrus tuos atvejus, kai tai prieštarauja Jūsų vaiko interesams.

17. Ar dalyvaudami šiame tyrime patirsite kokių nors išlaidų?

Už dalyvavimą biomedicininiuose tyrimuose atlygis nėra mokamas. Dalyvaudami šiame tyrime negausite finansinės naudos.

18. Ar Jūsų vaiko asmens duomenys bus konfidencialūs?

Biomedicininį tyrimą atliekant gauta sveikatos informacija, leidžianti nustatyti asmens tapatybę, yra konfidenciali ir gali būti teikiama tik Bendrojo duomenų apsaugos reglamento, Lietuvos Respublikos pacientų teisių ir žalos sveikatai atlyginimo įstatymo ir kitų teisės aktų, reglamentuojančių asmens duomenų tvarkymą, nustatyta tvarka.

Duomenų valdytojas yra Lietuvos Sveikatos Mokslų Universitetas, A. Mickevičiaus g. 9, LT 44307 Kaunas. Įmonės kodas 302536989

Siekiant apsaugoti duomenų konfidencialumą, Jūsų vaikui bus suteiktas specialus kodas, kuris bus nurodomas visuose dokumentuose, išskyrus sutikimo formą. Sąrašą, kuriame Jūsų vaiko vardas ir pavardė susiejami su kodu, saugos pagrindinis tyrėjas seife, į kurį prieigą turi tik jis ir įgaliotas tyrėjas. Kompiuteriai, kuriuose saugomi elektroniniai tyrimo dokumentai ir duomenys, apsaugoti slaptažodžiu. Prisijungimo kodus žino tik tyrėjai, šie duomenys atnaujinami kas mėnesį.

Jei sutiksite, kad Jūsų vaikas dalyvautų šiame tyrime, gydytojas tyrėjas ir tyrimo darbuotojai naudos tyrimui atlikti reikalingus Jūsų vaiko asmeninius duomenis: vardą, pavardę, gimimo datą, ūgį, svorį, KMI, informaciją apie traumos mechanizmą, traumos datą, buvusias kelio sąnario traumas, operacijos ir transplantato tipą, jo diametrą, papildomus pažeidimus. Duomenys bus renkami remiantis Jūsų ir

Jūsų vaiko pateikta informacija, šioje bei kitose gydymo įstaigose saugomais medicininiais dokumentais, taip pat valstybės registruose ir pan. esančia informacija.

Pagrindinis tyrėjas ir tyrėjai taip pat peržiūrės Jūsų vaiko medicinos dokumentus (ligos istoriją/ambulatorinę kortelę). Visa surinkta informacija bus saugoma konfidencialiai.

Atliekant šį tyrimą gauta sveikatos informacija nelaikoma konfidencialia ir gali būti paskelbta be Jūsų sutikimo, jeigu ją paskelbus nebus galima tiesiogiai ar netiesiogiai nustatyti Jūsų vaiko tapatybės.

19. Kas ir kokiu tikslu galės susipažinti su Jūsų vaiko asmens duomenimis?

Tyrimo metu mes tvarkysime Jūsų vaiko asmens duomenis, kad galėtume įvertinti operacijos ir transplantato pranašumą prieš kito tipo operaciją ir transplantato tipą. Tyrimo užsakovas turi tvarkyti Jūsų vaiko asmens duomenis mokslinio tyrimo tikslais.

Jūsų sutikimas yra jūsų vaiko asmens duomenų tvarkymo teisinė sąlyga. Jūs galite atšaukti šį sutikimą rinkti ir tvarkyti jūsų vaiko duomenis bet kuriuo metu nenurodydami priežasčių. Po atšaukimo jūsų vaiko duomenys nebus renkami. Tačiau iki sutikimo atšaukimo surinkti duomenys bus toliau tvarkomi šio biomedicininio tyrimo tikslais.

Šio biomedicininio tyrimo metu bus renkami ir tvarkomi Jūsų vaiko asmens duomenys, įskaitant duomenis apie sveikatą. Asmens duomenys gali būti skirtingų tipų:

1) identifikuojami asmens duomenys, tai yra iš pateiktos informacijos bus galima tiesiogiai identifikuoti asmenį (pvz., Jūsų vardas, gimimo data, adresas, socialinio draudimo numeris, nuotraukos ir pan.)

2) asmens duomenys, kuriems suteikti pseudonimai (užkoduoti duomenys), tai yra informacija, leidžianti tiesiogiai identifikuoti asmenį, bus pakeista kodu (pvz., numeriu) arba užblokuota (pvz., vaizdo įrašymo atveju), tačiau identifikavimas yra įmanomas.

3) anoniminiai duomenys, tai yra iš pateiktos informacijos asmens nebegalima identifikuoti.

Pasirašydami šią formą sutinkate, kad tyrėjai, tyrimus kontroliuojančios institucijos (tokios kaip Valstybinė vaistų kontrolės tarnyba, etikos komitetai) ir įgalioti tyrimo užsakovo (Lietuvos Sveikatos Mokslų Universiteto) tyrimą prižiūrintys asmenys galės susipažinti su visa šio tyrimo tikslais apie Jūsų vaiką surinkta informacija.

Prieigą prie identifikuojamų asmens duomenų turės tik tyrėjai ir kiti asmenys, kurie dirba tyrimo centre ar teikia jums sveikatos priežiūros paslaugas. Taip pat šiuos duomenis gali patikrinti užsakovo (Lietuvos Sveikatos Mokslų Universiteto) įgalioti atstovai ir Lietuvos ir (arba) užsienio šalių kompetentingų institucijų bei Lietuvos atsakingų tyrimų etikos komitetų atstovai, jei tai būtina vykdant atliekamo biomedicininio tyrimo priežiūrą. Visi asmenys, turintys prieigą prie šių duomenų, privalo laikytis konfidencialumo pagal nacionalinius duomenų apsaugos teisės aktus ir Bendrąjį duomenų apsaugos reglamentą.

Kitiems asmenims ar įmonėms bus teikiami tik užkoduoti sveikatos duomenys, neleidžiantys tiesiogiai nustatyti Jūsų vaiko tapatybės. „Užkoduoti“ reiškia, kad dokumentuose bus nurodomas ne Jūsų vaiko vardas ir pavardė, o specialus numeris, kurį susieti su Jūsų vaiku galės tik gydytojas tyrėjas. Kodų sąrašas visada bus saugomas tyrimo centre (ligoninėje), todėl asmenys, kurie nežinos kodo, negalės atpažinti Jūsų vaiko.

Jūs turite teisę sužinoti, kokie duomenys buvo surinkti, taip pat galite reikalauti ištaisyti neteisingus, neišsamius, netikslius savo vaiko asmens duomenis. Jei nuspręsite pasitraukti iš tyrimo anksčiau numatyto laiko, tyrėjai apie Jūsų vaiką neberinks naujos informacijos, bet negalės sunaikinti iki tol surinktų duomenų.

20. Kiek laiko bus saugomi tyrimo metu surinkti duomenys ir kas už tai bus atsakingas?

Visa informacija bus užrašoma specialiai biomedicininiam tyrimui sudaromuose elektroniniuose ir tyrimo centre saugoma 5 metus pasibaigus tyrimui. Tiek laiko saugomi duomenis užsakovo nustatyta tvarka siekiant užtikrinti duomenų kokybę ir kontrolę. Vėliau Jūsų vaiko asmens duomenys bus sunaikinti tyrimo centro nustatyta tvarka. Už dokumentų saugojimą tyrimo centre bus atsakingas pagrindinis tyrėjas.

21. Kas įvertino šį biomedicininį tyrimą? / Į ką kreiptis, jeigu iškiltų klausimų?

Dėl savo kaip tyrimo dalyvio teisių galite kreiptis į leidimą atlikti šį biomedicininį tyrimą išdavusį Kauno regioninį biomedicininių tyrimų etikos komitetą, Lietuvos sveikatos mokslų universitetas, Mickevičiaus g. 9, LT-44307, Kaunas, tel. (8-37) 326889, el. paštas: kaunorbtek@lsmuni.lt.

Jeigu turite klausimų dėl Jūsų vaiko asmens duomenų tvarkymo, kreipkitės į tyrėją prof. Emilį Čekanauską Tel. +37037327080, El. p. emilis.cekanauskas@kaunoklinikos.lt. Tyrėjas Jūsų paklausimą gali perduoti asmeniui, atsakingam už asmens duomenų apsaugą (duomenų apsaugos pareigūnui).

Šį biomedicininį tyrimą atliekančių institucijų duomenų apsaugos pareigūnų kontaktai:

Tyrimo centro duomenų apsaugos pareigūnas: Tomas Kuzmarskas, telefono ryšio numeris: +37037326268, el. pašto adresas:tomas.kuzmarskas@kaunoklinikos.lt, darbo vietos adresas: Eivenių g. 2, Kaunas.“

Tyrimo užsakovo duomenų apsaugos pareigūnas: Jūratė Karpavičienė, telefono ryšio numeris: +37037260122, el. pašto adresas: jurate.karpaviciene@lsmu.lt, darbo vietos adresas: A. Mickevičiaus g. 7, Kaunas.

Jūs turite teisę pateikti skundą dėl asmens duomenų tvarkymo Valstybinei duomenų apsaugos inspekcijai. Skundą galite pateikti paštu (adresu: L. Sapiegos g. 17, 10312 Vilnius) arba naudodamiesi Valstybinės duomenų apsaugos inspekcijos elektroninių paslaugų sistema: /go.php/lit/Prisijungti/37L. Valstybinės duomenų apsaugos inspekcijos kontaktinis telefono numeris (8-5) 212 7532, el. paštas: ada@ada.lt.

SUTIKIMAS DALYVAUTI BIOMEDICININIAME / KLINIKINIAME VAISTINIO PREPARATO TYRIME

Aš perskaičiau šią Informuoto asmens sutikimo formą ir supratau man pateiktą informaciją.
Man buvo suteikta galimybė užduoti klausimus ir gavau mane tenkinančius atsakymus.
Supratau, kad galiu bet kada pasitraukti iš tyrimo, nenurodydama(s) priežasčių[2].
Supratau, kad asmuo, dėl kurio dalyvavimo biomediciniame tyrime aš duodu sutikimą, gali bet kada pasitraukti iš tyrimo, nenurodydamas priežasčių.[3]
Supratau, kad norėdama(s) atšaukti sutikimą dalyvauti biomedicininiame tyrime, raštu turiu apie tai informuoti tyrėją/kitą jo įgaliotą biomedicininį tyrimą atliekantį asmenį.
Patvirtinu, kad turėjau užtektinai laiko apsvarstyti man suteiktą informaciją apie biomedicininį tyrimą.
Supratau, kad dalyvavimas šiame tyrime yra savanoriškas.
Patvirtinu, kad sutikimą dalyvauti šiame biomedicininiame tyrime duodu laisva valia.
Leidžiu naudoti asmens duomenis ta apimtimi ir būdu, kaip nurodyta Informuoto asmens sutikimo formoje.
Patvirtinu, kad gavau Informuoto asmens sutikimo formos egzempliorių, pasirašytą tyrėjo/ kito jo įgalioto biomedicininį tyrimą atliekančio asmens.

Mama/tėtis (teisinis globėjas ar kitas sutikimą turintis teisę duoti asmuo)

				MMMM-mm-dd	_:_
vardas	pavardė	atstovavimo pagrindas	parašas	pasirašymo data	pasirašymo laikas

Mama/tėtis (teisinis globėjas ar kitas sutikimą turintis teisę duoti asmuo)

				MMMM-mm-dd	_:_
vardas	pavardė	atstovavimo pagrindas	parašas	pasirašymo data	pasirašymo laikas

Patvirtinu, kad suteikiau informaciją apie biomedicininį tyrimą aukščiau nurodytam asmeniui.
Patvirtinu, kad asmeniui (ar kitam sutikimą duoti turinčiam teisę asmeniui) buvo skirta pakankamai laiko apsispręsti dalyvauti biomedicininiame tyrime, atsižvelgiant į biomedicininio tyrimo pobūdį, taip pat įvertinus kitas aplinkybes, galinčias daryti įtaką priimamam sprendimui.
Aš skatinau asmenį (ar kitą sutikimą turintį teisę duoti asmenį) užduoti klausimus ir į juos atsakiau.

Tyrėjas ar kitas jo įgaliotą biomedicininį tyrimą atliekantis asmuo

				MMMM-mm-dd	_:_
vardas	pavardė	pareigos tyrime	parašas	pasirašymo data	pasirašymo laikas

[2] Jei sutikimą dalyvauti tyrime duoda pats asmuo
[3] Jei sutikimą dalyvauti tyrime duoda kitas asmuo

Appendix Figure 6. *2000 IKDC Subjective Knee Evaluation Form (in Lithuanian)*

IKDC 2000 **SUBJEKTYVUS** kelio sąnario ištyrimas

E ( ) **V1** ( ) Gn ( ) **V2** ( ) Gn ( ) **V3** ( ) Gn ( )

PACIENTAS ______________________________ **Data** ____________ **Ø:**

Numeris ____________ Gimimo data: ____________ **Traumos data** ____________

Ūgis: ________ **Svoris**: ________ **Pusė**: K / D **Kontaktas**: T / N.

Op: ____________
V2: ____________
V3: ____________

SIMPTOMAI:

*Įvertinkite galimybes: kokią sunkiausią veiklą, Jūsų nuomone, galėtumėte atlikti, kurios metu nejaustumėte žymesnių nurodytų simptomų net ir tuo atveju, jei neužsiimate tokio pobūdžio veikla.

1. **Kokiu krūviu galite aktyviai judėti nejausdami skausmo kelio sąnaryje?**

$_5$☐ Labai sunki veikla, tokia kaip šokinėjimas ar sukimasis tarsi žaidžiant krepšinį ar futbolą

$_4$☐ Sunki veikla, tokia kaip sunkus fizinis darbas, slidinėjimas ar tenisas

$_3$☐ Vidutinio sunkumo veikla, tokia kaip vidutinis fizinis darbas, bėgiojimas ar bėgimas ristele

$_2$☐ Lengva veikla, tokia kaip ėjimas, namų ruošos ar kiemo darbai

$_1$☐ Neįmanoma atlikti aukščiau išvardytų veiksmų, nes pradeda skaudėti

2. **Ar dažnai jautėte kelio sąnario skausmą per paskutines 4 savaites ar po to, kai patyrėte traumą?**

	0	1	2	3	4	5	6	7	8	9	10	
Niekada	☐$_{11}$	☐$_{10}$	☐$_9$	☐$_8$	☐$_7$	☐$_6$	☐$_5$	☐$_4$	☐$_3$	☐$_2$	☐$_1$	Nuolatos

3. **Įvertinkite kelio sąnario skausmo stiprumą:**

Jokio	0	1	2	3	4	5	6	7	8	9	10	Stipriausias nepakeliamas
skausmo	☐$_{11}$	☐$_{10}$	☐$_9$	☐$_8$	☐$_7$	☐$_6$	☐$_5$	☐$_4$	☐$_3$	☐$_2$	☐$_1$	skausmas

4. **Ar buvo patinęs arba sustingęs kelio sąnarys per paskutines 4 savaites ar po to, kai patyrėte traumą?**

$_5$☐ Visai nebuvo

$_4$☐ Nežymiai

$_3$☐ Vidutiniškai

$_2$☐ Stipriai

$_1$☐ Labai stipriai

5. **Kiek galite aktyviai judėti nesutinus kelio sąnariui?**

$_5$☐ Labai sunki veikla, tokia kaip šokinėjimas ar sukimasis tarsi žaidžiant krepšinį ar futbolą

$_4$☐ Sunki veikla, tokia kaip sunkus fizinis darbas, slidinėjimas ar tenisas

$_3$☐ Vidutinio sunkumo veikla, tokia kaip vidutinis fizinis darbas, bėgiojimas ar bėgimas ristele

$_2$☐ Lengva veikla, tokia kaip ėjimas, namų ruošos ar kiemo darbai

$_1$☐ Neįmanoma atlikti aukščiau išvardytų veiksmų, nes kelio sąnarys sutinsta

6. **Ar buvo "užstrigęs" kelio sąnarys per paskutines 4 savaites ar po to, kai patyrėte traumą?**

$_1$☐ Taip $_2$☐ Ne

7. **Ar, aktyviai judant, kelio sąnarys stabilus? Kokia veikla galite užsiimti be žymios stabilumo stokos?**

$_5$☐ Labai sunki veikla, tokia kaip šokinėjimas ar sukimasis tarsi žaidžiant krepšinį ar futbolą

$_4$☐ Sunki veikla, tokia kaip sunkus fizinis darbas, slidinėjimas ar tenisas

$_3$☐ Vidutinio sunkumo veikla, tokia kaip vidutinis fizinis darbas, bėgiojimas ar bėgimas ristele

$_2$☐ Lengva veikla, tokia kaip ėjimas, namų ruošos ar kiemo darbai

$_1$☐ Neįmanoma atlikti aukščiau išvardytų veiksmų, nes sąnarys yra nestabilus

SPORTINĖ VEIKLA:

8. Kokią aukščiausią aktyvumo veiklą galit atlikti?

5☐ Labai sunki veikla, tokia kaip šokinėjimas ar sukimasis tarsi žaidžiant krepšinį ar futbolą

4☐ Sunki veikla, tokia kaip sunkus fizinis darbas, slidinėjimas ar tenisas

3☐ Vidutinio sunkumo veikla, tokia kaip vidutinis fizinis darbas, bėgiojimas ar bėgimas ristele

2☐ Lengva veikla, tokia kaip ėjimas, namų ruošos ar kiemo darbai

1☐ Neįmanoma atlikti aukščiau išvardytų veiksmų dėl kelio sąnario pažeidimo

9. Ar iškyla sunkumų:

		Visai nesunku	Minimaliai sunku	Vidutiniškai sunku	Labai sunku	Neįmanoma atlikti
a.	Lipti laiptais aukštyn	5☐	4☐	3☐	2☐	1☐
b.	Lipti laiptais žemyn	5☐	4☐	3☐	2☐	1☐
c.	Atsiklaupti	5☐	4☐	3☐	2☐	1☐
d.	Atsitūpti	5☐	4☐	3☐	2☐	1☐
e.	Atsisėsti sulenkus kelius	5☐	4☐	3☐	2☐	1☐
f.	Atsistoti iš sėdimos pozicijos	5☐	4☐	3☐	2☐	1☐
g.	Bėgti tiesiai	5☐	4☐	3☐	2☐	1☐
h.	Pašokti ir nusileisti ant sužeistos kojos	5☐	4☐	3☐	2☐	1☐
i.	Sustoti ir vėl greitai pradėti judėti	5☐	4☐	3☐	2☐	1☐

FUNKCIONAVIMAS

10. Kaip Jūs vertintumėte savo kelio sąnario funkciją 10 balų skalėje, kai 10 reiškia normalų arba labai gerą funkcionavimą, o 0 reiškia nesugebėjimą atlikti kasdienės veiklos, taip pat ir sportinės veiklos?

Kelio sąnario funkcija prieš trauma:

	0	1	2	3	4	5	6	7	8	9	10	
Negalima atlikti jokių įprastinių judesių	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Be apribojimų

Dabartinė kelio sąnario funkcija:

	0	1	2	3	4	5	6	7	8	9	10	
Negalima atlikti jokių įprastinių judesių	☐1	☐2	☐3	☐4	☐5	☐6	☐7	☐8	☐9	☐10	☐11	Be apribojimų

IKDC vertė _______________

Appendix Figure 7. *Lysholm Knee Scoring Scale and Tegner Activity Scale (in Lithuanian)*

Pacientas ____ Data ___________________________

Numeris _____________ Gimimo data: _______________ Traumos data ___________________

Lysholm skalė

Per paskutines 4 savaites:

Šlubavimas ☐ nėra (5) ☐ mažas ar periodiškas (3) ☐ stiprus ir dažnas (0)	**Pagalba einant** ☐ nereikia (5) ☐ lazdelė ar ramentas (2) ☐ ėjimas neįmanomas (0)
Skausmas ☐ nėra (25) ☐ nežymus, didesnis atliekant tiesimą (20) ☐ žymus, dažnas, atliekant tiesimą (15) ☐ žymus, pavaikščiojus >2km (10) ☐ žymus, pavaikščiojus <2km (5) ☐ pastovus (0)	**Nestabilumas** ☐ niekada nevargina (25) ☐ retas, sportuojant ar atliekant tiesimą (20) ☐ dažnas sportuojant ar atliekant tiesimą (15) ☐ pasitaikantis atliekant kasdieninę veiklą (10) ☐ dažnas atliekant kasdieninę veiklą (5) ☐ kiekviename žingsnyje (0)
Užsikirtimas ☐ neužsikerta, nėra viduje esančio trukdžio jausmo (15) ☐ viduje esančio trukdymo jausmas, bet neužsikerta (10) ☐ užsikerta kartais (6) ☐ užsikerta dažnai (2) ☐ užsikirtęs kelio sąnarys tyrimo metu (0)	**Tinimas** ☐ nėra (10) ☐ po aktyvaus judėjimo (6) ☐ po kasdieninio judėjimo (2) ☐ pastovus (0)
Lipimas laiptais ☐ problemų nėra (10) ☐ šiek tiek sutrikę (6) ☐ lipimas po laiptuką (2) ☐ neįmanomas (0)	**Pritūpimai** ☐ be problemų (5) ☐ šiek tiek sutrikę (4) ☐ ne mažiau 90 laipsnių (2) ☐ neįmanoma (0)
Bendras įvertinimas _______ / 100	

Tegner aktyvumo skalė

Apibraukite:

10. Varžybų sportas aukščiausias lygis (futbolas nacionalinėje ar tarptautinėje lygoje)	**5. Darbas ir sportas** Sunkus fizinis darbas (statybos, miško darbai) Varžybų sportas (dviračiai, lygumų slidinėjimas) Mėgėjiškas sportas (bėgiojimas, **bent 2 kartai per savaitę**)
9. Varžybų sportas (futbolas žemesnis lygis, ledo rutulys, slidinėjimas, gimnastika, krepšinis)	**4. Vidutiniškai sunkus darbas** (šaltkalvis, vairuotojas)
8. Varžybų sportas (badmintonas, lengvoji atletika, slidinėjimas, šuoliai)	**3. Lengvas darbas** (slaugymas) Mėgėjiškas sportas (plaukimas, ėjimas)
7. Varžybų sportas (tenisas, nuotolių bėgimas, lenktynės, rankinis, motokrosas) **Megėjiškas sportas** (futbolas, rankinis, ledo rutulys, lengvoji atletika)	**2. Lengvas darbas** (lengvas darbas, ėjimas nelygiu paviršiumi)
6. Mėgėjiškas sportas (tenisas, badmintonas, rankinis, slidinėjimas, **bent 5 kartus per savaitę**)	**1/0. Sėdimas darbas** (ėjimas lygiu paviršiumi) Nejudrumas

Appendix Figure 8. *ACL-RSI (ACL-Return to Sport After Injury) scale (in Lithuanian)*

Vardas: ______________________________ *Gimimo data:*____________________________

*Pavardė:*______________________________ *Šios dienos data:*__________________________

PKR-GST (Priekinis kryžminis raištis - grįžimas į sportą po traumos) klausimynas

1. Ar esate įsitikinęs, kad galite dalyvauti sporte, išlaikydamas ankstesnį lygį?

Visiškai neįsitikinęs 0 1 2 3 4 5 6 7 8 9 10 Visiškai įsitikinęs

2. Ar manote, kad sportuodami galite vėl susižeisti kelio sąnarį?

Tikrai taip 0 1 2 3 4 5 6 7 8 9 10 Tikrai ne

3. Ar Jūs nervinatės dėl galimybės sportuoti?

Labai nervinuosi 0 1 2 3 4 5 6 7 8 9 10 Visiškai nesinervinu

4. Ar pasitikite, kad Jūsų kelio sąnario veikla nesutriks sportuojant?

Visiškai nepasitikiu 0 1 2 3 4 5 6 7 8 9 10 Visiškai pasitikiu

5. Ar esate užtikrintas, kad galite sportuoti, nesirūpindami dėl kelio sąnario?

Visiškai neužtikrintas 0 1 2 3 4 5 6 7 8 9 10 Visiškai užtikrintas

6. Ar Jus trikdo tai, kad turite galvoti apie savo kelio sąnarį sportuojant?

Labai trikdo 0 1 2 3 4 5 6 7 8 9 10 Visiškai netrikdo

7. Ar bijote iš naujo susižeisti kelio sąnarį sportuodami?

Labai bijau	0	1	2	3	4	5	6	7	8	9	10	Visiškai nebijau

8. Ar esate įsitikinęs, kad kelio sąnarys atlaikys apkrovas?

Visiškai neįsitikinęs	0	1	2	3	4	5	6	7	8	9	10	Visiškai įsitikinęs

9. Ar bijote sportuojant atsitiktinai susižeisti kelio sąnarį?

Labai bijau	0	1	2	3	4	5	6	7	8	9	10	Visiškai nebijau

10. Ar mintys apie pakartotinę operaciją ir reabilitaciją stabdo Jus nuo sporto?

Tikrai taip	0	1	2	3	4	5	6	7	8	9	10	Tikrai ne

11. Ar pasitikite savo gebėjimu gerai vykdyti savo sporto veiklą?

Visiškai nepasitikiu	0	1	2	3	4	5	6	7	8	9	10	Visiškai pasitikiu

12. Ar sportuojant jaučiatės atsipalaidavęs(-usi)?

Tikrai ne	0	1	2	3	4	5	6	7	8	9	10	Tikrai taip

PKR-GST galutinis balas (balų suma x 100)/120 = __________%

CURRICULUM VITAE

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2015–2020	Professional Qualification as an Orthopaedic Traumatologist (Medical Doctor), Lithuanian University of Health Sciences
2009–2015	Master's degree in Medicine and Qualification as a Medical Doctor, Lithuanian University of Health Sciences

Work experience:

2015–2020	Resident in the Clinic of Orthopaedics and Traumatology, Hospital of Lithuanian University of Health Sciences, Kaunas Clinics
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Courses and internships:

2022	Internship: *ORTHOFIX Reconstructive Surgery Observership*, Pretoria, Republic of South Africa, 26–30 September 2022
2022	Practical Cadaver Course: *Smith & Nephew SNACE "Save the Meniscus"*, Athens, Greece, 27–28 June 2022
2018	Practical Cadaver Course: *First Course With Anatomical Specimens – Surgical Approaches to Lower Limb*, Barcelona, Spain, 13–14 September 2018

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Lithuanian Association of Orthopaedic Traumatologists (LTOD)
Lithuanian Arthroscopy and Sports Traumatology Association (LASTA)

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PADĖKA

Nuoširdžiai dėkoju mokslinio darbo pradžios vadovui prof. dr. Vidmantui Barauskui už suteiktą galimybę, palaikymą ir supratingumą.

Pagrindiniam mokslinio darbo vadovui prof. dr. Emiliui Čekanauskui už tikėjimą manimi ne tik mokslinėje srityje. Už supažindinimą su vaikų ortopedija ir traumatologija dar medicinos studijų metu ir visapusį įtraukimą į šią sritį, kuri šiuo metu yra mano mylimas darbas bei užima reikšmingą dalį mano gyvenimo. Taip pat už griežtą žodį, kai jo reikėdavo, už padrąsinimus ir pagalbą, kai buvo sunku, už džiaugsmą kartu, kai sekdavosi.

Esu labai dėkingas prof. dr. Laimonui Šiupšinskui, kurio tiesioginis darbas testuojant pacientų kelio sąnarių stabilumą buvo esminis šio tyrimo eigoje. Dėkoju už idėjas, patarimus mokslinėje ir praktinėje veikloje, nuoširdų dalinimąsi žiniomis sporto medicinos srityje.

Privalau paminėti, jog Laimonas supažindino mane su prof. dr. Vytautu Streckiu. Ši pažintis lėmė kur kas paprastesnį ir sklandesnį raumenų jėgos testavimą tyrimo pacientams. Dėka prof. dr. Vytauto Streckio noro padėti, jo profesionalumo ir prisitaikymo prie tiriamųjų dienotvarkės ši tyrimo dalis tapo įmanoma.

Dėkoju Vaikų chirurgijos skyriaus operacinės slaugytojoms, kurios turėjo kantrybės su mano nuolat kintančiomis operacijomis ir padėjo man jas atlikti.

Nuoširdi padėka Justinai, Justei, Jūratei ir Laurynui. Jūsų pagalbą sunku išmatuoti: nuo duomenų bazės rengimo, statistikos subtilybių, iki sudėtingiausių rašto darbų.

Savo nuostabiai ir mylinčiai šeimai: žmonai Vaidai, sūnums Taurui ir Ryčiui. Mamai ir sesėms. Mane matėte ir priėmėte visokį. Jūsų palaikymą jaučiau nuolat. Ačiū ir myliu Jus.