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Comparison of the Effects of Open and Closed Kinetic Chain Exercises Combined with Balance Training in Knee Osteoarthritis: A Randomized, Single-blinded, Prospective Study

Diz Osteoartritinde Denge Eğitimi ile Kombine Edilen Açık ve Kapalı Kinetik Zincir Egzersizlerinin Etkilerinin Karşılaştırılması: Randomize, Tek Kör, Prospektif Bir Çalışma

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Abstract

Objective: This study aimed to evaluate and compare the effects of open kinetic chain exercises (OKCE) and closed kinetic chain exercises (CKCE), in addition to balance exercises, on balance, fall risk, muscle thickness, and pennation angle measured by ultrasonography in patients with stage II or III knee osteoarthritis (KOA).

Materials and Methods: A total of 40 patients were randomly assigned to either an OKCE or CKCE group (20 patients per group) and participated in a home-based exercise program, including balance exercises, for six weeks. Clinical assessments were performed at baseline and after treatment, and included the visual analogue scale (VAS), the balance scale (BBS), the fall index, calculated using posturography (Tetrax®), and ultrasound imaging to measure rectus femoris (RF) muscle thickness and pennation angles of the vastus medialis (VM) and vastus lateralis (VL) muscles.

Results: Both groups demonstrated significant improvements in BBS scores, fall risk, resting and movement-related pain (VAS), RF muscle thickness, and pennation angles of VM and VL ($p<0.05$). However, no statistically significant differences were found between the OKCE and CKCE groups for any measured parameter ($p>0.05$). After Bonferroni correction, correlations were observed between fall risk and VL pennation angle in the OKCE group, and between fall risk and VM pennation angle in the CKCE group ($p<0.0125$).

Conclusion: Both OKCE and CKCE, when combined with balance exercises, may have a beneficial role in reducing pain, improving balance, reducing the risk of falls, strengthening muscles, and increasing muscle thickness and pennation angle in patients with KOA.

Keywords: Exercise, knee osteoarthritis, pennation angle, ultrasound

Öz

Amaç: Bu çalışmanın amacı, denge egzersizleri ile kombine edilen açık kinetik zincir egzersizleri (AKZE) ve kapalı kinetik zincir egzersizlerinin (KKZE), evre II veya III diz osteoartriti (DOA) olan hastalarda denge, düşme riski, ultrasonografi ile ölçülen kas kalınlığı ve pennasyon açısı üzerindeki etkilerini değerlendirmek ve karşılaştırmaktır.

Gereç ve Yöntem: Toplam 40 hasta rastgele iki gruba ayrıldı (AKZE grubu, n=20; KKZE grubu, n=20) ve denge egzersizlerini de içeren ev tabanlı egzersiz programını altı hafta süreyle uyguladı. Klinik değerlendirmeler kapsamında görsel analog ölçeği (VAS), Berg denge ölçeği (BBS), postürografi (Tetrax®) kullanılarak hesaplanan Fall Index ve ultrasonografi ile rektus femoris (RF) kas kalınlığı ile vastus medialis (VM) ve vastus lateralis (VL) kaslarının pennasyon açıları başlangıçta ve tedavi sonrasında ölçüldü.

Bulgular: Her iki grupta da BBS ölçeğinde, düşme riskinde, istirahat ve hareketle ilişkili ağrıda (VAS), RF kas kalınlığında ve VM ile VL kaslarının pennasyon açılarında istatistiksel olarak anlamlı iyileşme saptandı ($p<0,05$). Ancak ölçülen hiçbir parametrede AKZE ve KKZE grupları arasında istatistiksel olarak anlamlı fark bulunmadı ($p>0,05$). Bonferroni düzeltmesinden sonra, OKCE grubunda düşme riski ile VL pennasyon açısı arasında ve CKCE grubunda düşme riski ile VM pennasyon açısı arasında anlamlı bir negatif korelasyon gözlemlendi ($p<0,0125$).

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Sonuç: Sonuç olarak, denge egzersizleri ile birlikte uygulanan hem AKZE hem de KKZE'nin, DOA olan hastalarda ağrının azaltılması, dengenin iyileştirilmesi, düşme riskinin azaltılması, kas gücünün artırılması ile kas kalınlığı ve pennasyon açısının artırılmasında yararlı olabileceği düşünülmektedir.

Anahtar kelimeler: Egzersiz, diz osteoartriti, pennasyon açısı, ultrasonografi

Introduction

Osteoarthritis (OA) is the most common chronic joint disease, affecting approximately 302 million people worldwide and representing one of the leading causes of disability among older adults. The most frequently affected appendicular joints include the knees, hips, and hands (1). Globally, 18% of women and 9.6% of men over the age of 60 are diagnosed with symptomatic knee OA. Among individuals with OA, 80% develop joint movement limitations, and 25% experience difficulties in performing activities of daily living (2).

The primary goals of OA treatment are to reduce pain, preserve or improve joint range of motion and muscle strength, minimize fall risk, and enhance overall quality of life (3). To achieve these objectives, pharmacological and non-pharmacological treatment strategies are employed. Among non-pharmacological interventions, exercise plays a crucial role in managing knee OA. Recommended exercise modalities include range of motion exercises, strengthening exercises, aerobic exercises, balance exercises, proprioceptive exercises, open kinetic chain exercises (OKCE), and closed kinetic chain exercises (CKCE) (3-6). The extremities are composed of interconnected segments that function as a complex motor unit. In CKCE, the distal segment is either fixed or moves against resistance, wereas in OKCE, the joints at the distal end of the kinetic chain move freely. These exercises play an essential role in preserving or improving joint range of motion, enhancing muscle strength, reducing fall risk, and maintaining balance (7-9).

In recent years, ultrasonography (US) has become a valuable imaging modality for evaluating the microarchitecture and architecture of skeletal muscle. US is non-invasive, reliable, widely accessible, and cost-effective (10). Ultrasonographic imaging can assess different muscle architectures, including pennate and fusiform muscles, by measuring pennation angle and muscle thickness. The pennation angle is defined as the angle at which muscle fibers attach to the deep aponeurosis. This angle contributes to the transmission of muscle force to the tendon and determines the extent of change in muscle-fiber length. The degree of pennation affects the torque the muscle can generate. As torque and muscle thickness increase, muscle strength increases. Measuring muscle thickness and pennation angle via US allows clinicians to objectively assess post-exercise muscle strength (11,12).

To the best of our knowledge, no study has specifically evaluated the effects of OKCE and CKCE, in addition to balance exercises, on muscle thickness and pennation angle, as measured by US, in patients with knee OA.

This study, based on the hypothesis that the structural changes induced by OKCE and CKCE when combined with balance exercises would lead to increased muscle strength and improved dynamic stability of the knee joint, aimed to evaluate the effects of these exercise modalities on balance, fall risk, muscle thickness, and pennation angle in patients with stage II or III knee OA and to determine whether one method is superior to the other.

Materials and Methods

The study included 40 patients aged 50-75 years who were diagnosed with primary knee osteoarthritis (KOA) according to the American College of Rheumatology criteria.

Patients with stage II or III knee OA according to the Kellgren-Lawrence (KL) classification, without cognitive dysfunction and who agreed to participate in the study were included in the study. Patients were excluded if they had cognitive dysfunction, an inability to walk independently, visual or auditory impairments, or secondary conditions affecting balance (e.g., vitamin B12 deficiency or neurological disorders). Additional exclusion criteria were: a history of knee surgery or intra-articular knee injections within the past six months; bilateral knee pain; participation in a physical therapy program within the past six months; a history of osteomyelitis; local or systemic infections; malignancy; or systemic diseases that could prevent exercise participation (e.g., neurological, cardiovascular, or respiratory conditions). Patients with inflammatory rheumatic diseases affecting the knee joint, as well as those with a history of trauma or disease affecting hip and knee joint mobility, were also excluded.

A total of 40 patients who met the inclusion criteria and agreed to participate in the study were randomly divided into 2 groups: the OKCE group and the CKCE group. All 20 patients in the OKCE and CKCE groups completed the study by following home exercise programs (Figure 1).

Study Design

This prospective, single-blind, randomized study was conducted at the Physical Therapy and Rehabilitation outpatient clinic of the Eskişehir Osmangazi University Faculty of Medicine between December 2022 and August 2023. The study was designed as a single-blind trial. All outcome assessments, including ultrasonographic measurements, the visual analog scale (VAS), the Berg balance scale (BBS), and fall index evaluations, were performed at baseline and after the 6-week intervention by an independent physiatrist blinded to treatment allocation and exercise protocol. The physician responsible for exercise instruction and follow-up was not involved in outcome assessment. The study was approved by the Eskişehir Osmangazi University Faculty of Medicine Clinical Research Ethics Committee (ethical approval date: December 01, 2022, protocol code: E-80558721-

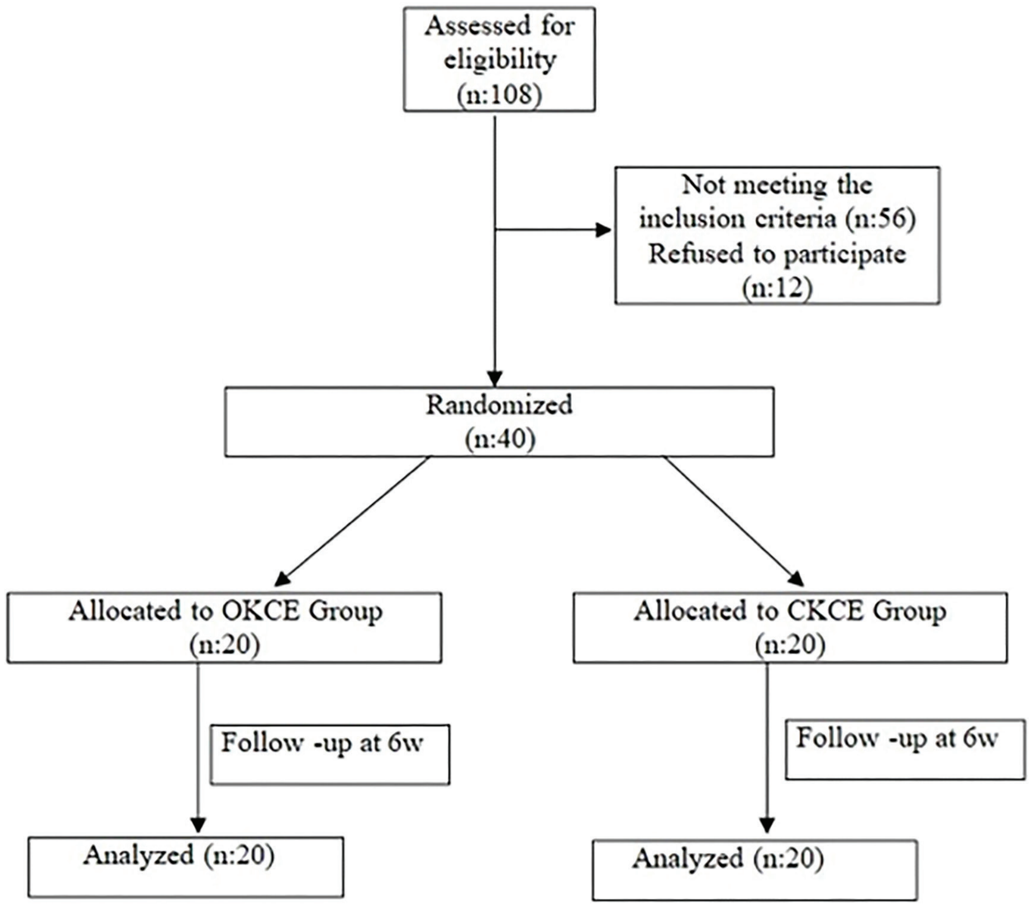

Figure 1. Study flowchart
OKCE: Open kinetic chain exercises, CKCE: Closed kinetic chain exercises

050.99-413731/10.11.2022). All participants received written and verbal information about the study, and those who agreed signed an informed consent form. The research was conducted in accordance with the "Declaration of Helsinki."

Randomization

Patients were randomly assigned to one of two groups using the sealed envelope method, a simple randomization technique. Each patient selected a sealed envelope labeled either "OKCE" or "CKCE," which the physician then opened and used to explain the details of the home exercise program.

Exercise Protocol

All participants in the study received their treatment as a home-based exercise program. Patients in group 1 performed an OKCE program, while those in group 2 performed a CKCE program; both groups also received education and performed balance exercises daily for six weeks. The home exercise programs were demonstrated to each patient by a physician, and the initial session was conducted under medical supervision. Patients performed each exercise in three sets of 10 repetitions. Exercise adherence was monitored through structured weekly follow-up phone calls throughout the six-week intervention period. During these calls, participants were questioned regarding exercise continuity, frequency, and potential barriers to adherence. Participants were encouraged to perform the prescribed exercises regularly. No participant demonstrated poor exercise adherence that required discontinuation.

The balance exercise program included normal walking, tandem walking, and figure-eight walking. The CKCE program consisted of sit-to-stand exercises, mini-squat exercises, forward and lateral stepping exercises, and step-up exercises. The OKCE program included straight-leg raises and hip abduction-adduction in the supine position, knee flexion-extension in the sitting position, and isometric quadriceps-strengthening exercises (6,13,14).

Clinical Assessments

Patients were evaluated at baseline and at the end of the 6-week exercise program.

Pain intensity at rest and during movement was assessed using the VAS, scored from 0 to 10, where 0 indicated no pain and 10 represented the worst pain ever experienced. Patients were asked to mark the average pain level they had experienced over the past week on the scale. Balance was evaluated using the BBS (15-17).

Fall Risk Assessment

Fall risk was assessed using a static posturography device (Tetrax, Sunlight Medical Ltd., Ramat Gan, Israel), which comprises four sensitive platforms that detect pressure changes under the toes and heels bilaterally. The collected data were processed digitally. The assessment was performed in 8 positions, each lasting 32 seconds, and the risk of falling was calculated by the software as the "Fall index." According to the Fall Index score, 0-36 indicate low fall risk, 37-58 indicate moderate fall risk, and 59-100 indicate high fall risk.

Ultrasonographic Measurement of Muscle Thickness and Pennation Angle

Ultrasound (US) evaluations were performed by a blinded physiatrist using a B-mode, linear-array transducer (Samsung L5-12/50 model, 7.5 MHz) of the US device (Samsung Sonoace X7, India). The assessments included measurements of the pennation angles of the vastus medialis (VM) and vastus lateralis (VL) muscles and of the muscle thickness of the rectus femoris (RF) in the affected extremity. The probe was positioned with minimal pressure to avoid tissue compression. Measurements were conducted while the participants were in a resting state, lying supine. The assessments were performed at the mid-thigh level, defined as the midpoint between the greater trochanter and the lateral femoral condyle.

For the RF muscle thickness measurements, the US probe was placed horizontally, and the distance between the superficial and deep aponeuroses was recorded (Figure 2). Pennation angle measurements were obtained at the same anatomical site by positioning the probe longitudinally and measuring the angle at which the muscle fascicles attach to the deep aponeurosis (Figure 3). All ultrasonographic assessments were performed by an experienced physiatrist. Each measurement was taken twice, and the arithmetic mean was calculated (18,19).

Statistical Analysis

Data analysis was performed using IBM SPSS for Windows, version 21 (SPSS Inc., Chicago, IL, USA). The Shapiro-Wilk test was used to assess the normality of variable distributions. Parametric tests were used for variables that followed a normal distribution; the independent samples t-test was applied for between-group comparisons, and the paired samples t-test was used for within-group comparisons. For variables that were not normally distributed, non-parametric analysis methods were preferred: the Mann-Whitney U test for between-group comparisons and the Wilcoxon signed-rank test for within-group comparisons. Chi-square tests were applied to cross-tabulation analyses. Descriptive statistics were presented as frequencies and percentages for categorical variables, and as mean ± standard deviation or median (25-75%) for continuous variables. Pearson correlation coefficients were calculated to assess relationships between variables. A p-value of <0.05 was considered statistically significant.

The required sample size was estimated using G*Power software (version 3.1.9.2), targeting a statistical power of 80% and a type I error rate of 5%. The calculation was based on pre- and post-intervention VAS scores derived from a pilot study involving OKCE (14), which indicated that a minimum of 19 participants per group was necessary. To further enhance the robustness of the analysis, 20 patients were ultimately recruited for each group.

Results

There were no statistically significant differences between the two groups in demographic and clinical characteristics (p>0.05). All participants were right-dominant. Additionally, no significant differences were found between the groups with respect to the affected side and KL classification (p=1) (Table 1).

Within-group comparisons showed significant improvements in both groups in the BBS and resting VAS (p=0.001), and in movement VAS, VM pennation angle, RF muscle thickness, and fall risk (p<0.001). The pennation angle of the VL also showed a significant improvement in the OKCE group (p<0.001) and the CKCE group (p=0.007). However, no statistically significant differences were found between the groups for any of the parameters (p>0.05) (Table 2).

Significant effect sizes were observed for the parameters assessed post-treatment in both groups. When examining the effect size coefficients for variables assessed using the Wilcoxon test, large effect sizes were found in the OKCE group for BBS (r=0.74),

Figure 2. The rectus femoris muscle thickness

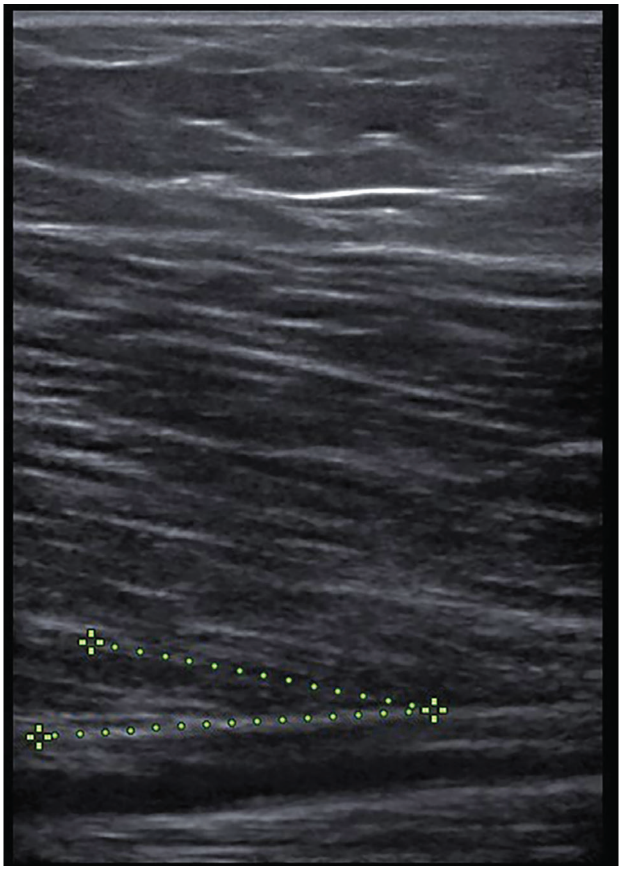

Figure 3. The pennation angle of vastus medialis

resting VAS (r=0.74), movement VAS (r=0.75), VM pennation angle (r=0.86), and RF muscle thickness (r=0.81). Similarly, in the CKCE group, large effect sizes were observed for BBS (r=0.74), resting VAS (r=0.76), movement VAS (r=0.83), VM pennation angle (r=0.86), and RF muscle thickness (r=0.84) (Table 2).

For parameters evaluated using the paired-samples t-test, the OKCE group showed Cohen's d values of 1.15 for the VL pennation angle and 1.25 for the Fall Index, both representing very large effect sizes. In the CKCE group, moderate-to-large and very large effect sizes were observed for the VL pennation angle (Cohen's d=0.68) and the Fall Index (Cohen's d=1.30), respectively (Table 2).

In the post-treatment evaluation of the OKCE group, a significant negative correlation was found between fall risk and the pennation angle of the VM (p=0.017). Similarly, a significant negative correlation was observed between fall risk and the VL pennation angle (p<0.001) (Table 3).

In the CKCE group, post-treatment assessment revealed a significant negative correlation between fall risk and the pennation angle of VM (p=0.012). Likewise, a significant negative correlation was found between fall risk and the VL pennation angle (p=0.018). Following Bonferroni correction, a significance threshold of p<0.0125 was adopted for the four simultaneous correlation analyses. Accordingly, a strong, statistically significant negative correlation (r=-0.721, p<0.001) was observed between fall risk and the VL pennation angle in the OKCE group. In addition, a statistically significant moderate negative correlation was found between fall risk and the VM pennation angle in the CKCE group (r=-0.548, p=0.012).

However, the correlation between fall risk and the VM pennation angle in the OKCE group (r=-0.528, p=0.017), as well as the correlation between fall risk and the VL pennation angle in the CKCE group (r=-0.523, p=0.018), did not remain statistically significant after Bonferroni correction (p>0.0125) (Table 3).

In the correlation analysis using change scores (post-treatment minus pretreatment), no statistically significant relationship was found between changes in fall risk and changes in VM and VL pennation angles in either group (p>0.05). In the OKCE group, a negative, non-significant relationship was observed between changes in fall risk and VM pennation angle (r=-0.14; p=0.55). In the same group, no significant relationship was found between the change in fall risk and the change in VL pennation angle (r=0.01; p=0.96). In the CKCE group, no significant relationship was found between changes in fall risk and changes in the VM pennation angle (r=-0.10; p=0.67) or the VL pennation angle (r=-0.16; p=0.51) (Table 4).

Discussion

In this study, we hypothesized that adding OKCE and CKCE would increase dynamic stability of the knee joint, leading to improved balance, reduced pain, and decreased fall risk through changes in muscle architecture and strength. Our study showed

Table 1. Comparison of demographic and clinical data of the groups

	OKCE group mean ± SD	CKCE group mean ± SD	p-value
Age (years)	62.6±6.01	62.7±9.71	0.969*
BMI (kg/m^2)	31.56±3.41	31.45±4.92	0.937*
Gender (n: females/males)	16/4	16/4	1#
Affected side (n: right/left)	9/11	10/10	1#
Kellgren-Lawrence scale (n: grade 2/3)	9/11	9/11	1#

OKCE: Open kinetic chain exercise, CKCE: Closed kinetic chain exercise, BMI: Body mass index, SD: Standard deviation, *Analyzed by independent samples t-test, #Analyzed by the chi-square tests; p<0.05: significant

Table 2. Intra and inter-group comparisons of assessment parameters

		OKCE group median (25-75%)	CKCE group median (25-75%)	p-value
BBS	Pre-exercise	52 (47.5-55.75)	52 (46.25-56.00)	0.934**
	Post-exercise	53.50 (51.25-56)	56 (49 -56)	0.504**
	p	**0.001**† r: 0.74	**0.001**† r: 0.74	
Resting VAS	Pre-exercise	3 (2.00-5.00)	3 (2.00-5.00)	1.000**
	Post-exercise	2 (1.25-3.00)	2.00 (1.00-3.75)	0.967**
	p	**0.001**† r: 0.74	**0.001**† r: 0.76	
Movement VAS	Pre-exercise	6.50 (5.00-8.00)	7 (5.25-8.00)	0.659**
	Post-exercise	4 (3.00-5.75)	5 (4.00-6.00)	0.217**
	p	**<0.001**† r: 0.75	**<0.001**† r: 0.83	
VM pennation angle	Pre-exercise	10.86 (10.08-12.64)	11.04 (09.85-12.78)	0.978**
	Post-exercise	11.38 (10.74-13.30)	11.06 (10.13-13.31)	0.507**
	p	**<0.001**† r: 0.86	**<0.001**† r: 0.86	
RF muscle thickness (cm)	Pre-exercise	1.11 (0.91-1.34)	1.13 (0.98-1.34)	0.465**
	Post-exercise	1.18 (0.93-1.39)	1.19 (1.09-1.39)	0.441**
	p	**<0.001**† r: 0.81	**<0.001**† r: 0.84	
VL pennation angle	Pre-exercise	14.35±2.43[a]	14.41±2.19[a]	0.942*
	Post-exercise	14.93±2.39[a]	14.67±2.15[a]	0.720*
	p	**<0.001**‡ cohen d: 1.15	**0.007**‡ cohen d: 0.68	
Fall index	Pre- exercise	44.35±25.51[a]	45.20±22.09[a]	0.911*
	Post-exercise	34.35±22.57[a]	27.60±12.24[a]	0.247*
	p	**<0.001**‡ cohen d: 1.25	**<0.001**‡ cohen d: 1.30	

OKCE: Open kinetic chain exercise, CKCE: Closed kinetic chain exercise, BBS: Berg balance scale, VAS: Visual analogue scale, VM: Vastus medialis, RF: Rectus femoris, VL: Vastus lateralis, SD: Standard deviation, [a]: Mean ± SD, **: Analyzed by Mann-Whitney U-test, *: Analyzed by independent samples t-test, †: Analyzed by the Wilcoxon t-test, ‡: Analyzed by the paired samples t-test, r: effect size for Wilcoxon signed-rank test, d: Cohen's d effect size for paired-samples t-test
"VL pennation angle and fall index values showed normal distribution according to the Shapiro-Wilk test and were therefore expressed as mean ± SD"

Table 3. Correlation between fall risk and muscle pennate angles at post-treatment evaluation

	VM pennation angle r (p)	VL pennation angle r (p)
OKCE fall risk	-0.528 (0.017)	-0.721 (**<0.001**)
CKCE fall risk	-0.548 (**0.012**)	-0.523 (0.018)

OKCE: Open kinetic chain exercise, CKCE: Closed kinetic chain exercise, VM: Vastus medialis, VL: Vastus lateralis, analyzed by Pearson's correlation coefficient
"The Bonferroni correction was applied to four simultaneous comparisons (adjusted significance level: p<0.0125). After correction, significant negative correlations remained between OKCE fall risk and VL pennation angle, and between CKCE fall risk and VM pennation angle"

that both home exercise programs were effective for patients with KOA across all assessment parameters; however, neither program was superior.

Few studies have evaluated the effectiveness of OKCE and CKCE in the treatment of KOA. Daşkapan (20) found that the VAS score decreased more in the OKCE group compared to the CKCE group. Similarly, Girgin et al. (14) demonstrated that both OKCE and CKCE were effective in reducing VAS and WOMAC pain scores in patients with KOA, without one being superior to the other. On the other hand, Olagbegi et al. (21) emphasized that OKCE, CKCE, and combined kinetic chain exercises were effective in reducing pain, with CKCE improving joint stability and decreasing pain. We share the view that both OKCE and CKCE improve joint stability, thereby alleviating pain. Although WOMAC is widely recommended for evaluating pain and physical function in knee OA, it was not included in the present study because the primary focus was on balance, fall risk, and changes in muscle architecture.

Table 4. Correlation analysis between change scores of fall risk and muscle pennation angles

	VM pennation angle r (p)$^{\Delta}$	VL pennation angle r (p)$^{\Delta}$
OKCE fall risk$^{\Delta}$	-0.14 (0.55)	0.01 (0.96)
CKCE fall risk$^{\Delta}$	-0.10 (0.67)	-0.16 (0.51)

$^{\Delta}$: Post-treatment value-pre-treatment value, OKCE: Open kinetic chain exercise, CKCE: Closed kinetic chain exercise, VM: Vastus medialis, VL: Vastus lateralis, analyzed by Pearson's correlation coefficient

In our study, US was used to evaluate the effects of exercise on muscle, specifically the components of the quadriceps femoris that contribute to knee joint stability. We measured the muscle thickness of the RF and the pennation angles of the VM and the VL.

Several studies have shown that different exercise programs, including concentric and eccentric isokinetic exercises, isometric quadriceps exercises, and isotonic quadriceps strengthening exercises, have been effective in increasing muscle thickness of the RF, VM, and VL in patients with KOA, as measured by US (22-26). However, we are not aware of any studies specifically examining the effects of kinetic chain exercises on RF muscle thickness in patients with OA. In healthy young adults, OKCE and CKCE were found to increase RF muscle thickness without one being superior to the other (27). Similarly, in our study, both OKCE and CKCE led to an increase in RF muscle thickness, but no superiority of one over the other was observed. Therefore, we believe that both OKCE and CKCE could help reduce symptoms such as weakness and pain in patients with KOA because of their impact on muscle thickness.

Another aim of this study was to evaluate the effects of OKCE and CKCE on the pennation angles of VM and VL, which, to the best of our knowledge, have not been previously assessed in the literature. Results from limited studies investigating the impact of various isometric, concentric, eccentric, isotonic, and isokinetic quadriceps-strengthening exercises on the pennation angles of the VM and VL are contradictory. The type, intensity, and duration of exercises that affect the pennation angle remain unclear. Considering our findings, kinetic chain exercises were not superior to one another, but they led to increases in the pennation angles of VM and VL. Kinetic chain exercises may enhance joint stability by increasing muscle torque and strength via increased pennation angles, thereby contributing to greater pain relief and a reduced risk of falls.

In our study, both OKCE and CKCE groups showed a reduction in fall risk and an improvement in the BBS, with no superiority observed between the two. While some studies suggest that CKCE may stimulate more proprioceptors and be more functional compared to OKCE, our results could also be related to the additional balance exercises performed in both groups (7-9,28). However, in our study, although statistically significant improvements and large effect sizes were obtained in BBS scores, the observed change did not reach the level of minimum detectable change (MDC ≈ 4-5 points) reported in the literature for older adults. A lthough the improvement in balance performance is statistically significant, its clinical significance may be limited.

Furthermore, in patients with OA, fall risk is associated with muscle strength loss (29-31). The observed negative correlation between pennation angle and fall risk may be explained by the biomechanical role of muscle architecture in force production. Pennation angle reflects the arrangement of muscle fascicles relative to the tendon and influences the physiological cross-sectional area of the muscle (11,12). An increase in pennation angle may enable greater packing of muscle fibers within a given muscle volume, thereby improving force-generating capacity and torque production (11,12,22). Since quadriceps strength plays an important role in knee stabilization, proprioceptive control, and postural balance, improved muscle force production may indirectly contribute to reduced fall risk in patients with knee OA (22,29-31).

After treatment, and following Bonferroni correction for multiple comparisons, significant negative correlations were observed between fall risk and VL pennation angle in the OKCE group, and between fall risk and VM pennation angle in the CKCE group. These findings suggest that lower pennation angles may be associated with higher fall risk in patients with knee OA. However, no significant correlations were found between changes in pennation angle and changes in fall risk over the treatment period. A lthough ultrasonographic assessment of pennation angle may provide objective information related to fall risk and functional stability, these findings should be interpreted with caution.

Another important consideration is the obesity status of the study population. The mean body mass index (BMI) for both groups was within the obesity range. Obesity is a recognized risk factor for knee OA and may influence balance, fall risk, muscle quality, and response to exercise interventions (3,29-31). Increased body weight may increase mechanical loading across the knee joint, alter lower-extremity biomechanics, and negatively affect postural control. Additionally, obesity-related metabolic and inflammatory changes may contribute to disease progression and muscle dysfunction. Therefore, BMI may have acted as a confounding factor affecting both clinical and ultrasonographic outcomes in the present study.

Study Limitations

The limitations of this study include the lack of long-term follow-up, the absence of a non-exercise control group, and the relatively small sample size. The absence of a non-exercise control group limits the interpretation of causality. Therefore, it cannot be definitively concluded whether the observed improvements were exclusively attributable to kinetic chain exercises, natural symptom fluctuation, placebo effects, or regression to the mean. However, the comparative design allowed evaluation of the relative effects of OKCE and CKCE when combined with balance exercises. A strength of this study, however, is the evaluation of the effects of exercise not only on clinical assessment parameters but also on microarchitecture, using US to measure pennation angles and muscle thickness. To our knowledge, this is the first study to evaluate the effects of OKCE and CKCE on the thickness of the RF muscle and the pennation angle of the VM and VL, measured using US in patients with KOA. Although all participants were right-side dominant, the involvement of the dominant versus non-dominant extremity may influence muscle function, proprioception, and response to exercise. This potential confounding factor should be considered in future studies.

Conclusion

Both OKCE and CKCE can be safely used in the treatment of KOA. Both exercise programs may contribute to reducing pain, improving balance, decreasing fall risk, strengthening muscles, and increasing muscle thickness and pennation angles. Future studies with larger sample sizes and longer follow-up periods, as well as investigations into the causal relationship between changes in pennation angles and muscle thickness and clinical outcomes are needed.

Ethics

Ethics Committee Approval: The study was approved by the Eskişehir Osmangazi University Faculty of Medicine Clinical Research Ethics Committee (ethical approval date: December 01, 20022, protocol code: E-80558721-050.99-413731/10.11.2022). The research was conducted in accordance with the "Declaration of Helsinki."

Informed Consent: Written informed consent was obtained from patients who participated in this study.

Footnotes

Authorship Contributions

Surgical and Medical Practices: N.K., O.A., Concept: N.K., O.A., Design: N.K., O.A., B.A., Data Collection or Processing: N.K., O.A., B.A., Analysis or Interpretation: N.K., O.A., B.A., F.B., C.B., Literature Search: N.K., O.A., B.A., F.B., Writing: N.K., O.A., B.A.

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