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What is This?
Effect of exercise and gait retraining on knee adduction moment in people with knee osteoarthritis

Nafiseh Khalaj¹, Noor A Abu Osman¹, Abdul H Mokhtar², Mahboobeh Mehdikhani¹ and Wan AB Wan Abas¹

Abstract
The knee adduction moment represents the medial knee joint load, and greater value is associated with higher load. In people with knee osteoarthritis, it is important to apply proper treatment with the least side effects to reduce knee adduction moment and, consequently, reduce medial knee joint load. This reduction may slow the progression of knee osteoarthritis. The research team performed a literature search of electronic databases. The search keywords were as follows: knee osteoarthritis, knee adduction moment, exercise program, exercise therapy, gait retraining, gait modification and knee joint loading. In total, 12 studies were selected, according to the selection criteria. Findings from previous studies illustrated that exercise and gait retraining programs could alter knee adduction moment in people with knee osteoarthritis. These treatments are noninvasive and nonpharmacological which so far have no or few side effects, as well as being low cost. The results of this review revealed that gait retraining programs were helpful in reducing the knee adduction moment. In contrast, not all the exercise programs were beneficial in reducing knee adduction moment. Future studies are needed to indicate best clinical exercise and gait retraining programs, which are most effective in reducing knee adduction moment in people with knee osteoarthritis.

Keywords
Knee joint load, gait modification, knee osteoarthritis, exercise, gait retraining

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Introduction
Osteoarthritis (OA) of the knee is one of the most common types of joint disease.¹⁻³ It is associated with clinical symptoms such as pain and stiffness in the knees, decreased range of motion and muscle weakness,⁴⁻⁷ which are responsible for limitations in an individual’s ability to perform physical activities and can lead to an impaired quality of life.⁸⁻¹⁰ Some biomechanical factors are related to knee OA, and the knee adduction moment (KAM) is one of them.

The KAM is a reliable external measure of medial compartment load of the knee during walking.¹¹⁻¹³ It results from the combination of the ground force acting at the knee joint during normal walking (stance phase) and the perpendicular distance that this force acts from the center of the knee joint¹²,¹⁴⁻¹⁶ (Figure 1). KAM shows two peaks during gait cycle: the first one is through the early stance and the second peak is during the late stance. The KAM during gait tends to thrust the knee into varus, increasing the load across the medial tibiofemoral articular cartilage¹⁶,¹⁷ (Figure 2).

Measurement of the knee joint moment provides a direct indication of the knee joint load. Larger KAMs correlate to increased joint loads, which are implicated in the knee OA progression,¹¹,¹³,¹⁸⁻²⁰ as well as being higher in people with knee OA.²¹⁻²⁵ This higher KAM was reported to be related to OA severity grade,¹⁸,²²,²⁶ varus alignments¹⁹,²²,²⁷ and the presence of pain in patients with symptomatic knee OA.²⁸

Importantly, KAM is one of only a few known modifiable risk factors for knee OA progression.¹⁹ Thus, preventive strategies targeting this mechanical risk factor are essential to reduce KAM during gait.

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and, consequently, reduce medial joint loading. Exercise programs and gait retraining are two nonsurgical intervention protocols that are used to reduce the KAM in people with knee OA. These interventions aim to slow the progression of knee OA and minimize the functional limitations. Gait retraining is a noninvasive and nonpharmacological treatment that modifies gait pattern by using different strategies. Several sources have proposed gait modifications as a means of influencing KAM. Their recommendations include barefoot gait, gait with the toes pointed outward, toe-in gait, shorter stride, medial thrust gait and increased medio-lateral trunk sway (Figure 3). These strategies helped to reduce the KAM during gait in people with knee OA. In addition, exercise programs are also intervention protocols used to diminish KAM. Muscle weakness may be one of the earliest features of OA, so training the appropriate muscle by using different types of exercise will influence disease progression.

The peak KAM has become a quantitative goal for clinical treatment of knee OA, and interventions that have the potential to both improve the symptoms and decrease the KAM are precious. However, according to the economic burden of surgical treatments, applying alternative treatments that are noninvasive and low cost with minimal side effects becomes essential. Given the essential role that KAM has on knee OA, this review aimed to examine the effect of exercise and gait retraining interventions on KAM in people with knee OA.

Method

The literature searches were performed in four electronic databases: ScienceDirect, Wiley, Springer and PubMed (1995–2012). The search terms included the following: knee OA, KAM, exercise, exercise therapy, gait retraining, gait modification and knee joint loading. Combination of these terms was used for searching (as appropriate); for instance, “gait modification and KAM.” The original electronic search produced 85 initial papers of which the team excluded 73 based on information contained in the title or abstract. All these studies were in English, and the search excluded review articles and studies that retrained the gait using gait aids. In addition, only studies that used gait modification strategies for the purpose of gait retraining were included. Finally, the team identified a total of 12 studies as relevant to this review. The study design, study size, anthropometric data, measurement protocols and results of all the articles were reviewed.

Results

KAM is a surrogate measure of medial knee joint load during gait that is often used in knee OA patients. Gait retraining and exercise programs are noninvasive simple treatments used to alter KAM in knee OA patients. Gait retraining was proposed as a method for lowering KAM by modifying gait pattern. Clinical guidelines reinforce the importance of conservative and nonpharmacological treatment for knee OA patients such as exercise. Exercise is one of the best treatments with little or no side effects. In total, 12 articles were selected for this review; 8 of these selected articles studied people with knee OA, and the rest studied healthy people with no knee OA and extended their results to...
knee OA patients. The summary and results of the reviewed articles can be found in Tables 1–3. In addition, Figure 4 provides information about participants (healthy and knee OA) and the interventions.

Table 1 presents characteristic data of the 12 studies and included sample (healthy or knee OA subjects), sample size, gender, age and body mass index (BMI). Weight means were calculated for some of the studies, as needed. The reviewed articles provided data on 201 participants allocated to intervention programs and 105 participants allocated to control group. The number of subjects ranged from 1 to 76. The age (mean) varied from 26 to 68 years. Three of these studies had control group, in which one of them was healthy44 and two were knee OA.45,46 Sled et al.44 and Bennell et al.45 did not use any intervention; however, Foroughi et al.46 used sham exercise for control group.

Table 2 provides brief information about the content of the studies, which assessed the effect of exercise on KAM. This table provides information on the OA severity grade, OA measurement protocols, type of intervention, motion measurement tool, duration of treatment and results. Exercise programs aimed to improve the strength of the lower extremity muscles, and their intensity ranged from moderate to high. However, the mode of exercise programs was different, and three of six studies applied home exercise programs. The treatment duration ranged from 4 to 12 weeks.

The measurement protocols for diagnosis of knee OA and indicating the severity were the Kellgren–Lawrence (K/L) scale and MRI. The K/L scale is used to diagnose the severity grade (four grades) of knee OA through the use of radiography (X-ray). According to K/L scale, grade 1 is doubtful knee OA, in which narrowing of the joint space and possible osteophytes can be seen. Grade 2 is mild knee OA, with small osteophytes and possible narrowing of the joint. Grade 3 is
<table>
<thead>
<tr>
<th>Author, year</th>
<th>Knee OA grade</th>
<th>OA measurement protocol</th>
<th>Type of intervention</th>
<th>Measurement tool</th>
<th>Treatment duration</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorstensson et al., 2007</td>
<td>1, 2, 3</td>
<td>K/L scale, KOOS</td>
<td>Supervised moderate exercise program (strength and motor control)</td>
<td>Vicon (six cameras); AMTI force plate</td>
<td>8 weeks (twice per week)</td>
<td>Reduction in peak knee adduction moment during one leg rise</td>
</tr>
<tr>
<td>King et al., 2008</td>
<td>1, 2, 3, 4</td>
<td>K/L scale, KOOS, ASES</td>
<td>Isokinetic resistance training (high intensity)</td>
<td>Motion capture system (eight cameras); force platform</td>
<td>12 weeks (three times per week)</td>
<td>No significant changes in knee adduction moment during gait in the index and the opposite knee (comfortable fast walking)</td>
</tr>
<tr>
<td>Sled et al., 2010</td>
<td>2</td>
<td>K/L scale</td>
<td>Home strengthening exercise program</td>
<td>Optotrak 3020 optoelectronic (two cameras); two AMTI force plates</td>
<td>8 weeks (three to four times per week)</td>
<td>No change in the mean pain values and levels of function</td>
</tr>
<tr>
<td>Thorp et al., 2010</td>
<td>2, 3</td>
<td>K/L scale, WOMAC</td>
<td>Home exercise; strengthening exercise</td>
<td>Optoelectronic (four cameras); force plate</td>
<td>4 weeks (eight training sessions)</td>
<td>Functional improvement (sit to stand) and knee pain reduction</td>
</tr>
<tr>
<td>Bennell et al., 2010</td>
<td>2, 3, 4</td>
<td>K/L scale, WOMAC, PASE</td>
<td>Home exercise designed to strengthen the muscles</td>
<td>Vicon (eight cameras); two force plates</td>
<td>12 weeks (five times per week)</td>
<td>Reduction in knee adduction moment following exercise intervention (self-selected normal, fast and slow walking)</td>
</tr>
<tr>
<td>Foroughi et al., 2011</td>
<td>1, 2, 3, 4</td>
<td>WOMAC, MRI</td>
<td>High-intensity resistance training</td>
<td>Motion Analysis Corporation (10 cameras); two force plates</td>
<td>6 months (three times per week)</td>
<td>Knee pain reduction</td>
</tr>
</tbody>
</table>

OA: osteoarthritis; K/L: Kellgren–Lawrence; KOOS: Knee Injury and Osteoarthritis Outcome Score; ASES: Arthritis Self-Efficacy Scale; WOMAC: Western Ontario and McMaster Universities Arthritis Index; MRI: magnetic resonance imaging.

Treatment duration: period of treatment (the number of sessions per week).

The median Kellgren–Lawrence grade for knee OA group was 2 and mean (SD) was 2.5 (0.91).

Control group had lower peak KAM than knee OA group.
<table>
<thead>
<tr>
<th>Author, year</th>
<th>Subjects</th>
<th>Type of intervention</th>
<th>Utilities used for intervention</th>
<th>Measurement tool</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fregly et al., 2007&lt;sup&gt;31&lt;/sup&gt;</td>
<td>Knee OA</td>
<td>Gait training by using gait modification (medial thrust gait pattern)</td>
<td>9 months self-training</td>
<td>Motion analysis (six cameras); force plate</td>
<td>Reduction in knee adduction torque by 39%–50% in the first peak and 37%–55% in the second peak. After 1.5 years of using this gait pattern, knee pain reduced without any problem in other joints (self-selected walking speed).</td>
</tr>
<tr>
<td>Simic et al., 2012&lt;sup&gt;47&lt;/sup&gt;</td>
<td>Knee OA</td>
<td>Gait modification by using increasing trunk lean motion (6°, 9°, 12°)</td>
<td>Trained by physiotherapist using visual real-time biofeedback</td>
<td>Vicon (eight MX cameras); three AMTI force plates</td>
<td>KAM was reduced following increased trunk lean during gait (gait speed similar to the natural walking trials).</td>
</tr>
<tr>
<td>Barrios et al., 2010&lt;sup&gt;48&lt;/sup&gt;</td>
<td>Healthy</td>
<td>Systematic gait retraining program</td>
<td>Real-time visual and verbal feedback</td>
<td>Vicon (eight cameras); force plate</td>
<td>20% average reduction in peak KAM (walking velocity maintained at 1.46 m/s ± 2.5%)</td>
</tr>
<tr>
<td>Hunt et al., 2011&lt;sup&gt;14&lt;/sup&gt;</td>
<td>Healthy</td>
<td>Gait retraining by lateral trunk lean (4°, 8°, 12°) during gait</td>
<td>Real-time visual biofeedback</td>
<td>Vicon (eight MX cameras); two force plates</td>
<td>Lateral trunk lean reduced the peak KAM, particularly in medium and large trunk lean condition (self-selected walking speed).</td>
</tr>
<tr>
<td>Shull et al., 2011&lt;sup&gt;49&lt;/sup&gt;</td>
<td>Healthy</td>
<td>Gait retraining&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Haptic device (wearable) real-time feedback</td>
<td>Vicon (eight cameras); force plate</td>
<td>KAM reduced by 29%–48% (self-selected walking speed).</td>
</tr>
<tr>
<td>Wheeler et al., 2011&lt;sup&gt;15&lt;/sup&gt;</td>
<td>Healthy</td>
<td>Gait retraining (self-selected gait modification)</td>
<td>Vibration and visual feedback</td>
<td>Vicon (eight cameras); split-belt force plate treadmill</td>
<td>Reduced KAM in altered gaits compared with baseline&lt;sup&gt;b&lt;/sup&gt;.</td>
</tr>
</tbody>
</table>

OA: osteoarthritis; KAM: knee adduction moment.

<sup>a</sup>Gait retraining consisted of increased toe-in, increased toe-out, increased trunk sway and increased tibia angle.

<sup>b</sup>Walking speed is not available.
moderate knee OA, which is characterized by multiple, moderately sized osteophytes; definite joint space narrowing and possible deformation of bone ends. Finally, grade 4 which is considered as severe knee OA and is presented by multiple large osteophytes, severe joint space narrowing, marked sclerosis and definite bony end deformity. In addition, various questionnaires were used to assess pain and physical abilities in individuals with knee OA, including the Western Ontario and McMaster Universities Arthritis Index (WOMAC), the Knee Injury and Osteoarthritis Outcome Score (KOOS) and the Arthritis Self-Efficacy Scale (ASES). WOMAC is a set of standardized questionnaires used to assess pain, stiffness and physical function in patients who suffer from OA of the knee and hip. KOOS is an instrument used to assess the patient’s opinion about his or her knee and any associated problems. In addition, ASES is a self-administered, disease-specific questionnaire that consists of 20 questions about physical function, pain and other symptoms.

Table 3 presents the information of the studies that involved gait retraining in both healthy subjects and people with knee OA. This table contains information on the type of intervention, the utilities used for intervention, the applied measurement tools and the final results. Six articles applied gait retraining in their studies: two of them provided data about knee OA patients and four about the healthy subjects. The gait modification was done by using biofeedback, which is a promising approach for gait modification training. A biofeedback gait training system can deal with measurement, analysis, training and evaluation of gait and provides precise “feedback” information to the user. In other words, it provides additional highly detailed sensory information (feedback) through sensory modalities, including visual, auditory and tactile biofeedback in response to physical action. It provides information on body sway and is used to attain the precise amount of lean required. The knee loading modification was feasible by using visual, audio, verbal and tactile feedback. Furthermore, one study used a haptic device for gait retraining. Haptic device is a sensible technology that provides both tactile and force feedback.

Discussion

The KAM is an important biomechanical risk marker (of knee load) that can be used as a surrogate measure for knee joint load during gait. Increased KAM is indicative of the increased load on knee joints, particularly medial compartment. The knee OA is associated with higher KAM, and the findings of Miyazaki et al. revealed that a one-unit increase in KAM is associated with up to a 6.5 times increase in the risk of knee OA progression. People with knee OA walked with higher KAM compared to healthy people, which demonstrates the increased knee joint load in a medial compartment of the knee. Moreover, the KAM is one of the known modifiable biomechanical risk factor for knee OA progression. Therefore, there is great interest in reducing the KAM by noninvasive treatment interventions in order to delay the progression of the disease. Some of the recent treatments used to reduce KAM in knee OA are gait retraining and exercise programs.

Gait retraining (gait pattern modifications) is a non-invasive early treatment for people with knee OA, and it can be effective in reducing KAM. The gait modifications that were used for gait retraining were toeing-out, toeing-in, walking with decreased stride length, walking with medial-lateral trunk lean and medial thrust gait. A few studies used trunk lean motion, and all the studies reported similar findings, which was increased in trunk lean and is associated with decreased KAM. Hunt et al. modified the gait pattern by increasing the lateral trunk lean motion to the dominant side (not bilaterally) by 4°, 8° and 12° soon after the initial foot contact. Their findings revealed that greater amount of trunk lean would result in larger decrease in KAM. Moreover, it is interesting to note that the combination of trunk lean (increased the trunk sway by 7°–17°) and toe-in in healthy subjects decreases the first peak of KAM, as confirmed by the findings of
Shull et al. They used different gait modification methods including increased toe-in, increased toe-out, increased trunk sway and increased tibia angle. In order to do the modification, haptic feedback was used, including tactor vibration motors (foot progression angle) and rotational skin stretch devices (trunk sway changes). Nonetheless, it is unclear whether multi-parameter, real-time feedback will be equally effective for older subjects because of a potential deficiency in their haptic sensation, proprioception, stability and endurance or learning abilities. Among all the studies that used lateral lean trunk motion for gait retraining, Simic et al. modified the gait pattern in knee OA patients. Likewise, they reported that trunk lean is a feasible gait modification, and increased lateral trunk lean toward the symptomatic limb significantly reduces knee load throughout stance phase. In addition, larger angles lead to greater reductions; knee OA patients attained early stance peak KAM reduction of 9.3% with a peak of 6.1° lean, 11.5% reduction with 8.7° lean and 14.9% reduction with 11.1° lean.

The foot progression which is toe-out and toe-in is one of the strategies used in gait retraining; it involves walking with an increased external and internal foot progression angle. Shull et al. and Wheeler et al. used foot progression to modify the gait pattern. Shull et al. increased toe-in and toe-out angle by 13° to 25° and reported that toeing-in caused reductions in the first peak of the KAM. Wheeler et al. suggested different gait modifications, and one of them was walking with foot progression. They reported that the toe-in is the most common reported modification, as well as toe-out gait reduced the second peak of KAM but not the first. In addition to reducing the KAM, greater toe-out angle is associated with a reduction in the possibility of knee OA progression. Decreasing the lever arm of the ground reaction force (GRF) vector about the center of knee joint might explain this reduction in KAM.

There were a few other studies that also used other gait retraining programs and reported the same results, which was reduction in KAM after intervention. Fregly et al. used an inverse dynamic-optimizing approach for an individual with bilateral knee OA; it was designed to produce “normal looking” gait motions that were capable of reducing both adduction torque peaks simultaneously. According to their procedure, normal looking means a gait motion whose trunk orientation, arm motion, foot path and pelvis translations are similar to the patient’s normal gait. The patient underwent 9-month self-training; although the patient experienced reduced knee pain without any problems at other joints, he was incapable to revert back to his pre-training gait. In addition, gait modification (hip internal rotation and adduction) in varus aligned healthy subjects also was associated with reduced KAM. Barrioz et al. applied eight gait training sessions by using treadmill and visual feedback. They instructed the subjects to walk while bringing their thighs inward. However, in contrast to Fregly et al. study, the training protocol did not alter the natural gait of participants. One significant limitation of gait retraining studies with healthy subjects was that the subjects were healthy and young who did not suffer from knee OA, and it is unclear that the methods would similarly reduce KAM in people with knee OA.

Weakness of muscles surrounding the knee may diminish the ability to protect the knee, disposing it to greater physical stress, structural damage and joint degeneration. Mikesky et al. reported that patients with higher quadriceps and hamstring strength walk with a lower knee joint loading. Therefore, prescribing exercise for people with knee OA is essential in order to reduce joint pain and load and increase the physical function. These exercise programs might be different in type (strengthening, aerobic and range of motion), duration, intensity and frequency. Although people with knee OA widely use strengthening exercise programs, the targeted muscles are different. Thorp et al. prescribed traditional exercise for strengthening the quadriceps and hamstrings, as well as hip muscle training (gluteus medius and tensor fascia latae) for a duration of 4 weeks (eight training sessions with physiotherapist). In addition to training sessions, they performed home exercise for 15 min on days when they did not have session with physiotherapist. KAM was reduced following their exercise intervention. In contrast to Thorp et al. findings, King et al. exercise program did not have any significant effect on KAM. They used isokinetic resistance training, three times a week for a duration of 12 weeks with a minimum of 1 day rest between sessions; each session lasted for 45 min. Their exercise training program consisted of 5 min warm up (stationary cycling), knee extensor and flexor stretches, and reciprocal concentric isokinetic knee extension and flexion exercises. Additionally, it was reported that the moderate strengthening exercise program only reduced KAM during one leg rise and had no significant effect on KAM during gait. Thorstensson et al. had 16 supervised exercise sessions during 8 weeks, aiming to improve strength and neuromuscular control of lower limbs. Although Thorp et al. exercise intervention was 4 weeks—shortest period among other reviewed exercise programs—it was effective in reducing KAM. Similarly, Thorstensson et al. exercise program was effective in KAM reduction, but only during one leg rise and not during gait. Both of these studies used supervised exercise program and asked their subjects to perform exercise at home as well as in sessions.

A few recent studies focused on strengthening the hip abductor and adductor muscles. Although the researchers used different exercise regimens for strengthening of these muscles, the findings were similar. Home strengthening exercises for hip abductor muscles, which were performed for both legs, did not reduce the KAM in people with knee OA. Sled et al. provided an exercise instruction booklet and graded resistance elastic band for all the participants and asked them to perform the exercise three to four

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times a week for a duration of 8 weeks and complete each set of exercise when they feel fatigue. Similar to this, a 12-week home exercise program (five times per week) designed to strengthen the hip abductor and adductor muscles had no significant effect on KAM but led to significant reduction in pain and improvement in physical function.\textsuperscript{45} Moreover, performing high-intensity resistance training three times per week for 6 months, which aimed to strengthen major lower limb muscles, including hip abductor and adductor, did not change the first peak of KAM compared to a control group who underwent the sham exercise.\textsuperscript{46} Reviewed studies used different exercise programs, and only two were effective in reducing KAM. This is due to different factors that affect the efficiency of exercise programs, for instance, the adherence of the patients to exercise and the mode of exercise.

Conclusion

The findings of the reviewed studies support the beneficial effect of gait retraining in knee OA, and from the few reviewed articles, it was found that gait retraining may have positive effect in reducing KAM. The reviewed studies have a number of limitations which are the number of subjects, using healthy participants and expanding the results to individuals with knee OA, not considering the effect of their intervention on the other joints and lack of follow-up which means it is unclear whether they have long-term side effects. Also, it is unclear whether these interventions, particularly using a biofeedback method, which was applied on healthy subjects, will be equally effective for older individuals with knee OA. However, more longitudinal studies are needed to investigate different gait modification protocols in knee OA patients considering the age, gender and knee OA severity and indicate which gait retraining program is more beneficial with fewer side effects. On the other hand, not all the exercise programs were beneficial for KAM reduction. The beneficial effect of exercise on reducing KAM depends on the types of exercise chosen by the therapist or researcher. Future studies need to investigate the effect of different types of exercise programs with different intensity and frequency on KAM, to indicate the best clinical exercise framework for individuals with knee OA.

Declaration of conflicting interests

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