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ORIGINAL ARTICLE

Yoshitaka Toda · Akiko Kato · Noriko Tsukimura

Dynamic effect of an elastically strapped lateral wedged insole on the subtalar joint in convenient foot print analysis using facsimile paper

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Abstract We previously reported that insoles with subtalar strapping lead to valgus realignment of the femorotibial angle during the static phase in patients with osteoarthritis of the knee (knee OA) with varus deformity. In a follow-up study, we assessed the effect of an insole with subtalar strapping during the dynamic phase of the gait. Twenty-eight female patients with unilateral medial compartment knee OA and thirty-eight age- and sex-matched control subjects were enrolled. Gait analysis was performed for each subject while barefoot, with the insole with subtalar strapping, and with the insole with talonavicular strapping. In the knee OA group, the average foot angle while barefoot (12.4 ± 2.3°) was significantly higher than that in the control group (10.6 ± 3.4°) ($P = 0.018$). In the knee OA group, the angle while barefoot was significantly reduced after wearing the insole with subtalar strapping (9.4 ± 2.3°) ($P < 0.0001$), but not with use of the insole with talonavicular strapping (11.1 ± 2.8°) ($P = 0.12$). There was no significant difference in the foot angle among the three conditions in the control group ($P > 0.05$). This result suggests that the insole with subtalar strapping contributes to an adaptive mechanism which reduces the adductive moment at the knee through decreasing both the femorotibial angle and the external rotation of the foot position during walking.

Key words Foot print · Gait analysis · Knee · Orthotic devices · Osteoarthritis (OA)

Introduction

The normal function of the knee joint requires a high degree of mobility while sustaining high loads during normal activities such as walking. Therefore, the knee joint is vulnerable to changes in the alignment of the lower extremities. For example, the presence of varus angulation at the knee has been associated with increased loading of the medial compartment of the knee and the progression of medial compartment osteoarthritis of the knee (knee OA).[1]

Andriacchi[2] reported that knee OA patients with varus deformity have a high adduction moment at the knee, and increasing the adduction moment during walking has been directly related to an increase in the medial compartment loading at the knee joint. The adaptive mechanism used by some patients with varus deformity to reduce the adduction moment of the knee joint has been related to an increased external rotation of the foot position (toe out) during gait. The mechanism of this technique simply involved moving the ground reaction vector closer to center of the knee joint, and thereby reducing the lever arm of the external ground reaction force (Fig. 1).

A mainstay of surgical therapy, high tibial osteotomy, is indicated for knee OA patients with severe varus deformity. The operation induces valgus realignment of the femorotibial angle by wedged tibial osteotomy. Andriacchi[2] reported that the adduction moment at the knee during gait was reduced, and external rotation of the foot position decreased, after high tibial osteotomy.

One of the first forms of conservative mechanical treatment for patients with medial compartment knee OA was a lateral wedged insole.[3,4] However, the effect of traditional insoles on knee OA was limited by the lack of subtalar strapping. The femorotibial angle (FTA) was not significantly corrected by the inserted insoles owing to the loss of mechanical advantage at the subtalar joint. Yasuda and Sasaki[3] reported that this resulted in an effect which was fundamentally different from surgical correction of the femorotibial angle with high tibial osteotomy.

In researching conservative alternatives to surgical correction of the femorotibial angle, this limitation of inserted insoles was addressed through the development of a novel lateral wedged insole with elastic strapping of the subtalar joint. In our previous study,[5] standing radiographs with unilateral insole use were used to analyze the talocalcaneal, talar tilt, and femorotibial angles for each subject with and

Y. Toda (✉) · A. Kato · N. Tsukimura
Kishoukai Toda Orthopedic Rheumatology Clinic, 14-1 Toyotsu-cho, Suita 564-0051, Japan
Tel. +81-6-6387-4114; Fax +81-6-6378-2210
e-mail: fwjh2766@mb.infoweb.ne.jp

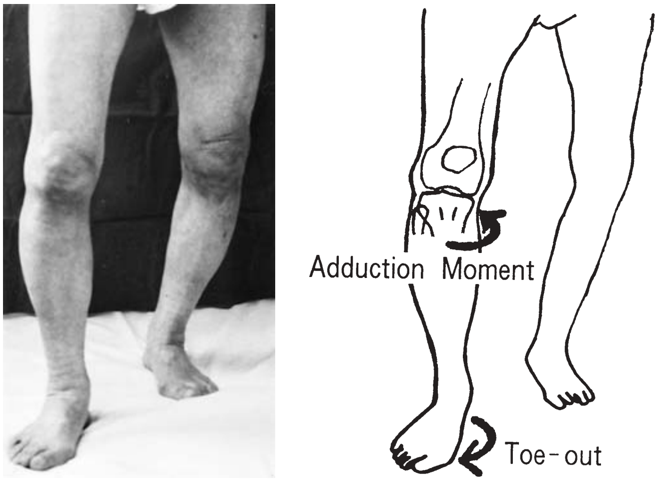

Fig. 1. Typical gait style of a patient with genu varum and medial compartment knee OA

without an inserted or a subtalar strapping insole. The talocalcaneal angle was significantly increased for both the subtalar strapping and inserted insole groups compared with those with without insole use. However, the talar tilt angle was significantly decreased only in the subtalar strapping insole group. There was no significant difference in the talar tilt angle with the inserted insole. A significant difference in the femorotibial angle with insole use was detected in the subtalar-strapping group. However, the femorotibial angle was not significantly changed in the inserted insole group. Thus, the insole with subtalar strapping may provide a conservative alternative to high tibial osteotomy while preserving the therapeutic advantage.[5]

Despite advances in our understanding of the lower extremity anatomic realignment induced by the subtalar-strapping insole, the dynamic effects of the insole during gait have not yet been elucidated. If the insole could provide a conservative alternative to high tibial osteotomy, the adduction moment at the the knee and external rotation of the foot position during gait may be reduced for knee OA patients with varus deformity.

This determination requires an assessment of the dynamic effects of the insole during gait by measuring forces during gait with an instrument such as a force platform, or an observation of the adduction moment of the knee joint using three-dimensional gait analysis as reported by Crenshaw et al.[6] However, such an analysis would necessitate the use of expensive instruments, and other investigators cannot easily reproduce such methods.

Shores[7] reported a method of footprint analysis which is both quantitative and objective, while remaining both convenient and economical. We postulate that if genu varum induces external rotation of the foot during gait, valgus realignment by the insole with subtalar strapping may lead to internal rotation of the foot, which is similar to the effect of high tibial osteotomy as reported by Andriacchi.[2] Therefore, in the current study, we assessed the dynamic effect of the insole during gait using the foot angle to represent the degree of internal or external rotation of the foot, as described by Shores.[7]

Material and methods

Twenty-eight new female outpatients, aged 45–69, were enrolled in the study. They all complained of unilateral knee pain along the medial joint space, and they all met the American College of Rheumatology criteria for knee OA, i.e., knee pain, radiographic osteophyte, and at least one of the following items: age >50 years, morning stiffness for >30 min, or crepitus on motion. Thirty-eight age- and sex-matched control participants without knee OA were also enrolled (i.e., the control group).[8]

Patients were excluded from the knee OA group if their contralateral femorotibial angle in standing radiographs exceeded 176°, as this is considered as the standard value for a Japanese adult.[9] Control participants, who were recruited from a community senior center, were defined as subjects who had no knee problems in the preceding 20 years, and who had no swelling, tenderness, or bony prominence in either knee on physical examination by three orthopedic surgeons.

The insoles with subtalar strapping consisted of urethane wedges with elevations of 10 mm. They were fixed to an ankle sprain supporter which was designed to fit around the ankle and subtalar joints (the subtalar insole). Similar wedges with strapping around the talonavicular joint were regarded as insoles with talonavicular strapping (the talonavicular insole) (Fig. 2).[10]

Baseline gait analysis was performed by having each subject walk barefoot. The insoles were attached to the affected lower extremity in knee OA patients, and to the right foot in control subjects. The participants were instructed to walk at their regular speed looking straight ahead. Each participant practiced walking three times before the baseline footprint analysis.

We found that ethyl alcohol would leave an indelible footprint on facsimile paper. The subjects' soles were painted with ethyl alcohol using a household spray, and they then walked on parallel strips of facsimile paper cut in 2-m segments, beginning 50 cm from the end of the paper. With the appropriate insole in place, gait analysis was then performed for participants without an insole, with talonavicular strapping insoles and subtalar strapping insoles respectively.

Following the method of Shores,[7] longitudinal lines bisecting each footprint were drawn (line A–J in Fig. 3). The length of one footprint was divided into three equal parts and a line through the posterior third of the footprint perpendicular to the longitudinal line was drawn (line C–D in Fig. 3). The intersections between these two lines in two ipsilateral feet were then connected (line F–F in Fig. 3). This line was considered to be the line of progression. The foot angle (θ in Fig. 3) is the angle between the longitudinal line of the second step and the line of progression (Fig. 3).

Fig. 2. Construction of the two types of lateral wedged insoles. **A** The ends of the insole with subtalar strapping were wrapped in a figure of eight around the ankle and subtalar joints. **B** The insole with talonavicular strapping was bound to the foot with a bandage

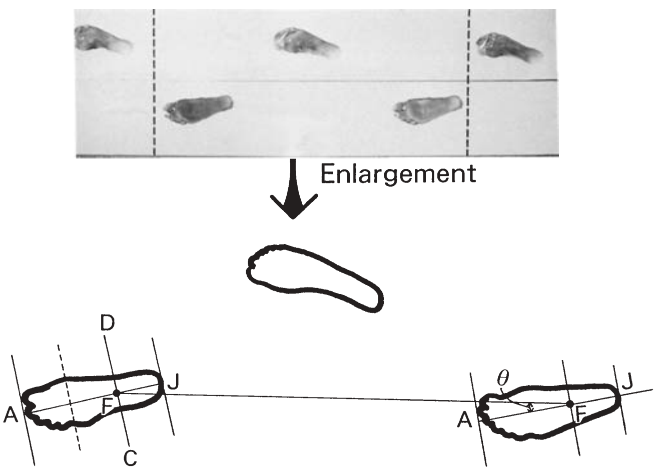

Fig. 3. Analysis of footprints on facsimile paper

The footprint assessment was carried out by three orthopedic surgeons before they were informed of the category of the participants. In this study, we assessed the insole with talonavicular strapping instead of the inserted insole that was used in the previous study, because the inserted insole is difficult to attach to bare feet.[5]

Statistical analysis

The values of age and foot angle between the control and knee OA groups, and the foot angle with and without insole use in each group, were compared using one-way analysis of variance.

Results

Characteristics of the participants

Subjects in the knee OA group had a median age of 62.0 (95% confidence interval 58.1–65.9) years, a median disease duration of 2.5 (95% confidence interval 1.3–4.7) years, and a median femorotibial angle in standing radiographs of 179.7° (95% confidence interval 177.7–183.0). There was no significant difference in age between the control group (median 59 years; 95% confidence interval 56.3–62.5 years) and the knee OA group.

Foot angle

The value of the foot angle without insole use, while barefoot, in the knee OA group (12.4 ± 2.3°) was significantly higher than that in the control group (10.6 ± 3.4°) (P = 0.018) (Table 1), showing that external rotation of the foot position during gait was greater in the knee OA group than in the control group.

This angle was decreased after wearing the subtalar insole in 23 out of 28 patients (82%) in the knee OA group, and in 15 out of 38 patients (39%) in the control group. In the knee OA group, the foot angle with subtalar and talonavicular insole use changed by an average of −3.0° and −1.2°, respectively, with respect to that without insole use (Fig. 4).

The foot angle with a subtalar insole was significantly lower than the angle without an insole ($P < 0.0001$) and that with a talonavicular insole ($P = 0.022$) in the knee OA group. However, the angle was not significantly changed by the talonavicular insole compared with that without insole use ($P = 0.12$) in the knee OA group. In contrast, there was no significant difference in the foot angle among the three conditions in the control group ($P > 0.05$) (Table 1).

Discussion

In the knee OA group, the foot angle ipsilateral to the knee with the varus deformity was significantly larger than that angle in the control group, and was significantly reduced after wearing the insole with subtalar strapping but not after wearing the insole with talonavicular strapping. We inferred from these results that the insole with subtalar strapping induces an adaptive mechanism to reduce the adductive moment at the knee by decreasing the femorotibial angle and thus decreasing the external rotation of the foot position during walking, as was also shown by Andriacchi[2] after high tibial osteotomy. We concluded that the insole with subtalar strapping may have a therapeutic effect on valgus realignment not only during the static, but also during the dynamic, phase.

The foot angle with use of the insole with subtalar strapping in the knee OA group was 9.4 ± 3.3° in this study. This angle is greater than that without an insole in the control

Table 1. Comparison of footprint analysis with and without insoles

	Barefoot	Foot angle (°)	
		Talonavicular insole	Subtalar insole
Control group (n = 38)			
Mean ± SD	10.6 ± 3.4	10.9 ± 3.4	10.7 ± 2.7
Median	10	10.6	11
95% CI	9.4–11.7	9.8–12	9.8–11.6
Knee OA group (n = 28)			
Mean ± SD	12.4 ± 2.3[a]	11.1 ± 2.8	9.4 ± 3.3[b]
Median	12	12.1	10
95% CI	11.5–13.2	10.1–12.2	8.1–10.7

[a] Significantly different from the barefoot test in the control group, $P = 0.018$
[b] Significant difference with respect to the angle without insole use (barefoot), $P < 0.0001$, and that with talonavicular insole use, $P = 0.022$
CI, confidence interval

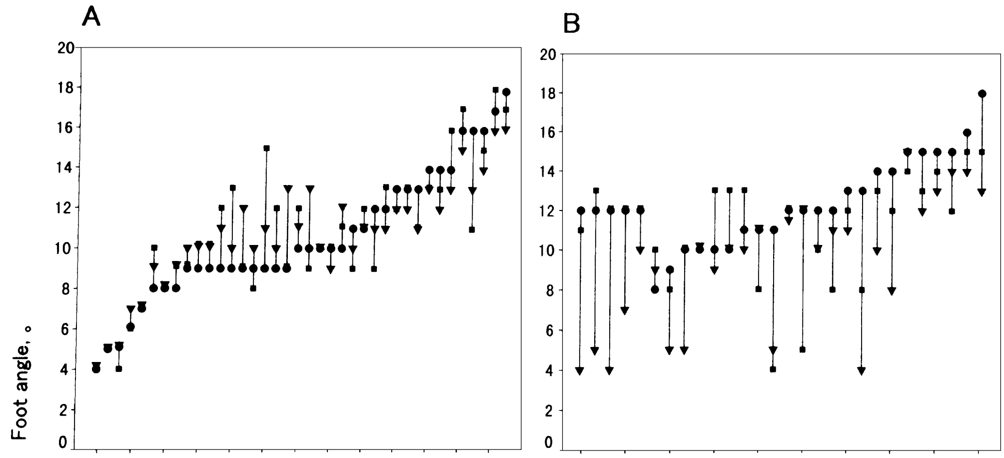

Fig. 4. Comparison of foot angles with and without insoles in each group. **A** Control group (n = 38). **B** Knee osteoarthritis (*OA*) group (n = 28). *Circles*, barefoot; *squares*, talonavicular insole; *triangles*, subtalar insole

group (10.6 ± 3.4°). There seems to be a large correction. However, participants wearing the insole with subtalar strapping for 8 weeks showed a significantly decrease in the visual analogue scale of knee ratings compared with the baseline values, and these significant differences were not seen in the participants wearing the inserted insole in our previous study.[5] We presumed that a little over-correction in the foot angle may be needed for a clinical improvement in patients with medial knee OA. Future studies should assess the correlation between the change in foot angle and the efficacy of the insole.

The indications are that an insole with subtalar strapping gives symptomatic relief of knee OA which is independently correlated with age and lower extremity lean body mass per body weight, but not with femorotibial angle, as was found without the insole in our previous study.[10] A decrease in lean body mass is characteristic of the aging process. Thus, without the muscular support of an anatomic realignment, patients may retain their previous varus stance and gait, thus negating the effect of insole therapy. Our previous data suggest that the insole with subtalar strapping might best be utilized by patients with lower extremity lean body mass per body weight of >18%.

The current study was limited in that it did not clarify whether the femorotibial angle without insole use was attributable to a change in the foot angle. It would be necessary to measure the femorotibial angle while barefoot in the control group. One possible hypothesis is that by correcting the varus deformity of the knee, the insole with subtalar strapping may regulate the external rotation of the foot position during gait. This may not lead to a reduction of the foot angle for participants without knee OA. If so, there was no significant difference in the foot angle among the three conditions in the control group in this study.

Another possible limitation of this study was that the adductive moment at the knee and the femorotibial angle during gait were not directly measured using a precise instrument. Such a detailed measurement would allow a clearer evaluation of the dynamic effect of the insole with subtalar strapping. However, it is important that even a simple and economical footprint analysis can demonstrate a significant difference in the foot angle between insoles with subtalar or with talonavicular strapping. Also, the results of footprint analysis can be readily understood by patients without a medical background.

Recently, remarkable progress has been made in surgical techniques such as high tibial osteotomy for the treatment of knee OA. However, some patients with knee OA are hesitant to undergo surgical treatment. Therefore, if conservative therapy such as the use of an insole can provide a low-cost, effective complementary alternative to surgical treatment, it will be very useful for patients as well as for the health-care economy.

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