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Myofascial and balance tests after anterior cruciate ligament reconstruction in adolescent patients

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Abstract

Study aim: The functional assessment of patients after anterior cruciate ligament reconstruction (ACLR) is one of the key points in deciding whether one can safely return to physical activity. The aim of this study is to investigate the usefulness of the NEURAC® tests and single leg balance test (SLBT) in the functional evaluation of adolescent patients after ACLR to detect differences between the operated and non-operated extremity.

Material and methods: A total of 31 physically active, adolescent patients (mean age: 15.7 ± 1.4 years) who underwent primary single-bundle ACLR using the autogenous semitendinosus-gracilis tendon graft were evaluated using the NEURAC® and SLBT tests (mean time from surgery to examination was 6.6 ± 1.0 months). All patients were operated on by the same surgeon, and postoperative physiotherapy was carried out using a standardized protocol.

Results: Only one of the NEURAC® tests showed significant differences between the operated and non-operated extremities: prone bridging (3.58º vs. 3.97º, $P = 0.01$). Several weak and moderate, significant correlations between NEURAC® and SLBT tests were observed in the operated (r from –0.42 to 0.37) and non-operated (r from –0.37 to –0.43) extremities

Conclusions: The NEURAC® tests in comparison to SLBT seems to be more effective for detecting functional differences between the operated and non-operated extremity in adolescent patients about 6 months post-ACLR. Correlations between the outcomes of the NEURAC® tests and SLBT are not clear.

Keywords: Anterior cruciate ligament reconstruction – Returning to sport – Physical functional performance – NEURAC® myofascial tests – Biodex Balance System

Introduction

The anterior cruciate ligament (ACL) plays an important role in knee joint stabilization by limiting the anterior translation of the tibia in relation to the femur and by restraining rotational, varus and valgus forces at the knee [2]. Injury of the ACL occurs in approximately 50% of knee joint injuries and more than 70% of ACL injuries are sport-related [14, 25]. Athletes who participate in disciplines related to sudden changes in the direction of movement, jumps and landing, such as football, handball, basketball, volleyball rugby and skiing [2, 21, 28, 48, 51] are at risk. Isolated tears of ACL account for occur in 24% of football players, 15% of handball players and 13% of skiers [48].

Approximately 60% of all ACL injuries are caused by the non-contact mechanism [28, 40]. The incidence of a non-contact ACL tear is greater among pivoting sports athletes between 15 and 40 years of age [5, 33, 44]. In amateurs, 3% suffer from ACL injury every year, while in elite athletes this rate is close to 15% [34]. Females damage their ACL 2 to 8 times more frequently than males [33, 35].

The purpose of anterior cruciate ligament reconstruction (ACLR) is to restore the ligament structure, which is associated with improving the passive stability of the knee joint and increasing its functional capabilities. The whole process aims to create optimal conditions for a safe return to physical activity. The ultimate goal of both the patient and the medical staff is to restore the pre-injury sports level [10, 50]. However, the final success of the

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treatment is influenced by many factors, from the choice of graft type and the method of its fixation, to the process of postoperative physiotherapy and patient education [51]. As far as these two issues are concerned the range of approaches is, however, somewhat broad [13, 17, 29, 37, 46]. Even after returning to sport activity, there is still a risk of injury to both the reconstructed ACL and the ACL in the healthy extremity. The incidence of ACL re-rupture is 5–11% and 8–21% for the ligament in the contralateral extremity [42, 43, 49].

Criteria for returning to unrestricted returning sports after ACLR are constantly being discussed in the literature [2, 12, 32, 36], however, no consensus exists as to the time interval from surgery to sport readiness, the most efficient rehabilitation programme, or a standardised diagnostic protocol that will allow safe return to pre-operative training loads and reduce the risk of subsequent injuries. Many authors underline that functional evaluation after ACLR should be based on objective criteria [5, 6, 18, 33] and some authors [6, 30, 47] emphasise the value of functional tests aiming to evaluate factors such as muscle strength, joint stability, neuromuscular control and the overall function of the lower extremity as crucial when deciding about the return to sport after ACLR. It is wildly known that side-to-side asymmetries are common in the human musculoskeletal system in a different body regions and in different types of population [1, 8, 16, 20, 22, 24, 39], but from therapeutic perspective the important feature that characterises patients after ACLR is the value of the side-to-side difference as well as motor control deficits in the lower extremity and the core region [11, 32, 35]. Those differences are observed between operated and non-operated extremities during functional activities in comparison to healthy people [11, 53], for example regarding jumping [19, 38], squatting [15], lateral step-down manoeuvre [19], stair climbing [15] and single-leg hopping or jumping [19, 38, 42].

Taking all this into consideration, in order to reliably decide about safer return to sports activity after ACLR, larger amount of valid functional test is needed. It is also desirable so these tests would show side-to side differences between the operated and non-operated extremities. The NEURAC® approach is based on myofascial side-to-side sling tests and exercises and might be use as well as screening tool as functional training platform for the athletes [31] or patients presenting various movement disabilities [26, 27, 41, 54]. Biały et al. demonstrated certain superiority of the NEURAC® myofascial chains tests over the Functional Movement Score (FMS™) battery of tests in detecting side-to-side asymmetries in adult patients after ACLR. He concluded that the exclusive utilization of the FMS™ tests in the early phase of the recovery can potentially lead to overestimation of the subjects' functional performance and might expose them to excessive loads during treatment. This was not the case for the NEURAC® tests. The report was the first information on the use of NEURAC® tests in the ACLR population with a promising results [9].

In this study we try to push this matter a bit forward and provide further information on utilization of NEURAC® tests in functional diagnostics after ACLR, utilization of single leg balance test (SLBT) after ACLR in adolescent patients as well as establish correlations between the NEURAC® and SLBT. We consider the NEURAC® and SLBT simple, functional tests aiming to evaluate the overall neuromuscular control (whole body balance) and demonstrating side-to-side asymmetries. This justifies its usefulness for ACLR patients. Our final goal is to broaden the battery of functional tests which might help in safe return to sports activity after ACLR. We try to achieve this by comparing the operated and non-operated lower extremities in the target group.

Material and methods

Participants

The study included 31 physically active, adolescent patients (female: 16, mean age: 15.7 ± 1.4 years, ACLR in dominant (N = 19) and non-dominant (N = 12) extremity) who underwent primary single-bundle ACLR using the autogenous semitendinosus-gracilis tendon graft. Patients included in the study met the inclusion criteria, i.e.: no history of previous ACLR, no additional extra – or intra-articular repairs (e.g. posterior lateral complex reconstruction, menisci repair). The ACLR was performed by one and the same surgeon with 20 years of experience in ACLR. The mean time from surgery to examination was 6.6 ± 1.0 months. All enrolled adolescent patients participated in recreational sports. The primary sport activity at the time of the ACL injury was: skiing (32.3%), soccer (25.8%), volleyball (12.9%), martial arts (9.7%), basketball (9.7%), cycling (3.2%), handball (3.2%) and running (3.2%). Patients did not attend any preoperative rehabilitation. Postoperative rehabilitation was carried out using a similar standardised rehabilitation protocol, based on that described by Wilk et al. [52], and supervised by a physiotherapist who was not related to this study. In every postoperative phase each patient received similar guidelines according to knee range of motion: oedema management, muscle strength training and proprioception drills as well as an exercise progression. Patients attended rehabilitation twice a week up to 3 months and once a week between 3-6 months post-ACLR. The demographic characteristics of the study participants are presented in Table 1. The research was approved by the local Research Ethical Committee (No. 3/2017).

Table 1. Demographic characteristics of the study participants

Study group (N = 31)	
Male/female ratio	15:16
Age [years][a]	15.7 ± 1.4
Height [m][a]	171.0 ± 8.5
Body mass [kg][a]	62.7 ± 8.4
Time interval from ACL surgery to assessment [months][a]	6.6 ± 1.0
ACLR right/left extremity ratio	16:15
ACLR dominant/nondominant extremity ratio	19:12
Sport/activity at the time of injury[b]	
Skiing	10 (32.3%)
Soccer	8 (25.8%)
Volleyball	4 (12.9%)
Martial arts	3 (9.7%)
Basketball	3 (9.7%)
Cycling	1 (3.2%)
Handball	1 (3.2%)
Running	1 (3.2%)

[a] Mean ± standard deviation, [b] number of participants (% of the group).

Measures

On the day of measurement, all participants were asked about their well-being, health condition and the presence of any pain, especially within the musculoskeletal system. Patients were free to terminate the tests in case of any pain occurrence at any stage of the examination. The measurements were preceded by the 10-minute warm-up on the cycle ergometer, during which the entire test procedure was explained to the participant. They were carried out by one physiotherapist with 10+ years of experience in orthopaedic physiotherapy.

First, the SLBT was performed using the Biodex Balance System (Biodex Medical Systems, Shirley, New York, USA) which detects the postural sway. Each subject was examined in static (platform locked in a horizontal position) and dynamic (platform tilts up to a maximum 20 degrees from horizontal position in all directions) conditions. Dynamic measurement can be performed from the most difficult (least stable) setting (level 1) to the easiest (most stable) setting (level 12). In frames of the study it was performed at level 4. The SLBT returns three types of output measures: anterior/posterior stability index (APSI), medial/lateral stability index (MLSI) and overall stability indices (OSI), which is a composite of the APSI and MLSI. These indices are in fact the standard deviations of the angle of inclination of the platform in relation to horizontal. In case of the dynamic test they depict the true inclination of the platform. In case of static test – the device first calculates the projection of the subject's centre of mass on the platform and subsequently determines the supposed angle of platform inclination related to the given position of the centre of mass projection. Therefore, results are given in angular degrees. Standard deviations are regarded a better descriptor of the postural sway (in comparison with mean values) since they offer a sense of variability of the sway, not only its mean magnitude. Therefore, low values of the mentioned indices indicate low variability of the sway, which is not the case when mean values are in use, i.e. low mean value may be obtained together with a large standard deviation (the sway is in fact large). The calculation formula for the OSI, APSI and MLSI was described previously [3, 4]. The patient assumed the single-leg standing position on the circular platform of the device with the contralateral extremity flexed to 90° at the knee joint (Figure 1) and tried to maintain this position for 10 seconds. The static and dynamic SLBT tests consisted of one measurement containing three 10-second trials without visual feedback. First, the non-operated extremity was examined, then the operated extremity was tested. The reliability of the measurements was assessed previously. The intraclass correlation coefficient ($ICC_{3.3}$) of stability indices for static measurements was 0.80–0.88 and $ICC_{3.5}$ for dynamic measurements was 0.65–0.77 [3, 7].

In the next step of the procedure (after a 5 minute rest interval), four basic myofascial chain tests according to the NEURAC® concept were performed: supine pelvic lift (SPL), supine bridging (SB), prone bridging (PB) and side-lying hip abduction (SLHA) (Figure 2). Each of these myofascial tests has five standardized levels of difficulty. In order to pass the given level subjects had to independently assume and maintain the end position without any pain and misalignment of body segments. At each level, the quality of movement from the starting to the end position, the ability to maintain the end position for ± 3 seconds (one regular breathing cycle) and the quality of the return the starting position were assessed. Passing the level 3 was expected for a healthy, moderately fit person without any musculoskeletal problems. During the test the weight-bearing extremity was defined the tested extremity. At each testing level, the participant was asked to lift up the body to a straight position by pressing the lower extremity into the sling. Passing one level resulted in progression to the next level. When the patient performed the trial incorrectly, he received verbal feedback from the examiner. If the level was not passed again the test was terminated and the last completed level was considered the outcome. The non-operated extremity was examined first. Within NEURAC®, completing levels 1 or 2 only is considered as a presence of so called "weak link" (due to either biomechanical and/or neuromuscular dysfunction).

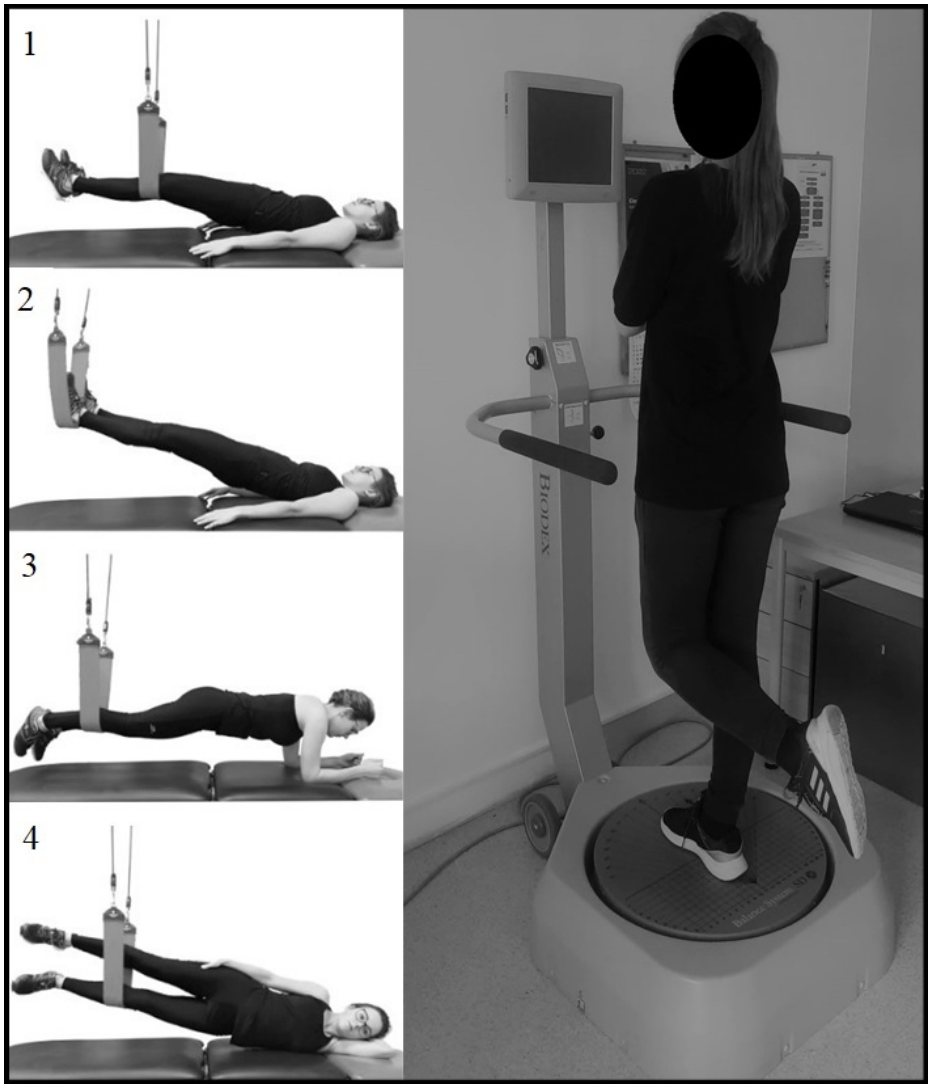


Figure 1. Left section: images of four NEURAC® myofascial chain tests (1–4: properly performed level 3; 1 – supine pelvic lift, 2 – supine bridging, 3 – prone bridging, 4 – side-lying hip abduction). The patient was asked to lift up to a straight body position by pressing the lower extremity into the sling. Right section: patient position during single leg balance test (SLBT), all measurements were taken without visual feedback

Side to side differences at level 3 or higher are considered neuromuscular imbalances [27]. The NEURAC® tests were performed according to the methodology described previously [9, 27].

Statistical analysis

The results of one measurement of the NEURAC® tests and one measurement consisting of the averaged results of three dynamic and static trials of the SLBT tests were analysed. Due to the fact, that the NEURAC® tests were scored in the ordinal scale and the outcomes of the SLBT tests showed significant deviations from the normal distribution (as assessed using the Shapiro-Wilk test) non-parametric statistics were employed. The Mann-Whitney U test was used to assess the inter-extremities differences and the r-Spearman correlation coefficient was used to assess correlations. The critical level of statistical significance was set at $P < 0.05$. The interpretation of the r-Spearman correlation coefficient was in accordance to Schober's et al. proposition: <0.1 negligible, 0.10–0.39 weak, 0.40–0.69 moderate, 0.70–0.89 strong, ≥0.90 very strong correlation [45]. The Statistica 13.3 software (TIBCO Software Inc., Palo Alto, USA) was used to compute all calculations.

Results

Statistical analysis of the NEURAC® test results showed significant differences between the operated and non-operated extremity for the PB test (3.58º vs. 3.97º, $P = 0.01$). No significant inter-extremity differences were

noted for the remaining NEURAC® as well as for SLBT tests (Table 2).

Several significant correlations between NEURAC® and SLBT tests were observed. In case of the operated extremity the following significant correlations were found: positive, weak correlations between the SB test and dynamic APSI (r = 0.37), sum of the NEURAC® tests and dynamic APSI (r = 0.36), negative, weak/moderate correlations between the SLHA test and static OSI (r = –0.39) and the SLHA test and static APSI (r = –0.42). For the non-operated extremity significant were: negative, weak/moderate correlations between the SB test and static APSI (r = –0.37), the SB test and static OSI (r = –0.37), the SLHA test and dynamic APSI (r = –0.38), the SPL test and static APSI (r = –0.43), sum of the NEURAC® tests and dynamic APSI (r = –0.42) (Table 3).

Table 2. Comparison of the results of the NEURAC® tests (in points) and the single leg balance test (in degrees) between the operated (O) and non-operated (NO) extremities. The values are presented as the mean ± standard deviation with the obtained *P* value

Test	O	NO	*P*
SPL	3.55 ± 0.57	3.42 ± 0.62	0.47
SB	3.58 ± 0.50	3.81 ± 0.40	0.13
PB	3.58 ± 0.62	3.97 ± 0.41	0.01*
SLHA	3.58 ± 0.67	3.52 ± 0.57	0.66
SUM	14.29 ± 1.60	14.71 ± 1.35	0.25
S APSI	2.83 ± 2.02	2.47 ± 1.23	0.98
S MLSI	1.86 ± 1.29	1.63 ± 1.20	0.43
S OSI	3.69 ± 1.95	3.17 ± 1.41	0.39
D APSI	1.86 ± 0.84	1.97 ± 1.21	0.73
D MLSI	1.48 ± 1.51	1.64 ± 1.45	0.39
D OSI	2.49 ± 1.54	2.83 ± 1.73	0.68

* – statistically significant, SPL – supine pelvic lift, SB – supine bridging, PB – prone bridging, SLHA – side-lying hip abduction, SUM – sum of the NEURAC® tests, S – static conditions, D – dynamic conditions, APSI – anteroposterior stability index, MLSI – mediolateral stability index, OSI – overall stability index.

Discussion

In this study our ultimate goal was to broaden the spectrum of functional tests which could be advantageously utilized in post-ACLR diagnostics. We tried to achieve this by assessing the SLBT as far as its discriminative properties between the operated and non-operated lower extremities are concerned as well as by determining its correlation with outcomes of NEURAC® tests, previously compared to the popular Functional Movement Screening™ tests [9].

Comparing current data with reported results [9] we can reveal certain similarities. Generally, the outcomes of NEURAC® tests fall within comparable ranges. Also, we again found out that the PB test from NEURAC® test battery was the only one that showed side-to-side differences.

Table 3. The r-Spearman correlations coefficients between the results of the NEURAC® tests (columns) and the single leg balance test (rows) tests for the operated and non-operated extremities separately

Test	S APSI	S MLSI	S OSI	D APSI	D MLSI	D OSI
Operated						
SPL	0.09	–0.14	0.14	0.26	0.01	0.14
SB	0.03	–0.09	0.12	0.37*	0.11	0.24
PB	–0.05	0.22	0.12	0.19	0.31	0.30
SLHA	–0.42*	–0.08	–0.39*	0.06	0.23	0.08
SUM	–0.11	–0.03	0.01	0.36*	0.27	0.31
Non-operated						
SPL	–0.43*	0.09	–0.28	–0.20	0.01	–0.18
SB	–0.37*	–0.13	–0.37*	–0.26	–0.04	–0.21
PB	–0.18	0.20	–0.09	–0.09	0.30	0.20
SLHA	0.03	–0.11	–0.02	–0.38*	–0.15	–0.29
SUM	–0.27	0.03	–0.18	–0.42*	–0.07	–0.30

* – statistically significant, SPL – supine pelvic lift, SB – supine bridging, PB – prone bridging, SLHA – side-lying hip abduction, SUM – sum of the NEURAC® tests, S – static conditions, D – dynamic conditions, APSI – anteroposterior stability index, MLSI – mediolateral stability index, OSI – overall stability index.

In the previous study this was also the case for the SB test and the summary score of all NEURAC® tests. Currently we noticed that recorded differences between the operated and non-operated extremities were smaller. This might be a consequence of the fact that this time we selected a younger sample (mean 15.7 vs. 26.9 years in [9]) and the time from ACLR to measurements was longer (6.6 months vs. 3.4 months in [9]). It is possible that with time inter-extremity differences gradually become smaller and it is more difficult to break the threshold of statistical significance. Younger subjects might also demonstrate quicker recovery than adults. This may explain why only one of the NERAC® tests revealed significant differences between the two lower extremities. Moreover significant results in this particular test (PB) can by justified by incomplete recovery of the quadriceps muscle strength in the operated extremity as compared to the non-operated extremity which was previously reported [23]. In conclusion we can claim that PB test shows the highest discriminative properties as far as functional status of the two lower extremities is concerned. With time other tests show a decreasing value. Therefore, in adolescents about six months post-ACLR it seems better to use selected NEURAC® test, preferably the PB test, not all possible tests or summary score of all tests.

With regard to SLBT, no significant inter-extremity differences were found in both static and dynamic conditions. Several explanations are possible. First, in adolescent patients six months post-ACLR functional differences between lower extremities might have already disappeared. Second, the test is not sensitive enough to detect subtle differences. The dilemma of what is true may only be solved by applying the SLBT in older samples and not that long after ACLR. We do not tend to hastily neglect the diagnostic value of SLBT, however, it was not demonstrated in this particular study group. It might also be the case that different angular position of the knee joint may reveal differences between lower extremities. In the current study we decided to maintain the straight knee position (almost locked position) in which stability is influenced by many periarticular structures not only ACL. Perhaps, by adding a degree of flexion one might impose greater demands (both mechanical and proprioceptive) on native ACL/ACL graft and potentially existing inter-extremity differences would come to the light.

Among other observations we noticed that medial/lateral stability indices were always smaller than anterior/posterior indices, which was predictable and linked to the shape and dimensions of the support plane – the foot (Table 2). The operated extremity presented itself more stable during dynamic SLBT, the non-operated extremity – during static SLBT. This results might be explained by the foot and hip strategy for maintaining lower extremity balance in dynamic conditions for operated extremity which is more difficult to execute during static SLBT. It is also difficult to judge whether the recorded outcomes of SLBT were low or high since no standardised reference values exist in the literature yet.

As far as correlations between the NEURAC® tests and SLBT are concerned, in case of non-operated extremity almost all correlations are negative (Table 3). This means that the fitter subjects are (score higher in NEURAC® tests) the more stable body position they show (score less in SLBT). This was, however, not the case for the operated extremity, in case of which there were fewer negative correlations in static conditions, and no negative correlation in dynamic conditions. This would mean the fitter the subjects are the less stable body position they show. The situation is difficult to explain. Is this always that larger postural sway (i.e. stability indices in SLBT) indicates poorer balance? Or maybe larger sway says: "The individual can allow his/her centre of mass to travel further forth and back, it does not do any harm". It is currently difficult to judge what is right and what is wrong. In case of the non-operated extremity the probable explanation seems simpler and more intuitive: higher fitness = smaller postural sway (better stability). In case of the operated extremity (especially for dynamic SLBT) the explanation looks more unorthodox: higher fitness = larger postural sway (better stability, too?). In any case we can be sure that outcomes of SLBT explain maximally 43% of variance of the NEURAC® tests score and vice versa. The issue presented here calls, of course, for further investigation.

There are several limitations of this study. First, due to its post-ACLR character we were unable to collect preoperative NEURAC® and SLBT outcomes, which would have provided a convenient baseline measurement to compare to changes in functional outcomes over time. Second, our study was conducted only on generally young, physically active recreational athletes, thus attempts of generalization should be taken with due care (e.g. to a high-level athletes population). This also applies to the fact that our current subjects were 6.6 (on average) months post-ACLR. In addition, our SLBT was performed in almost straight position of the tested lower extremity with its knee joint nearby the locked position. Tests in other positions of the knee should be undertaken in the future with a perspective of obtaining different results.

Conclusions

In adolescent patients about 6 months post-ACLR it is impossible to detect functional inter – extremity differences in maintaining body balance using the SLBT in both static and dynamic manner. In such specific study group the diagnostic value of SLBT was not confirmed. The only test capable to show inter-extremity differences was the

PB test from NEURAC® battery of functional tests which can be considered an indicator of differences in the side-to-side quadriceps femoris strength values. This observation stands in line with previous data.

Correlations between the outcomes of the NEURAC® tests and SLBT are not unambiguous. At their most they are of weak and moderate strength. For the non-operated extremity they are always negative. For the operated extremity positive correlations appear more often. This phenomenon is difficult to explain and needs further investigation.

In summary, the PB test from the NEURAC® tests battery can be used to detect functional differences between the lower extremities in adolescents post-ACLR. However, the use of the SLBT tests do not appear to be of diagnostic value in detecting such differences.

Conflict of interest: Authors state no conflict of interest.

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