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The effectiveness of massage on pain, external knee adduction moment, and muscle Co-contraction in individuals with medial compartment knee osteoarthritis

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ABSTRACT

Background: The pain, external knee adduction moment (EKAM), and muscle co-contraction are increased in knee osteoarthritis (KOA). Massage therapy decreases pain in KOA, yet KOA is a mechanical disease and biomechanical changes need to be investigated as well. Therefore, the current study aims to investigate the effectiveness of massage on these outcomes in individuals with medial KOA.

Methods: A cohort of fifteen participants with confirmed medial compartment KOA (2 males, 13 females, age: 61.33 (6.16) years; height: 1.62 (0.06) m; mass: 65.39 (4.04) kg; BMI: 24.74 (4.04) kg/m^2) was given a six-week massage. Outcomes assessed pre- and post-intervention were: Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores, temporal-spatial variables, knee joint kinematics and kinetics in sagittal, frontal, and transverse planes, vertical ground reaction force (GRF), and knee antagonist muscle co-contraction during gait. The paired *t*-test were used for statistical analysis.

Results: Fifteen participants completed the study. Significant improvements were observed in WOMAC scores (pain, stiffness, function, and total), walking speed, step length, 1st peak GRF, sagittal plane knee joint range of motion during stance, and medial muscle co-contraction in early and mid-stance ($p < 0.05$). However, no significant change was found in EKAM and knee adduction angular impulse (KAAI) ($p > 0.05$).

Conclusion: Massage therapy, as a stand-alone treatment, reduces pain, improves function, and decreases medial muscle co-contraction in individuals with medial KOA. Although EKAM did not change, the results suggest a reduction in medial muscle co-contraction might be a mechanism by which pain is improved.

1. Introduction

Osteoarthritis (OA) is one of the most common forms of muscular and skeletal disease characterized by loss of articular cartilage, subchondral bone sclerosis, and meniscal degeneration [Gerwin et al., 2006]. It can affect many joints of the human body, especially in the weight-bearing joints such as the knee [Felson and Zhang, 1998]. It is estimated that KOA involves about 10–13% of those over 60 years worldwide [Hunter and Bierma-Zeinstra. 2019]. Tang et al. (2016) reported that about 8.1% of Chinese people aged over 60 years had symptomatic KOA, which was the leading cause of disability in China. The main symptoms of KOA are joint pain, stiffness, and limited range of motion (ROM) which if left untreated could seriously affect an individual's function during their daily activities [Nelson et al., 2014; Schuring et al., 2017]. Due to the aging of the population and increasing prevalence of obesity, KOA has become a leading cause of disability and poses significant personal and economic strain [Hunter and Bierma-Zeinstra. 2019].

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Knee loading during gait has been implicated in the development of pain and progression of medial compartment KOA [Amin et al., 2004; Miyazaki et al., 2002; Kean et al., 2012]. It has been widely accepted that external knee adduction moment (EKAM) and knee adduction angular impulse (KAAI) are surrogate measures of the medial compartment knee loading [Amin et al., 2004; Miyazaki et al., 2002; Kean et al., 2012; Fukaya et al., 2019], although they are only one of many predictors of KOA [Long et al., 2017]. However, Walter et al. (2010) indicated that only decreasing EKAM may not guarantee decreased knee loading during gait, as co-contraction of agonist and antagonist muscles (i.e. simultaneous activation of the quadriceps and hamstrings) around the knee has also been reported to be a determinant of knee loading [Hodges et al., 2016; Winby et al., 2009]. One previous study indicated that increased medial knee muscle co-contraction was associated with greater progression of KOA [Hodges et al., 2016]. Since increased knee loading has been proven to play a critical role in the disease process [Miyazaki et al., 2002; Hodges et al., 2016], many interventions have made reduction of knee loading during gait their primary target.

Massage therapy is known to improve pain, physical function, and quality of life in KOA [Perlman et al., 2019; Pehlivan and Karadakovan. 2019]. The underlying mechanisms of massage improvements in KOA are not well-defined. One previous study demonstrated that massage therapy is beneficial in reducing joint overload by modifying muscle co-contraction [Cruz-Montecinos et al., 2016]. This indicates that the biomechanical mechanisms of massage therapy in the management of KOA might be correlated with the changes in muscle co-contraction. However, only the immediate effects of massage therapy on muscle co-contraction during stair descent were reported in the previous study, neither EKAM nor KAAI were reported. Therefore, the relationship between pain, knee loading and the short-term effects of massage on muscle co-contraction are unknown.

According to the review of the existing literature, no previous study investigated the short-term effects of massage on pain, knee loading and muscle co-contraction. Therefore, the purpose of the study was to investigate the short-term effects of massage on pain, knee loading, and antagonist muscle co-contraction in individuals with medial KOA. The primary hypothesis of this study was that the massage would decrease pain. The secondary hypothesis suggested that massage would recover dynamic walking without significantly increasing EKAM and KAAI during gait. Finally, the massage would reduce the muscle co-contraction of the affected knee during gait.

2. Materials and methods

2.1. Study design

An uncontrolled pre-post design was used to examine the short-term effect of massage on pain, EKAM, and muscle co-contraction in individuals with medial compartment KOA. The outcome assessors were not involved in the in providing intervention. This study was approved by the China Ethics Committee of Registering Clinical Trials (ChiECRCT, 20170055) and the University of Salford Research, Enterprise and Engagement Ethical Approval Panel (Reference number: HSR1617-173), and written informed consent of all participants was obtained. Also, this study was registered in Chinese Clinical Trial Registry (ChiCTR-INR-17012499).

2.2. Sample size estimation

The sample size was calculated using G*Power (Version 3.1, University of Kiel, Germany) using data from a previous study assessing the effect of a three-week massage on reducing WOMAC pain in patients with medial KOA and reported an effect size of 0.74 [Pehlivan and Karadakovan. 2019]. Assuming alpha of 0.05 and power of 0.8, 13 participants were adequate to power this study. In order to account for a 20% dropout rate in a longitudinal study, the obtained sample size of n = 15 is more than adequate to test the study hypothesis.

2.3. Participants

Participants were recruited based on the following eligibility criteria for participation in the study: (i) aged 40 years and above, (ii) diagnosed with medial KOA according to the American College of Rheumatology (ACR) clinical criteria [Hochberg et al., 1995] with X-ray demonstrating Kellgren & Lawrence (KL) grade 2–3 in the affected painful knee, (iii) could walk independently without any assistance. The exclusion criteria were: (i) not meeting the inclusion criteria; (ii) diagnosed with any neurological diseases; (iii) using any other type of treatments during the last four weeks; (iv) with a history of knee surgery or on the waiting list for any knee surgery.

2.4. Assessment procedure

Demographic data of all participants were recorded (age, gender, weight, height, KL grades). Outcomes were assessed before the start of the six-week massage and within one week after the end of it.

2.4.1. Clinical assessment

The WOMAC score is a widely used self-administered health status measure used in assessing pain, stiffness, and function in patients with KOA [Jun et al., 2020]. The scale contains a total of 24 items and three dimensions. The WOMAC questionnaire used in this study was rated on a 0–10 numeric rating scale for every subscale, thus, the total scale ranged of 0–240 points with higher scores indicating worse function. The WOMAC scales (pain, stiffness, function, and total) were measured at baseline and six weeks [Zhao et al., 2023].

2.4.2. Gait biomechanical outcomes

Motion data from walking were collected using a sixteen-camera three-dimensional motion analysis system (VICON MX T40 series, UK) at a sampling rate of 100 Hz. The ground reaction force (GRF) data were collected using four integrated force plates (BP400600, AMTI, USA) at a sampling rate of 1000Hz. The retro-reflective markers (14 mm) were attached securely to the anatomic landmarks, i.e., the greater trochanter, femur medial/lateral epicondyle, tibia medial/lateral malleolus of both limbs and the anterior superior iliac spine and posterior superior iliac spine on both sides were used to define and track the pelvis, the marker on the posterior calcaneus (heel) and markers on the head of metatarsal 1, 2 and 5 were used to tack the motion of the foot, and the 4-marker clusters were used to track the motion of both legs and femurs according to the calibrated anatomical system technique (CAST) [Cappozzo et al., 1995]. Participants were asked to wear same type of shorts and T-shirt which were offered by researchers. A static trial was collected to calibrate the gait model prior to the gait tasks (Fig. 1). All the participants were asked to walk at their self-selected speed and gait data were collected from five successful trials. Considering the kinematic and kinetic data may be influenced by different types of shoes between sessions, participants in the current study were asked to wear the same type of standard shoes (Huili, Shanghai Huili Footwear Co. Ltd, China) which were offered by investigators. The kinematic and kinetic data were processed by Visual 3D (C-Motion, Rockville, Maryland) (Fig. 2). Gait cycle events of initial contact and toes off were determined based on the force plate data when force accessed or reduced below 10 Neutron. The heel strike ending this gait cycle was identified by Visual 3D. A cut-off frequency of 6Hz low pass filter was used for kinematics signals and 25Hz for the raw analog signals. The kinematic data were derived from the motion data based on the 3D biomechanical model established with the captured static data, which were computed using the default Cardan rotation sequence (X-Y-Z). Joint moments were expressed as external moments, referenced about the local coordinate system of the proximal segment [Jones et al., 2013]. In this study, only

Fig. 1. Static model marker placement (anterior and posterior views).

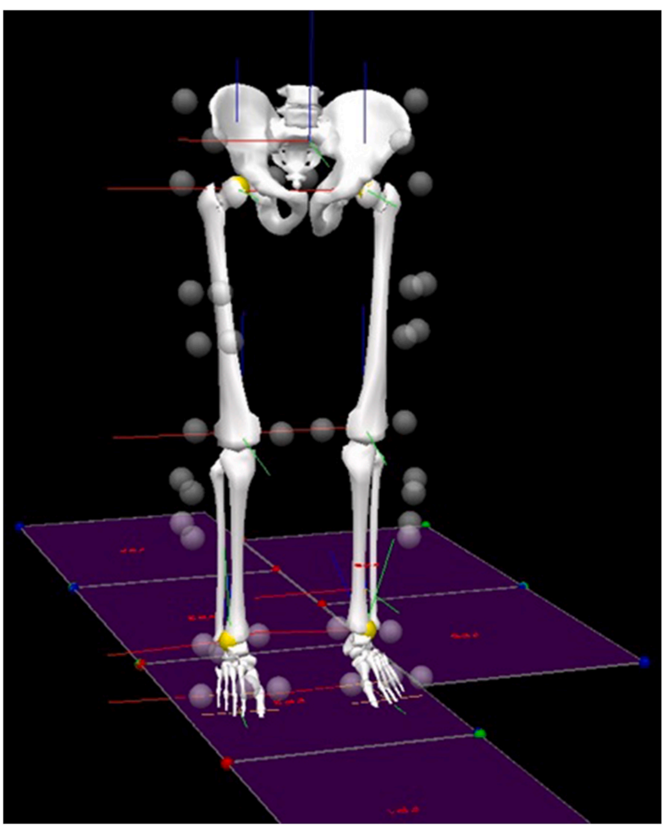

Fig. 2. Visual 3D model.

the symptomatic knee was evaluated. For participants with bilateral medial KOA, the more symptomatic side was deemed as the test limb.

2.4.3. Muscle co-contraction

Surface electromyography (sEMG) data were collected using a wireless Noraxon Telemyo system (Noraxon, USA) at a sampling rate of 1500 Hz with electrodes placed on the affected side vastus lateralis (VL), vastus medialis (VM), biceps femoris (BF), and semitendinosus (ST) muscles according to the SENIAM guidelines [Hermens et al., 2000] (Fig. 3). The sEMG data during the walking trials were normalised to the maximum voluntary isometric contraction (MVIC) values. The method of the MVIC values collecting was based on the previous study [Zeni et al., 2010]. Average co-contraction between VL/BF and VM/ST was calculated in early-stance (0%–32%), mid-stance (33%–67%), and late stance (68%–100%) according to the equation reported by one previous study: $sEMG_{Lower}/sEMG_{Higher} \times (sEMG_{Lower} + sEMG_{Higher})$, where $sEMG_{Lower}$ is the sEMG activity of the least active muscle and $sEMG_{Higher}$ is the sEMG activity of the more active muscle between the two antagonists [Rudolph et al., 2000]. The activity of each muscle was calculated by averaging the mean of the normalised sEMG activity of the five trials.

The sEMG signals were filtered with a 20Hz high pass filter to remove noise and skin movement artifact and then rectified before applying the low pass Butterworth filter (6Hz) to smoothen a linear envelope, afterwards the sEMG signals could be presented as time normalised to the stance phase of affected limbs using gait event data calculated from the force platforms [Preece et al., 2016]. The MVIC data were filtered in the same way as the sEMG data from walking.

Test–retest reliability tests were performed on 10 subjects with

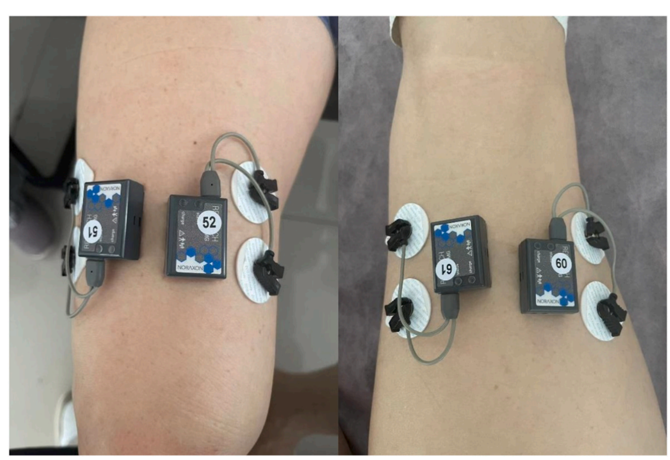

Fig. 3. Illustration of the electrode sites used in the investigation for the vastus lateralis/biceps femoris and vastus medialis/semitendinosus based on SENIAM guidelines.

medial KOA performing 5 level ground walking trials assessed at a seven-day interval to assess the data quality of the gait variables and muscle co-contraction, which were fair to excellent intra-rater reliability for the biomechanical measurement (intra-class correlation coefficient (ICC), range 0.71–0.97).

Peak knee angles, knee joint range of motion (ROM), and peak knee joint moments during the stance phase in the sagittal, frontal, and transverse planes were assessed at baseline and six weeks. The walking speed, cadence, and muscle co-contraction were also assessed at baseline and six weeks.

2.5. Intervention

All the massage sessions were provided by a well-qualified massage doctor with a minimum of three years of clinical experience. The participants were instructed to lie in a supine position at the lateral edge of the treatment bed and expose the skin of the affected knees to the massage doctor. The massage doctor applied rolling manipulation from the quadriceps femoris to the patella, pressing and kneading both sides of the patella for 10 min. To perform rolling manipulation, the massage doctor stood on the homolateral side of the treatment bed with his feet separately. After that the massage doctor positioned the proximal little finger of the back of the palm of his operating upper limb neat the treatment site with the metacarpophalangeal joint flexed slightly. The massage doctor extended his elbow with should force slightly, and turn outwards and swung forward his forearm, with the wrist joint gradually flexed and moved forward, and then flexed his elbow slightly with the forearm turned inwards and swung backward, and the wrist joint gradually extended and moved backward [Niu et al., 2021]. The proximal back edge of the palm continues to move back and forth on the treatment site.

After that, the participants were instructed to lie prone on the treatment bed. The massage doctor applied rolling manipulation from the middle of the thigh to the top of the calf for 5 min. Finally, the massage doctor rubbed the sides of the knee joint, and the edge of the patella and clearance for 5 min. For participants with bilateral medial KOA, both sides were treated. Participants underwent massage therapy twice a week for six weeks.

2.6. Statistical analysis

Statistical analysis was performed by using IBM SPSS Statistics for Windows, Version 24.0. (IBM Corp., Armonk, N.Y., USA). The Shapiro–Wilk test was used to determine the normality distribution of data. For data that did not present normal distribution, logarithmic transformation was carried out [de Matos Brunelli Braghin et al., 2019]. Paired T-test was performed to identify whether the clinical or biomechanical outcomes were significantly changed after intervention. Mean deviations between pre- and post-intervention and the 95% CI were extracted and tested statistically, for which a statistically significant difference was defined as a $p < 0.05$. The effect size was calculated with the Cohen-d test by using G*Power (Version 3.1.7) and classified as small ($\geq$0.2 and < 0.5), medium ($\geq$0.5 and < 0.8), and large ($\geq$0.8).

3. Results

The flow of participants into the study is shown in Fig. 4. A total of fifteen individuals with medial KOA were recruited and successfully went through the massage focused study. Demographic and characteristic data expressed as Mean (SD) (Table 1) showed no change in body height and body mass during the study. No participants missed a session with 100% compliance. Clinical and biomechanical results were successfully collected in all participants at baseline and after receiving the six-week massage were presented in Table 2.

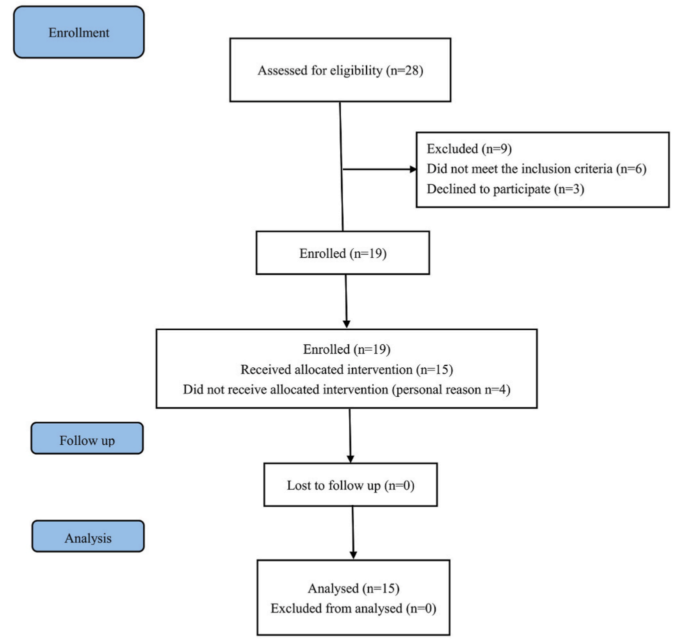

Fig. 4. CONSORT flow chart of study recruitment.

Table 1
Characteristics of participants (Mean (SD)).

Gender	Male 2 Female 13
Age (years)	61.33 (6.16)
Height (m)	1.62 (0.06)
Body Mass (kg)	65.39 (15.22)
Body mass index (kg/m^2)	24.74 (4.04)
KL grade of KOA	grade 2 = 10, grade 3 = 5
Bilateral KOA, yes: no	5:10

3.1. Clinical outcomes

The data from second test after six-week of massage indicated that significant reductions in WOMAC pain (33.2%, Cohen's d = 1.67), WOMAC stiffness (47.5%, Cohen's d = 0.91), WOMAC function (24.83%, Cohen's d = 1.01), and WOMAC total score (28.7%, Cohen's d = 1.47) in comparison with baseline assessments ($p < 0.05$). Large effect sizes were observed in WOMAC pain, stiffness, function, and total.

3.2. Gait biomechanical outcomes

The data from second test after six-week of massage indicated that walking speed and step length were significantly increased by 8.9% (Cohen's d = 0.40) and 7.3% (Cohen's d = 0.52) ($p < 0.05$) respectively. Small to medium effect sizes were observed in walking speed and step length.

The kinematic data showed that the knee joint ROM in the sagittal plane during stance significantly increased by 15.1% (Cohen's d = 0.99) ($p < 0.05$) after the six-week massage. However, the changes in other kinematic data did not reach a significant level ($p > 0.05$). A significant greater 1st peak GRF (5.8%, Cohen's d = 1.00) was found after six-week massage ($p < 0.05$). Large effect sizes were observed in knee joint ROM in the sagittal plane and 1st peak GRF. However, no statistical change was found in other kinetic data ($p > 0.05$).

3.3. Muscle co-contraction

After the six-week massage, the muscle co-contraction between VM and ST significantly decreased in early and mid-stance ($p < 0.01$,

Table 2
Mean (SD) for all variables at baseline and post six-week massage.

Variables	Pre	Post	Mean Difference	95% CI for Difference	P value	Effect Size
WOMAC pain	15.67 (3.64)	10.47 (1.73)	5.20 (3.41)	3.31-7.09	**<0.01***	1.67
WOMAC stiffness	5.07 (3.03)	2.66 (1.05)	2.40 (2.47)	1.03–3.77	**<0.01***	0.91
WOMAC function	43.73 (12.03)	32.87 (8.90)	10.87 (9.91)	5.38-16.36	**<0.01***	1.01
WOMAC total	64.47 (14.33)	46.00 (9.42)	18.47 (12.31)	11.65-25.28	**<0.01***	1.47
Walking speed(m/s)	1.01 (0.15)	1.10 (0.12)	−0.09 (0.10)	−0.14 to −0.03	**<0.01***	0.52
Step length (m)	0.55 (0.05)	0.59 (0.05)	−0.04 (0.03)	−0.05 to −0.02	**<0.01***	0.40
PKF at IC (°)	6.32 (3.99)	5.64 (2.76)	0.68 (3.89)	−1.80-3.14	0.56	0.20
PKF during ES (°)	14.45 (5.07)	15.45 (3.79)	−1.00 (3.91)	−3.16-1.16	0.34	0.22
Knee_ROM_X during SP (°)	37.85 (6.31)	43.56 (4.86)	−5.71 (4.90)	−8.82 to −2.59	**<0.01***	0.99
PKADD during SP (°)	−3.64 (3.31)	−3.06 (2.49)	−0.58 (2.34)	−1.88-0.72	0.36	0.17
PKABD during SP (°)	3.02 (2.81)	3.47 (4.10)	−0.45 (3.63)	−2.46-1.56	0.64	0.14
Knee_ROM_Y during SP(°)	6.67 (2.61)	6.54 (4.04)	−0.13 (4.32)	−2.52-2.26	0.91	0.06
PKIR during SP (°)	4.21 (5.46)	4.02 (5.65)	0.19 (6.60)	−3.47-3.85	0.91	0.03
PKER during SP (°)	−8.84 (5.99)	−10.27 (5.44)	1.43 (5.68)	−1.71-4.57	0.34	0.26
Knee_ROM_Z during SP (°)	13.04 (3.32)	14.29 (5.06)	−1.24 (5.92)	−4.52-2.03	0.43	0.29
KFM (Nm/(BW*Ht)%)	2.02 (0.87)	2.37 (0.89)	−0.35 (0.69)	−0.73-0.03	0.07	0.44
KEM (Nm/(BW*Ht)%)	−2.07 (0.73)	−2.36 (0.60)	0.30 (0.57)	−0.02-0.6	0.06	0.46
EKAM1 (Nm/(BW*Ht) %)	2.96 (0.71)	3.06 (0.76)	−0.09 (0.21)	−0.21-0.02	0.10	0.13
EKAM2 (Nm/(BW*Ht) %)	2.27 (0.84)	2.31 (0.79)	−0.03 (0.43)	−0.20-0.27	0.76	0.05
KAAI (Nm.s/(BW *Ht)%)	1.16 (0.29)	1.18 (0.29)	−0.02 (0.11)	−0.08-0.03	0.38	0.07
KIRM (Nm/(BW*Ht)%)	0.73 (0.35)	0.82 (0.28)	−0.09 (0.20)	−0.20-0.02	0.11	0.28
KERM (Nm/(BW*Ht)%)	−0.67 (0.30)	−0.76 (0.30)	0.10 (0.23)	−0.03-0.22	0.13	0.33
1st GRF (BW)	1.03 (0.06)	1.09 (0.05)	−0.06 (0.04)	−0.08 to −0.03	**<0.01***	1.00
2nd GRF (BW)	1.07 (0.05)	1.08 (0.05)	−0.01 (0.03)	−0.03-0.01	0.19	0.10
VL/BF Early stance	27.89 (12.95)	23.00 (11.97)	4.89 (16.33)	−4.16-13.93	0.27	0.39
VL/BF Mid stance	7.84 (4.23)	6.21 (3.67)	1.63 (3.89)	−0.52-3.79	0.13	0.40
VL/BF Late stance	6.31 (5.23)	5.28 (3.28)	1.03 (5.02)	−1.75-3.81	0.44	0.22
VM/ST Early stance	25.65 (12.73)	14.27 (3.71)	11.37 (11.26)	5.13–17.60	**<0.01***	1.01
VM/ST Mid stance	5.94 (2.73)	4.07 (2.20)	1.88 (2.93)	0.25-3.50	**0.03***	0.72
VM/ST Late stance	5.37 (2.68)	3.76 (2.11)	1.61 (3.56)	−0.36-3.58	0.102	0.65

*: $P < 0.05$
Abbreviation: PKF at IC: peak knee flexion angle at initial contact; PKF during ES: peak knee flexion angle during early stance phase; Knee_ROM_X during SP: knee sagittal plane range of motion during stance phase; PKADD during SP: peak knee adduction angle during stance phase; PKABD during SP: peak knee abduction angle during stance phase; Knee_ROM_Y during SP: knee frontal plane range of motion during stance phase; PKIR during SP: peak knee internal rotation angle during stance phase; PKER during SP: peak knee External rotation angle during stance phase; Knee_ROM_Z during SP: knee transverse plane range of motion during stance phase; KFM: peak knee flexion moment; KEM: peak knee extension moment; EKAM1: first peak knee adduction moment; EKAM2: second peak knee adduction moment; KAAI: knee adduction angular impulse; KIRM: peak knee internal rotation moment; KERM: peak knee external rotation moment; 1st GRF: first peak of ground reaction force; 2nd GRF: second peak of ground reaction force.

Cohen's d = 1.01 and 0.03, Cohen's d = 0.72, respectively) ($P < 0.05$) but not late stance ($p > 0.05$), whereas average co-contraction between VL and BF did not decrease significantly in any part of the stance phase ($p > 0.05$). Large effect sizes were observed in early and mid-stance medial muscle co-contraction.

4. Discussion

The outcome of the current study showed that the six-week massage significantly reduced WOMAC scores compared to the baseline. These findings correspond to previous studies [Perlman et al., 2019; Pehlivan and Karadakovan. 2019], which reported short-term massage provided a statistically significant improvement in KOA symptoms. Similar findings have been found with self-massage and aromatherapy massage [Atkins and Eichler, 2013, Efe Arslan et al., 2019]. Moreover, the observed difference between the WOMAC pain score at pre- and post-massage was bigger than the minimal detectable change (MDC) (12% from the baseline) that was reported in a previous study [Angst et al., 2001]. Thus, the magnitude of change in WOMAC scores is highly clinically significant and our first hypothesis was accepted.

The results of this study showed that the massage had statistically remarkable effects on temporal-spatial parameters. In our study patients had significantly improved walking speed and step length after receiving a six-week massage. The results are concordant with the results of previous studies [Perlman et al., 2019; Sabet et al., 2021], although there were some differences in the techniques used. Sabet et al. (2021) used Swedish massage in their intervention protocol three times per week for four weeks and Perlman et al. (2019) revealed positive effects of full-body therapeutic massage on timed 50-ft walk of patients with KOA. The improvement in the temporal-spatial parameters may be attributed to the pain relief in the affected knee after the six-week massage as the decreased walking speed has been confirmed to be associated with the increase of pain in KOA [Astephen et al., 2008]. From one respect, the increase in walking speed can be regarded as a positive indicator of symptom relief, however, increased walking speed would proportionally result in a greater GRF and ultimately higher knee loading and then deteriorate the knee condition and cause further progression of KOA [Purser et al., 2012]. The results from this study indicated that although walking speed and 1st peak GRF significantly increased, no correspondent significant increase in the EKAM and KAAI was observed, thus, the massage has improved clinical and functional symptoms in the knee, recovered dynamic walking without causing a significant increase in medial compartment knee loading (EKAM and KAAI). Therefore, the second hypothesis was accepted.

Knee joint agonist muscle co-contraction has been proven to increase the knee contact force and speed up the rate of cartilage loss in individuals with KOA [Hodges et al., 2016]. Therefore, interventions to change muscle co-contraction may help to slow the progression of KOA. Our results indicated that the massage significantly reduced medial muscle co-contraction (VM/ST) in early and mid-stance. This finding suggested that massage would achieve the effect of reducing the knee contact force which would reduce the pain and potentially slow the progression of KOA [Hodges et al., 2016]. Furthermore, the reduction in medial co-contraction in the early stance phase could also suggest an improvement in shock absorption where the reduction in knee joint ROM at the frontal plane lowered the need for increased co-contraction to maintain the stability of the knee during gait. Thus, the reduction in medial co-contraction in early and mid-stance may have been a consequence of the decreased frontal plane knee joint ROM which stabilized the joint during gait. In contrast to our results, one previous study [Cruz-Montecinos et al., 2016] demonstrated that manual therapy could increase lateral muscle co-contraction of the knee, this might be due to the difference between dynamic functional tasks, as stair descent needs greater muscle co-contraction to enhance the stability of the knee than that in level walking. Therefore, further research is needed to investigate the effect of massage on muscle co-contraction in individuals with KOA during stair climbing.

Knee flexion ROM improved significantly after intervention with a six-week massage in the current study, this result is concordant with observations from previous clinical trials [Alkhawajah and Alshami, 2019, Kaya Mutlu et al., 2018]. Randomized controlled trial (RCT) studies reported improvement of knee flexion ROM following massage therapy in patients with KOA [Alkhawajah and Alshami, 2019, Kaya Mutlu et al., 2018]. Yokochi et al. (2023) reported improvement of knee flexion ROM following a single treatment of massage in patients with total knee arthroplasty.

Admittedly, the study had several limitations. Firstly, the current study only investigated the clinical and biomechanical effects of massage at short follow-up (six weeks), so it is unknown if these lead to the long-term effects of this treatment. Secondly, the effects of massage on structural changes have not been investigated in the current study. Hence, it is uncertain whether massage would improve other objective variables such as the bone marrow lesions by magnetic resonance imaging (MRI). Thirdly, the cohort study design with a small sample size may lead to a risk of bias, which might influence the ability to find statistically significant differences in other variables.

5. Conclusion

This study was carried out to understand the potential biomechanical mechanisms of massage in the management of KOA. The biomechanical data supported the idea that changes in pain were correlated with medial muscle co-contraction, but we did not find evidence that massage altered the EKAM or KAAI. Future work is to conduct further well-designed randomized controlled trials with larger sample sizes and long-term follow-up to assess certain benefits of massage therapy.

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Authorship

All named authors meet the International Committee of Medical Journal Editors (ICMJE) criteria for authorship for this article, take responsibility for the integrity of the work as a whole, and have given their approval for this version to be published.

Data availability

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

CRediT authorship contribution statement

Min Zhang: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Anmin Liu:** Writing – review & editing, Methodology. **Fuwei Pan:** Resources. **Jiehang Lu:** Resources. **Hongsheng Zhan:** Funding acquisition. **Richard K. Jones:** Supervision, Methodology.

Declaration of competing interest

The authors have no conflict of interest regarding any of the material in the manuscript and meet the criteria for authorship as defined as submission guidelines.

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