Osmangazi Journal of Med, 2025;47(3):422-429
DOI: 10.20515/otd.1635016

Research Article
Araştırma Makalesi

Osmangazi Journal of Medicine
e-ISSN: 2587-1579

Effect of Body Composition and Hamstring Flexibility on Closed Kinetic Chain Lower Extremity Stability in Young Adults: A Cross-sectional Study

Genç Erişkinlerde Vücut Kompozisyonu ve Hamstring Esnekliğinin Kapalı Kinetik Zincir Alt Ekstremite Stabilitesi Üzerine Etkisi: Kesitsel Bir Çalışma

Hande ÖZDEMİR

Department of Physical Medicine and Rehabilitation, Trakya University Faculty of Medicine, Edirne, Türkiye

ORCID ID of the authors
HÖ. 0000-0002-1717-9604

Correspondence / Sorumlu yazar:
Hande ÖZDEMİR

Department of Physical Medicine and Rehabilitation, Trakya University Faculty of Medicine, Edirne, Türkiye

e-mail: handeozdemirmd@gmail.com

Abstract: The kinetic chain refers to the coordination of segments of the body for holistic movement; its assessment and enhancement have the potential to improve sports performance and reduce the risk of injury. This study aims to explore the relationship between body composition, hamstring flexibility, and closed kinetic chain lower extremity stability. A total of 92 young adults who were uninjured and exhibited a moderate level of physical activity were the subjects of a series of tests designed to ascertain their body composition using bioimpedance analysis, hamstring flexibility using the sit-and-reach test, and lower extremity kinetic chain function using the closed kinetic chain lower extremity stability test (CKCLEST). An analysis revealed no discernible relationship between the CKCLEST test score and body composition measurements or sit-and-reach test scores, with a statistical significance level of $p<0.05$. It is important to recognise that factors such as body composition and flexibility may not directly influence CKCLEST results. The findings of this study are anticipated to facilitate a more efficacious utilisation of CKCLEST in clinical practice and a more profound comprehension of its potential benefits.
Keywords: Body composition, Closed kinetic chain, Flexibility, Lower extremity, Physical activity.

Özet: Kinetik zincir, bütünsel hareketler için vücut segmentlerinin koordinasyonunu ifade eder; değerlendirilmesi ve geliştirilmesi spor performansını iyileştirme ve yaralanma riskini azaltma potansiyeline sahiptir. Bu çalışma, vücut kompozisyonu, hamstring esnekliği ve kapalı kinetik zincir alt ekstremite stabilitesi arasındaki ilişkiyi araştırmayı amaçlamaktadır. Yaralanmamış ve orta düzeyde fiziksel aktivite düzeyine sahip toplam 92 genç yetişkine, vücut kompozisyonlarını değerlendirmek için biyoimpedans analizi, hamstring esnekliğini değerlendirmek için otur-eriş testi ve alt ekstremite kinetik zincir fonksiyonunu belirlemek için kapalı kinetik zincir alt ekstremite stabilite testi (CKCLEST) uygulanmıştır. Yapılan analizler sonucunda, $p<0,05$ istatistiksel anlamlılık düzeyi ile, CKCLEST test puanıyla vücut kompozisyonu ölçümleri veya otur-eriş test skorları arasında önemli bir ilişki olmadığı görülmüştür. Vücut kompozisyonu ve esneklik gibi faktörlerin, CKCLEST sonuçlarını doğrudan etkilemeyebileceğinin akılda tutulması önemlidir. Bu çalışmanın bulgularının, CKCLEST'in klinik uygulamada daha etkili bir şekilde kullanılması ve potansiyel faydalarının daha derinlemesine anlaşılmasını kolaylaştırması beklenmektedir.
Anahtar Kelimeler: Vücut bileşimi, Kapalı kinetik zincir, Esneklik, Alt ekstremite, Fiziksel aktivite.

Ethics Committee Approval: The study was approved by Trakya University Noninterventional Clinical Research Ethical Committee (TÜTF-GOBAEK 14/07 02.09.2024).

Informed Consent: The author declared that informed consent was obtained from the participants in the study.

Authorship Contributions Concept, data collection, processing, analysis, interpretation, literature search, writing: HÖ.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study received no financial support.

Received : 07.02.2025
Accepted 09.04. 2025
Published :. 11.04.2025

How to cite/ Atıf için: Ozdemir H, Effect of Body Composition and Hamstring Flexibility on Closed Kinetic Chain Lower Extremity Stability in Young Adults: A Cross-sectional Study, Osmangazi Journal of Medicine, 2025;47(3):422-429

1. Introduction

The kinetic chain refers to the coordinated activation of extremity muscles to perform activities requiring flexibility, strength, proprioception, and endurance (1). In closed kinetic chain activity, the terminal joint encounters resistance, restricting free movement, while open kinetic chain activity allows the terminal joint to move freely (2). Muscle activation patterns generate segment movements and positions, with length-dependent patterns controlling joint distortions and force-dependent patterns harmonizing movements across multiple joints. These patterns create stability and allow for voluntary muscle activity (3).

The realization that closed kinetic chain exercises can enhance dynamic stability via approximation and co-contraction of joints, as well as the resulting compression, has led to a notable rise in the incorporation of such activities into clinical rehabilitative regimens. Moreover, it has prompted the notion that the evaluation of stability via closed kinetic chain activities may elucidate whether patients are prepared to resume their activities or if they require additional rehabilitation (4).

The Closed Kinetic Chain Lower Extremity Stability Test (CKCLEST) is a performance-based assessment that provides quantitative data for evaluating lower extremity stability in closed kinetic chains. It is a practical and economical tool that can be utilised in both clinical and sports settings. The test involves quantifying the number of times subjects make contact with their opposite foot to the outside diagonal of the other foot in a closed kinetic chain position (push-ups), alternating with three trials for 15 seconds (5).

Research shows that a higher body mass index (BMI) is negatively correlated with hamstring flexibility, indicating that increased body fat may hinder muscle flexibility (6). Additionally, greater hamstring flexibility is linked to improved dynamic stability in the lower extremities during closed kinetic chain exercises, which are considered more effective than open kinetic chain exercises for enhancing balance and stability (7). Given these relationships, there is a pressing need for further research to investigate how body composition, hamstring flexibility, and closed kinetic chain stability are interconnected, particularly across different populations and athletic contexts (8). Understanding these dynamics could lead to targeted interventions designed to improve lower extremity function and overall physical performance. The present study was designed with the objective of evaluating a potential correlation of body composition and hamstring flexibility with closed kinetic chain lower extremity stability in young adults.

2. Materials and Methods

2.1.Participants

This cross-sectional study was conducted at Trakya University Faculty of Medicine between September 2024 and January 2025. The inclusion criteria were that the participants should be 18–25 years of age; be undergraduate students at the Faculty of Medicine or Faculty of Health Sciences of the Trakya University (Türkiye), and have a moderate levels of physical activity according to the Saltin-Grimby physical activity scale (1). Exclusion criteria encompassed individuals who had experienced pain or chronic comorbidities that could impact the study's assessments, or those who had experienced a fracture or dislocation of the lower extremity within the previous 12 months.

Subjects volunteered for the study in accordance with the Declaration of Helsinki and signed the Informed Consent Form. The necessary permission and approval for the study was obtained from the University Clinical Research Ethics Committee (TÜTF-GOBAEK-14/07/02.09.2024).

2.2. Sample Size Calculation

In accordance with the methodology proposed by Lepinet et al. (2), the effect size was calculated to be 0.60. The study was designed to include a total of 90 volunteers, with an 80% power and a 5% error level.

2.3. Measurements

The data collection process encompassed the following components: demographic data, eligibility assessment, signed informed consent forms, body composition analysis, assessment of hamstring flexibility, and assessment of lower extremity closed kinetic chain function. All assessments were conducted on the same day of the week between the hours of 9:00 and 12:00. To ascertain the level of physical activity within the context of the fitness assessment, participants were requested to indicate which description most closely aligns with their level of physical activity during their leisure time over the past year, as defined by the Saltin-Grimby physical activity scale (1). Individuals who indicated screen (computer, TV) activities, reading books, or other sedentary pursuits were classified as inactive. Those who reported engaging in moderate-intensity physical activities, such as walking or cycling for a minimum of four hours per week, were categorized as moderately active. Individuals who responded that they participated in recreational sports, heavy outdoor activities, or rowing for a minimum of four hours per week were classified as highly active. Finally, those who indicated that they engaged in heavy exercise or participated in sports competitions on most days of the week were considered to be very highly active. Individuals who did not meet the criteria for a moderate physical activity level were excluded from the study.

2.3.1. Body Composition Analysis

A Tanita MC-780 multi frequency segmental Body Composition Analyzer (Tanita Corporation, Tokyo) was employed for the purpose of conducting a body composition analysis of the participants. The height of the participants was measured by using a stadiometer, and their age and height were entered into the equipment manually. The bioimpedance analysis measurements were conducted in accordance with the instructions provided by the manufacturer. The participants were instructed to assume an upright posture with their bare feet touching the sole of the analyzer while wearing light clothing (3) . The data provided included measurements of weight (total body), percent fat mass, fat mass, fat free mass, trunk muscle mass, appendicular skeletal muscle mass. In addition, fat mass index, fat free mass index, and appendicular skeletal muscle mass index values were calculated by dividing fat mass, fat free mass, and appendicular skeletal muscle mass values by the square of the height and fat mass to fat-free mass ratio was obtained by dividing fat mass value by fat free mass value (4-6). BMI was calculated according to the following formula: body mass in kilograms divided by the square of stature in meters (kg/m^2) (7).

2.3.2. Sit-and-Reach Test (SRT)

The assessment of hamstring flexibility was conducted through the administration of the SRT. The SRT was conducted in accordance with the guidelines set forth in the EUROFIT manual, utilizing a standard SRT apparatus. The participants were instructed to assume a seated position without shoes, with the knees fully extended, the feet positioned at shoulder width with the soles of the feet resting on the test bench, the arms extended with the palmar side of the hands facing down, the head between the arms, and to bend forward with the body while maintaining the maximum reach position for one to two seconds (Figure 1). Subsequently, the distance reached by the fingers was determined in centimeters. The test was repeated twice, and the largest value was recorded (8, 9).

Figure 1. Sit-and-reach Test application

2.3.3. The CKCLEST Test

The CKCLEST was conducted in accordance with the methodology delineated by Arikan et al (10). The evaluator introduced the participants to the CKCLEST method, explaining its procedure. The test required the provision of a stable floor, a mat, and a chronometer. The initial position entailed assuming a plank posture on the mat with the forearms on the floor, the feet positioned at shoulder width and in contact with the floor, and the body forming a straight line (Figure 2a, 2b). Subsequently, the subject was required to bring one foot diagonally outside the other foot, making contact with the side of the other foot, and return to the starting position (Figure 2c, 2d). This movement was repeated with both feet for a period of 15 seconds. The number of times the foot touched the side of the other foot and the floor was recorded. Prior to the administration of the actual test, each subject was provided with an opportunity to familiarize themselves with the procedure. The test was repeated three times, with a one-minute interval between repetitions, and the highest score achieved was used as the data.

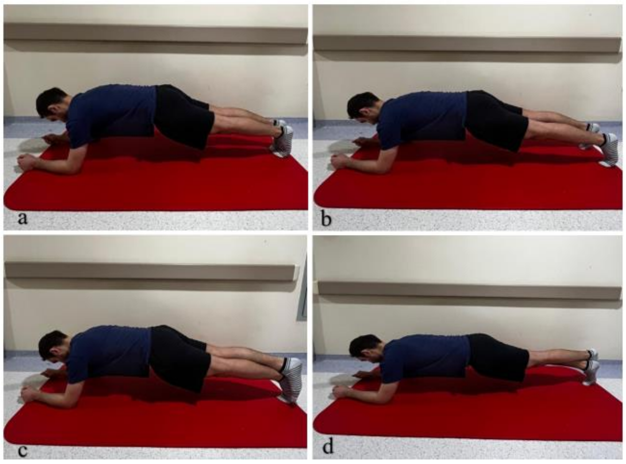

Figure 2. The Closed Kinetic Chain Lower Extremity Stability Test starting position (a,b) and application (c,d)

2.4. Statistical analysis

The analysis was conducted using the IBM SPSS Statistics software, version 23. The Shapiro-Wilk test was employed to ascertain the normal distribution of the data (values of P>0.05 were deemed indicative of normal distribution). Categorical data are presented as a frequency (%), while numerical data are presented as a mean (standard deviation) and a median (minimum-maximum). As the assumption of normal distribution was not confirmed, the Mann-Whitney U test was used for comparisons between groups, and Spearman correlation test was used to assess the relationship between CKCLEST scores and body composition measurements and SRT scores. A p-value less than 0.05 was considered statistically significant.

3. Results

A total of 92 young adults, comprising 46 females and 46 males aged 20-25 years, who were uninjured and had a moderate level of physical activity, were evaluated in the study. Table 1 provides an overview of the average weight, height, BMI, and body composition measurements, as well as SRT scores and CKCLEST scores of the participants. A statistical difference was observed between male and female participants in terms of body composition measurements, excluding fat mass, and SRT scores. However, CKCLEST test scores were found to be similar.

Table 1. Demographic characteristics, body composition measurements, SRT and CKCLEST scores of the participants

	Total (N=92) Mean (SD) Median (min-max)	**Female (N=46) Mean (SD) Median (min-max)**	**Male (N=46) Mean (SD) Median (min-max)**	**p**
Age, years	22.48 (1.15) 22.0 (20.0-25.0)	22.59 (0.96) 22.5 (21.0-25.0)	22.37 (1.32) 22.0 (20.0-25.0)	0.359
Weight*, kg	69.91 (15.85) 69.1 (43.4-113.5)	61.16 (13.37) 58.3 (43.4-113.5)	78.65 (13.14) 77.15 (50.6-110.2)	<0.001
Height*, cm	171.84 (9.21) 171.0 (153.0-195.0)	165.11 (6.11) 165.0 (153.0-180.0)	178.57 (6.44) 178.0-167.0-195.0)	<0.001
BMI*, kg/m^2	23.51 (4.39) 23.4 (16.5-39.3)	22.40 (4.51) 22.0 (17.1-39.3)	24.62 (4.00) 24.5 (16.5-36.9)	0.002
Percent FM*, (%)	21.63 (7.90) 20.65 (4.2-44.9)	25.27 (7.26) 24.35 (12.7-44.9)	17.99 (6.81) 17.15 (4.2-33.9)	<0.001
FM, kg	15.53 (8.13) 14.0 (2.5-51.0)	16.29 (8.55) 14.9 (5.8-51.0)	14.76 (7.69) 13.75 (2.5-35.3)	0.380
FFM*, kg	51.77 (11.16) 51.75 (34.9-83.2)	42.60 (5.21) 42.25 (34.9-59.4)	60.95 (7.25) 60.15 (40.7-83.2)	<0.001
FM/FFM*	0.30 (0.14) 0.27 (0.05-0.86)	0.37 (0.15) 0.34 (0.15-0.86)	0.24 (0.11) 0.22 (0.05-0.54)	<0.001
FMI*, kg/m^2	5.31 (2.83) 4.39 (0.79-17.65)	5.95 (3.01) 5.59 (2.27-17.65)	4.67 (2.52) 4.19 (0.79-12.51)	0.024

FFMI*, kg/m^2	17.36 (2.45) 13.29-23.20	15.62 (1.64) 15.17 (13.47-20.55)	19.09 (1.82) 19.03 (13.29-23.20	<0.001
TMM*, kg	28.04 (4.97) 28.0 (19.2-41.8)	24.30 (3.02) 24.05 (19.2-34.4)	31.78 3.51) 31.20 (23.3-41.8)	<0.001
ASMM*, kg	23.62 (6.14) 23.25 (15.0-37.3)	18.30 (2.28) 18.4 (15.0-25.0)	28.93 (3.64) 28.85 (17.40-37.30)	<0.001
ASMMI*, kg/m^2	7.89 (1.48) 7.82 (5.68-2.15)	6.71 (0.70) 6.50 (5.92-8.75)	9.07 (1.05) 9.10 (5.68-12.15)	<0.001
SRT score*	24.66 (9.98) 24.0 (3.0-48.0)	26.92 (8.41) 26.25 (12.0-48.0)	22.40 (10.97) 22.0 (3.0-48.0)	0.032
CKCLEST score	14.66 (3.39) 14.0 (9.0-28.0)	14.22 (3.00) 13.5 (9.0-25.0)	15.11 (3.71) 15.0 (9.0-28.0)	0.162

ASMM: Appendicular skeletal muscle mass, ASMMI: Appendicular skeletal muscle mass index, CKCLEST:The Closed Kinetic Chain Lower Extremity Stability Test, FFM:fat free mass, FFMI: fat free mass index, FM:fat mass, FMI: fat mass index, SRT: Sit-and-reach test, TMM: trunk muscle mass

**Significant difference between males and females (p<.001)*

Mann-Whitney U test

Level of significance set at p < 0.05

Analysis of the data showed no significant correlation between CKCLEST test scores and weight, height, BMI, percentage of total body fat, total fat mass, fat-free mass, fat-free mass index, fat mass to fat-free mass ratio, fat mass index, fat-free mass index, trunk muscle mass, skeletal muscle mass and skeletal muscle mass index. Furthermore, a lack of correlation was identified between CKCLEST test scores and SRT scores. The results of the correlation analysis are shown in Table 2.

Table 2. The correlations between CKCLEST scores and body composition measurements and SRT scores

		Weight	Height	BMI	Percent FM	FM	FFM	FM/FFM	FMI	FFMI	TMM	ASMM	ASMMI	SRT score
CKCLEST score	Rho p	0.047 0.658	0.149 0.156	-0.013 0.904	-0.119 0.258	-0.060 0.571	0.099 0.349	-0.125 0.237	- 0.095 0.368	0.054 0.609	0.101 0.339	0.102 0.335	0.070 0.510	0.175 0.095

ASMM: Appendicular skeletal muscle mass, ASMMI: Appendicular skeletal muscle mass index, CKCLEST:The Closed Kinetic Chain Lower Extremity Stability Test, FFM:fat free mass, FFMI: fat free mass index, FM:fat mass, FMI: fat mass index, SRT: Sit-and-reach test, TMM: trunk muscle mass

Spearman correlation test

Level of significance set at p < 0.05

4. Discussion

The findings of the present study demonstrate that closed kinetic chain lower extremity stability test scores are comparable between genders, and that health-related physical fitness parameters, including body composition and hamstring flexibility, do not exert a significant influence on stability during lower extremity closed kinetic chain activities in individuals with moderate physical activity.

Body composition, muscle strength and endurance, and flexibility are physiological parameters that are associated with health-related physical fitness (11). Each of these parameters has the potential to influence the risk of injury and to affect performance in both daily life and sports activities (12-16). The study conducted by Arikan et al. (10) revealed a moderate correlation between lower extremity closed kinetic chain stability and lower extremity muscle strength and endurance, which are health-related fitness parameters. In the study conducted by Almansoof et al. (17), a positive and moderate correlation was observed between soleus extensibility and lower extremity closed kinetic stability. To the best of my knowledge, the association of CKLEST with body composition and hamstring flexibility has never been evaluated before.

Factors affecting lower extremity stability tests are important considerations in developing rehabilitation protocols. While existing research suggests that women and men exhibit different kinematic patterns during rehabilitation exercises, the current study found no significant difference in closed kinetic chain lower extremity stability between genders. Previous findings emphasise that women generally exhibit smaller peak knee flexion angles and larger peak hip extension angles during rehabilitation exercises compared to men during closed kinetic chain rehabilitation exercises (18). In addition, women were observed to have greater anterior pelvic tilt, hip anteversion, quadriceps angles, tibiofemoral angles and genu recurvatum than men (19). These kinematic differences extend to upper limb stability tests where different ground reaction force patterns have been observed between males and females (20). Nevertheless, despite the aforementioned differences, the results of the current study are consistent with the notion that anthropometric factors, including upper and lower limb length and foot size, exert minimal influence on postural balance control in both sexes (21). The findings of the study call into question the assumption of inherent sex differences in closed kinetic chain lower extremity stability, suggesting that stability assessments may need to be more closely tailored to individual abilities rather than broad sex-based distinctions. In conclusion, while there are documented kinematic and anatomical differences between men and women, the study highlights the importance of focusing on personalised rehabilitation approaches. Such approaches should prioritise individual variability in stability rather than relying solely on gender-specific guidelines. Future studies should continue to investigate the underlying mechanisms contributing to these findings and further validate the applicability of the results in different populations.

Research has found that the strength of the lower extremity extensors in closed kinetic chain exercises is more closely related to jump performance compared to open kinetic chain exercises (22). Fat free mass is a significant factor linking body mass and jumping height, highlighting lower-extremity strength and neuromuscular performance in determining jump height (23). Conversely, fat mass has a negative impact on muscle strength and jump test performance in both young and older adults. (24). Studies have shown that regional and whole-body fat free mass correlate with strength in various exercises, with the relationship improving as muscle mass and thigh area increase (25). Higher appendicular skeletal muscle mass is associated with improved dynamic balance and stronger lower extremity strength in healthy college men (5). In women, lower extremity lean mass, particularly in those with lower lean mass, has been demonstrated to influence knee loading during landing and may impact biomechanical changes during prolonged exercise (26). While these studies suggest that lean mass plays a significant role in lower extremity performance and stability, the relationship between body composition and closed kinetic chain stability is complex and involves multiple factors beyond just muscle mass. Ferreira et al. (21) reported that body composition variables generally do not affect stability tests in individuals with a normal BMI, thereby supporting the results of the current study, which found no correlation between body composition and closed kinetic chain lower extremity stability. These findings emphasise the necessity for a more comprehensive approach to assessing lower extremity stability, incorporating factors beyond mere body composition, to ensure the efficacy of rehabilitation protocols.

Fascia is a network of connective tissue that supports the body and affects its biomechanics. Myofibroblasts regulate tissue tension and can influence muscle function. Myofascial chains show that muscles work together in interconnected ways, maintaining skeletal stability. Different myofascial chains of muscle groups, including the superficial back line and the thoracolumbar fascia, play a critical role in facilitating force transmission, coordinated movements, stability, and load transmission between the limbs and the core (27). The bi-articular hamstrings and gastrocnemius, elements of the superficial back line, work in a closed kinetic chain network to coordinate greater ranges of motion in the hip, knee, and ankle and contribute to a higher level of regulation (28). Analyses at the level of individual muscle groups revealed that the biarticular hamstrings and gastrocnemius serve to enhance the flexibility afforded by the motor control strategy (29). The study found no correlation between lower extremity closed kinetic chain stability and hamstring flexibility assessed by the sit and reach test. This contrasts with the findings of Almansoof et al. (17), who observed a significant positive correlation between weight-bearing ankle dorsiflexion and closed kinetic chain stability in male recreational athletes. Similarly, Encarnación-Martínez et al. (30) discovered that reduced hamstring flexibility, measured through the passive straight leg raise test, was associated with lower anterior reach on the modified star excursion balance test in physically active sport science students. These differences could stem from various factors, such as the method used to assess hamstring flexibility, the type of participants involved, and the specific measures of stability. The SRT is a test that has important benefits such as being easy to apply, requiring minimum skill, and evaluating large-scale flexibility in the evaluation of hamstring flexibility. However, the relationship of this test with lower extremity stability is not as direct as with ankle dorsiflexion. Therefore, the fact that the SRT does not correlate with CKCLEST is an indication of the complexity of lower extremity function and the interaction of many factors. Mitchell et al. (31) found that when hip and knee flexion and ankle dorsiflexion were combined, ankle dorsiflexion range of motion decreased, suggesting different positions in the test can affect results. While the studies by Almansoof et al. (17) and Encarnación-Martínez et al. (30) provide evidence that flexibility is positively associated with dynamic stability under certain conditions, the findings of the current study suggest that this relationship may not be universally valid and may depend on the context and specific tests used, highlighting the need for further research to better understand the complex interactions between different flexibility measures and closed kinetic chain lower extremity stability. Differences in testing methods and participant characteristics may significantly influence the results, and a more comprehensive approach to flexibility and stability assessment is needed to fully explain these relationships.

The present study involved young, uninjured individuals with moderate physical activity levels, which limits the generalisability of the findings to different populations with injuries, different health conditions, age groups, and physical activity levels. Future research should explore the performance of the CKCLEST test in diverse clinical groups. The cross-sectional design of the study precludes the drawing of definitive conclusions about cause-and-effect relationships, underscoring the necessity for longitudinal studies to evaluate changes in CKCLEST scores over time and their correlation with rehabilitation outcomes. Additionally, future studies could incorporate biomechanical analyses to enhance understanding of the muscles and joints involved in the test. The study's limitations also stem from the lack of control over participants' psychological state and motivation, introducing uncertainty into the interpretation of results. It is recommended that future studies take these factors into consideration when analysing CKCLEST performance, with the aim of achieving a more comprehensive understanding of test results and individual differences. Furthermore, these future studies will enhance the application of CKCLEST in clinical and sporting fields, as well as provide valuable insights into assessing and improving lower extremity stability.

5. Conclusion

The absence of a significant correlation between CKCLEST and body composition, as well as the SRT, in this study carries important implications for the clinical applications of the test. The finding that the CKCLEST is independent of gender, body composition and indirectly of the nutritional status of individuals suggests that this test is a reliable tool for assessing lower extremity stability. The results of study offer a significant advantage in the comparison and evaluation of individuals with different body structures. The present study lends support to the notion that, in clinical practice, greater emphasis should be placed on neuromuscular control, coordination, strength, and endurance as opposed to body composition or hamstring flexibility when assessing lower extremity stability. Consequently, rehabilitation programmes must be adapted to incorporate these principles.

REFERENCES

1. Grimby G, Börjesson M, Jonsdottir I, Schnohr P, Thelle D, Saltin B. The “Saltin–Grimby physical activity level scale” and its application to health research. Scand J Med Sci Sports. 2015;25:119-25.
2. Lepinet U, Tanniou J, Communier EC, Créach V, Beaumont M. Impact of anthropometric data and physical activity level on the closed kinetic chain upper extremity stability test (CKCUEST) score: A cross-sectional study. Phys Ther Sport. 2023;64:91-6.
3. Kyle UG, Bosaeus I, De Lorenzo AD, Deurenberg P, Elia M, Gómez JM, et al. Bioelectrical impedance analysis—part I: review of principles and methods. Clin Nutr. 2004;23(5):1226-43.
4. Kyle UG, Morabia A, Schutz Y, Pichard C. Sedentarism affects body fat mass index and fat-free mass index in adults aged 18 to 98 years. Nutrition. 2004;20(3):255-60.
5. Kim S-E, Hong J, Cha J-Y, Park J-M, Eun D, Yoo J, et al. Relative appendicular skeletal muscle mass is associated with isokinetic muscle strength and balance in healthy collegiate men. J Sports Sci. 2016;34(21):2114-20.
6. Xiao J, Purcell S, Prado C, Gonzalez M. Fat mass to fat-free mass ratio reference values from NHANES III using bioelectrical impedance analysis. Clin Nutr. 2018;37(6):2284-7.
7. Douketis JD, Paradis G, Keller H, Martineau C. Canadian guidelines for body weight classification in adults: application in clinical practice to screen for overweight and obesity and to assess disease risk. CMAJ. 2005;172(8):995-8.
8. Zanevskyy I, Zanevska L. Evaluation in the sit-and-reach flexibility test. J Test Eval. 2017;45(2):346-55.
9. Szulc P, Bartkowiak P, Boch-Kmieciak J, Lewandowski J, Owczarkowska E. The eurofi t sit and reach suppleness test competence of ballet school students. Trends Sport Sci. 2013;2(20):101-6.
10. Arikan H, Maras G, Akaras E, Citaker S, Kafa N. Development, reliability and validity of the Closed Kinetic Chain Lower Extremity Stability Test

(CKCLEST): a new clinical performance test. Res Sports Med. 2022;30(5):475-90.
11. Katzmarzyk PT, Malina RM, Song T, Bouchard C. Physical activity and health-related fitness in youth: a multivariate analysis. Med Sci Sports Exerc. 1998;30(5):709-14.
12. Grier TL, Canham-Chervak M, Bushman TT, Anderson MK, North WJ, Jones BH. Evaluating injury risk and gender performance on health-and skill-related fitness assessments. J Strength Cond Res. 2017;31(4):971-80.
13. Jones BH, Hauret KG, Dye SK, Hauschild VD, Rossi SP, Richardson MD, et al. Impact of physical fitness and body composition on injury risk among active young adults: a study of Army trainees. J Sci Med Sport. 2017;20:S17-S22.
14. Lisman PJ, de la Motte SJ, Gribbin TC, Jaffin DP, Murphy K, Deuster PA. A systematic review of the association between physical fitness and musculoskeletal injury risk: part 1—cardiorespiratory endurance. J Strength Cond Res. 2017;31(6):1744-57.
15. de la Motte SJ, Gribbin TC, Lisman P, Murphy K, Deuster PA. Systematic review of the association between physical fitness and musculoskeletal injury risk: Part 2—Muscular endurance and muscular strength. J Strength Cond Res. 2017;31(11):3218-34.
16. de la Motte SJ, Lisman P, Gribbin TC, Murphy K, Deuster PA. Systematic review of the association between physical fitness and musculoskeletal injury risk: part 3—flexibility, power, speed, balance, and agility. J Strength Cond Res. 2019;33(6):1723-35.
17. Almansoof HS, Nuhmani S, Muaidi Q. Correlation of ankle dorsiflexion range of motion with lower-limb kinetic chain function and hop test performance in healthy male recreational athletes. PeerJ. 2023;11:e14877.
18. Dwyer MK, Boudreau SN, Mattacola CG, Uhl TL, Lattermann C. Comparison of lower extremity kinematics and hip muscle activation during rehabilitation tasks between sexes. J Athl Train. 2010;45(2):181-90.
19. Nguyen A-D, Shultz SJ. Sex differences in clinical measures of lower extremity alignment. J Orthop Sports Phys Ther. 2007;37(7):389-98.
20. Welch ES, Watson MD, Davies GJ, Riemann BL. Biomechanical analysis of the closed kinetic chain upper extremity stability test in healthy young adults. Phys Ther Sport. 2020;45:120-5.
21. Ferreira BAdS, Benetti FA, Luna NMS, Brech GC, Bocalini DS, Maifrino LBM, et al. Anthropometric factors and body composition and their relationship with dynamic balance tests. Rev Bras Med Esporte. 2020;26:401-5.
22. Blackburn JR, Morrissey MC. The relationship between open and closed kinetic chain strength of the lower limb and jumping performance. J Orthop Sports Phys Ther. 1998;27(6):430-5.
23. Alotaibi MM, Alqahtani MM, Almutairi MK, Singh H, Ithurburn MP, Lein Jr Jr DH. Fat-free mass mediates the association between body mass and jump height in healthy young adults. J Sports Med Phys Fitness. 2024.
24. Moore B, Bemben D, Lein D, Bemben M, Singh H. Fat mass is negatively associated with muscle strength and jump test performance. J Frailty Aging. 2020;9:214-8.
25. Massini DA, Macedo AG, Almeida TA, Espada MC, Santos FJ, Castro EA, et al. Single-and Multi-Joint Maximum Weight Lifting Relationship to Free-Fat Mass in Different Exercises for Upper-and Lower-Limbs in Well-Trained Male Young Adults. Int J Environ Res Public Health. 2022;19(7):4020.
26. Montgomery MM, Tritsch AJ, Cone JR, Schmitz RJ, Henson RA, Shultz SJ. The influence of lower extremity lean mass on landing biomechanics during prolonged exercise. J Athl Train. 2017;52(8):738-46.
27. Almansoof HS, Nuhmani S, Muaidi Q. Role of kinetic chain in sports performance and injury risk: a narrative review. J Med Life. 2023;16(11):1591.
28. Levin S, de Solórzano SL, Scarr G. The significance of closed kinematic chains to biological movement and dynamic stability. J Bodyw Mov Ther. 2017;21(3):664-72.
29. Cleather DJ, Southgate DF, Bull AM. The role of the biarticular hamstrings and gastrocnemius muscles in closed chain lower limb extension. Journal of theoretical biology. 2015;365:217-25.
30. Encarnación-Martínez A, García-Gallart A, Pérez-Soriano P, Catalá-Vilaplana I, Rizo-Albero J, Sanchis-Sanchis R. Effect of hamstring tightness and fatigue on dynamic stability and agility in physically active young men. Sensors. 2023;23(3):1633.
31. Mitchell B, Bressel E, McNair PJ, Bressel ME. Effect of pelvic, hip, and knee position on ankle joint range of motion. Phys Ther Sport. 2008;9(4):202-8.