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Effect of rocker bottom shoes on plantar pressure distribution in patients with osteoarthritis of first metatarsophalangeal joint

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Abstract

Introduction Surgical streategy for patients with grades 3–4 osteoarthritis (OA) of the first metatarsophalangeal (MPT) joint is generally accepted. There is a variety of conservative treatments including NSAIDs, orthopedic insoles, physical therapy and pharmacological blockade to be offered for patients having contraindications or unwilling to undergo surgery. However, the role of orthopedic footwear can be underestimated.

The **aim** of the study was to evaluate results of dynamic in-shoe pedobarography with standard shoes and rocker bottom shoes used by patients with grades 3–4 OA of first MPT joint.

Material and methods Plantar pressure was evaluated in 12 patients wearing standard shoes and rocker bottom shoes. Major biomechanical parameters were analyzed to evaluate the force, walking speed and distribution of plantar pressure.

Results The in-shoe dynamic pedobarography revealed a significant decrease in the values of peak ($p = 0.011$) and average ($p = 0.019$) pressure for the whole foot and the forefoot ($p = 0.029$) with use of rocker bottom shoes. A decreased length of the stance phase was noted ($p = 0.027$). No changes were found in walking speed ($p = 0.604$), duration of the swing phase ($p = 0.495$) and duration of the step cycle ($p = 0.721$).

Conclusion A significant decrease in plantar pressure and the force in the forefoot was observed in patients with first MPT joint OA using rocker bottom shoes compared to those using shoes with a standard sole, with no differences in time indicators and walking speed.

Keywords: hallux rigidus, osteoarthritis, rocker bottom shoes, pedobarography

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INTRODUCTION

Osteoarthritis (OA) of the first metatarsophalangeal (MTP) joint is one of the most common foot pathologies. Bilateral condition is diagnosed in 79 % of cases, and the disease is more common for women [1]. The disease often affects middle-aged patients, who develop major clinical manifestations, such as pain and limited joint motion in advanced stages of the condition that can lead to disability [2, 3].

Severe stages of the disease are normally treated with surgery, which may include arthrodesis, total replacement of the 1st metatarsal joint, cheilectomy and shortening osteotomies of the first metatarsal bone [4, 5].

If there are contraindications to surgery or the patient's unwilling to undergo it, conservative treatment may be necessary as the primary management. Conservative treatment for OA of the first MTP joint include a combination of NSAIDs, physical therapy, and specialized orthopedic insoles [6, 7]. With a variety of available orthopedic products tha would help relieve pain during everyday physical activity the role of orthopedic footwear can be underestimated [8, 9].

Dynamic pedobarography is commonly used to assess changes in the kinematics of the lower limbs [10, 11], the repeatability and reproducibility of its use are confirmed by scientific publications [12, 13].

The **aim** of the study was to evaluate results of dynamic in-shoe pedobarography with standard shoes and rocker bottom shoes used by patients with grades 3–4 OA of first MPT joint.

MATERIAL AND METHODS

Study design

Study type: Prospective, single-center, non-randomized cohort study. The study included patients scheduled for treatment at the S.S. Yudin City Clinical Hospital for grade 3–4 OA of the first MTP joint.

Inclusion criteria:

— patient consent to participate in the study;

— clinically and radiologically confirmed diagnosis of "osteoarthritis of the first MTP joint grade 3–4»;

— surgical intervention intended for treatment of OA of the 1st MTP joint;

— patients aged 18 years and older;

— the ability to walk 100 m or more without rest;

— the patient must wear closed shoes to allow the examination to be produced;

— absence of orthopedic insoles in the patient's shoes.

Non-inclusion criteria:

— previous surgical interventions for OA of the 1st MTP joint;

— concomitant pathology of the lower extremities;

— concomitant systemic diseases;

— NSAIDs used in the previous 2 weeks;

— intra-articular injections performed in the previous 3 months.

Patients were selected for the study during a preoperative consultation or during hospitalization prior to surgery.

The diagnosis of grade 3–4 first MTP joint OA was made by the consulting physician based on a patient's medical history, clinical examination and radiographic findings (Fig. 1).

Fig. 1 Dorsal plantar radiography of a patient included in the study showing radiographic signs of OA of the 1st MTP joint of both feet

The study group consisted of 12 individuals including nine (75 %) femal and three (25 %) male patients. The mean age of the patients was 63.3 years (range, 45–71).

The average VAS score in the study group measured (7.0 ± 2.3) points (range, 3 to 10), the AOFAS HS (American Orthopedic Foot and Ankle Society Hallux Scale) questionnaire scored (47.6 ± 14.1) (range, 27 to 69). The range of motion of the first MCP joint was (11.6 ± 6.5)° (range, 5 to 25).

Patients were examined for a range of motion in the first MTP joint using a goniometer, the severity of pain assessed with the VAS and AOFAS questionnaires, dynamic pedobarography performed using the patient's shoes (Fig. 2) and orthopedic shoes with a sole rounded in the anteroposterior direction (Fig. 3).

Fig. 2 Examples of standard patient footwear

Fig. 3 Orthopedic rocker-bottom shoes

Step Analysis

Examinations were performed by a single investigator using a single protocol. First the patients used standard shoes, and then they were requested to use rocker-bottom shoes. After an adaptation period (15 minutes of walking), patients performed four walking tests each 10 meters long indoors

on a hard surface using standard shoes. The first and the last steps were excluded from the analysis. Then the patients were asked to use rocker-bottom shoes. We did not determine the number of steps for each test due to the different stride lengths. The patients chose to walk at a speed they wanted.

In-shoe dynamic pedobarography was performed using a Tekscan F-Scan64 system (Tekscan Inc.), which consists of a 0.229 mm thick insole equipped with 64 100 Hz sensors (one sensor per 1 cm^2) measuring a pressure range of 852 kPa. The in-shoe sensors were connected to a transmitter, which transmitted data to a personal computer via Bluetooth. Specialized software was used to evaluate and analyze the measurments.

The insole size was selected individually for each patient based on their shoe size. The peak pressure (kPa), average pressure (kPa), force (kg), walking speed (steps/min), and stride phase time (sec) were measured. Distribution across foot regions was performed automatically using software.

Statistical analysis

The results obtained during the study were analyzed using the Jamovi 2.6.13 statistical program. The normality of distribution was tested using the Shapiro – Wilk test. For a normal distribution, the data were presented as mean values with the minimum and maximum values. In non-normal distribution samples, quantitative data were described using the median (Me) and the lower and upper quartiles. Plantar pressure was analyzed using the Mann – Whitney U parameter for two independent groups. Statistical significance was determined using the p-test of 5 % ($p \leqslant 0.05$).

RESULTS

Comparison of biomechanical parameters of walking in standard shoes and rocker-bottom shoes showed no statistically significant differences in gait speed, swing phase time, step cycle time and ground contact time of both feet (Table 1).

A statistically significant decrease in peak and average pressure, stance phase time walking in rocker-bottom shoes as compared to standard shoes. Analysis of strength parameters revealed differences in overall strength and forefoot strength. However, no changes were observed in hindfoot strength (Tables 2 and 3).

Table 1

Step cycle time values

Description	Measurements		*p*
	Standard shoes	Rocker-bottom shoes	
Walking speed, steps/min	46.80 ± 3.70 (41,20–51,00)	48.01 ± 4.60 (41.20–50.90)	0.604
Step cycle time, sec	1.28 ± 0.90 (1.17–1.46)	1.21 ± 0.15 (1.18–1.44)	0.721
Stance phase, sec	0.73 ± 0.09 (0.71–0.87)	0.63 ± 0.09 (0.47–0.83)	0.027
Swing phase, sec	0.55 ± 0.10 (0.44–0.66)	0.56 ± 0.10 (0.47–0.66)	0.495

Table 2

Strength and time indicators measured in the study groups

Description	Strength, kg			Contact time, sec		
	Standard shoes	Rocker-bottom shoes	*p*	Standard shoes	Rocker-bottom shoes	*p*
Hindfoot	53.9 ± 27.8 (33.7–85.5)	57,1 ± 27,3 (43,4–117,7)	0.088	0.53 ± 0.12 (0.4–0.64)	0,56 ± 0,09 (0,5—0,67)	0.706
Forefoot	83.7 ± 30.2 (60.9–139.7)	51.6 ± 20.6 (28.6–68.4)	0.020	0.52 ± 0.12 (0.45–0.62)	0.53 ± 0.12 (0.45–0.67)	0.847
Foot	134.3 ± 43.9 (99.7–183.7)	84,6 ± 30,7 (55,0–138,2)	0.026	0.71 ± 0.90 (0.64–0.82)	0,70 ± 0,20 (0,67–0,72)	0.216

Table 3

Pressure measured in the study groups

Type of pressure	Standard shoes	Rocker-bottom shoes	p
Peak pressure, kPa	759.3 ± 196.7 (568–961)	412.7,4 ± 222.3 (255–667)	0.011
Average pressure, kPa	386.0 ± 103.2 (313–566)	217.0 ± 94.5 (208–420)	0.019

Analysis of peak and average pressure with use of standard shoes allows us to conclude that 10 (83.3 %) patients had peak pressure in the forefoot (Fig. 4).

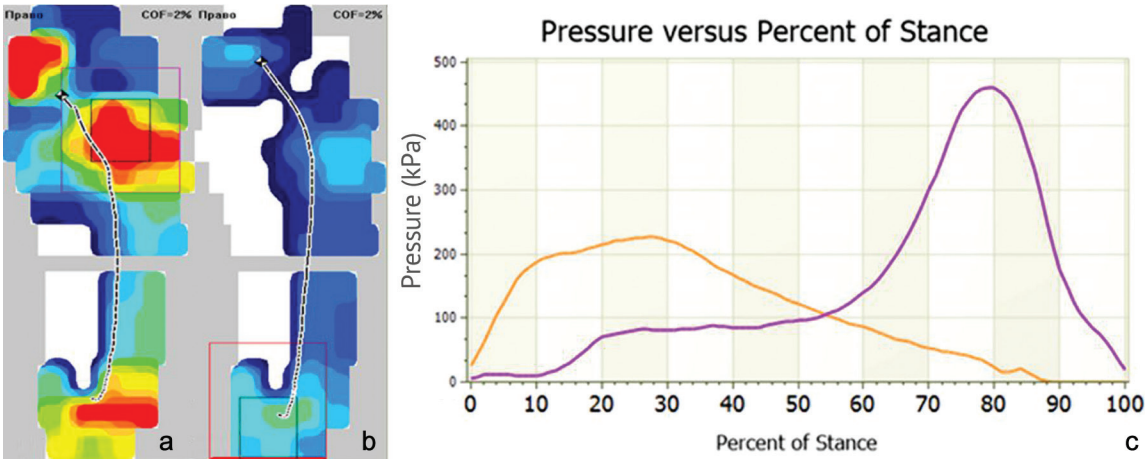

Fig. 4 Dynamic pedobarography of the patient showing (a) pressure distribution on the foot with use of standard shoes; (b) pressure distribution on the foot with use of rocker-bottom shoes; (c) graphical representation of changes in pressure distribution with use of standard shoes (graph marked in orange) and rocker-bottom shoes (graph marked in purple). A decrease in the red indicator suggests a significant reduction in plantar pressure when using orthopedic shoes. In shoes with a rolling sole, The peak pressure zone is shifted to the rearfoot with use of rocker-bottom shoes. The square red indicator confirms a change in the location of the maximum pressure zone.

Peak pressure was measured in the rearfoot in seven (70 %) of 10 cases using rocker-bottom shoes. No statistically significant difference was observed in peak pressure ($p = 0.101$) or strength ($p = 0.088$) in the rearfoot with use of standard shoes and rocker-bottom shoes. This suggests that changes in rolling occur due to a decrease in forefoot parameters.

DISCUSSION

The motion in the first MTP joint is crucial for the foot biomechanics. Extension of the first MTP joint with the forefoot rolling over results in the "winch mechanism", which elevates the medial longitudinal arch, supinates the rearfoot, and ultimately produces an energetically efficient toe push-off during the propulsive phase of the gait [2].

Impaired motion of the first metatarsal joint leads to changes in gait biomechanics, with a decrease in peak pressure under the head of the first metatarsal bone [14]. Internal rotation of the foot occurs, and the center of pressure during the step shifts laterally, increasing the load on the lateral part of the foot, and overloading of the lesser rays [15]. These changes correspond to a low-gear roll, which occurs through the oblique axis connecting the second and fifth metatarsal bones [16]. Pronation of the hindfoot can be observed in patients with limited range of motion of the first metatarsal joint [17].

We found a limited number of publications evaluating the long-term results of conservative treatment of patients with OA of the first MTP [18]. J. Grady et al. reported the largest series evaluating the results of conservative treatment of OA of the first MTP [19]. The effectiveness of treatment based on the reduction in pain was 55 %, with 84 % of patients using orthopedic insoles.

Conservative treatment of patients with OA of the first MTP using orthopedic insoles is based on several approaches. The first involves limited extension of the first MTP reducing the time of loading on the first ray with use of Morton's extension insoles which have an extended frame in the projection of the first MTP (Fig. 5). A drawback with the method includes greater lateralization of the load vector when rolling over the forefoot [20]. Limited movement of the first MTP can be caused by pronation of the rearfoot.

Fig. 5 Morton insole with extended frame in the projection of 1 MTP

The second approach to conservative treatment for OA of the first MTP joint is based on the formation of an internal longitudinal arch and correction of hindfoot pronation, using insoles with a cast-arch support [21]. Additional space is needed for orthopedic insoles in the shoe, and their use can be difficult due to osteochondral exostoses at the first MTP joint and limited space in the forefoot.

In this case, the selection of footwear for the patients becomes crucial. Rocker-bottom shoe-wearing is one of the most commonly used modifications of therapeutic footwear to allow patients with various foot and ankle pathologies benefit from its use [22, 23]. Although the role of footwear in the treatment of patients with OA of the first MTP joint was reported as early as the beginning of the 20th century, there is a paucity of publications devoted to this topic [24, 25].

The rounded shape of the sole stimulates foot rollover as the body weight passes through the support point [26]. Pressure distribution in this case occurs primarily on the midfoot [27]. The design of the sole, which is provided by softening and rigid inserts, provides additional cushioning during heel strike and limits extension in the forefoot enhancing the effect of the sole shape. Limitations in foot joint motion in the sagittal plane affect the kinematics of the lower limbs [28, 29].

Limited motion of the first MTP leads to an artificial decrease in the efficiency of the "winch mechanism", which is impaired in patients with stage 3–4 OA of the first MTP. A decreased force of the toe pushoff with the forefoot rolling over results in a longer double support phase, smaller oscillations of the body's center of mass and step length [9, 30, 31]. However, rocker-bottom shoees do not affect the speed of movement, which is consistent with the results of our study [32]. Limited extension of the first MTP joint in patients with OA can reduce pain intensity by using a semi-rigid and rounded sole in the toe area of shoes and a rocker-bottom. The sole shape can reduce the load and pressure in the forefoot [33], as confirmed by the results of our study, increasing the peak pressure and force in the rearfoot [34].

CONCLUSION

Results of in-shoe dynamic pedobarography suggested a reduction in plantar pressure and the force in patients with OA of the first MTP joint with use of rocker-bottom shoes compared to the values recorded with use of standard shoes. The rocker-bottom design hasdno effect on walking speed or step time. The reduction in peak plantar pressure and force occurs primarily in the forefoot.

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