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Effect of Obesity on Proprioception and Balance

Obezitenin Propriosepsiyon ve Denge Üzerine Etkisi

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ABSTRACT Objective: The aim was to investigate the effects of obesity on proprioception and balance. **Material and Methods:** The study included 31 patients diagnosed with obesity and 31 healthy controls. Proprioceptive assessment was performed on the dominant shoulder and knee joints of the participants using the Cybex Isokinetic Dynamometer, applying the active repositioning method. It was assessed in the knee joint from 80° to 60°, 40°, 20°, and 10° flexion to extension. In the shoulder joint, it was evaluated at 4 different angles, from neutral and 30° external rotation (ER) to 10° internal rotation and ER. Static and dynamic balance were assessed using the SportKAT device. **Results:** The mean age of the obese and control groups was 30.51±5.25 and 30.67±5.02 years, respectively (p=0.902). The mean Body Mass Index (BMI) was 33.68±3.11 for the obesity group and 21.40±1.74 for the control group (p=0.001). The angular error values in active repositioning for the knee joint at 60°, 40°, 20°, and 10° were higher in the obesity group (2.68±1.06, 2.77±1.09, 2.73±1.06, and 2.44±0.79, respectively) than in the control group (1.05±0.36, 1.15±0.60, 1.23±0.39, and 1.27±0.36, respectively) (p<0.001). Static and dynamic Balance Index measurements were significantly higher in the obese group (p<0.001). BMI was positively correlated with angular knee joint proprioception error (r=0.74, r=0.65, r=0.59, r=0.60), static balance impairment (r=0.77), and dynamic balance impairment (r=0.42). **Conclusion:** As the BMI increased, the angular error values for proprioception also increased and static and dynamic stabilometric measurements were found to be more impaired in obese patients.

Keywords: Obesity; postural balance; proprioception

ÖZET Amaç: Bu çalışmanın amacı, obezitenin propriosepsiyon ve denge üzerindeki etkilerini araştırmaktı. **Gereç ve Yöntemler:** Çalışmaya obezite tanısı almış 31 hasta ve 31 sağlıklı kontrol grubu dâhil edilmiştir. Proprioseptif değerlendirme, katılımcıların baskın omuz ve diz eklemlerinde Cybex İzokinetik Dinamometre kullanılarak aktif yeniden konumlandırma yöntemi ile gerçekleştirilmiştir. Diz ekleminde 80° fleksiyondan 60°, 40°, 20° ve 10° ekstansiyona doğru; omuz ekleminde ise nötr pozisyondan ve 30° dış rotasyondan [external rotation (ER)], 10° iç rotasyona ve ER'ye doğru 4 farklı açıda değerlendirme yapılmıştır. Statik ve dinamik denge değerlendirmeleri SportKAT cihazı ile gerçekleştirilmiştir. **Bulgular:** Obezite ve kontrol gruplarının ortalama yaşları sırasıyla 30,51±5,25 ve 30,67±5,02 yıl olup, gruplar arasında anlamlı fark bulunmamıştır (p=0,902). Ortalama Beden Kitle İndeksi (BKİ) obezite grubunda 33,68±3,11, kontrol grubunda ise 21,40±1,74 olarak ölçülmüş ve gruplar arasındaki fark istatistiksel olarak anlamlı bulunmuştur (p=0,001). Diz ekleminde aktif yeniden konumlandırma sırasında 60°, 40°, 20° ve 10° açılarında açısal hata değerleri, obezite grubunda (2,68±1,06, 2,77±1,09, 2,73±1,06 ve 2,44±0,79) kontrol grubuna göre (1,05±0,36, 1,15±0,60, 1,23±0,39 ve 1,27±0,36) anlamlı derecede yüksek bulunmuştur (p<0,001). Obezite grubunda statik ve dinamik Denge İndeksi ölçümleri anlamlı derecede daha yüksek bulunmuştur (p<0,001). BKİ ile diz eklemindeki açısal propriosepsiyon hatası (r=0,74, r=0,65, r=0,59, r=0,60), statik denge bozukluğu (r=0,77) ve dinamik denge bozukluğu (r=0,42) arasında pozitif korelasyon olduğu tespit edilmiştir. **Sonuç:** BKİ arttıkça, propriosepsiyon açısal hata değerlerinde artış gözlenmiş ve obez bireylerde statik ve dinamik stabilometrik ölçümlerin daha fazla bozulduğu belirlenmiştir.

Anahtar Kelimeler: Obezite; postüral denge; propriosepsiyon

Balance is the ability to maintain control of the body over the support surface to prevent falls. Static balance refers to the ability to maintain equilibrium without movement, whereas dynamic balance is the ability to move without losing balance or falling.[1] Proprioception, an essential component of both static

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and dynamic balance, is the capacity to be aware of the position of body parts in space, both consciously and unconsciously, through sensory inputs from the somatosensory, vestibular, and visual systems.[2,3] Proprioception plays a pivotal role in the maintenance and regulation of joint stability.[4] Impaired proprioception adversely affects the ability to coordinate movement and preserve balance. Disruption in the transmission of proprioceptive signals from the joints can lead to chronic joint trauma, which in turn can result in joint dysfunction and instability.[5]

In a study evaluating static and dynamic balance through stabilometric assessment, it was demonstrated that obesity increases postural instability.[6] In a study conducted by Almurdi et al., it was shown that students with a high BMI had decreased postural balance.[7] Another study examining postural balance in overweight and obese children from an anthropometric profile perspective observed that obesity-related anthropometric characteristics contributed to deficiencies in both static and dynamic postural balance.[8]

Although there are a limited number of studies examining the effect of obesity on balance, only one study has investigated its effect on proprioception, and it was conducted in an adolescent group.[9] The aim of this study was to investigate the effects of obesity on proprioception and balance in adults.

MATERIAL AND METHODS

The study included 31 volunteer obese patients referred from the Endocrinology and Metabolism Department outpatient clinic to the Physical Medicine and Rehabilitation Department outpatient clinic at Dokuz Eylül University, along with 31 age- and gender-matched healthy controls. Our clinical research was conducted in accordance with the Declaration of Helsinki of the World Medical Association. Participants aged 20-40 years with a Body Mass Index (BMI) between 30 and 40 and with normal thyroid function tests (TFT), vitamin B_{12} levels, and oral glucose tolerance tests (OGTT) were included in the study. Exclusion criteria included individuals with a history of knee or shoulder joint pain, trauma, or surgery, hypermobility, Diabetes Mellitus, neurological, musculoskeletal, or vestibular system disorders that could affect balance, abnormal TFT, low vitamin B_{12} levels, and those with cardiovascular diseases and/or significant shortness of breath that would prevent measurement with the Cybex device. The participants' age, gender, dominant side, height, and weight were recorded. Knee and shoulder was examined, and only those with full joint range of motion were included in the study. Written informed consent was obtained from all participants.

Proprioceptive assessments for the volunteers included in the study were conducted using the Cybex Norm Isokinetic Dynamometer (Cybex International, Inc., Ronkonkoma, New York, USA), an isokinetic testing and treatment device available at our clinic, utilizing the continuous passive motion mode. The proprioception of the knee joint was assessed using the active repositioning method. Patients and healthy volunteers were seated on the Cybex Norm Isokinetic Dynamometer in the most comfortable position, with the back inclined at a 60° angle. Their legs were allowed to hang freely from the chair, and the distance between the popliteal fossa and the chair was adjusted to 4-6 cm. The thigh was stabilized with a strap. Initially, the continuous passive motion mode of the device was selected, and the device was moved at different speeds to passively teach the target angles to the patients, asking them to concentrate on these angles.

For active repositioning of the knee joint, the participants closed their eyes, and the dominant leg was held at 80° knee flexion in the resting position. Patients and healthy volunteers were then asked to actively achieve the target flexion angles of 60°, 40°, 20°, and 10° sequentially. The starting position for all angles was 80°. Before each measurement, the participants were allowed 2 s of rest at the 80° starting position, and the measurement was repeated three times, with the average value recorded. Before transitioning from one angle to another, the participants rested at the starting position for 10 s. Once the dynamometer was switched to the active mode, they were asked to move their leg to the target position and press the button to stop the dynamometer once they were confident they had reached the correct angle. The angular deviation between the achieved and taught positions was recorded as the absolute error value, which represented the active repositioning outcome.[10]

Knee proprioception measurement was performed in a seated position rather than a standing position due to the multiple variables that could affect the results, such as applied pressure on the feet during standing, the necessity to maintain balance, and the inability to assess the hip, ankle, and knee positions simultaneously. Additionally, a seated position allows better focus on the knee joint.[11]

The proprioception of the shoulder joint was evaluated using the active repositioning method. Patients and healthy volunteers were placed in a supine position on the Cybex Norm Isokinetic Dynamometer. The arm of the dominant shoulder, measured, was positioned with the elbow at 90° flexion and the shoulder at 90° abduction. It was ensured that the shoulder did not make contact with the device's table. For the shoulder proprioception measurement, the starting angles of 0° neutral position and 30° external rotation (ER) were selected. The target angles were then defined as follows: first, 10° internal rotation (IR) and 10° ER from the neutral position, and second, from 30° ER, 10° IR (20°) and 10° ER (40°).

Initially, the continuous passive motion mode of the device was selected, and the device was moved at different speeds to passively teach the target angles to the patients, asking them to focus on these angles. Proprioception was measured at four different angles . Measurements were repeated three times at each angle, with a 2-s rest period between trials, and the average of the values was recorded.

The kinesthetic ability training device, Sport-KAT 2000 (SportKAT Kinesthetic Ability Trainer, KAT 2000, Breg, Vista, CA), which has been validated in previous studies, was used for balance measurement. The Sport-KAT 2000 consists of a moving platform supported by a small pivot at its central point. The stability of the platform is regulated by adjusting the pressure within a circular pneumatic cushion positioned between the platform and the base of the unit. The platform is stabilized when inflated and becomes highly unstable when deflated. The inclination sensor at the front of the platform is connected to a computer that records deviations from the platform's reference position 18.2 times per second during the test. The Balance Index (BI) quantifies an individual's ability to maintain the platform in proximity to its reference position. Each patient underwent both a static and a dynamic test. Each test consisted of five measurements, with a 1-min rest period between each test. The static test was performed on one leg (dominant side), with the arms crossed over the shoulders and the other leg at 20° flexion. The patient was asked to hold the cursor in the center of the screen for 30 s while maintaining balance. The dynamic test was performed on both legs, with the patient again crossing the arms over the shoulders. A distance of 10.5 cm was maintained between the two feet. The patient was asked to track a cursor that rotated 360° clockwise on the screen while maintaining balance. In both tests, the results were scored as BI. The BI measures the individual's ability to maintain the platform near the reference position; a lower BI indicates better balance.[4]

STATISTICAL ANALYSIS

The statistical analysis of the study was performed using the IBM SPSS 15.0 (USA) software. The normality of all data was assessed using the Kolmogorov-Smirnov test. It was determined that all variables, except for age, did not follow a normal distribution. The mean and standard deviation values for all continuous variables were calculated. For the comparison of continuous variables between groups, variables that did not follow a normal distribution (proprioceptive measurements and BI scores) were analyzed using the Mann-Whitney U test, while the Student's t-test was used for comparison of the age variable, which followed a normal distribution. The relationship between proprioceptive measurements, BI scores, and BMI was assessed using the Spearman correlation test. Statistical significance was considered at ($p<0.05$).

RESULTS

The demographic characteristics of the 31 patients diagnosed with obesity and the 31 healthy controls, matched by age and gender, with normal BMI values, are presented in Table 1. No significant differences were found between the obese group and the

TABLE 1: Demographic data.

	Obese group (n=31) (X̄±SD)	Control group (n=31) (X̄±SD)	p value
Age (years)	30.51±5.25	30.67±5.02	0.902
Weight (kg)	95.25±13.27	59.53±12.83	0.001*
Height (cm)	163.14±31.22	165.77±21.29	0.700
BMI (kg/m^2)	33.68±3.11	21.40±1.74	0.001*

*p<0.05 was considered significant; SD: Standard deviation; BMI: Body mass index.

control group in terms of age and height (p>0.05), while significant differences were observed in terms of BMI and weight (p=0.001).

PROPRIOCEPTION ASSESSMENT

In both groups, proprioception of the dominant knee was assessed using the active repositioning method, with measurements taken at 60°, 40°, 20°, and 10° extension from the 80° flexion position. It was found that the angular error values were significantly higher in the obese group during active repositioning. The higher angular error values suggest impaired proprioception (p<0.001) (Table 2).

No significant difference was found between the groups in terms of angular error values when evaluated using the active repositioning method at two different starting positions of 0° and 30° ER, with 10° IR and ER movements (p>0.05) (Table 3).

TABLE 2: The comparison of knee active repositioning angular error values between groups.

	Obese group (n=31) (X̄±SD)	Control group (n=31) (X̄±SD)	p value
60°	2.68 ±1.06	1.05±0.36	<0.001*
40°	2.77±1.09	1.15±0.60	<0.001*
20°	2.73±1.06	1.23±0.39	<0.001*
10°	2.44 ±0.79	1.27±0.36	<0.001*

*p<0.05 was considered significant; SD: Standard deviation.

TABLE 3: The comparison of shoulder active repositioning angular error values between groups.

	Obese group (X̄±SD)	Control group (X̄±SD)	p value
From neutral 10° IR	0.93±0.45	0.94±0.39	0.819
From neutral 10° ER	0.98±0.43	0.98±0.43	0.857
30° ER to 10° IR (20°)	1.03±0.39	1.16±0.49	0.539
30°ER to 10°ER (40°)	1.00±0.53	0.95±0.41	0.908

SD: Standard deviation; IR: Internal Rotation; ER: External Rotation.

BALANCE ASSESSMENT

When the results of the static and dynamic balance tests were evaluated, it was found that the balance scores were significantly lower in the obese group (p<0.001) (Table 4).

The relationship between proprioception angular error values and BMI was assessed for the knee joint at 60°, 40°, 20°, and 10° flexion, with the following Spearman correlation (r) values found: 0.74, 0.65, 0.59, and 0.60, respectively (p<0.001). For the static and dynamic stabilometric measurements, the r values were 0.77 and 0.42, respectively (p<0.001). A significant and positive correlation was found between the proprioception angular error values, static and dynamic stabilometric measurements, and BMI (Table 5, Table 6).

As the BMI increased, the angular error values for proprioception also increased (Figure 1, Figure 2, Figure 3, Figure 4), and static and dynamic stabilometric measurements were found to be more impaired in obese patients (Figure 5, Figure 6).

TABLE 4: The comparisonof static and dynamic stabilometric measurement values between groups.

	Obese group (X̄±SD)	Control group (X̄±SD)	p value
Static (BI)	523.80±156.58	271.29±66.00	<0.001*
Dynamic (BI)	1536.03±297.87	1220±403.93	<0.001*

*p<0.05 was considered significant; SD: Standard deviation: BI: Balance index.

TABLE 5: Relationship between proprioception sense angular error values and BMI.

	(BMI)	
Error values	r value	p value
Knee at 60°	0.74	<0.001*
Knee at 40°	0.65	<0.001*
Knee at 20°	0.59	<0.001*
Knee at 10°	0.60	<0.001*

*p<0.05 was considered significant; BMI: Body mass index.

TABLE 6: Relationship between static and dynamic stabilometric measurements and Body Mass Index.

	(BMI)	
	r value	p value
Static (BI)	0.77	<0.001*
Dynamic (BI)	0.42	<0.001*

*p<0.05 was considered significant; BMI: Body mass index.

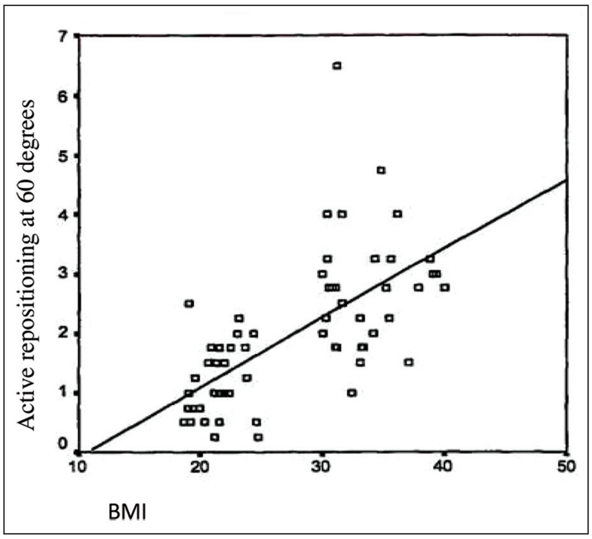

FIGURE 1: Relationship between body mass index and mean angular error values of active at 60 degrees of knee flexion.
BMI: Body mass index.

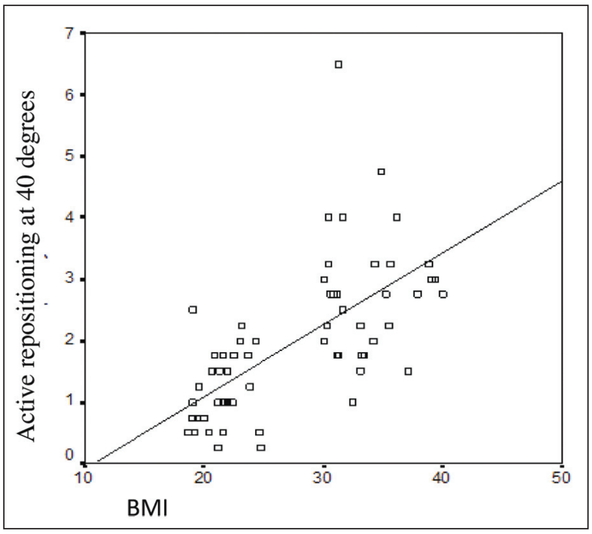

FIGURE 2: Relationship between body mass index and mean angular error values of active at 40 degrees of knee flexion.
BMI: Body mass index

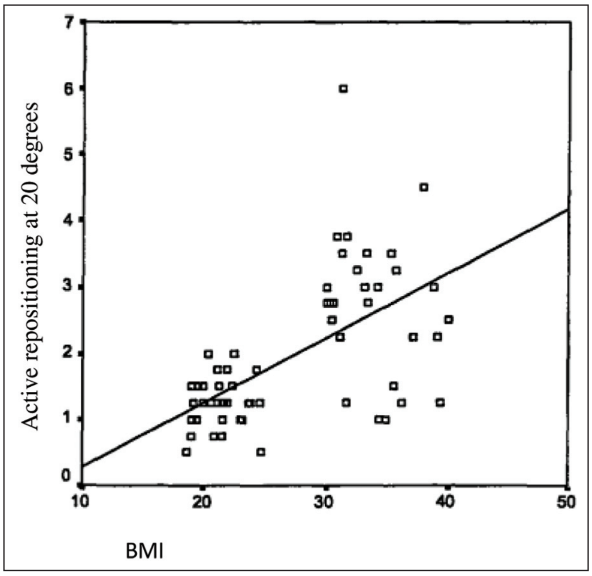

FIGURE 3: Relationship between body mass index and mean angular error values of active at 20 degrees of knee flexion.
BMI: Body mass index

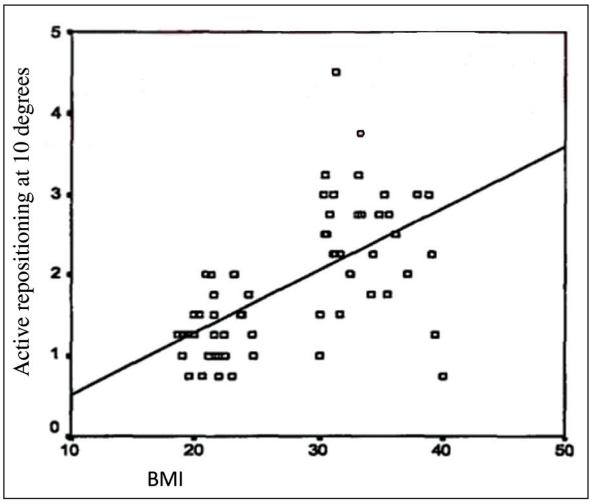

FIGURE 4: Relationship between body mass index and mean angular error values of active at 10 degrees of knee flexion.
BMI: Body mass index.

DISCUSSION

In our study, which aimed to investigate whether obesity affects balance and proprioception by causing ligament and articular damage in joints, we compared the load-bearing knee joints of obese individuals with the non-load-bearing shoulder joints of healthy controls in terms of proprioception. We found that proprioception, as measured by active repositioning, was more impaired in the load-bearing knee joint of the obese group than in the shoulder joint. However, no statistically significant difference was observed between the obese and control groups in terms of proprioception in the shoulder joint, which is a non-weight-bearing joint.

Proprioception is defined as the sense of position and movement of the extremities and is the result of sensory inputs originating from the skin, muscles, and joint structures.[12] Proprioceptive sensation plays

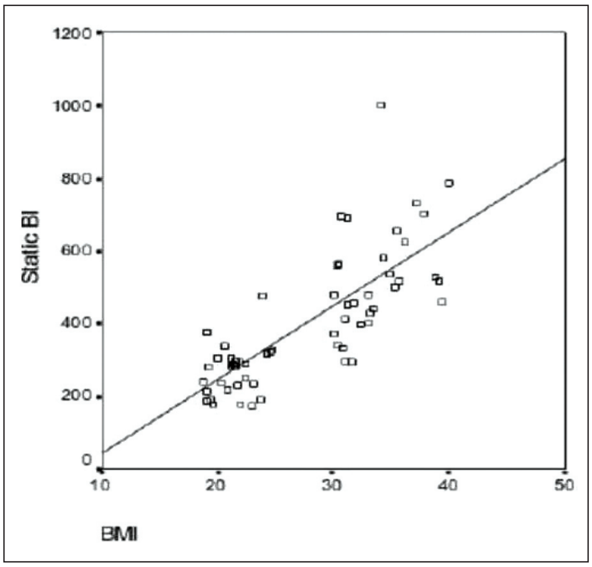

FIGURE 5: The association between body mass index and static balance index of patients.
BI: Balance index; BMI: Body mass index.

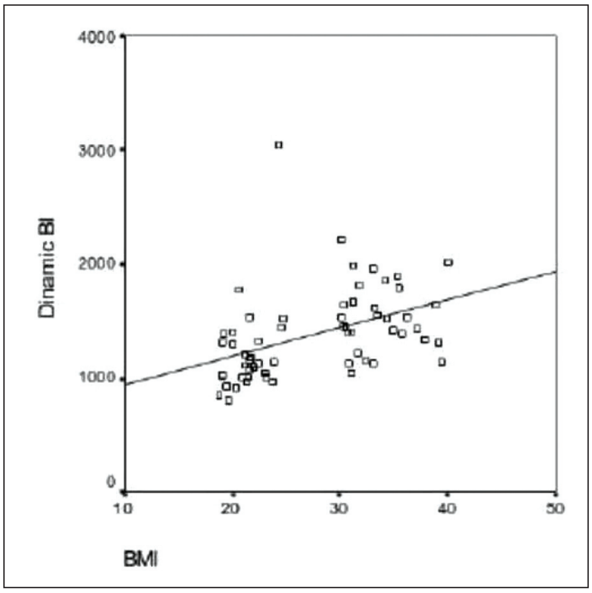

FIGURE 6: The association between body mass index and dynamic balance index of patients.
BI: Balance index; BMI: Body mass index.

a crucial role in maintaining and preserving joint stability. Studies have shown that proprioception is negatively affected by factors such as age, degenerative joint diseases, ligament injuries, surgical interventions, and hypermobility. It has been demonstrated that lesions in the articular cartilage negatively affect the proprioceptive mechanisms of the knee.[13] The posterior cruciate ligament (PCL), which plays a crucial role in the stabilization of the knee joint, is a tissue rich in mechanoreceptors, and the density of these mechanoreceptors is known to determine the sensitivity of proprioception.[14-16] A study has highlighted the significance of adding balance exercises to the postoperative rehabilitation programs of patients who underwent surgery due to PCL injuries, as these exercises are beneficial for correcting impaired proprioception.[17]

A few studies have demonstrated that an increase in BMI elevates the risk of ligament and articular damage in the knee joint.[18,19] These findings suggest that obesity may influence proprioception and balance and could be a significant predisposing factor for injuries.

Excessive body weight has been shown to induce mechanical overloading on the joint, leading to increased activation of mechanoreceptors, which in turn accelerates cartilage damage or osteophyte formation, ultimately contributing to the progression of degeneration in the knee joint.[20] This mechanism supports the potential for mechanoreceptor damage in obesity and aligns with our findings.

A study examining the relationship between the proprioceptive sensation of the knee joint and body weight found that in individuals with a high BMI, proprioception was significantly reduced in the squat position, where the load-bearing is increased.[21] In a study investigating proprioceptive function in the ankle and knee joints of obese children, which supports the findings of our study, it was shown that proprioception was more impaired in the knee joint. It was suggested that the change in proprioception in obese children could be related to reduced postural control and changes in the function of proprioceptors in the joint capsule, ligaments, and tendons of the knee joint as a result of prolonged and inappropriate loading.[9]

In our study, the proprioception measurements of the knee and shoulder were conducted using an isokinetic testing device, which has been widely utilized in many studies and provides more objective results.[9,22,23] The active repositioning method, which demonstrates active joint position sense, was used in the measurements. This method allows for a more functional evaluation of afferent pathways by stimulating both the joint and muscle receptors.

Balance control is related to sensory inputs from the vestibular, visual, and somatosensory systems. The organization of these inputs within the central nervous system results in coordinated neuromuscular responses that ensure the maintenance of the center of gravity during situations of balance disruption.[4] In our study, where we also assessed balance, we found that both static and dynamic balance were statistically worse in the obese group than in the control group. In a limited number of studies on obese children and adolescents, an increase in postural instability and fall risk has been identified.[18,19] Bernard et al. linked these findings to balance problems caused by the forward displacement of the body's center of mass due to increased abdominal fat and suggested that weight loss could lead to a more stable balance.[24] A study investigating deficiencies in postural stability in obese individuals found that changes in the center of mass and pressure center, affecting step width, made obese individuals more prone to falling.[25]

Similarly, Teasdale et al. demonstrated that postural stability measurements improved in obese and morbidly obese men following weight loss.[26] In a study by McGraw et al. on obese adolescents, postural stability was found to be impaired in both the anteroposterior and mediolateral directions. The authors suggested that these findings were more attributable to excess body weight rather than postural instability.[27] Hue et al. also found a strong correlation between obesity and postural instability in adult men.[28] A study evaluating the effects of weight loss and balance training on clinical balance performance in individuals who underwent bariatric surgery concluded that balance exercises, performed 4 times a week for 4 weeks, had a positive contribution to balance.[6] However, proprioceptive aspects were not evaluated in these studies. As is well known, proprioceptive function is a crucial element of both static and dynamic balance.[4] Our study suggests that the balance dysfunction observed in obesity is not solely due to excess weight and changes in the center of mass, but may also be secondary to proprioceptive impairment resulting from overloading and mechanoreceptor deformation. Evaluating changes in the proprioceptive sense in the knees after weight loss in obese patients could have strengthened the study. Because there are very few studies examining the relationship between obesity and proprioception, we had limited opportunity to compare our results. Therefore, the findings we have identified could be considered a foundational study for future research.

LIMITATIONS OF OUR STUDY

Increasing the sample size could have potentially increased the accuracy and validity of the findings. Additionally, the cross-sectional design of the study, in which all measurements were taken in a single session, prevented the changes in participants' balance and proprioception over time. Repeating proprioception measurements after weight loss in obese participants may have contributed to the increased reliability of the results. Additionally, using the Cybex Norm Isokinetic Dynamometer for proprioception assessment may have caused difficulties for some participants in terms of adapting to the movements of the device, which may have led to distraction and decreased focus. Therefore, including alternative proprioceptive assessment methods in addition to the dynamometer could have further increased the accuracy of the findings. While BMI is widely used in obesity-related research, its limitations as a non-gold standard measurement suggest that including other anthropometric assessments such as waist-hip ratio and waist circumference may provide more comprehensive information. Further research is needed to investigate the temporal changes and long-term effects of obesity-related balance disorders and proprioceptive dysfunctions.

CONCLUSION

The present study indicates that obesity adversely affects both balance and proprioception in the weight-bearing knee joint, while having no significant impact on proprioception in the non-weight-bearing shoulder joint. Additionally, it has been observed that an increase in the Body Mass Index (BMI) of the participants correlates with a deterioration in both static and dynamic stabilometric measurements.

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