

Received: 2017.05.02  
Accepted: 2017.06.12  
Published: 2017.12.01

# Characteristics of Plantar Loads During Walking in Patients with Knee Osteoarthritis

Authors' Contribution:

Study Design A  
Data Collection B  
Statistical Analysis C  
Data Interpretation D  
Manuscript Preparation E  
Literature Search F  
Funds Collection G

BCDEF **Zhiwang Zhang**  
ACDEF **Lin Wang**  
BCE **Kaijun Hu**  
AEG **Yu Liu**

Key Laboratory of Exercise and Health Science of the Ministry of Education, Shanghai University of Sport, Shanghai, P.R. China

**Corresponding Authors:**

Lin Wang, e-mail: wanglin@sus.edu.cn, Yu Liu, e-mail: yuliu@sus.edu.cn

**Source of support:**

Financial support for this research was provided by the Shanghai City Committee of Science and Technology Key Project (No. 14490503800) and the National Natural Science Foundation of China (No. 81572213)

**Background:**

Knee osteoarthritis (KOA) is a common disease that can change the load on lower limbs during walking. Plantar loads in patients with KOA may provide a basis for clinical decisions regarding footwear and foot orthoses. This study aimed to compare plantar loads in females with and without KOA during gait.

**Material/Methods:**

Plantar pressure during walking was recorded in 23 females with KOA and 23 females without KOA. Maximum force (MF), contact area (CA), and peak pressure (PP) were measured at 7 different regions underneath the foot, named heel (M1), midfoot (M2), first metatarsophalangeal joint (MPJ) (M3), second MPJ (M4), third to fifth MPJ (M5), hallux (M6), and lesser toes (M7).

**Results:**

PPs for M2 and (M3) in females with KOA were higher than those in females without KOA. High PPs were also found in females with KOA for M2, M3, and M4.

**Conclusions:**

Increased plantar loading in females with KOA may lead to foot pronation and gait changes during walking. Plantar loading may be offered to patients with KOA when considering footwear and foot orthoses.

**MeSH Keywords:**

**Female • Osteoarthritis, Knee • Walking**

**Full-text PDF:**

<https://www.medscimonit.com/abstract/index/idArt/905136>

 2013

 2

 1

 38



## Background

Osteoarthritis (OA) is a chronic localized joint disease associated with pain, swelling, stiffness, limited ability to walk, and decreased balance function [1]. Approximately 17% of individuals who are age 45 years or older have symptomatic knee OA (KOA) [2]. Limitation in physical activity may increase risk of mortality and secondary health complications in patients with KOA [3,4]. Geriatric patients with KOA who maintain a low physical activity level also can reduce the possibility of depression [5].

When KOA causes cartilaginous changes, it can lead to abnormal subchondral bone attrition and formation of osteophytes [6,7]. The mRNA expressions and protein of the receptor for advanced glycation end-product (RAGE) and high-mobility group protein B1 (HMGB1) are increased in KOA patients, indicating that they have KOA [8]. The levels of macrophage migration inhibitory factor (MIF) may be related with severity of self-reported pain in OA patients [9]. These changes can lead to mechanical changes of the lower limbs because the entire lower extremities move as a linked kinetic chain. During walking, the foot may present a significant effect on absorbing load on heel contact, adapting to different surfaces, and propelling the body forward [10]. Varus limb alignment is commonly observed in patients with medial compartment knee OA and may affect the progression and incidence of knee OA [11,12]. Recent studies also reported that patients with medial compartment knee OA develop a more pronated foot posture [12,13] and that foot kinematic patterns are a less mobile, everted foot type [14] compared to controls. Moreover, the degree of varus alignment may also affect foot motion during walking, which may lead to a compensatory response to allow typical function of the foot during walking [14]. In addition, footwear and orthotic interventions have been used to change knee loading by altering foot motion [15–17].

Therefore, several studies have investigated the characteristics of plantar loads in patients with KOA during walking [2,18–20]. The mean maximum force in foot distribution in patients with painful knee OA is associated with function, specific pain mechanisms, pain intensity, and radiological findings. [20]. Lidtke et al. compared foot center of pressure (COP) indices between 25 individuals with medial KOA and 25 controls [18]. High lateral COP is observed across the feet of individuals with KOA during the contact and mid-stance phases of gait compared with controls. Kristyn et al. [2] calculated the intraclass correlation coefficients (ICCs) for lateral heel pressure (LHP); ICCs for LHP were excellent (0.79–0.83). In addition, mean plantar pressure, peak plantar pressure, and velocity of the COP in subjects with unilateral KOA increase when walking speed changes from slow to fast in comparison with the contralateral leg [19].

These studies have provided useful information about KOA factors that can influence plantar loads of patients. However, no study has specifically evaluated the differences in plantar loads between elderly women with medial KOA and those without medial KOA during walking at their preferred speed. Therefore, the present study aimed to determine the characteristics of plantar loads in patients with KOA. We hypothesized that patients with KOA would show greater plantar loading compared with their counterparts without KOA.

## Material and Methods

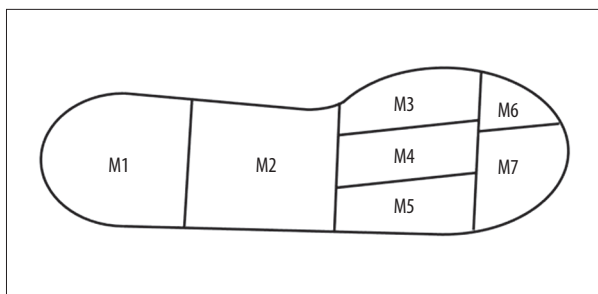
### Participants

All participants were recruited from the Guohe Community Center, Lanxin Community Center, and Dongfang Community Center in Shanghai, China. Inclusion criteria of patients were: age 60–90 years; mild to moderate knee OA (Lequesne Knee Score=1 to 7); diagnostic criteria of definite OA of the knee (unilateral or bilateral) according to radiography with reports of pain symptoms for at least 3 months, based on the Classification Criteria of the American Rheumatism Association for KOA [21]. Exclusion criteria were: a medical condition involving hip or knee trauma, intra-articular hip or knee injection within the last month; terminal illness; uncontrolled hypertension; and other illness judged by the patient or study physician to make participation in this study inadvisable [22]. The approximate number of participants needed in each group to attain 80% power in a T testing hypotheses at 0.05 significant level was 21; this number is appropriate in comparing measurements of different groups if the estimated effect size is larger than 0.9.

A total of 23 elderly women with KOA (the OA group) were included in the study. This group had a mean age of  $64.2 \pm 6.6$  years, height of  $154.2 \pm 5.2$  m, weight of  $55.5 \pm 3.5$  kg, and body mass index (BMI) of  $23.3 \pm 1.9$   $\text{kg} \cdot \text{m}^{-2}$ . The control group consisted of 23 elderly women with a mean of age of  $62.1 \pm 2.4$  years, height of  $156.8 \pm 4.0$  cm, weight of  $55.7 \pm 5.0$  kg, and BMI of  $22.6 \pm 1.8$   $\text{kg} \cdot \text{m}^{-2}$ . The demographic information of the subjects is presented in Table 1. The Ethics Committee of the Shanghai University of Sports approved the study, and all individuals were requested to sign a written informed consent.

### Experimental procedures

To assess dynamic plantar pressure distributions, each subject walked on a 10-m walkway at a self-selected speed while wearing the same brand of sports shoes, and 3 successful trials were defined for each leg. The plantar loading data were collected during the stance phase. Both sides of the foot were assessed and the averaged data of the both sides were used in data analysis. Several trials were practiced until participants



**Figure 1.** The plantar masks. M1 – heel, M2 – midfoot, M3 – first metatarsophalangeal joint (MPJ), M4 – second MPJ, M5 – third to fifth MPJ, M6 – hallux, M7 – lesser toes.

could walk with comfortable velocity. Plantar pressure was measured using the Novel Pedar-X system (Novel, Germany). Each insole contained 99 force sensors with a spatial resolution of approximately 10 mm (2 sensors per cm<sup>2</sup>). They were all calibrated using a standard calibration device (Trublu Calibration, Novel, Munich, Germany). The insole was connected to the Pedar-X box by a cable, which was attached to the waist of each participant. The data were collected and filtered by the Pedar<sup>®</sup>-X data acquisition software. The plantar pressure data were sampled at 50 Hz by Bluetooth technology.

**Characteristics of plantar load assessment**

Using the Novel Pedar-X system software, the plantar surface was divided into 4 areas: heel (30% of foot length), midfoot (30% of foot length), forefoot (25% of foot length), and toes (15% of foot length). Then, the plantar surface was subdivided into 7 regions: heel (M1), midfoot (M2), first metatarsophalangeal joint (MPJ) (M3), second MPJ (M4), third to fifth MPJ (M5), hallux (M6), and lesser toes (M7) [23,24]. The 7 regions are shown in Figure 1.

We used Novel<sup>®</sup> multimask software to determine the following parameters for each of the 7 areas: maximum force (MF), peak pressure (PP), and contact area (CA) of the stance phase. The maximum plantar force was normalized to body weight.

**Statistical analysis**

Demographic characteristics including participant age, weight, height, and BMI, and the plantar measurements were summarized as mean±standard deviation; these data in the KOA group were

compared with those in the controls. All data underwent normality testing (simple K-S test) and the data were normally distributed. The independent-samples *t* test was used to determine whether differences were statistically significant. Scores on plantar loading were average values across both limbs in the final analysis.

**Results**

The demographic characteristics of both groups were similar in terms of average age, weight, height, and BMI (Table 1). All plantar loading parameters are summarized in Table 2. The KOA group had increased PP for M2 and M3. High MF were also found in the KOA group for M2, M3, and M4. These increased values mean the impact on the KOA group was strong during the gait cycle. In addition, only the female group with KOA had increased CA in M2 in comparison with the controls.

**Discussion**

This study aimed to compare plantar loading characteristics of females with and without KOA during walking. The OA group had high MF and PP under M2 and M3, and high MF under M4. Significant differences in pressure distribution mean that the OA group experienced more impact from the ground during walking in comparison with the controls.

The pathomechanics of KOA may be affected by abnormal foot posture and pronated foot position. In the present study, females with KOA had higher MF and PP under M2 than females without KOA had. The large plantar loads may be caused by the large arch index of the KOA group. The arch index is a significant predictor of plantar loading and explains up to 61% of the MF and 48% of the PP [23]. The lower the foot arch, the higher the arch index [25]. In a previous study, the KOA group had a lower foot arch and a higher arch index than the controls [26]. A pronated foot was associated with increased CA under M2 during walking [27]. In the present study, higher CA under M2 was observed in females with KOA than in females without KOA. Thus, the situation may be due to the pronated foot, which dominated in the KOA group [26]. A study [28] revealed that ankle alignment is significantly associated with knee alignment in patients with KOA before TKA. Norton et al. [29] demonstrated that valgus hindfoot alignment and varus knee

**Table 1.** Participant characteristics. Data are the means (±SD).

Group	N	Age (y)	Height (m)	Weight (kg)	BMI (kg/m <sup>2</sup> )
OA	23	64.2±6.6	154.2±5.2	55.5±3.5	23.3±1.9
Control	23	62.1±2.4	156.8±4.0	55.7±5.0	22.6±1.8

\* Indicated statistically significant (p<0.05) differences.

**Table 2.** Comparison of plantar loading parameters during gait for females with and without KOA.

Variable	Region	OA	Control	P-value
PP (kPa)	M1	252.9±52.5	243.7±52.5	0.581
	M2	132.8±28.3	116.5±30.0	0.031
	M3	295.1±100.4	224.3±62.4	0.024
	M4	273.8±103.9	244.6±56.1	0.183
	M5	156.1±43.1	157.9±49.3	0.981
	M6	231.9±77.6	219.6±79.4	0.531
	M7	139.4±49.4	142.9±44.9	0.801
MF (%BW)	M1	69.5±15.2	67.1±11.3	0.817
	M2	30.3±7.1	23.6±7.4	0.043
	M3	32.9±10.0	26.5±6.2	0.037
	M4	35.2±9.1	30.3±5.1	0.041
	M5	17.7±5.4	16.7±4.9	0.843
	M6	14.3±6.5	13.5±5.6	0.901
	M7	12.0±4.7	12.6±3.2	0.973
CA (cm <sup>2</sup> )	M1	28.9±2.9	28.6±1.7	0.982
	M2	41.5±5.8	36.5±7.3	0.043
	M3	13.8±1.6	13.1±1.3	0.875
	M4	13.6±0.8	13.2±1.3	0.922
	M5	12.7±0.6	12.8±0.3	0.986
	M6	7.1±1.7	6.6±1.6	0.684
	M7	10.3±1.1	10.8±0.4	0.899

Date are means (±SD). PP – peak pressure; MF – maximum force; CA – contact area; M1 – heel; M2 – midfoot; M3 – 1<sup>st</sup> metatarsophalangeal joint; M4 – 2<sup>nd</sup> metatarsophalangeal joint; M5 – 3<sup>rd</sup>–5<sup>th</sup> metatarsophalangeal joint; M6 – hallux; M7 – lesser toes.

deformity are related and that a varus hindfoot alignment with a valgus knee deformity are also related in patients who underwent TKA. Thus, the relationship between alignment and plantar pressure should be further investigated.

The increased MF and PP under M3 may be associated with the decreased range of motion (ROM) under M3 [23]. The dorsiflexion angle was positively correlated with plantar pressures under M3 [30]. In our investigation, increased MF and PP may be associated with decreased ROM under M3. Restricted ROM under M3 can alter foot function, thereby leading to inefficient gait and the development of plantar calluses [31]. The force and pressure generated under M3 increased loading on anatomical structures, which may in turn result in foot pain. Previous studies showed that fallers generate a significantly higher PP under the foot than non-fallers [32], and high peak plantar pressure levels in the metatarsals are significantly associated with greater risk of ulcer formation [33]. The current

results show that the increased plantar pressure level of the KOA group should be given much attention.

In the present study, the PP at M4 region in the OA group was higher than in the control group, which may indicate less absorbance of impact force in KOA patients. Previous studies found that patients with KOA develop a more pronated foot posture [11,12]. This may explain the higher plantar pressure at M4 region among KOA patients during walking. Furthermore, a study found that long walking changes the walking pattern because of leg fatigue and may cause overuse injuries in the metatarsal bones [33]. The higher plantar loads at the 2<sup>nd</sup> head of the metatarsal bones may be a potential risk for KOA patients.

Foot mechanics during walking are interrelated to knee and hip joint kinematics because the entire lower extremities act as an integrated kinetic chain; a biomechanical abnormality in the joint can influence the loading at any other point in the

lower extremities. Increased rearfoot eversion, rearfoot internal rotation, and forefoot inversion are associated with reduced knee adduction moments during the stance phase of walking [14,34]. In other words, medial knee joint loading is reduced in people with OA who walk with great foot pronation. A supinated, externally rotated foot, which progresses with a toe-out gait, may decrease the adduction peak moment acting on the knee [35,36]. Furthermore, subjects with early KOA show no difference in terms of measured gait parameters [37]. These results indicate that these differences above should be tested in future studies with plantar loading and biomechanical changes in the lower extremities.

The present results highlight the importance of interventions for KOA according to individual characteristics. Foot orthoses

are a common intervention for KOA and are a potential simple treatment for patients with KOA by reducing the external knee adduction moment [15,38]. The results of the present study and those of previous studies suggest that individuals with KOA may benefit from soft orthoses to decrease plantar loading.

## Conclusions

Females with KOA experience greater plantar loading at mid-foot, first metatarsophalangeal joint and second metatarsophalangeal joint loading in comparison with females without KOA. Increased plantar loading may lead to foot pronation and gait changes during walking. Reducing plantar loading by using foot orthoses should be further explored.

## References:

- Kan L, Zhang J, Yang Y et al: The effects of yoga on pain, mobility, and quality of life in patients with knee osteoarthritis: a systematic review. *Evid Based Complement Alternat Med*, 2016; 2016: 6016532
- Leitch KM, Birmingham TB, Jones IC et al: In-shoe plantar pressure measurements for patients with knee osteoarthritis: Reliability and effects of lateral heel wedges. *Gait Posture*, 2011; 34: 391–96
- Nuesch E, Dieppe P, Reichenbach S et al: All cause and disease specific mortality in patients with knee or hip osteoarthritis: population based cohort study. *BMJ*, 2011; 342: d1165
- van Dijk GM, Veenhof C, Spreuouwenberg P et al: Prognosis of limitations in activities in osteoarthritis of the hip or knee: a 3-year cohort study. *Arch Phys Med Rehabil*, 2010; 91: 58–66
- Mesci E, Icacasioglu A, Mesci N et al: Relation of physical activity level with quality of life, sleep and depression in patients with knee osteoarthritis. *North Clin Istanbul*, 2015; 2: 215–21
- Creaby MW, Bennell KL, Hunt MA: Gait differs between unilateral and bilateral knee osteoarthritis. *Arch Phys Med Rehabil*, 2012; 93: 822–27
- Bennell KL, Hinman RS: A review of the clinical evidence for exercise in osteoarthritis of the hip and knee. *J Sci Med Sport*, 2011; 14: 4–9
- Sun XH, Liu Y, Han Y et al: Expression and significance of high-mobility group protein B1 (HMGB1) and the receptor for advanced glycation end-product (RAGE) in knee osteoarthritis. *Med Sci Monit*, 2016; 22: 2105–12
- Zhang PL, Liu J, Xu L et al: Synovial fluid macrophage migration inhibitory factor levels correlate with severity of self-reported pain in knee osteoarthritis patients. *Med Sci Monit*, 2016; 22: 2182–86
- Menz HB, Lord SR: Foot problems, functional impairment, and falls in older people. *J Am Podiatr Med Assoc*, 1999; 89: 458–67
- Felson DT, Goggins J, Niu J, et al. The effect of body weight on progression of knee osteoarthritis is dependent on alignment. *Arthritis Rheum*, 2004; 50: 3904–9
- Sharma L, Song J, Dunlop D et al: Varus and valgus alignment and incident and progressive knee osteoarthritis. *Ann Rheum Dis*, 2010; 69: 1940–45
- Anne Reilly K, Louise Barker K, Shambley D et al: Influence of foot characteristics on the site of lower limb osteoarthritis. *Foot Ankle Int*, 2006; 27: 206–11
- Levinger P, Menz HB, Morrow AD et al: Foot kinematics in people with medial compartment knee osteoarthritis. *Rheumatology (Oxford)*, 2012; 51(12): 2191–98
- Hsu WC, Jhong YC, Chen HL et al: Immediate and long-term efficacy of laterally-wedged insoles on persons with bilateral medial knee osteoarthritis during walking. *Biomed Eng Online*, 2015; 14: 43
- Barrios JA, Crenshaw JR, Royer TD et al: Walking shoes and laterally wedged orthoses in the clinical management of medial tibiofemoral osteoarthritis: A one-year prospective controlled trial. *Knee*, 2009; 16: 136–42
- Yeh HC, Chen LF, Hsu WC et al: Immediate efficacy of laterally wedged insoles with arch support on walking in persons with bilateral medial knee osteoarthritis. *Arch Phys Med Rehabil*, 2014; 95: 2420–27
- Lidtko RH, Muehleman C, Kwasny M et al: Foot center of pressure and medial knee osteoarthritis. *J Am Podiat Med Assoc*, 2010; 100: 178–84
- Fernandes WC, Machado A, Borella C et al: Influence of gait speed on plantar pressure in subjects with unilateral knee osteoarthritis. *Rev Bras Reumatol*, 2014; 54: 441–45
- Rosland T, Gregersen LS, Eskehave TN et al: Pain sensitization and degenerative changes are associated with aberrant plantar loading in patients with painful knee osteoarthritis. *Scand J Rheumatol*, 2015; 44: 61–69
- Altman R, Asch E, Bloch D et al: Development of criteria for the classification and reporting of osteoarthritis. Classification of osteoarthritis of the knee. *Arthritis Rheumatol*, 1986; 29: 1039–49
- Wang XQ, Huang LY, Liu Y et al: Effects of tai chi program on neuromuscular function for patients with knee osteoarthritis: Study protocol for a randomized controlled trial. *Trials*, 2013; 14: 375
- Menz HB, Morris ME: Clinical determinants of plantar forces and pressures during walking in older people. *Gait Posture*, 2006; 24: 229–36
- Hong Y, Wang L, Li JX et al: Comparison of plantar loads during treadmill and overground running. *J Sci Med Sport*, 2012; 15: 554–60
- Cavanagh PR, Rodgers MM: The arch index: A useful measure from footprints. *J Biomech*, 1987; 20: 547–51
- Levinger P, Menz HB, Fotoohabadi MR et al: Foot posture in people with medial compartment knee osteoarthritis. *J Foot Ankle Res*, 2010; 3: 29
- Teyhen DS, Stoltenberg BE, Eckard TG et al: Static foot posture associated with dynamic plantar pressure parameters. *J Orthop Sport Phys*, 2011; 41: 100–7
- Gao F, Ma J, Sun W et al: Radiographic assessment of knee-ankle alignment after total knee arthroplasty for varus and valgus knee osteoarthritis. *Knee*, 2017; 24: 107–15
- Norton AA, Callaghan JJ, Amendola A et al: Correlation of knee and hind-foot deformities in advanced knee OA: Compensatory hindfoot alignment and where it occurs. *Clin Orthop Relate Res*, 2015; 473: 166–74
- Alentorn-Geli E, Gil S, Bascuas I et al: Correlation of dorsiflexion angle and plantar pressure following arthrodesis of the first metatarsophalangeal joint. *Foot Ankle Int*, 2013; 34: 504–11
- Heng ML, Chua YK, Pek HK et al: A novel method of measuring passive quasi-stiffness in the first metatarsophalangeal joint. *J Foot Ankle Res*, 2016; 9: 41
- Mickle KJ, Munro BJ, Lord SR et al: Foot pain, plantar pressures, and falls in older people: A prospective study. *J Am Geriatr Soc*, 2010; 58: 1936–40
- Ledoux WR, Shofer JB, Cowley MS et al: Diabetic foot ulcer incidence in relation to plantar pressure magnitude and measurement location. *J Diabetes Complications*, 2013; 27: 621–26

34. Levinger P, Menz HB, Morrow AD et al: Relationship between foot function and medial knee joint loading in people with medial compartment knee osteoarthritis. *J Foot Ankle Res*, 2013; 6: 33
35. Guichet JM, Javed A, Russell J et al: Effect of the foot on the mechanical alignment of the lower limbs. *Clin Orthop Relat Res*, 2003; (415): 193–201
36. Andrews M, Noyes FR, Hewett TE et al: Lower limb alignment and foot angle are related to stance phase knee adduction in normal subjects: A critical analysis of the reliability of gait analysis data. *J Orthop Res*, 1996; 14: 289–95
37. Duffell LD, Southgate DF, Gulati V et al: Balance and gait adaptations in patients with early knee osteoarthritis. *Gait Posture*, 2014; 39: 1057–61
38. Chapman GJ, Parkes MJ, Forsythe L et al: Ankle motion influences the external knee adduction moment and may predict who will respond to lateral wedge insoles?: An ancillary analysis from the SILK trial. *Osteoarthritis Cartilage*, 2015; 23: 1316–22