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Abstract

The objective of this study is to summarize literature regarding the relationship between high heel use and development of knee osteoarthritis. Knee osteoarthritis is a progressively degenerative disease commonly observed in women with well documented biological and environmental risk factors. Deviations in walking mechanics caused by walking in high heels result in compressive forces on the medial aspect of the knee joint consistent with degenerative changes in the cartilage indicative of knee osteoarthritis. Frequent high heel wearing may also degrade the knee joint capsule, resulting in pain. Due to genetic predisposition, women are already at high risk for knee osteoarthritis development, so further stress placed on the joint capsule and cartilage by wearing high heels accentuates the risk of knee osteoarthritis development. This review also explores potential psychosocial motivations for wearing high heels to give context to frequent use of heels, despite high levels of associated pain and injury. Further recommendations are presented to reduce risk of injury with high heel use for women who choose to wear heels.

Key words: knee osteoarthritis, high heel wear, varus forces

Introduction

As the supportive foundation of the body, foot posture and motion are vital to maintaining balance and locomotive functions. According to the American Podiatric Medical Association, over half of adult women in the United States wear high heels and 71% of these women experience pain associated with high heel use.[1] Though the number of women who wear heels is on the decline, 39% of women still wear high heels at least once a week.[1] As women continue to wear high heels despite high levels of reported pain, research involving alterations to walking mechanics associated with footwear is invaluable for increasing public awareness of the potential long-term detriments of high heel use. Wearing heels frequently can create muscle imbalance,[2] decrease balance,[3] and may contribute to the development of knee osteoarthritis (OA).[2,4–6] Research also shows that walking in high heels places excess force on the medial aspect of the knee, causing degradation of the joint capsule.[2,4,6,7]

Knee osteoarthritis is an incurable, progressively debilitating disease process, so prevention is vital.[8] Young women are the primary consumers of high heeled shoes, but the effects of frequent use likely extend much further into life. The potential link between high heels (a fashion choice for younger women) and knee osteoarthritis (a degenerative condition most common in older adult women)[9,10] needs further examination. Therefore, exploration of potential risk factors of knee OA is key to informing public health. The purpose of this study is to synthesize research regarding biomechanical risk factors associated with the development of knee OA, particularly the repetitive use of high heeled shoes.

Knee Osteoarthritis Etiology

Osteoarthritis is the most common form of arthritis[10] and the leading cause of disability in the United States.[9] This condition typically affects the knee, hip, and ankle joints. Recent studies

suggest that around 14 million people in the United States currently suffer from symptoms of knee OA.[9] Exploring pathophysiology and non-modifiable and modifiable risk factors for knee OA is important due to its high prevalence in the older population.

Pathophysiology

Knee osteoarthritis is a progressive degenerative disease typically characterized by damage to the hyaline cartilage surfaces of synovial joints, which increases friction, reduces the capacity of the joints to absorb shock from daily movements, and may cause inflammation of the joint capsule.[8] More severe cases of knee OA experience a narrowing of the joint space and osteophyte formation, alongside the usual symptoms of joint stiffness, dull, aching pain, bony tenderness, and crepitus.[8] Since Knee OA involves joint damage, it is commonly diagnosed through radiological examination of the density of joint cartilage surface.[8,10] Radiographs allow detection of joint space changes, osteophyte development, and joint deformities which are then rated on the four point Kellgren and Lawrence scale.[8,10]

Risk Factors

Non-modifiable risk factors

i) *Age and Sex*- Old age is a significant risk factor for development of knee OA, as the joints experience normal wear over time.[9] Although arthritis is commonly considered a malady of older adults, new studies show an increase in incidence of knee OA in people under the age of 65 years as well.[9] Such emerging research suggests the urgency of additional literacy on knee osteoarthritis risk, to combat the increased prevalence among younger populations. Sex is also a large determinant of knee OA development, as females experience higher rates and greater severity of symptoms of knee OA than males.[9,10] Estimates place lifetime risk of symptomatic knee OA development at 40% in men and 47% in women, indicating almost half the female

population may develop knee OA.[10] Hypothesized explanations for this discrepancy suggest that biologically, females possess thinner cartilage and lower initial cartilage volumes compared to men,[10] suggesting that over time similar levels of wear would have greater consequences for the female sex.

ii) *Ethnicity* - Additionally, people of color, especially African-American communities, are more likely to develop symptomatic knee OA than white people.[9] Indeed, higher rates of knee OA occur in marginalized communities such as in females or people of color.[9,10] However, the factors that predispose people of color and minority groups to knee OA remain unknown. Further research is needed to explore how racial differences in OA incidence are impacted by socioeconomic factors. Additional research can also target the intersections of several risk factors (e.g., being an older female in the marginalized groups) to explore why knee osteoarthritis is more common in these communities. The co-occurrence of knee OA for minority groups can be further investigated from both biological and sociological perspectives to enrich understanding of other potential risk factors for OA. Understanding risk factors relating to knee OA development is a starting point in the education process; however, the etiology of knee osteoarthritis is complicated and further involves interaction between non-modifiable genetic factors and modifiable environmental risk factors.[8–10]

iii) Genetics, a non-modifiable risk factor, accounts for approximately 30-65% of one's risk of developing OA.[9] At least three distinct loci have been identified on the human genome that directly relate to OA development, suggesting a highly heritable factor that is exacerbated by a variety of environmental factors.[9,10] With respect to knee OA, the joint anatomy is influenced by both genetic and environmental factors, as genes determine the phenotypic presentation of bones, with daily activities further shaping the joint in response to environmental stresses. Knee

malalignment is one of the strongest predictors of knee OA,[10] as altered joint posture results in uneven stresses on different sides of a joint. Similarly, leg length discrepancy and incongruous joint shape are also risk factors for knee OA development that could lead to uneven joint stresses.[10] This demonstrates that the improper physical alignment of the lower extremity, specifically the knee joint, can have adverse effects on overall health and wellness. Such genetic and phenotypic factors are compounded with factors such as obesity, lower extremity injury, and repetitive joint use, which further increase the risk for knee OA.[9,10]

Modifiable risk factors:

i) *Interactions between obesity and occupational activities:* Compared to non-obese individuals, those who are obese are three times more likely to develop knee OA.[9,10] Repetitive weight bearing movements that involve the joint moving to the near ends of range of motion, such as kneeling or squatting, also increase risk of knee OA, especially in people who are overweight or obese.[8,10] This subjects people with jobs that require frequent heavy lifting or kneeling at higher occupational risk for negative long-term health effects that may not present until later in life.[8] Due to the cumulative effects of risk factors, the risk of developing knee OA is further increased for people who are obese and in occupations that necessitate repeated transitioning from a kneeled to standing position and vice versa.

ii) *Trauma to the knee joint:* Individuals who have experienced knee joint trauma, such as Anterior Cruciate Ligament (ACL) sprains, meniscal tears, and articular cartilage damage, are four times more likely to develop knee OA compared to those with no history of such trauma.[9,10] It is known that in the older population, females are more at a risk for developing knee OA.[9,10] Interestingly, in the young population the injuries (e.g., ACL sprain) that exacerbate the risk for knee OA are also more common in females compared to males.[11]

iii) *High heel use:* Data from the American Podiatric Medical Association shows that over half of adult women wear high heels, and the majority of these women experience leg pain associated with high heel use.[1] High heel use is currently being explored in literature as a critical risk factor for knee OA development due to the repetitive nature of walking and the substantial deviations in leg joint postures observed with high heel gait compared to normal walking mechanics.[4] In summary, education on the potential causes and mechanisms of osteoarthritis development is of the utmost importance, as the effects of OA are debilitating and irreversible. While many risk factors for knee OA are non-modifiable such as age, sex, and genetics, many others involve lifestyle choices including activity levels, occupation, and choice of footwear.

Walking Mechanics Associated with Knee OA and High-Heel Use

i) *Walking mechanics associated with knee OA:* Symptoms of knee OA such as pain, stiffness, and decreased joint range of motion (ROM) limit movement and significantly reduce one's ability to complete daily tasks.[12] For example, individuals with knee OA move much slower while climbing and descending stairs compared to healthy controls.[12] Overall knee ROM in the sagittal plane for participants with knee osteoarthritis was 5 degrees lower when compared to healthy study participants.[12] Limitations in knee ROM is evident during the gait cycle, as people with knee osteoarthritis are unable to fully straighten the leg while walking due to pain. While sagittal plane posture and movement deviations are commonly observed in people with knee OA, the disease also affects motion in the frontal plane.

Knee OA most commonly affects the medial joint compartment, which is associated with changes in joint posture, torques, and forces in the frontal plane.[13] Typically, individuals with medial compartment knee OA show a bow-legged posture or a tendency towards a bow-legged posture. This bow-legged posture is a result of and is worsened by abnormal joint torques

(external knee adduction torque).[13] High levels of these torques exacerbate the bow-legged tendency, which further increase forces on the medial or inner side of the joint. Furthermore, these increased medial joint forces are associated with the development and progression of knee OA.[2,4,6,7] Analyzing changes in motion and torque exerted by external forces, such as gravity, are important for understanding factors that impact knee joint health during walking. High heels are of particular interest when examining knee OA risk because of the cultural relevance of high heels and the link between high heel wear and gait alterations that significantly increase the risk for knee OA.

ii) *Walking mechanics associated with high heel use:* The consequences of high heel use on walking kinematics are well studied and suggest an association between frequent high heel use and eventual development of knee OA. This can be attributed to a variety of factors, as walking in high heels greatly alters joint forces and torques.[2,4,5,7,14] Frontal plane torques are of particular interest because high levels of these torques increase predisposition for a bow-legged tendency, which increases forces in the medial compartment of the knee joint. [4,13]

The use of high heels is associated with higher ground reaction forces (GRFs) and alterations in peak torques throughout the gait cycle.[2,4,5,7] Walking in high heels results in higher peak vertical and anterior-posterior GRFs, suggesting a deficit in force absorbing mechanisms, as the body is improperly aligned.[4] Joint torques in the frontal plane are of particular interest because compressive forces on the medial aspect of the knee mimic joint mechanics evident in the knee OA disease progression. Further, increased GRFs magnify external adduction torques that place greater forces on the medial compartment of the knee, causing degenerative changes consistent with the development of knee osteoarthritis.[2,4,6,7] The magnitude of torque increase

gives insight as to the severity of stress on the knee, and therefore the likelihood of developing knee OA.

Higher peak knee varus forces and torques (i.e., those that cause inward joint angulation or bow-legged posture) are present in both higher and wider heeled shoes,[4,5,14] which indicates that increased forces are present for both stiletto and wedged style heels. A study by Kerrigan et al. supports this contention, as peak knee varus torque was significantly higher in shoes with both a narrow (average 1.2 cm) and wide (average 4.5 cm) base for the same height (average 7 cm).[14] Another study from Kerrigan and colleagues furthered this finding, as walking in wide based 1.5 inch heels also increased varus torque when compared to barefoot walking.[5] The shoes used in the Kerrigan study featured a wide base and a lower heel height, like many more "sensible" women's dress shoes. However, these studies indicate that even shoes deemed "sensible" produce the high adduction torques associated with development of knee OA. Adduction torques at the knee are consistent with stress on the medial compartment of the knee that may lead to degenerative changes to knee joint cartilage. This biomechanical link between high heel use and increased varus forces suggests a relationship between frequent high heel use and the development of knee osteoarthritis.

Psychosocial Factors as an Explanation for Widespread High-Heel Use

Despite the known health risks and high reported levels of pain associated with high heel use,[1] women continue to wear them. There are various hypotheses concerning the social pressure, or desire, for females to wear high heels. Research on why women wear heels often focuses on an evolutionary or mating perspective, which posits that women wear high heels to appear more attractive to men.[15–18] Indeed, high heels may increase women's attractiveness by elongating the appearance of legs,[18] optimally increasing the lumbar curvature of the spine,[15] and

exaggerating the femininity of female gait.[17] While there is clear evidence that wearing high heels increases women's attractiveness to men, women also may wear heels because of self-perceived increases in attractiveness. Women who wear heels regularly rate themselves as attractive,[18] and furthermore, while wearing high heel shoes at a given moment women rate themselves as more attractive,[16] suggesting a strong relationship between high heel use and self-perceived attractiveness.

Wearing high heels increases perceived attractiveness and that may subsequently increase odds of fulfilling an evolutionary objective of attracting a sexual partner. Research suggests that women are more likely to wear high heels on a date with a male perceived to be attractive than one whom is perceived to be unattractive.[18] Research on male attraction to women in heels presents evidence of potential psychosocial benefits for women to wear heels, as they are rewarded with male attention.[16] While evolutionary hypotheses are important for understanding the potential factors that lead women to wear high heels, other hypotheses propose a more immediately obvious benefit of wearing high heels to appear taller.

Frequent high-heel use may be attributed also to the obvious gain in height it causes. Women who are shorter are more likely to wear heels than taller women.[18] This may be due to perceived attractiveness of women with longer legs,[18] but may also be reminiscent of Western heterosexual dating norms in which the male partner is taller than the female.[16] Meaning, women who are taller may avoid wearing high heels to maintain a height below their partner's. Women who wear heels to appear taller may also do so purely for internal gains in self-esteem, but it is important to examine the external psychosocial motivations for why women might wear high heels as well.[16] Research on high heels and attraction is strictly heteronormative and further research is needed concerning high heels and attraction across non-heterosexual orientations.

Such research may indicate if certain sexual orientations are at higher risk for the various negative health effects of continuous high heel use, due to psychosocial pressures to continue wearing heels. Additionally, the proposed research follows a Western cultural framework and therefore is only indicative of potential psychosocial factors experienced by American and European women. The cultural relevance of high heels in the Western countries emphasizes the importance of research on heels and the resultant pain and injury.

High heel wearing is known to have direct association with musculoskeletal pain, hallux valgus, ankle inversion injuries, and other lower-extremity injuries.[16] Frequent heel use may also result in joint changes consistent with knee osteoarthritis, though currently no direct causative link between high heel use and osteoarthritis development exists in the literature.[16] Still, despite the numerous health risks, there are many personal and psychosocial reasons women may choose to wear heels. Ultimately, women should maintain the autonomy to choose footwear without regard to social pressures or opinions. Women considering high heels may benefit from reviewing the following evidence that could mitigate some of the harmful effects associated with high heel use.

Prevention

The easiest and most effective measure to reduce injury and disease risk associated with high heel use is to greatly limit the frequency of high heel use or to avoid wearing high heels altogether.[19] Limiting the use of high heels will reduce the likelihood of developing knee OA. However, if women choose to continue wearing shoes due to various personal and psychosocial reasons, there are certain habits that may mediate the negative effects of high heeled walking. Stretching the plantar fascia and calf muscles regularly can help alleviate back pain caused by high heels.[20] When choosing high heels, buying heels with a wider toe box and thicker heel

allows weight to be more evenly distributed, which may increase balance by widening the base of support, thereby reducing injury such as ankle sprains.[19,20] Additionally, engaging in general musculoskeletal strengthening may improve balance and reduce the risk of lower extremity injury.[19]

Summary and Conclusion

The profound negative health consequences of high heel wear necessitate methodical research to illuminate specific harmful aspects of high heel wearing. While there is ample research demonstrating that high heel use places similar stress on the medial compartment of the knee as seen in the disease progression of knee OA, no definitive causal link has been developed in the literature.[2,4,6,7,14]A study to determine this cause-effect relationship would require a longitudinal intervention design that is unethical in practice, as it would subject participants to a known health detriment. Alternatively, a longitudinal observational study that tracks women who regularly wear high heels versus those who do not could be helpful in determining a causal relationship. However, in such longitudinal studies several factors that could influence the disease outcome cannot be typically controlled. Additionally, current research does not quantify what frequency of high heel use is associated with detrimental health effects. While the number of women who wear heels daily has significantly decreased since the early 2000s, around one-third of women still wear high heels at least once weekly.[1,4] Due to paucity of research on the relationship between frequency of high heel use and harmful health effects, it unclear whether this subset of the population is at higher risk for knee OA because of their high heel use.

High heels are well demonstrated to be detrimental to the lower extremity health of those who wear them. While some effects- such as feet and muscular pain- are immediate, other negative consequences of frequent high heel wear may not present until later in life. These

negative later life consequences, such as knee OA, may become more prevalent due to an interaction of several risk factors such as advancing age, being of the female sex, and frequent high heel use. This suggests that while high heel wearing is more common in younger women, it may produce long standing effects for older adult women who may have to navigate the pain of knee osteoarthritis. Such health consequences have profound impacts on basic and instrumental activities of daily living later in life. In summary, the daily footwear choices young women make may predispose them to poor joint health and pain with advancing age. Educating young women on the link between high heels and knee OA is important so they can make an informed choice about footwear use as it relates to bodily health and function later in life. Overall, it would be ideal to limit or avoid high heel use to prevent the development of debilitating conditions later in life. However, for women who choose to continue wearing high heels, adopting practices that may forestall negative health outcomes is paramount to maintaining lifelong health and wellness.

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