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REVIEW

Gait- and postural-alignment-related prognostic factors for hip and knee osteoarthritis: Toward the prevention of osteoarthritis progression

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ABSTRACT. Osteoarthritis (OA) is a chronic progressive disease, and thus, prevention of this progression is an important issue. Currently, there is little evidence of the effect of exercise therapy for the prevention of hip and knee OA progression. An understanding of prognostic factors is the basis for the prevention of progression. Previous research indicates that in case of knee OA, abnormalities in knee alignment (varus or valgus) while standing, varus thrust during walking, increased knee flexion in the early stance phase, abnormal displacement of the femur in relation to the tibia, and an increase in knee adduction and flexion moment are risk factors for disease progression. At the same time, the prognostic factors in hip OA are anterior spinal inclination while standing, decreased mobility of the thoracolumbar spine, and increased cumulative hip loading during daily walking. Further research is required to investigate these prognostic factors, particularly the modifiable factors, to analyze the relationships between these factors, and to verify the structural and clinical efficacy of modifying these factors through interventions.

Key words: Osteoarthritis, Spine, Joint moment, Cumulative loading

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Osteoarthritis (OA) is the most common joint disease among middle-aged and elderly individuals worldwide. OA is characterized by restricted range of motion (ROM), symptoms, such as joint pain, stiffness, and a decline in muscle strength, and posture and gait abnormalities. OA decreases quality of life and is associated with increased mortality[1]. The most important issue related to OA is that it is a chronic progressive disease. Therefore, the prevention of OA progression is an important public health problem that may contribute to increased health longevity in aging populations.

OA is a multifactorial disease, and previous studies have accumulated a sound body of knowledge regarding the multiple causes of its progression[2-4]. These causes include age, gender, genetics, past injury, and abnormalities in bone morphology. Furthermore, several interventional studies on exercise therapy designed to inhibit the structural progression of the disease have been performed in patients with knee OA[5-7]. Nevertheless, to date, the effectiveness of appears to be limited, and there is no consensus on its overall efficacy to prevent the progression of the disease. One reason for this is that the exact targets of exercise therapy, that is, the prognostic factors that are modifiable through exercise, are not sufficiently understood. In fact, until recently, almost no modifiable prognostic factors for hip OA had been identified. The first step in the creation of effective interventional methods to prevent OA progression therefore has to be to focus on understanding the prognostic factors for OA, particularly the modifiable prognostic factors. This review is a summary of the prognostic factors in hip and knee OA that are related to postural alignment and gait.

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Postural Alignment and Knee OA Progression

Generally, in patients with knee OA, knee varus (or valgus) deformation and flexion contractures occur as the disease progresses. The more severe the degree of varus or

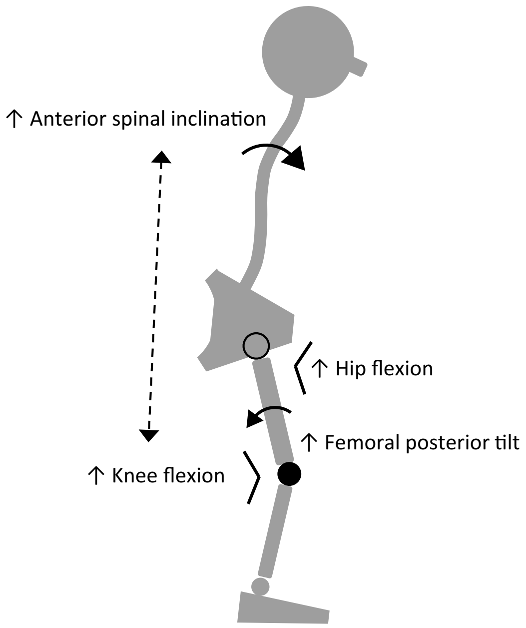

Figure 1. Postural alignment characteristics of patients with knee osteoarthritis
In the sagittal plane, femoral posterior tilt, hip flexion, and anterior spinal inclination are observed. Increased anterior spinal inclination is related to an increased knee flexion angle when standing. In the frontal plane, knee varus or valgus deformity occurs.

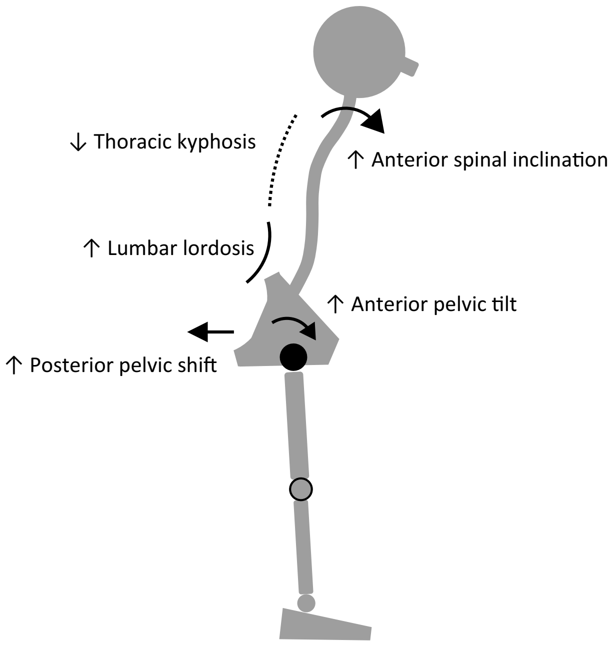

Figure 2. Patients alignment characteristics of patients with hip osteoarthritis
In the sagittal plane, pelvic anterior tilt, increased lumbar lordosis, and anterior spinal inclination are observed. Anterior spinal inclination is a prognostic factor for hip osteoarthritis. To maintain mechanical balance when standing, patients develop posterior pelvic shift and decreased thoracic kyphosis. In the frontal plane, pelvic tilt, scoliosis, and lateral trunk shift occur.

valgus deformation, the more frequently knee OA progression will occur[8]. Changes in the standing posture of patients with knee OA include, in the sagittal plane, femoral posterior tilt, hip joint flexion, and anterior spinal inclination[9,10] (Figure 1). Furthermore, increased anterior spinal inclination is related to an increased knee flexion angle when standing[9] (Figure 1). The close relationship between the alignment of the knee and the spine in a standing position can be seen in populations without knee OA. For example, the larger the knee flexion angle when standing, the smaller the lumbar lordosis angle[11]. Individuals with a tendency toward knee flexion or those with patellofemoral joint pain tend to have a smaller anterior tilt of the sacrum[12]. These data suggest that there is a close relationship between abnormal knee and spinal alignment. This is known as the knee-spine syndrome[11,12]. Abnormalities of the standing posture have also been linked to low back pain as a complication of knee OA. Although it has been reported that there is no difference in postural alignment when standing based on whether or not the individual has low back pain[10], reduced lumbar lordosis and increased posterior pelvic tilt have been reported to be related to low back pain in patients with knee OA, independent of their body mass index[13].

Postural Alignment and Hip OA Progression

Anatomically and functionally, the hip and the spine are closely related, and as a result, changes in the postural alignment of the entire body tend to accompany hip OA progression. What is widely known as the hip-spine syndrome describes how the pathologies of the hip joint and the spine are intimately related[14].

In general, patients with hip OA are likely to show increased anterior pelvic tilt, increased lumbar lordosis, and increased anterior spinal inclination when evaluated by means of the sagittal vertical axis (horizontal offset from a C7 plumb line to the posterosuperior corner of S1; Figure 2). In the frontal plane, it can be seen that the greater the hip pain or leg length discrepancy, the greater the scoliosis and lateral trunk shift[15]. It has also been reported that the greater the Sharp angle (i.e., the more severe the degree of acetabular dysplasia), the greater the sacral anteversion and lumbar lordosis[16]. In cases of secondary hip OA accompanying acetabular dysplasia, anterior pelvic tilt is thought to compensate for the reduced acetabular coverage. Nevertheless, in many cases of pre- to early-stage hip OA, no visible increase in lumbar lordosis is observed[17]. In general, with increasing age, anterior pelvic tilt in a standing position in-

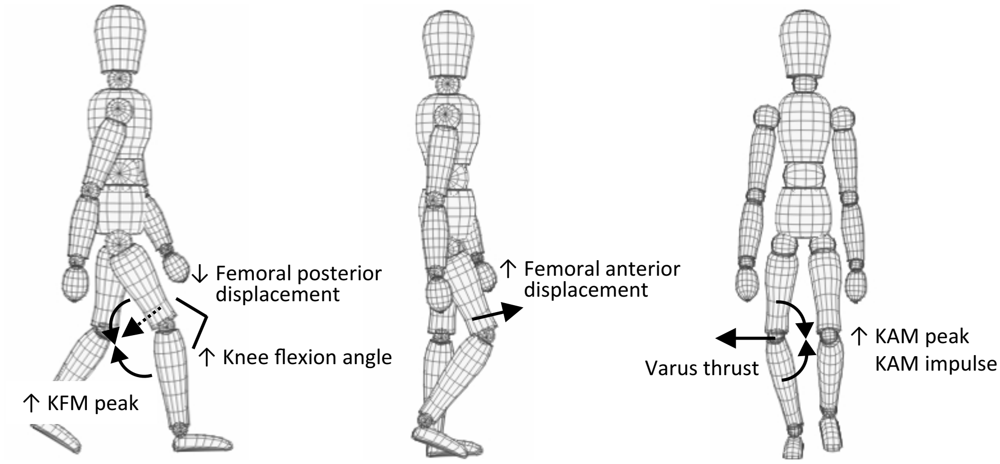

Figure 3. Gait characteristics related to progression of knee osteoarthritis
Changes in the kinematics and kinetics of the knee joint during walking are related to knee osteoarthritis progression.

creases, and lumbar lordosis tends to decrease[18]. In patients with advanced and terminal-stage hip OA, lumbar lordosis is maintained in comparison to healthy individuals of the same age (i.e., their lumbar lordosis is larger than that of healthy individuals)[17]. The deformation of the hip joint progresses as OA progresses, in turn, leading to reduced ROM. Therefore, unlike the normal changes in spinal alignment with increasing age, anterior pelvic tilt and lumbar lordosis are either maintained or increased. Furthermore, hip OA progression, limited hip ROM, and increased anterior tilt of the sacrum lead to increased anterior spinal inclination[15,19]. At the same time, posterior pelvic shift and decreased thoracic kyphosis have been observed in patients with advanced hip OA[20] (Figure 2). Posterior pelvic shift and decreased thoracic kyphosis seem to compensate for the disrupted mechanical balance of the standing posture that result from the increased anterior spinal inclination accompanying hip OA progression.

Changes in the postural alignment observed in hip OA are not only related to the disturbed balance of the entire body and low back pain, but may also promote hip OA progression. A prospective cohort study of patients with pre- to advanced stage hip OA reported that anterior spinal inclination excluding the pelvis was a risk factor for subsequent hip OA progression[21]. Spinal malalignment may cause changes in the mechanical environment of the hip joint that, in turn, may lead to OA progression. In addition, spinal dysfunction, such as decreased mobility of the thoracolumbar spine, may influence hip OA progression[21]. Decreased spinal mobility interferes with the aforementioned compensatory mechanisms for the disrupted balance in the standing posture. Furthermore, it can increase the mechanical stress on the hip joint when performing daily activities, such as rising from a chair and squatting, because many of these require coordinated movements of the hip and spine. This, in turn, is thought to lead to the degeneration of the hip cartilage. Therefore, problems with postural alignment and spinal flexibility are among the few prognostic factors of OA that are modifiable through exercise therapy, requiring particular attention by both clinicians, when assessing and treating patients, and researchers, when investigating preventive measures against hip OA progression.

Gait and Knee OA Progression[22,23]

Among the spatial-temporal characteristics of gait, the one most common characteristic of patients with knee OA is an increased stride time. As knee OA becomes increasingly severe, stride time increases. Although this is often accompanied by decreased gait speed, there is currently no consensus on the exact effect of knee OA on gait speed.

In patients with knee OA, changes in gait kinematics include varus thrust, defined as a dynamic thrust of the knee laterally during the stance phase. Varus thrust is considered a risk factor for subsequent knee OA progression[24] (Figure 3). In the sagittal plane, the knee position at initial contact during the stance phase has a tendency toward flexion, after which flexion decreases during the loading response phase. These changes get more pronounced as knee OA progresses. In recent years, it has been reported that the more the knee is flexed during the initial contact and/or the loading response, the more likely it is that knee OA will subsequently progress[25] (Figure 3). In addition to changes in joint angle, an increase in anterior displacement of the femur in relation to the tibia during the swing phase and a decrease in posterior displacement of the femur in relation to the tibia during initial contact may encourage knee OA progression[25] (Figure 3). Furthermore, lateral trunk lean toward the affected side during gait is observed in patients with severe knee OA.

Theoretically speaking, the increased length of the moment arm in conjunction with the increased knee varus

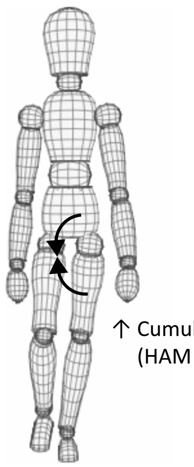

Figure 4. Gait characteristics related to progression of hip osteoarthritis
Increased cumulative hip loading, which is the product of the external hip adduction moment impulse and daily physical activity (steps/day), is related to hip osteoarthritis progression.
HAM, hip adduction moment

deformity leads to an increased external knee adduction moment (KAM) during gait. KAM is related to the mechanical stress on the medial compartment of the knee. Increases in peak KAM[26] and KAM impulse[27] are known to be risk factors for knee OA progression (Figure 3). Increased peak external knee flexion moment (KFM) during the standing phase is also considered a risk factor for knee OA progression[28] (Figure 3). However, a systematic review of the gait of patients with knee OA indicated that their KAM and KFM are not necessarily larger than those of healthy individuals[22]. This means that in a situation in which the load on their knees is increased during gait, patients with knee OA adopt a compensatory gait that reduces KAM, KFM, and knee pain by changing gait speed, trunk lean, foot angle, and other factors[29]. The substantial variations in the first peak KAM in patients with knee OA can be explained by different knee alignment (25%), pain score (1%), gait speed (1%), toe-out angle (12%), and lateral trunk lean (13%)[29]. Given that these patients experience a continuous decline in the quality of their cartilage starting from the early pre-OA stage[30], it seems likely that loads that are not necessarily high compared to healthy individuals may represent an overload for OA cartilage cells.

Gait and Hip OA Progression[31-33]

The gait speed in patients with hip OA is lower than that in healthy individuals. This is the result of the decreased step and stride length rather than decreased cadence. In comparison to healthy individuals, patients with hip OA tend to have an increased stance and decreased swing time on the affected side. However, when their affected side is compared to their healthy side, it has a shorter stance and longer swing time, indicating a characteristic asymmetry.

Many previous studies have identified a decreased hip extension angle in hip OA as a change in kinematics. A decreased hip extension angle in the early stage of hip OA indicates that the patient is attempting to avoid pain, whereas in the later stage, it is thought that hip flexion contracture plays a role in addition to pain. Knee flexion decreases during the loading response, and extension tends to decrease from the mid-stance to the terminal stance phase. In the frontal plane, many patients present with a decreased (or increased) hip adduction angle as well as trunk lean toward the stance side. Investigations of joint moment have indicated that the decreased external hip extension moment in relation to the decreased hip extension angle and the decreased external hip adduction moment (HAM) and hip rotation moment are characteristic findings. The HAM values in the early stage of hip OA are even lower when compared to those of healthy individuals[34].

In knee OA, as mentioned above, several kinematic and kinetic characteristics during gait are known to be risk factors for knee OA progression. On the basis of this knowledge, attempts have been made to prevent disease progression by decreasing the load on the knee through gait modification[35]. However, until recently, no risk factors for disease progression had been found among the gait characteristics in hip OA. A recent prospective cohort study in patients with hip OA therefore focused on this point and conducted a detailed analysis of their gait to identify the risk factors for hip OA progression[36]. It was found that increased cumulative hip loading during walking as part of patients' daily activities has an effect on subsequent hip OA progression (Figure 4). Cumulative hip loading is calculated by multiplying the hip load (especially the HAM impulse) during a single gait cycle by the mean number of steps per day, which then indicates the total load placed on the hip during that day. The hip contact force during gait can be predicted using HAM[37]. As mentioned above, HAM is often lower in patients with hip OA than in healthy individuals. However, the contact area on the joint surface that receives this load is smaller in patients with secondary hip OA because of acetabular dysplasia, and as a result, patients with hip OA experience greater mechanical stress than healthy individuals[38]. These data suggest the importance of addressing gait disturbances in patients with hip OA by considering both their gait pattern and how they affect HAM as well as any potential excessive physical activity in daily life. Although it is not known what types of load affect articular cartilage negatively, animal experiments have confirmed that cartilage degeneration is dependent on both load magnitude and duration[39,40]. There is a possibility that accumulated micro-injuries, similar to fatigue failure in engineering materials, may have a major effect on cartilage

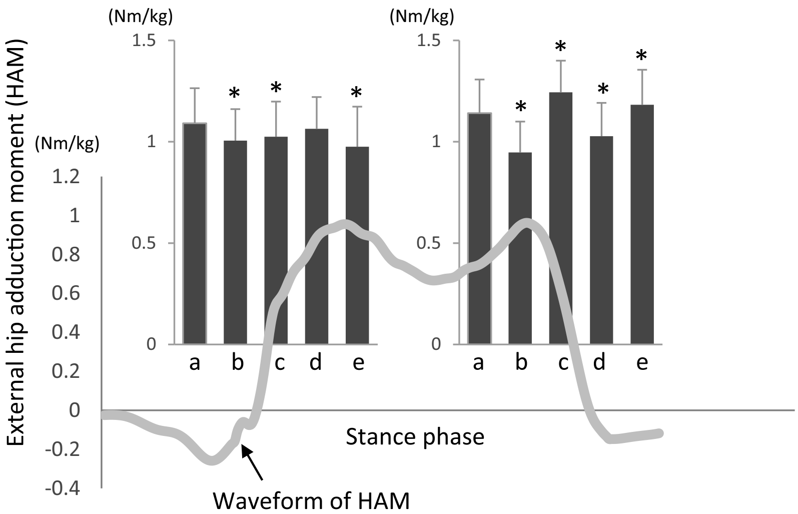

Figure 5. Changes in step width and foot angle have an effect on HAM
The bar graphs on the left and right show the early and late stance phase hip adduction moment peaks, respectively (Nakanishi K., 2017).
a, natural gait; b, wide-base gait; c, narrow-base gait; d, toe-out gait; e, toe-in gait
HAM, hip adduction moment
* Significant difference as compared to natural gait ($P < 0.05$)

cells.

Clinical Implications

To prevent the progression of knee OA, it is essential to reduce excessive or abnormal gait-related mechanical stresses on the knee joint, indicated by increased KAM. Several interventions, such as strengthening exercises and gait modifications using medial thrust, trunk lean, and real-time feedback, have been reported to reduce KAM[41]. However, it is not yet clear whether the sustained long-term effects of these interventions and improved knee joint loading may prevent disease progression. Therefore, it is necessary to develop interventions that can effectively and continuously improve KAM and assess whether such reduced load could prevent disease progression in knee OA.

For patients with hip OA, improving spinal alignment and mobility as well as reducing excessive cumulative hip loading could help in preventing disease progression. Generally, spinal malalignment and decreased spinal mobility that occur with aging can be improved through mobilization, stretching, and back extensor and abdominal muscle strengthening[42]. These methods should be effective in patients with hip OA. Cumulative hip loading during gait can be decreased by reducing excessive physical activity and improving gait patterns. Controlling physical activity by recording the number of steps per day can be accomplished using a pedometer. However, methods for reducing excessive HAM are not yet fully understood. Experiments in healthy volunteers have achieved gait-related changes in HAM by changing the step width and foot angle while keeping the step length and cadence constant. Thus, increasing the step width is one easy way to reduce HAM[43] (Figure 5). Further research is required to determine how to reduce cumulative hip loading in patients with hip OA and whether such modifications could prevent disease progression.

Conclusion

This review summarizes the changes in postural alignment and gait observed in patients with knee and hip OA, focusing on prognostic factors for OA. The prognostic factors in knee OA are thought to be abnormal knee alignment while standing, varus thrust during gait, increased knee flexion in the early stance phase, abnormal displacement of the femur in relation to the tibia, and increased KAM and KFM. The prognostic factors in hip OA are anterior spinal inclination while standing, decreased mobility of the thoracolumbar spine, and increased cumulative hip loading as a result of excessive walking in daily life. As OA onset and progression are multifactorial phenomena, there remains a need to continue searching for prognostic factors, especially those that are modifiable, analyze the interrelations between these factors, and investigate the structural and clinical efficacy of modifying these factors through interventions.

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