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FACULTY OF PHYSICAL EDUCATION AND SPORT
DOCTORAL SCHOOL IN SPORT SCIENCE AND PHYSICAL EDUCATION
DOMAIN: SPORT SCIENCE AND PHYSICAL EDUCATION

NEWS IN FUNCTIONAL REHABILITATION AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

PHD THESIS SUMMARY

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2022

CUPRINS

Keywords: ligamentoplasty, body weight distribution, center of gravity oscillations, muscle strength, balance, functional status.

INTRODUCTION

The functional rehabilitation of patients with anterior cruciate ligament reconstruction is a complex and dynamic process and we can see in the literature a variety of research that highlights the ways to improve the rehabilitation protocols.

The need for studies that are focussed on identifying ways to improve the functional rehabilitation process after anterior cruciate ligament reconstruction is due to the fact that the incidence of injuries at this level is a common orthopedic condition, with an estimated incidence of 78 per 100,000 people with an average age of 32 in Sweden and up to 84 per 100,000 people in the United States (Domnick, Raschke & Herbort, 2016) and the other studies show that the incidence of ligament reconstruction increased by 22% (Tang, Zhang, George, Su & Huang, 2021).

In our country, reconstruction of the anterior cruciate ligament is a common surgical procedure, with very good long-term results, but it has been reported that in some cases persisits knee instability, which is a risk factor for the association of meniscus and cartilage injuries or even for recurrence (Mogos, Sendrea & Stoica, 2017). At the same time, it was mentioned that localized lesions at this level have always been a challenge for the teams of specialists involved, leading to the development and modification of different treatment protocols over the years (Herdea et al., 2022).

The topic of research *News in Functional Rehabilitation after Anterior Cruciate Ligament Reconstruction* is aimed to patients with this surgery intervention and according to current studies and to my own clinical experience they can have functional deficits of the operated knee and even after following the standard functional rehabilitation protocol they have difficulties in symmetrical loading of the weight at the lower limbs, as well as disorders of postural balance; these parameters are not always given the necessary attention in the protocol and that is why I want to illustrate that the basic objectives should be to improve the distribution of body weight and the balance. One of the devices that can be used in this regard is the Global Postural System, the main novelty of our research and it can be used for the process of stabilometric assessment of patients and as equipment for stabilometric re-education exercises.

The inclusion of this device in the protocol will lead to the improving of the load of the body weight distribution and to the improvement of the balance parameters, from the perspective of the oscillations of the center of gravity in relation to the support polygon in the antero-posterior and mid-lateral axis, in terms of the length of the center of gravity curve and its maximum speed. All these aspects described in the functional rehabilitation protocol could be quantified in a guide of good practices for clinicians in the field of recovery, in case it will be approved by the specialists.

PART I- THEORETICAL BASIS OF THE RESEARCH TOPIC

CHAPTER 1. ANATOMO-PATHOLOGICAL NOTIONS OF THE ANTERIOR CRUCIATE LIGAMENT

The anatomical and pathological notions regarding the anterior cruciate ligament (ACL) are described in order to highlight the role that it plays in the knee joint and to describe how the lesions at this level lead to functional deficits; thus, in the following will be described elements of anatomy and biomechanics, the production mechanisms of its lesion, news on therapeutic conduct, but also innovative methods of diagnosis and functional assessment for patients with surgical reconstruction.

1.1. ELEMENTS OF ANATOMY AND BIOMECHANICS OF ANTERIOR CRUCIATE LIGAMENT

Over time the research on ACL has been of considerable interest due to its role in maintaining knee stability, as well as its biomechanical role in limiting the internal rotation of the tibia, which is described as fundamental (Musahl, Herbst, Burnham & Fu, 2018). Like any other ligament, it connects one bone to another and works to create joint stability (Muscolino, 2011), being one of the four main ligaments of the knee joint.

The notions of anatomy of the ACL are essential when a reconstruction is required after an injury at this level; the anatomical study should address its biomechanical properties, kinematics, anatomical position and correlation, as well as its functional properties. In this regard, it is known that the anatomical center of the ACL at the femoral imprint is 43% of the proximal to distal length of the lateral intercondylar wall and the radius of the femoral groove plus 2.5 mm anterior to the posterior articular margin (Markatos, Kaseta, Lallos, Korres & Efstathopoulos, 2013). The ACL extends superiorly, posteriorly and laterally, twisting as it extends from the tibia to the femur. Its main function is to prevent the anterior movement of the tibia on the femur, to control the lateral rotation of the tibia in flexion and, to a lesser extent, to control the extension and hyperextension of the knee (Diermeier et al., 2020; Musahl et al., 2020). The origin of the ACL is described at the medial wall of the lateral femoral condyle and the insertion is in the middle of the intercondylar area; it is oval and is located in the posterior area of the lateral femoral condyle. The tibial insertion is also oval and is found at the center of the tibial plateau and the structure is similar to a chondral apophyseal enthesis. Near the anchorage region on the femur and tibia there are mechanoreceptors, which have an important function in the kinematics of the knee joint (Cone, Howe & Fisher, 2019; Sonnery-Cottet et al., 2017).

1.2. THE MECANISM OF ANTERIOR CRUCIATE LIGAMENT INJURY

The mechanism of ACL injuries is diverse, the most common causes being traumatic factors or repetitive mechanical overload at the knee. ACL lesions are common during multiplanar mechanisms, with evidence of lateral torsion movement, knee abduction, flat foot position on original ground contact and increased hip flexion (Hewett, Myer, Ford, Paterno & Quatman, 2016).

An ACL injury usually occurs without contact with another player. A contactless injury has been defined as the absence of any physical contact with another player or object at the time of the injury, which means that it involves uncontrolled biomechanics of the lower limbs. The most common form of non-contact injury is deceleration. During the change of direction, a force is formed which demands excessive ACL and a lesion may occur at this level. In case of a jump, the ligament can be damaged during the landing action, the knee being in hyperextension (Della Villa, Hagglund, Della Villa, Ekstrand & Walden, 2021; Padua et al., 2018). The same is true of Cronstrom, Creaby & Ageberg (2020), who emphasized the idea that ACL lesions occur during non-contact episodes, usually within 50 milliseconds of foot contact with the ground, with the knee almost extended. torso tilt and knee abduction.

1.3. DIAGNOSTING METHODS FOR ANTERIOR CRUCIATE LIGAMENT LESIONS

Over time, a variety of methods have been described to facilitate the validation of ACL lesions. These methods are useful because ACL lesions can be partial or total and the severity of the lesion is also the main aspect for the selection of treatment, which may depend on the results of the physical examination or the information collected through certain investigations.

According to Koster, Harnsen, Lichtenberg & Bloemers (2018) there are three physical examination tests commonly used to assess ACL injury. The best known and most commonly used technique is the anterior drawer test. The other two tests, the Lachman test and the pivot change test, are more difficult to perform and are less commonly used. One of the best known tests is the Lachman test, which is clinically considered to be a reliable physical examination for ACL injury, but would involve some subjective judgment (Tanaka et al., 2017).

The technological developments allow for imaging assessments that are characterized by accuracy and precision, including ultrasound imaging, surgical exploration or nuclear magnetic resonance (MRI). The measuring instruments available to the clinician are not perfectly, but they provide valuable information in the clinical context; if the clinical examination or MRI is negative, the likelihood of the patient having a lesion is low (Ardem et al., 2018).

1.4. THE TREATMENT OF ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

The ACL injuries have always been a topic that has prompted specialists to recommend conservative or surgical treatment, in order to allow the patient to return to daily activities and / or sports activities. Cryotherapy, restrictive strengthening, continuous passive movement, electrotherapy and exercises aimed at reducing inflammation, restricting excessive knee movements or strengthening muscles to improve knee stability and to protect the joint are common conservative treatment options. However, conservative approaches to managing these lesions sometimes fail (Raines, 2017).

The ACL anatomical reconstruction is a surgical technique that adapts the procedure to the patient's particularities, by preoperative measurements on simple radiographs and magnetic resonance imaging and intraoperative measurements that map the native ACL anatomy for accurate reproduction (van Eck, Widhalm, Muraswki & Fu, 2015).

Regardless of the type of surgery or graft used, patients undergoing surgical reconstruction of ACL require a rehabilitation program in order to recover and return to daily activities before the injury. Rehabilitation after ACL reconstruction should consider controlling postoperative pain and oedema, protecting the graft for healing, regaining full range of motion, regaining muscle strength in the knee, hip, improving neuromuscular control and gradually progressing to active are needed to return to sports activities (Yabroudi & Irrgang, 2013; Mostafaee et al., 2017).

CHAPTER 2. FUNCTIONAL REHABILITATION OF PATIENTS WITH ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

The ACL reconstruction aims to restore the function of the knee, which must be protected from meniscal injuries (Korpershoek, de Windt, Vonk, Krych & Saris, 2020). On the other hand, when it comes to functional rehabilitation after ACL reconstruction, we can review a number of approaches to the rehabilitation program, which has as its main objective the recovery of the functional deficit, especially since most patients in this category are young and active. dynamic and tend to experience a higher load on the knee joints on a daily basis (Shimizu et al., 2020). At the same time, it has been stated that the main goal of physical therapy after ACL reconstruction is to restore the patient's normal gait patterns (Winiarski & Czamara, 2012).

One of the essentially therapeutic goals for patients with ACL reconstruction is the achieving systemic progression, which is initiated immediately of the postoperative period, when it must be ensured control of pain, inflammation and postoperative oedema be (Gokeler, Dingenen, Mouton & Sei, 2017) . In the same time, the protocol for these patients should also aim at the protection of the graft, the strengthening of the muscles that stabilize the knee, hip and trunck and a gradual progression to functional activities (Yabroudi & Irrgang, 2013).

The need to protect the graft and ensure that it can be integrated is emphasized in countless studies and clinicians responsible for recovering the patients with ligament reconstruction need to consider issues such as the time it takes to heal tissues, but also the individual characteristics of patients. which also counts their motor performance (Cote, 2016).

In the specialized literature can be found a series of programs in which innovative aspects have been included, in order to limit to the maximum the risk of recurrence; such interventions are necessary as it has been suggested that a successful return to the previous level of activity after ACL reconstruction is not guaranteed and the prevalence of a second injury may be up to 30% due to neuromuscular and functional deficits (Di Stasi , Myer & Hewett, 2013).

We can see that there is a great diversity in the approach of ACL reconstruction patients, but one of the best known protocols is the one described by Shelbourne and Nitz at the end of the 20th century; their protocol was a guide for a significant number of clinicians and focused on the complete extension of the knee to overcome some of the complications after surgery, recovery of strength and relief of knee pain, while maintaining joint stability and the association of this protocol with the use of modern surgical techniques seem to lead to optimal results (Xu, 2021). At the same time, focused postoperative surgery on the lower limbs included standardized exercises, with individualized progression, functional and cardiovascular exercises and we can count eight areas of the exercise program like retraining physiological movement, lower limb strength, balance, hip strength - abductor, leg strength, torso strength, hip extensors and knee flexors strength and cardiovascular exercises. Regarding the level of performance of the exercises, it was based on: good technique, minimal irritability, principles of resistance training related to muscle strength and objectives and feedback specific to each patient (Patterson, Barton, Culvenor, Cooper & Crossley, 2021).

It is necessary to improve the condition of patients after ligamentoplasty, and this involves the use of a program focused on optimizing rehabilitation processes and practices, as well as the patient's progress by performing gradually more demanding tasks, from the point where the patient manages to walk alone. to be able to perform extremely complex sports movements (Buckthorpe, Tamisari & Villa, 2020).

CHAPTER 3. USE THE STABILOMETRIC PLATFORM AFTER ANTERIOR CRUCIATE LIGAMNET RECONSTRUCTION

Re-education of balance, proprioception and stability is one of the essential objectives for patients who have undergone surgical reconstruction of ACL and the restriction period of use the operated lower limb are aspects that will lead to changes in these parameters. In order to determine how the parameters of balance and body weight distribution in the lower limbs are influenced by the functional rehabilitation program, it is necessary to use specific assessment tools, which provide objective information and allow clinicians the possibility of interventions to lead to improving functional status of patients. One of these instruments is the stabilometric platform, which has gained ground recently, its use especially in the orthopedic-traumatic sphere can guarantee the achievement of therapeutic objectives (De la Torre, Marin, Polo & Marin, 2020). The Global Postural System (GPS) is a modern postural analysis equipment through can be performed stabilometers, can be collected the information with a functional assessment character and can be performed stabilometric re-education exercises. GPS can be used to analyze posture, but also to observe load deficits on body weight or balance disorders. Over time, it has been established that it is an advanced postural analysis system that uses non-invasive diagnostic and assessment techniques and and biofeedback treatments help to improve posture and maintain results over time (Raines, Buldus & Monea, 2021).

This device is a reliable method of assessing pelvic asymmetry in a clinical setting. Its hardware consists of two vertical aluminum bars with side bars, a lead wire for postural reference and an adjustable mirror at the top, attached to a stable platform, which can be calibrated by means of two reference lines and four fingerprints pointing in different directions. GPS is advantageous compared to a traditional photographic system (Yu et al., 2020). The Global Postural System 400 can be used to perform stabilometers for ACL reconstruction patients and one of the parameters is the degree of distribution of body weight (DBW) in the lower limbs (LL), exemplified in both kilograms (Weight on left foot / Weight on right foot), as well as in percentage (% distribution of total weight on the left foot /% distribution of total weight on the right foot), which recommends it to be used in order to identify balance disorders or stability deficits (Toprak, 2018).

At the same time, the parameters related to the average distance of projection of the center of gravity (ADCG) within the support polygon (SP) on the two axes can be determined, namely vertical or x-axis (Average distance from ideal barycentre {0} - mm) and horizontal / transverse or y-axis, curve length (expressed in mm) and maximum speed (expressed in mm / s); this last parameter is a derivative of the center of gravity, which can be expressed in meters per second (Lee et al., 2020).

THEORETICAL CONCLUSIONS

The ultimate goal of patients with ACL reconstruction is to return to sports before injury, and to achieve this, it is necessary to use efficient and high-performance functional re-education techniques and methods. On the one hand, it is essentially that this category of patients benefit from a complex evaluation process, which includes parameters related to muscle strength and joint mobility, but also parameters related to the distribution of body weight in the lower limbs and the balance; on the other hand, it is ideal that the improvement of these parameters be achieved following the application of modern methods, which allow the objectification of the results.

After analyzing the literature, we can conclude that the incidence of ACL injuries is increasing, and surgical reconstruction becomes a mandatory solution in the event of a total injury. In these cases we can discuss a consensus on the need to follow a functional rehabilitation protocol, through which to achieve the normalization of functional status.

Over time, attempts have been made to identify solutions that allow clinicians to achieve the best results for patients with ligamentoplasty and among these solutions is the use of stabilometric platforms. They are numerous, diverse and equipped with technological software that allows the collection of information on the degree of load of body weight at the level of the lower limbs and the oscillations of the center of gravity in relation to the supporting polygon, but with limited use in this area. We consider it is essentially like patients with ACL reconstruction to benefit from an assessment of the above parameters as it has been shown in numerous studies that they have weight loading asymmetries as well as balance disorders and their lack of uniformity can expose them to the risk of recurrence.

It can be stated that the global postural system is a modern equipment that can be integrated into the functional rehabilitation process specific to patients with ACL reconstruction as it allows objective and detailed assessment of body weight distribution, center of gravity oscillations relative to polygon, length the curve and the maximum speed of the center of gravity, as well as its integration into the functional rehabilitation protocol.

PART II- PERSONAL CONTRIBUTIONS
CHAPTER 4. THE ASSESSMENT OF BODY WEIGHT DISTRIBUTION AND BALANCE PARAMETERS AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION - PRELIMINARY STUDY

4.1. RESEARCH PREMISES

The premises of the research are directly related to the patients who are undergoing the ACL reconstruction, patients with whom I have worked since the beginning of my career as a physiotherapist. We have noticed since then that there are different types of approaches for these patients,and recovery specialists have to select one of the existing protocols, but without the certainty that the result of the selection is the most effective method of functional re-education. That is why the object of the present research refers to ways to streamline the functional re-education of ACL reconstruction.

The main reason for choosing the theme is the personal affinity for orthopedic cases, especially for orthopedic cases that are located at the knee resulting in ACL injuries that require surgical reconstruction. As can be seen in the literature, the incidence of these cases has increased in recent years, an aspect that we could notice from the position of physiotherapist and the need to streamline the functional re-education of these patients is obvious from the fact that not all manage to recover the functional deficit and thus return to the physical level before the injury. Through this research, I want to identify ways in which patients with ACL reconstructions are determined to follow a functional rehabilitation protocol that leads to the normalization of their functional status.

4.2. PURPOSE, OBJECTIVES, TASKS, HYPOTHESES

The ***aim*** of this research is to highlight how the recovery protocol specific to patients with anterior cruciate ligament reconstruction can be improved by identifying the parameters related to the distribution of body weight in the lower limbs and the oscillations of the center of gravity relative to the supporting polygon. In terms of research ***objectives*** and tasks, they are as follows:

► to identify of innovative technological equipment used in functional rehabilitation after ACL reconstruction:
● to study the specialized literature regarding the novelties in the field of functional rehabilitation;
● to describe of the stabilometric platform and how it can be used in ACL reconstruction patients;

► selection of research subjects from the Medical Recovery Center - Kinego:
● assessment of parameters related to body weight distribution and center of gravity fluctuations in relation to the support polygon in patients with anterior cruciate ligament reconstruction;
● description how the functional rehabilitation protocol for patients with anterior cruciate ligament reconstruction can be improved as a result of the stabilometric assessment;

► collecting, analyzing and interpreting the results obtained:
● performing statistical analysis through the SPSS program (version 20.0);
● making graphs that highlight the results obtained;
● a thorough interpretation of the results obtained and their comparison with the results of similar research;

► to draw conclusions highlighting the importance of using the stabilometric platform in patients with ACL reconstruction.

The ***independent variable*** was represented by the functional status of the subjects after reconstruction, while the ***dependent variables*** were the distribution of body weight, balance parameters and morpho-functional indices of the thigh.

The research started from the ***hypotheses*** below:

1. We assume that the use of the GPS 400 stabilometer platform will allow the accurate identification of the oscillations of the center of gravity in relation to the supporting polygon and the distribution of body weight.

2. We assume that the level of morpho-functional parameters of the force at the thigh influences the oscillations of the center of gravity in relation to the supporting polygon and the distribution of body weight.

4.3. RESEARCH ORGANIZATION AND CONDUCT

The research included a number of twenty subjects diagnosed with ACL lesions who underwent surgery. The subjects were divided into two groups: in the first group (n = 10) we included subjects in recovery, the period from surgery being up to 4 months (group 1); in the second group (n = 10) were included the subjects who completed the functional re-education program, after 6 months from the surgery (group 2). The *inclusion criteria* were the diagnosis of the subjects, the therapeutic approach of the ligament injury (surgical reconstruction), the completion of the functional re-education program, the agreement on testing somato-functional parameters and those related to DBW in the lower limbs and the parameters related to the fluctuations of the center of gravity in relation to the supporting polygon.

The *exclusion criteria* were the existence of an associated pathology such as orthopedic disorders in the lower limbs, inner ear disorders or neurological disorders that may be responsible for the association of balance disorders. The subjects included in the research were both female (n = 8) and male (n = 12), aged between 20 and 55 years. They underwent ACL reconstruction surgery by autograft of the gracilis and semitendinosus tendons, the technique used being all graft inside (AGI). In order to functionally assessement we performed muscle balance using a scale from 0 to 5, measuring the circumference of the thigh, as well as evaluating the distribution of body weight in the lower limbs and oscillations of the center of gravity relative to the support polygon via GPS 400 stabilometer platform.

4.4. RESULTS AND DISCUSSIONS

Hypothesis 1 testing

In order to test hypothesis 1, a series of statistical analyzes were performed, such as the t test and the independent t test, as well as a series of figures to illustrate the results obtained.

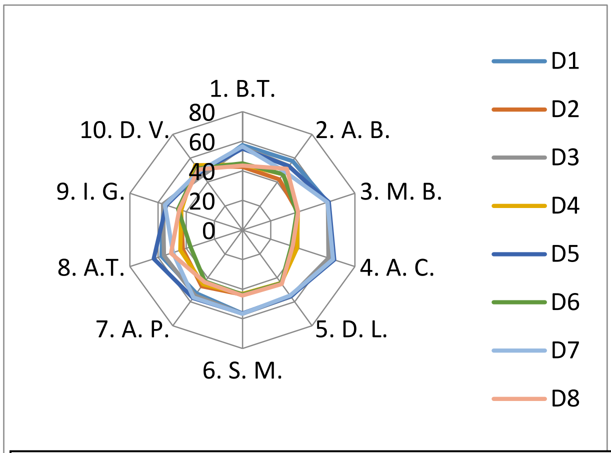
Table 1 shows the results of the subjects in terms of body weight distribution parameter for the four assessment positions (eyes open, eyes closed, head turned towards healthy limb, head turned towards diseased limb).

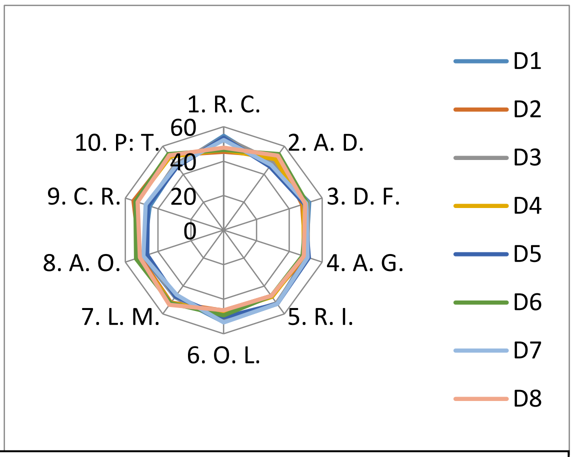
Table 1. Centralization the results obtained in the evaluation of body weight distribution

Group	**Evaluation position (Average ± Standard average error)**							
	Distribution of body weight							
	D1	D2	D3	D4	D5	D6	D7	D8
Group 1	**56,39** ±1.38	**43,61** ±1.38	**55,61** ±1.32	**44,39** ±1.32	**56,95** ±1.56	**43,05** ±1.56	**55,15** ±1.59	**44,95** ±1.58
Group 2	**49,84** ±1.05	**50,16** ±1.05	**50,01** ±.77	**49,89** ±.77	**48,99** ±.97	**51,01** ±.97	**49,63** ±.87	**50,37** ±.87

Legend: D1 = body weight distribution on healthy lower limb, eyes open; D2 = body weight distribution on diseased lower limb, eyes open; D3 = Body weight distribution on healthy lower limb, eyes closed; D4 = body weight distribution on diseased lower limb, eyes closed; D5 = distribution of body weight on the healthy lower limb, with the head turned towards the healthy lower limb; D6 = body weight distribution on the diseased lower limb, with the head turned towards the healthy lower limb; D7 = body weight distribution on the healthy lower limb, with the head turned towards the diseased lower limb; D8 = body weight distribution on diseased lower limb, head twisted towards diseased lower limb.

According to the table above and the figures below we can conclude that the parameter of body weight distribution shows medium and large differences in loading healthy limb-diseased limb among the positions tested in the case of group 1, while group 2 has minimal loading differences of this parameter among all evaluated positions.





Figures 1 and 2. Distribution of body weight group 1/ group a 2-a

Given these results we can say:

› the two groups show significant differences in DBW in all positions tested as they are in different recovery periods;

› we did not find statistically significant differences for the two groups in terms of comparing test positions, except for group 2 in the case of the closed eye- head to healthy LL, which shows that the body distribution parameter is not decisively influenced by the test position, but has approximately the same ratio of healthy limb to diseased limb; the difference in minimum load specific to group 2 subjects may be due to the fact that they load body weight without the tendency to protect the diseased knee.

Our results can be seen as a slight contrast to some studies that show that there are asymmetries of the quadriceps of the operated lower limb compared to the healthy one; at six months postoperatively, an asymmetry was described in 20% of research cases (Joreitz et al., 2016). At the same time De Fontenay, Monteil, Blache & Argaud (2014) observed a deficit of 14% for the operated lower limb compared to the healthy one in terms of total loading time, which leads them to the conclusion of a weight loading deficit. Another study (Huang, Keijers et al., 2017) found that subjects with anterior cruciate ligament reconstruction experienced greater contact on the healthy lower limb, with patients tending to reduce pressure on the affected knee, to protect him.

After analyzing the results obtained, we can state that, postoperatively, in group 1 there are significant differences in the load ratio of healthy limb-diseased limb and in some cases these differences may persist after the completion of the rehabilitation program; studies highlighting the distribution of body weight are valuable because they point out that the persistence of asymmetries may be a risk factor for recurrence or for the onset of osteoarthritis (Meyer, Gette, Mouton, Seil & Theisen, 2017).

Table 2. Centralization the results obtained in the evaluation of the average distance of the center of gravity in relation to the supporting polygon

Group	Evaluation position (Average ± Standard average error)							
	Average distance of center of gravity							
	CX1	CX2	CX3	CX4	CY1	CY2	CY3	CY4
Group 1	**136,5** ±18.41	**128,1** ±12.48	**131,3** ±31.6	**104,1** ±17.90	**140,1** ±20.36	**147,6** ±25.24	**109,8** ±29.81	**77,6** ±17.41
Group 2	**43,2** ±11.28	**38,6** ±12.53	**55,1** ±12.02	**58,6** ±7.32	**86,5** ±19.72	**84,3** ±23.68	**125,2** ±14.92	**100** ±22.37

Legend: CX1 = average distance of the center of gravity on the x-axis, with eyes open; CX2 = average distance of the center of gravity on the x-axis, with eyes closed; CX3 = average distance of the center of gravity on the x-axis, head twisted towards the healthy lower limb; CX4 = average distance of the center of gravity on the x-axis, head twisted towards the diseased lower limb; CY1 = mean distance from the center of gravity on the y-axis with the eyes open; CY2 = mean distance from the center of gravity on the y-axis, with eyes closed; CY3 = average distance of the center of gravity on the y-axis, head twisted towards the healthy lower limb; CY4 = Average distance of the center of gravity on the y-axis, head twisted towards the diseased lower limb.

The results obtained regarding the parameter of oscillations of the center of gravity in relation to the supporting polygon partially support studies showing that the center of gravity shows an alteration among patients with reconstruction of the anterior cruciate ligament compared to healthy individuals, both while walking and while running and findings about the similarity of the center of gravity can provide valuable information about knee function and gait performance (Huang et al., 2017).

Table 3. Centralization the results obtained in the evaluation of the length of the curve of the center of gravity in relation to the supporting polygon

Group	Evaluation position (Average ± Standard average error)			
	L1	L2	L3	L4
Group 1	**2657,5** ±221.06	**3204,8** ±221.32	**2858,3** ±210.92	**2872,4** ±227.35
Group 2	**2224,5** ±91.12	**2993,9** ±160.57	**2460,8** ±96.48	**2362,3** ±106.15

Legend: L1 = lungimea curbei centrului de greutate, cu ochii deschiși; L2 = lungimea curbei centrului de greutate, cu ochii închiși; L3 = lungimea curbei centrului de greutate, capul răsucit spre membrul inferior sănătos; L4 = lungimea curbei centrului de greutate, capul răsucit spre membrul inferior bolnav;
MI = membrul inferior.

The analysis of the results regarding the length of the center of gravity curve leads to the drawing of the following findings:

› this parameter is considerably influenced by the test position, obtaining statistically significant results among both groups suggesting that it would be necessary to investigate how the length of the center of gravity curve affects the balance; these results could also suggest that the recovery protocol used by group 2 would be more effective in improving this parameter, requiring the introduction of balance exercises from various positions or the performance of balance re-education exercises using technological equipment like stabilometric platform;

› there are no statistically significant differences between the mean values of the two groups of subjects and it is necessary to compare the results with a control group (healthy subjects) to determine to what extent the length of the center of gravity curve is normal or lower.

Table 4. Centralization the results obtained in the evaluation of the maximum speed of the center of gravity in relation to the supporting polygon

Group	Evaluation position (Average ± Standard average error)			
	V1	**V2**	**V3**	**V4**
Group 1	**551** ±61.38	**794,6** ±90.16	**630,7** ±54.59	**1684,1** ±949.01
Group 2	**681,3** ±209.16	**959,6** ±303.61	**847,4** ±303.97	**754,4** ±285.65

Legend: V1 = maximum speed of center of gravity, eyes open; V2 = maximum speed of center of gravity, eyes closed; V3 = maximum speed of the center of gravity, head turned towards the healthy lower limb; V4 = maximum speed of the center of gravity, head twisted towards the diseased lower limb.

The analysis of the results regarding the maximum speed of the center of gravity leads to the enumeration of the following aspects:

› this parameter is little influenced by the test position, both groups showing statistically significant results in the pair of open eyes and closed eyes, suggesting that the cancellation of the visual stimulus leads to poorer results in both subjects undergoing functional re-education, as well as in the case of those who have completed the rehabilitation protocol;

› the fact that there are no statistically significant differences between the mean values of the two groups means that both groups of subjects have similar values of this parameter, and it is necessary to compare the results with a control group (healthy subjects) to determine whether the maximum center of gravity speed falls within normal values.;

The combination of the small amplitude of the curve length and the high values of the speed of projection of the center of gravity in relation to the supporting polygon could suggest that postural reactions are present and the results obtained are due to impaired muscle strength. The results obtained with respect to the rate of oscillation of the center of gravity partially confirm other studies, which concluded that the size and velocity of the oscillation of the center of gravity were significantly higher in the group of patients with ligamentoplasty, and the measurement of center of gravity oscillations in order to establish functional rehabilitation strategies (Lechmann, Paschen & Baumeister, 2017).

After analyzing the results obtained regarding the oscillations of the center of gravity, we can say that patients with ACL reconstruction need to assess body balance (affected parameter), and therapists should use the healthy lower limb as a reference (Zult et al., 2016). We consider this assessment is important as the persistence of deficiencies in neuromuscular control of the affected lower limb can be categorized as a risk factor for recurrence (Abrams et al., 2014).

The results obtained support hypothesis 1 because, through the GPS 400 stabilometer platform, we identified concrete and truthful data both on the distribution of body weight in the lower limbs and on the oscillations of the center of gravity relative to the supporting polygon, which can lead to efficiency functional rehabilitation protocol.

Hypothesis testing 2

To test hypothesis 2, we performed the Pearson correlation, in order to analyze how the morpho-functional indices of muscle strength influenced the DBW and the oscillations of the center of gravity in relation to the supporting polygon and thus we can highlight the following aspects:

- group 1 shows a ***strong positive correlation*** between muscle strength and DBW on the healthy limb-twisted head towards the healthy limb and DBW on the diseased limb-head twisted towards the healthy limb (***r = .640***). Group 2 does not record statistically significant Pearson correlation values (***p> 0.05***);

- Pearson correlation shows that for group 1 there is a significant correlation only in the situation of muscle strength-average distance of the center of gravity on the y-axis, head to healthy limb, where ***r = -0,770***- strong negative correlation, while for all other correlations the results are not statistically significant and in the case of group 2 the correlations are not statistically significant (***p> 0.05***), suggesting that the value of muscle strength significantly influences only group 1, at the average distance of the center of gravity on the y-axis, head to healthy member, while for the other positions the results are not significant;

- Pearson correlation shows that there are no statistically significant correlations of mean values for the two groups between muscle strength / thigh circumference difference and center of gravity curve length (***p> 0.05***), except for group 1, where thigh circumference difference and curve length with his eyes closed he records an ***r = .749***;

- the Pearson correlation shows that there are no statistically significant correlations for the two groups between muscle strength / difference in thigh circumference and maximum speed of center of gravity ***(p> 0.05***).

After analyzing the results obtained, it can be stated that they do not support hypothesis 2 because we identified only in isolated situations statistically significant correlations between morpho-functional indices of muscle strength and body weight distribution and parameters of center of gravity in relation to the supporting polygon.

4.5. Partial conclusions

Following the functional evaluation by the GPS 400 stabilometric platform of the patients of the anterior cruciate ligament reconstruction, we can say that hypothesis 1 is supported by the obtained results as we accurately identified data about the oscillations of the center of gravity relative to the support polygon and and about the distribution of body weight in the lower limbs.

It was highlighted that, in the case of body weight distribution, better results were obtained by the subjects of group 2, who completed the functional rehabilitation protocol, compared to the subjects of group 1, who were at the time of evaluation in the functional re-education stage; on the other hand, the differences between the results of the two groups regarding the balance parameters were not as obvious, which could lead to the idea that the rehabilitation protocol does not prove to be effective enough to improve the mentioned parameters.

The level of morpho-functional strength indices at the thigh could influence the oscillations of the center of gravity relative to the supporting polygon, as well as the distribution of body weight in the lower limbs, but according to our results, hypothesis 2 is not supported because we did not identify significant correlations between body weight distribution and balance parameters and morpho-functional indices of muscle strength than in isolated situations. We can say that group 2 obtained better results than group 1 regarding the tested parameters, aspect that could be attributed to the better score registered at the level of the muscle balance and on the difference of the smaller thigh circumference, but the fact that we did not obtain significant correlations between the morpho-functional indices of the thigh and the distribution of body weight and balance parameters lead us to the idea that their evolution is not directly proportional.

All this information would suggest that, in order to obtain an improvement in weight distribution and balance parameters, it is not enough to perform exercises to improve muscle strength, but it is necessary to intervene by effective means, with specific addressability.

CHAPTER 5. THE IMPORTANCE OF USING THE GPS 400 STABILOMETRIC PLATFORM IN FUNCTIONAL REHABILITATION AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION - MAIN STUDY

5.1. RESEARCH PREMISES

This research started from the ***premise*** that the functional rehabilitation protocol for patients with ACL reconstruction could be improved, following the introduction of stabilometric re-education exercises, which is also the ***subject*** of research.

One of the ***reasons*** for this study is directly related to the results of the preliminary study, in which we identified that patients with surgical reconstruction of ACL may have asymmetries of the distribution of body weight in the lower limbs, as well as balance disorders; that is why we consider that identifying the ways to improve these parameters is beneficial.

Another ***reason*** behind this research is the personal opinion that patients with ACL injuries follow postoperative protocols that place special emphasis on regaining muscle strength and joint mobility, but the goals of restoring balance and stability are given far too little importance, which could result in a lack of normalization of their functional status. Therefore, the subjects of the research are represented by patients with surgical reconstruction of ACL who received the recommendation to follow the recovery protocol at the Medical Recovery Center- Kinego, where I am a physiotherapist and the research period was about one year, from May 2021 to May 2022.

5.2. PURPOSE, OBJECTIVES, TASKS, HYPOTHESES

Patients undergoing anterior cruciate ligament reconstruction surgery require a period of functional recovery for at least six months; from practical experience I can say that some of them give up this rehabilitation process earlier as aspects related to pain, oedema, muscle strength or joint mobility are improved and they consider that can resume sports activities early; however, certain functional deficits in body weight distribution or balance disorders may persist in this way. **The purpose of this research** is directly related to this personal finding and consists in identifying ways to improve the functional status of the mentioned category of patients (one of these ways referring to the use of the stabilometric platform as a technological tool of evaluation, but also as part of the functional rehabilitation protocol).

The objectives and **tasks** of the research are as follows:

● selection of research subjects from patients with ACL reconstruction:

- monitoring patients during functional rehabilitation through the innovative method of assessment using the stabilometric platform;
- application and implementation of the kinetotherapeutic intervention plan for patients with anterior cruciate ligament reconstruction, in which we have included, among other things, as a novelty the stabilometric re-education exercises;
- collecting accurate data on the distribution of body weight in the lower limbs of patients after anterior cruciate ligament reconstruction;
- collecting truthful data on balance parameters in patients with anterior cruciate ligament reconstruction;

● identification of the efficiency of the functional rehabilitation protocol followed by the subjects included in the research:

- making a comparison between the initial and final results obtained by the research subjects and their interpretation;
- making a comparison between the results obtained by ligamentoplasty subjects and those of a control group (healthy subjects) and their interpretation;

- comparison of the results obtained with the results of topical studies on the same topic;

● presentation of conclusions highlighting the importance of using the stabilometric platform in patients with ACL reconstruction.

Table 5 highlights the **independent variables** and **dependent variables** specific to this research.

Table 5. Dependent and independent research variables

Independent variable	*Dependent variable*
1. The functional rehabilitation protocol described in Table 5.3, using the GPS 400 stabilometer platform;	1. Distribution of body weight;
2.Age;	2. Balance parameters: a. The average distance of the center of gravity from the supporting polygon on the x and y axes; b. The length of the center of gravity curve; c. Maximum center of gravity speed.
3. Gender.	

The hypotheses of this research are stated as follows:

Main hypothesis 1

We assume that the completion of the functional rehabilitation protocol, in which were introduced stabilometric re-education exercises performed on the GPS 400 platform, will lead to the correction of the loading of the body weight.

Secondary hypothesis 1.1

We assume that gender influences the efficiency of the functional rehabilitation protocol, in which were introduced stabilometric re-education exercises performed on the GPS 400 platform, in terms of correcting the degree of loading of body weight.

Secondary hypothesis 1.2

We assume that age influences the efficiency of the functional rehabilitation protocol, in which were introduced stabilometric re-education exercises performed on the GPS 400 platform, in terms of correcting the degree of loading of body weight.

Main hypothesis 2

We consider that the completion of the functional rehabilitation protocol, in which were introduced the stabilometric re-education exercises performed on the GPS 400 platform, will lead to the improvement of the balance parameters.

Secondary hypothesis 2.1

We consider that the gender influences the efficiency of the functional rehabilitation protocol, in which platform were introduced the stabilometric re-education exercises performed on the GPS 400, in terms of improving the balance parameters.

Secondary hypothesis 2.2

We consider that the age influences the efficiency of the functional rehabilitation protocol, in which platform were introduced the stabilometric re-education exercises performed on the GPS 400, in terms of improving the balance parameters.

Main hypothesis 2

We assume that, following the functional rehabilitation protocol, in which were introduced the stabilometric reeducation exercises performed on the GPS 400 platform, we will find an association between the body weight distribution and the balance parameters.

5.3. RESEARCH ORGANIZATION AND CONDUCT

This research included a total of ***55 subjects***, aged between 21 and 52 years, both female (n = 26) and male (n = 29), who were divided in 2 groups: group 1 included a number of 28 subjects (13 female and 15 male) who underwent ACL reconstruction, who were initially tested (four weeks postoperatively) and who followed the functional rehabilitation protocol after which they were finally tested (6 months postoperatively) and group 2 included a number of 27 subjects (13 female and 14 male), representing the control group (healthy subjects) and being evaluated only once during the study.

Subjects in both groups were ***assessed using the GPS 400*** stabilometer platform. It should be noted that the subjects of group 1 followed the functional rehabilitation protocol for a period of 6 months and the frequency of sessions was approximately 3 sessions per week, with a session duration of approximately 60 minutes.

The activity of ***subjects assessement*** was directed in order to collect data related to the distribution of body weight and the oscillations of the center of gravity in relation to the supporting polygon. In order to achieve this goal it was used the GPS 400 stabilometric platform, in the recovery office where the functional rehabilitation activity of the subjects was performed. The Global Postural System (GPS) is a computer system whose hardware includes a digital camera, a ruler frame and a fixed platform that allows consistent identification of stabilometric landmarks and the stabilometric platform, a component of the posturograph, is an innovative method of evaluation, but with limited research in the field of orthopedics (Neculăeș & Botez, 2011; Yu, 2020).

The ACL reconstruction functional rehabilitation protocol is divided into four phases, over a period of six months. Each phase is temporarily delimited and involves the achievement of certain clear objectives and the use of specific kinetic means that are effective and allow progress from one phase to another. There is an innovative method of recovering post-reconstruction patients from the anterior cruciate ligament, which is intended to be a guide of good practice for specialists in the field as the objectives and methodological-practical indications are clearly established for each recovery phase and the model of stage and session programs it is efficient and effective, even if they are indicative. It is well known that the dosage of exercises and the selection of kinetic means are individualized according to the particularities of each patient and their temporary functional status and in the protocol the dosage of exercises is purely indicative.

Among the ***novelty elements of the functional rehabilitation protocol*** we list:

- performing isometric contractions, with the attachment of an elastic band at the thigh, to improve proprioception;
- introduction of hold-relax neuroproprioceptive facilitation techniques to promote joint mobility;
- performing closed kinetic chain exercises until the end of the third recovery phase;
- the realization of some applicative routes in order to correct the way of accomplishing the gait and to improve its parameters;
- ***introduction of stabilometric re-education exercises*** using the stabilometric platform in order to improve both body weight distribution and balance parameters.

During the exercises, the patients followed the position of the center of gravity inside the support polygon on the platform monitor and used the default reference point available on the screen; the physiotherapist determined this reference point in the software to guide patients on the degree of joint load corresponding to each phase of work. The reference point was a red square shape positioned on the screen and the software allowed to identify some units that were the maximum deviations in the single support. During the first stabilometric re-education sessions, these pre-established units were larger, but as the protocol progressed, the units experienced a downward curve, in order to increase the difficulty of the exercises. This method of re-educating the load of body weight at the level of the lower limbs and improving the oscillations of the center of gravity offered the patient the opportunity to achieve the degree of load and to successfully equalize the balance of forces at the level of the healthy / sick limb, to control in real time the position of the center of gravity inside the supporting polygon.

5.4. RESULTS AND DISCUSSIONS

The analysis of the results was performed by the graphical method and in order to illustrate in a more objective way this aspect, below are the graphical representations of the results of the groups of subjects included in the research. Such representations were made for the parameters of the distribution of body weight at the level of the lower limbs and for the parameters of balance (average distance of the center of gravity in relation to the support polygon on the x and y axes, length of the curve and maximum velocity of the center of gravity) for all four tested positions: eyes open, eyes closed, head towards healthy / dominant limb and head towards diseased / non-dominant limb.

Testing the main hypothesis 1

In order to test the main hypothesis 1, we performed a series of statistical analyzes through which we aimed to compare the initially results with the final ones of group 1, as well as the comparison of the finally results of group 1 with those of group 2.

The distribution of body weight (DBW) showed obvious improvements from the initially assessment to the finally assessment in all four test positions, with a tendency for the final assessment values to be specific to the level of the minimum load difference. At the same time, the t test reveals results that are statistically significant for all evaluated pairs, this being true for all four evaluation positions (**p <0.05**) and this aspect involves identifying a statistical significance of the difference between the initial and final averages; we can also distinguish that the two groups obtained similar results of DBW at the level of the lower limbs in the case of all evaluated positions, the results being within normal parameters (minimum loading differences), and from a statistical point of view the independent t test shows that the averages of the two groups do not show significant differences of the average values for any of the tested positions, the value of the significance threshold being **p> 0.05**. The analysis of this information may suggest that the follow-up of rehabilitation protocol, which included stabilometric re-education exercises, is proving to be an effective attitude to equalize the loading of body weight at LL level and patients have no longer the tendency to protect affected limb.

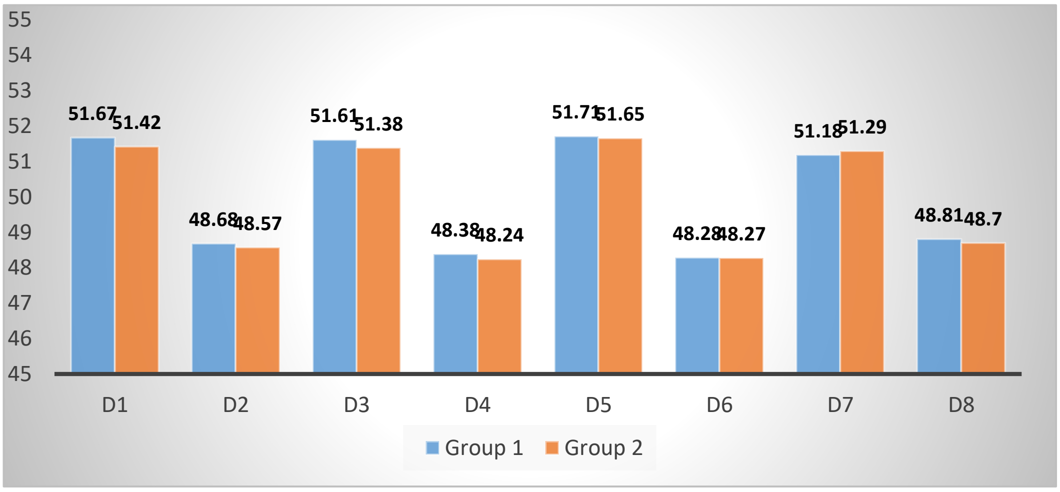


Figure 3. Arithmetic mean for the body weight distribution of the two groups

In this context, we consider that studies that highlight how to load body weight in patients undergoing surgery for anterior cruciate reconstruction and, especially after the completion of the functional rehabilitation protocol and even at a distance of more than 6 months, are very important. The lack of normalization of this parameter may be responsible, on the one hand, for the installation of a functional deficit in the operated lower limb, due to the excessive tendency to protect it, and on the other hand may lead to mechanical overloads in the healthy lower limb, thus even in cartilage lesions, due to these overloads. This is also confirmed by a topical study, which offers a new perspective on body weight loading after reconstruction of the anterior cruciate ligament as significant changes were observed from 2 to 8 years post-intervention in the non-uniform weight loading mode lower limbs and these have been associated with pathological changes in the femoral cartilage (Erhart-Hledik, Chu, Asay, Favre & Andriacchi, 2020).

The presence of asymmetries in body weight loading may be associated with long-term pathological changes, and the association between lower limb weight loading and persistent knee symptoms is unclear and this hypothesis needs to be investigated; the existence of differences in neuromuscular control between affected / dominant and healthy / non-dominant limbs may have important implications for the specific rehabilitation of athletes and for the resumption of sports activities (Pietrosimone et al., 2019; Souissi et al., 2020).

The analysis of the results obtained and their correlation with those of similar studies highlights the idea that equalization of body weight load should be among the basic objectives of the functional rehabilitation protocol specific to postligamentoplasty patients and stabilometric rehabilitation exercises achieved through the stabilometric platform, proves to be an effective strategy in order to achieve this goal.

Testing the secondary hypothesis 1.1

In order to test the secondary hypothesis 1.1, we performed the analysis of variance (ANOVA), in order to verify if there are significant differences between the average values of the subjects according to gender and the results are presented below. In this way it can be seen whether the groups of subjects present scores with different averages according to gender for the DBW parameter, creating a database in which the subjects of both groups were included, but divided according to gender (final results of group 1 -13 women and 15 men and group results 2-14 women and 15 men).

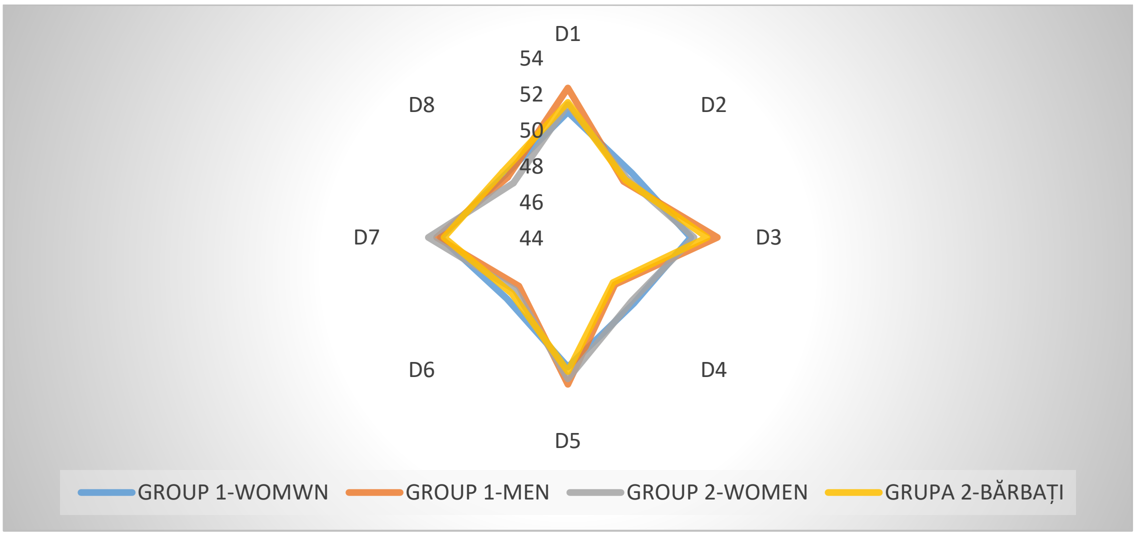


Figure 4. Average body weight distribution values for the two groups by gender

The results of the analysis of variance revealed that the average values of the two groups divided according to gender do not show statistically significant differences for this parameter, for any of the positions examined (**p> 0.05**). This illustrates that the DBW is not distinct in gender-based research subjects because they have similar values and the functional rehabilitation protocol, in which were introduced stabilometric re-education exercises, is proving to be effective in improving weight distribution in post-reconstruction subjects, both male and female, the averages being within normal values, with minimal differences in load.

Testing the secondary hypothesis 1.2

In order to highlight whether the follow-up of the functional rehabilitation protocol determines changes in the DBW at LL level according to age, we divided the subjects of group 1 into two age ranges (15 subjects in the age range 21-36 years, respectively 13 subjects in the age range 37 -52 years); the mean values of body weight distribution do not show statistically significant differences by age for any of the positions examined (p> 0.05), which means that the functional rehabilitation protocol is effective in improving this parameter regardless of age range.

Testing the main hypothesis 2

In order to test the main hypothesis 2, the same statistical analyzes were performed as in the case of DGC, and the results regarding the equilibrium parameters (ADCG in relation to PS, curve length and maximum velocity of the center of gravity) are presented below.

The ADCG parameter experienced considerable improvements from initially to finally assessment, this being true for all test positions, both in the antero-posterior axis (x-axis) and in the mid-lateral axis (y-axis). From a statistical point of view, we identify significant results between the initially and finally averages among all test positions (**p <0.05**). Carrying out such an assessment is important in the case of post-ligamentoplasty patients as it reveals information about the balance parameter and how it is disturbed. In order to analyze the clinical relevance it might be helpful to make a comparison between the final values of the group of subjects with ligamentoplasty and the results of a control group (group of healthy subjects).

Aspects related to the assessment of the mean distance of the center of gravity in ACL reconstruction patients have been addressed in current studies, which partially confirm our results and in which it was concluded that post-surgical reconstruction of this ligament and following the rehabilitation protocol, many patients present a significantly low static postural stability, as well as increased center of gravity speeds (Lehmann et al., 2021). In the same context and for the same category of subjects, postural balance was quantified based on the antero-posterior and mid-lateral displacements of the center of gravity along the x and y axes, including balancing speed (Lehmann, 2017). Another study supports our results regarding the evaluation method, stating that through the stabilometric analysis, deviations of the center of gravity in the frontal plane were identified among patients with orthopedic diseases (Neculăeș, 2014).

The data presented in this study were collected through the GPS 400 stabilometer platform, but there are many other similar devices with the same use. For example, postural stability was determined from anterior-posterior, medial-lateral, and general stability indices using the Biodex stability system. As a result of the use of this device, no significant differences in postural stability were observed in the lower limbs in patients with isolated ruptures of the anterior cruciate ligament and in those with ligament lesions combined with medial meniscus lesions (Park, Jeong, Lee , Cho & Lee, 2015). Assessing the average distance center of gravity parameter in ACL reconstruction patients proves to be a valuable measure as in this way we can analyze how patients with such interventions manage to maintain balance both antero-posteriorly and medially. laterally and thus we could obtain objective data on the efficiency of the functional rehabilitation protocol and on the benefits brought to it by introducing the stabilometric re-education exercises, carried out through the stabilometric platform.

It can be seen that the results on the length of the curve have improved from the initially to the finally evaluation for all evaluation positions and from a statistical point of view the average of the initially and finally values differs significantly, this being true in the case of all evaluated positions (**p <0.05**). The analysis of this information leads to the idea that patients with ligamentoplasty postoperatively show an obvious impairment of the length of the center of gravity curve, and the rehabilitation protocol, which included stabilometric re-education exercises, proves to be effective in improving this parameter; In the same context, we can see that the highest initially and finally values are valid for the test position with the eyes closed, which could significantly affect the length of the center of gravity curve in case of cancellation of the visual stimulus.

We have provided evidence of an improvement in the maximum speed of the center of gravity from initially to finally assessment for all assessed positions. From a statistical point of view, the average of the initially and finally values show significant differences in the test positions with the eyes open and the head turned towards the healthy limb, while for the other positions the average results do not show significant differences (**p> 0.05**). Analyzing this information may suggest that the average speed of the center of gravity is changing among ACL reconstruction patients, and the rehabilitation protocol, which included stabilometric re-education exercises, is proving partially effective in improving it, which could mean a minimal change in this postoperative parameter or a partial efficiency of the rehabilitation protocol. We consider that in order to provide a clinical significance of these results it would be necessary to compare them with the results obtained by a control group (healthy subjects).

The balance parameter has been targeted in numerous studies that have focused on patients undergoing ACL reconstruction surgery and postural balance has been quantified based on antero-posterior and mid-lateral displacement of the center of gravity and including balancing speed; the balancing area described the area of the ellipse covered by 95% of the trajectory of the center of gravity (Lehmann, 2017; Lehmann, 2021). The partial results of our study are supported by other studies, in which it was noted that balance exercises could partially improve the indications of dynamic stability in the early stages of post-surgical rehabilitation and that such exercises should be part of the rehabilitation program (Akbari, Ghiasi, Mir & Hosseinifar, 2016).

Some studies have suggested that patients may adapt their sensory-motor control strategies after ACL reconstruction by increasingly involving visual information to maintain postural balance. The results of our study show higher values of the maximum speed of the center of gravity in the test position with the eyes closed, and this is supported by other studies in which a significantly lower postural stability was demonstrated when vision was obstructed (Lehmann, 2021).

The preliminary results of our study reveal a high efficiency of the functional rehabilitation protocol, which included stabilometric re-education exercises performed on the stabilometric platform, and in terms of balance parameters (oscillations of the center of gravity relative to the support polygon on antero-posterior and mid-lateral axes, curve length and maximum speed) we can say that we have obtained an obvious improvement of all parameters from the initial evaluation to the final one.

Testing the secondary hypothesis 2.1

The analysis of variance (ANOVA) was performed to see if there are significant differences between the mean values of the subjects according to gender, and the results are presented below. In this way it can be seen whether the groups of subjects have scores with different averages depending on gender for the equilibrium parameters (ADCG in relation to SP on the antero-posterior and mid-lateral axis, curve length and maximum speed of center of gravity). A database was created in which the subjects of both groups were included, but divided according to gender (final results of group 1-13 women and 15 men and results of group 2-14 women and 15 men).

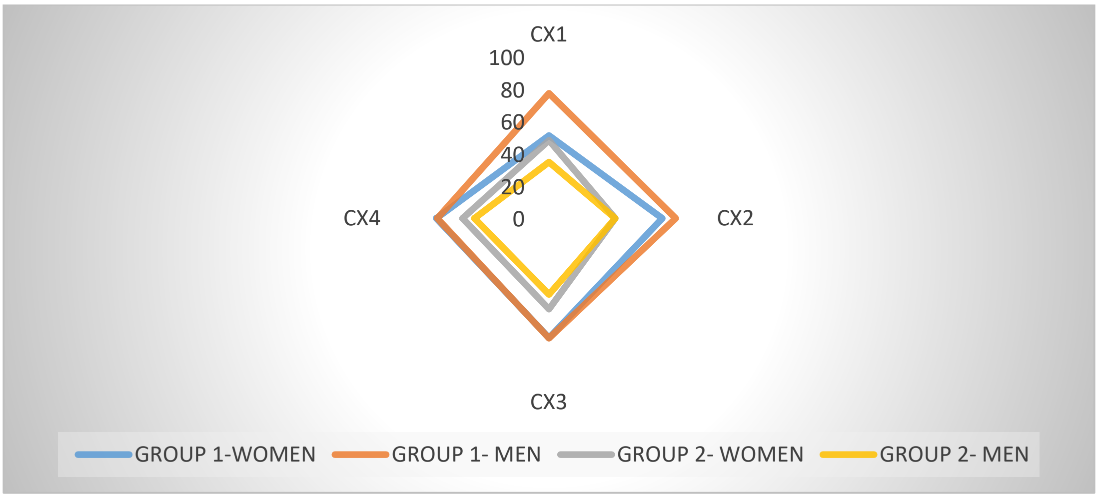


Figure 5. Mean values for mean center of gravity distance on the x-axis, by gender, for the two groups

Our results are partially supported by other studies, which showed that kinematic asymmetries were characteristic of both men and women after anterior cruciate ligament injuries and after surgery, and the persistence of limb loading asymmetries in men and women at 6 months after reconstruction indicates that current rehabilitation efforts are inadequate for some individuals, regardless of gender (Di Stasi, Hartigan & Snyder-Mackler, 2015). In the same context, the biomechanical profiles related to "rigid gait" and the dynamic lower extremity valgus were identified in men and women who received the approval to resume sports activities after surgical reconstruction of the anterior cruciate ligament and both men and women have asymmetries in the joints knees (Hartigan et al., 2016). Taking into account all this information, we can state that post-ligamentoplasty patients have impaired balance parameters and the functional rehabilitation protocol does not require the customization of kinetic means used by gender except for the curve length parameter, which is effective for both female and for males.

Testing the secondary hypothesis 2.2

In order to highlight whether following the functional rehabilitation protocol causes changes in the parameters of age balance, we divided the subjects of group 1 into two age ranges (15 subjects in the age range 21-36 years, respectively 13 subjects in the age range 37-52 for years); thus we performed the analysis of variance (ANOVA) and obtained the following results:

► regarding the results of the average distance of the center of gravity in relation to the support polygon on the antero-posterior and medial-lateral axis, it is distinguished that this parameter does not show statistically significant differences in the mean values according to age for any of the positions. examined (**p> 0.05**), which can be translated into the effectiveness of the functional rehabilitation protocol regardless of the age range;

► the results of the length of the center of gravity curve show no statistically significant differences by age for any of the positions examined (**p> 0.05**), which means that the functional rehabilitation protocol is proves effective in improving it regardless of age range;

► the results of the maximum speed of the center of gravity are the same as for the length of the curve, the average values of this parameter show no statistically significant differences according to age for any of the positions examined **(p> 0.05**), which means that the functional rehabilitation protocol is proving effective in improving it regardless of the age range.

Testing the main hypothesis 3

In order to determine how the functional rehabilitation protocol influences the body weight distribution and the balance parameters in the case of patients with LIA reconstruction, we performed the Pearson correlation.

We can say that the results partially support the main hypothesis 3 as we identified statistically significant correlations between body weight distribution and average center of gravity distance on the x and y axes, curve length and maximum center of gravity speed only for certain assessment positions. At the same time, our results partially support the results of other studies, in which the correlations between the neuromuscular control index and the levels of functional activity were assessed by Pearson's correlation coefficient and a relationship of interdependence between balance and muscle strength knee function improved in parallel with dynamic postural stability (Park et al., 2020; Lee et al., 2019).

In the same vein, the analysis of the above data supports the idea that both the distribution of body weight and the parameters of balance have experienced an obvious improvement, even with the presence of significant correlations between them; at the same time, these results may suggest that the functional rehabilitation protocol for patients with cruciate ligament reconstruction influences both body weight distribution and balance parameters and supports the results of other studies that have shown the effectiveness of including stabilometric rehabilitation exercises to improve balance parameters and body weight distribution in the case of neurological or orthopedic patients (Lucaci & Neculăeș, 2020; Neculăeș, 2014), but their evolution is partially linear and the improvement of body weight distribution does not necessarily mean the improvement of the center of gravity parameters. These results could also suggest that the improvement of these parameters should also be achieved by means and methods with individual addressability.

5.5. PARTIAL CONCLUSIONS

The therapeutic approach of active patients after anterior cruciate ligament reconstruction requires improvements in order to prevent the installation of asymmetries of body weight loading in the lower limbs and to improve balance parameters, which can be translated by normalizing functional status and resuming the risk of recurrence.

According to the results obtained we can say that the main hypotheses 1 and 2 are supported because we identified a normalization of the degree of body weight loading and an obvious improvement of the balance parameters, comparing the final results of the subjects of group 1 with the results of group 2 expressing similar results, with statistical relevance. Regarding the comparison of the results of the two groups included in the study according to gender and age, the analysis of variance highlighted the idea that the functional rehabilitation protocol leads, to a large extent, to an equal improvement in body weight distribution and parameters of balance among both female and male subjects, as well as regardless of their age range, aspects that support the secondary hypotheses 1.1, 1.2, 2.1 and 2.2.

Another conclusion relates to the fact that the results obtained partially support the main hypothesis 3 as we have identified to a small extent an interdependence between body weight distribution and balance parameters, which means that the means of the functional rehabilitation protocol must be specifically targeted, in order to influence these parameters particularly.

The innovative method of functional rehabilitation applied to the subjects of this study, with the introduction of stabilometric re-education exercises performed through the GPS 400 stabilometric platform, can be considered a reliable and effective strategy to achieve a degree of symmetry of body weight loading and center of gravity oscillations relative to the supporting polygon.

FINAL CONCLUSIONS

After studying the literature we can say that, among the current functional rehabilitation of patients with ACL reconstruction, is the use of technological equipment. They can be used both for the evaluation process, in order to identify some functional parameters, and as actual tools for their improvement; however, there is minimal use of stabilometric platforms calibrated to a software-type system, aimed at assessing body weight distribution or balance parameters and subsequently focusing on strategies to improve them.

According to the results of the preliminary study and the main study, we can say that the use of the GPS 400 stabilometer platform proves to be a technological equipment that can streamline the functional reeducation protocol, by integrating stabilometric reeducation exercises and obtaining load correction body weight and improvement of balance parameters (average distance of the center of gravity relative to the supporting polygon in the antero-posterior and mid-lateral axis, the length of the curve and the maximum speed of the center of gravity). In this context, the originality of the work is also noticeable, which can really enhance the existing protocols.

Following this research, we consider that the main element of novelty, which can add value to functional rehabilitation, is the detailed description of the rehabilitation protocol followed by the subjects included in the second study. We have shown that this protocol is effective for a range of patients in the 21-52 age range, both for females and males. If validated by expert commissions, then it could be quantified as a good practice guide for clinicians in the field, ensuring the normalization of the functional status of patients with anterior cruciate ligament reconstruction and thus achieving the goal of improving life quality in the case of this category of patients.

LIMITS AND FUTURE RESEARCH DIRECTIONS

From the point of view of the limits of the research, a number of factors can be listed, such as the selection of the subjects included in the study, the way of carrying out their evaluation or the way of interpreting the results obtained.

The number of subjects included in the study was 55, aged ranged from 21 to 52 years; however, if we were to analyze the average age of the two groups, we can see fairly close values between them (group 1-33.35 years, with a standard average error ± 8.07 years and group 2-32.37 years, with a standard average error ± 9.72 years), which means that the results of the research can be considered eloquent. Another aspect that could have been within the limits of the research may be the way in which patients followed the specific indications and recommendations for rehabilitation; each subject received a series of clear and easy-to-follow recommendations and in the recovery work they were followed exactly, but outside the practice, such issues were more difficult to manage.

We can say that, in order to carry out a research that would allow to offer a more significant perspective on the topic approached, it would have been necessary to include a larger number of subjects and this would have been done exactly, but there were situations that led to the limitation of the number of subjects (pandemic situation, change of address, health or personal reasons); however, the analysis of the results contained in this research gives us the opportunity to draw preliminary conclusions, which should also be the starting point for future research in this field.

Another limitation of the research refers to the follow-up of patients until the completion of the functional re-education process, for a period of six months; we have studied in the literature that these patients may present with certain functional deficits even two years after the postoperative period and, in order to verify the effectiveness of the protocol described in the research, the subjects should be followed up in the long term.

Taking into account the latest statement, a future direction of research is outlined, which refers to the achievement of a study in which subjects with ACL reconstruction to go through the protocol described in this study and to carry out a long-term follow-up of them, by performing periodic stabilometric assessments (12 months, 18 months and 24 months postoperatively). Another future direction of research could be the evaluation of parameters that highlight, in addition to the distribution of body weight and the oscillations of the center of gravity in relation to the supporting polygon, the effort capacity of the subjects and thus to achieve certain correlations between them.

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