PLANTAR PRESSURE DISTRIBUTION FEATURES IN ATHLETES WITH PLANTAR FASCIITIS

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Plantar fasciitis (PF) is one of the leading causes of heel pain in athletes. Since the disease etiology and pathogenesis are poorly understood, determination of impaired biomechanical patterns will make it possible to develop effective and safe therapeutic strategies. The study was aimed to reveal biomechanical changes typical for athletes with PF. Analysis of the results of baropodometric examination of 60 athletes, who were assessed and treated at the Federal Research and Clinical Center of Sports Medicine and Rehabilitation of FMBA of Russia due to foot disorders (1–2 degree combined platypodia and PF), was conducted. Athletes were divided into two groups based on the fact of having/not having a verified diagnosis of PF. The study involved 24 males (40%) and 36 females (60%), the athletes' median age was 24 (19; 28) years. During the study we noted a trend towards higher incidence of PF in female athletes (p = 0.066). Hammertoe deformity was often found in athletes with PF ($p < 0.05$). Athletes with combined platypodia and PF showed overload or insufficient load in the posterior part of the affected foot, depending on pain severity, in static tests (r = 0.592, p = 0.001). The dynamic tests revealed deformation of the general pressure vector and changes in the general center of pressure velocity ($p < 0.01$). Baropodometric examination showed that athletes with PF had deficit or excess increase of plantar pressure in the heel of the affected foot, along with deformation of the general pressure vector.

Keywords: plantar fasciitis, sport, biomechanics, baropodometry, heel pain

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Compliance with the ethical standards: the study was approved by the Ethics Committee of the Pirogov Russian National Research Medical University (protocol No. 225 dated 23 January 2023). All athletes submitted the consent to study participation.

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ОСОБЕННОСТИ РАСПРЕДЕЛЕНИЯ ПОДОШВЕННОГО ДАВЛЕНИЯ СТОП У СПОРТСМЕНОВ С ПЛАНТАРНЫМ ФАСЦИИТОМ

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Плантарный фасциит (ПФ) — одна из ведущих причин болевого синдрома в пяточной области среди спортсменов. Поскольку этиология и патогенез заболевания непонятны, определение нарушенных биомеханических паттернов позволит разработать эффективные и безопасные терапевтические стратегии. Целью работы было выявить биомеханические изменения, характерные для спортсменов с ПФ. Проведен анализ результатов бароподометрического обследования 60 спортсменов, проходивших обследование и лечение на базе Федерального научно-клинического центра спортивной медицины и реабилитации ФМБА России по поводу патологии стоп (комбинированного плоскостопия 1–2 степени и ПФ). Спортсмены были разделены на две группы в зависимости от наличия/отсутствия у них верифицированного диагноза «плантарный фасциит». В исследовании приняли участие 24 мужчины (40%) и 36 женщин (60%), медиана возраста спортсменов составила 24 (19; 28) года. В ходе исследования было отмечено наличие тенденции к более частому развитию ПФ у спортсменок (p = 0,066). У спортсменов с ПФ часто встречалась молоткообразная деформация пальцев стопы (p < 0,05). У спортсменов с комбинированным плоскостопием и ПФ в статических тестах выявлена перегрузка или недостаточная нагрузка на задний отдел пораженной стопы, в зависимости от степени выраженности болевого синдрома (r = 0,592, p = 0,001). В динамических тестах определялись деформация общего вектора давления и изменения скорости общего центра давления (p < 0,01). У спортсменов с ПФ по результатам бароподометрического обследования наблюдались дефицит или избыточное повышение подошвенного давления в пяточной области на пораженной стопе и деформация общего вектора давления.

Ключевые слова: плантарный фасциит, спорт, биомеханика, бароподометрия, боль в пяточной области

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Plantar fasciitis (PF) is one of the leading causes of foot pain in the adult population. According to the data provided by various authors, the prevalence of PF among athletes varies between 4.5 and 10%. Furthermore, PF is slightly less common among men, than among women [1–3]. The severity of pain occurring in case of the plantar fascia overload often hampers and quite often leads to interruption of the training and competitive activity.

At the same time, it is still unclear, which factors underlie the PF development and whether these factors are different in athletic population. The authors of the systematic review emphasize that all the currently distinguished risk factors of PF

Table 1. Sequence of the tests performed and their description

Test	Description
Static test	Feet are standing parallel, the width of the iliac spines of the pelvis apart. The test is conducted for 30 s. The athlete keeps still during testing
Dynamic tests	
Sagittal test	Feet are standing parallel, the width of the iliac spines of the pelvis apart. The test is conducted for 30 s. The athlete makes the physician-commanded low-amplitude forward and backward movements (in ankle joints only)
Frontal test	Feet are standing parallel, the width of the iliac spines of the pelvis apart. The test is conducted for 30 s. The athlete makes the physician-commanded low-amplitude right and left movements (in ankle joints only)
Test involving standing on the forefoot	Feet are standing parallel, the width of the iliac spines of the pelvis apart. The test is conducted for 30 s. The athlete stands on the forefoot, lifting the heels of both feet 3–4 cm above the platform, by the physician's command
Jump test	Feet are standing parallel, the width of the iliac spines of the pelvis apart. The test is conducted for 30 s. The athlete jumps, synchronously and symmetrically lifting both feet off the platform by 3–4 cm and trying not to bend the knees when taking off and landing, by the physician's command. The athlete makes 4–5 jumps with intervals

have no strong evidence base [4], and high body mass index (BMI) that is usually announced as the leading risk factor has absolutely nothing to do with prediction of the risk of the plantar fascia inflammation onset in athletes [5].

The important role of biomechanical problems with the foot in the PF pathogenesis is reported more and more often [4]. The changes in foot biomechanics associated with PF are poorly understood, however, it is their leading role in the development of the plantar fascia aseptic inflammation that seems to be the most logical, especially in athletic population [6, 7]. Identification of disturbed biomechanical patterns will make it possible to not only better understand the PF pathogenesis, but also get closer to understanding the effective methods to adjust the disorder.

The study was aimed to determine biomechanical changes typical for athletes with PF.

METHODS

The analysis of the results of baropodometric examination of 60 athletes conducted in 2021–2023 at the Federal Research and Clinical Center of Sports Medicine and Rehabilitation of FMBA of Russia by the experts of the rehabilitation treatment department was performed. The inclusion criteria were as follows: sports category (Candidate for Master of Sport of Russia or higher), athletes' age 16–40 years, undergoing baropodometric examination at the Center, combined flat foot.

A total of 24 males (40%) and 36 females (60%) were included in the study. The athletes' median age was 24 (19; 28) years. The athletes were divided into two groups based on having/not having a verified diagnosis of PF: group 1 — athletes with 1–2 degree combined flat foot and PF (n = 30), group 2 — athletes with 1–2 degree combined flat foot and no PF, who had subjective symptoms (pain, feeling uncomfortable in the feet) (n = 30). Athletes with unilateral PF only were included in group 1; the cases of bilateral process were extremely rare. The assumption of possible PF was based on the fact of the presence of rather typical clinical manifestations in an athlete (kickoff heel pain), and the diagnosis was verified based on the MRI data (plantar fascia hypointense lesions and thickening). Patients with the verified diagnoses of the disorders affecting bone tissues of the foot were excluded from the study. Pain severity was estimated using a 10-point visual analogue scale (VAS).

Biomechanical examination was conducted using the WINTRACK baropodometric hardware-software system (Medicapteurs; France). The study was performed in accordance with the algorithm including the series of tests that was substantiated at the rehabilitation treatment department of the Federal Research and Clinical Center of Sports Medicine and Rehabilitation of FMBA of Russia. The details of the tests conducted are provided in Table 1. The static test was assessed based primarily on the changes in plantar pressure of the forefoot and hindfoot, while the dynamic tests were assessed based on the changes in the general center of pressure (GCP) speed on the X and Y axes.

Statistical data processing was performed using the IBM SPSS Statistics 23 software package (IBM; USA). Given small sample size, nonparametric statistical methods were used for data analysis. The quantitative data descriptive statistics were presented as the median and quartiles, while qualitative traits were described using the absolute and relative frequency values. The nonparametric Mann–Whitney U test was used for comparative intergroup analysis, and the Wilcoxon test was used for intragroup analysis. Discrete values were compared using the chi-squared test (χ^2) with the Yates continuity correction. The differences were considered significant at the statistical significance level below 0.05.

RESULTS

Characteristics of the studied groups

The study involved representatives of various sports: handball, skeleton, football, track and field, fencing, basketball, tennis. The more detailed characteristics of the studied groups are provided in Fig. 1 and Table 2.

Table 2. Characteristics of the studied groups with descriptive statistics

Characteristic	Group 1	Group 2	p
Age, years (Me (Q_1; Q_3))	24 (19; 30)	24 (20; 27)	0.781
Female (abs. (%))	22 (77.3%)	14 (46.7%)	0.066
BMI, kg/m^2 (Me (Q_1; Q_3))	22.69 (21.25; 23.9)	22.72 (20.11; 24.05)	0.843
Hammertoe deformity (abs. (%))	9 (30%)	2 (6.7%)	0.046*

Note: * — significant difference (p < 0.05).

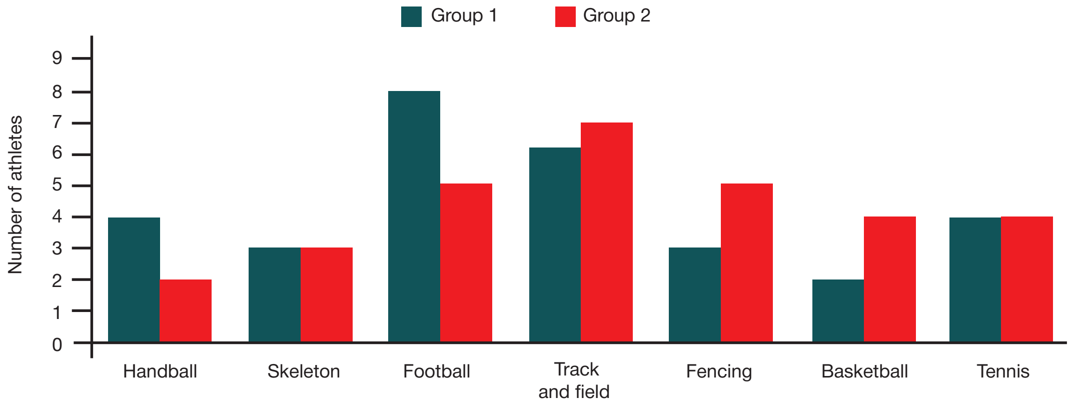

Fig. 1. Distribution of athletes by sports

Despite the fact that statistical significance has not been achieved, the trend towards more frequent development of PF in female athletes can be noted. Hammertoe deformity was significantly more common in male athletes with PF ($p = 0.046$). PF was most common in football players and track and field athletes. BMI did not show any statistical significance as a potential risk factor of PF in athletes ($p > 0.05$).

Results of the baropodometric examination of athletes in the static test

The distribution of plantar pressure in athletes based on the baropodometric examination results is provided in Table 3 and Fig. 2.

Intragroup comparison revealed no significant differences in the groups 1 and 2 ($p > 0.05$). However, the following feature was identified during analysis of the results (Fig. 2): in athletes with PF, the posterior part of the affected foot was either overloaded (plantar pressure exceeding 30%) (Fig. 3A), or insufficiently loaded (plantar pressure below 22%) (Fig. 3B).

Intergroup comparison also revealed no significant differences between the forefoot ($p = 0.637$) and hindfoot ($p = 0.229$).

When assessing the relationship between plantar pressure in the posterior part of the foot with PF and pain severity on VAS, it was found that the degree of the deficit of support on the limb affected with PS in the static test was determined by pain severity ($r = 0.592$, $p = 0.001$) (Fig. 4).

Results of the baropodometric examination of athletes in the dynamic tests

In the study, the most vivid changes of the general pressure vector (GPV) were detected in the sagittal dynamic test. Fig. 5 presents the test results of athletes with PF. The left athlete's foot is affected in Fig. 5A, the right athlete's foot is affected in Fig. 5B.

GPV shift and deformation in the area of pain localization were reported. Furthermore, imbalance of plantar pressure distribution under the affected foot is associated with the plantar pressure decrease in the forefoot.

GPV changes are indirectly reflected in the dynamic changes of GCP speed. The most significant changes in the GCP speed on X axis were reported in the sagittal dynamic test, while that on Y axis were reported in the frontal dynamic test. The analysis showed that changes in GCP speed on X

Table 3. Distribution of plantar pressure in athletes based on the results of baropodometric examination in the static test

Region of the foot	Group 1			Group 2		
	Foot with PF Me (Q_1; Q_3)	Contralateral foot Me (Q_1; Q_3)	*p*	Right foot Me (Q_1; Q_3)	Left foot Me (Q_1; Q_3)	*p*
Forefoot, %	21 (14; 28)	23 (19; 24)	0.992	22 (21; 24)	21 (19.75; 24)	0.539
Hindfoot, %	26.5 (20; 36)	29.5 (27; 31.25)	0.346	28 (25.75; 30)	27.5 (26.75; 30)	0.81

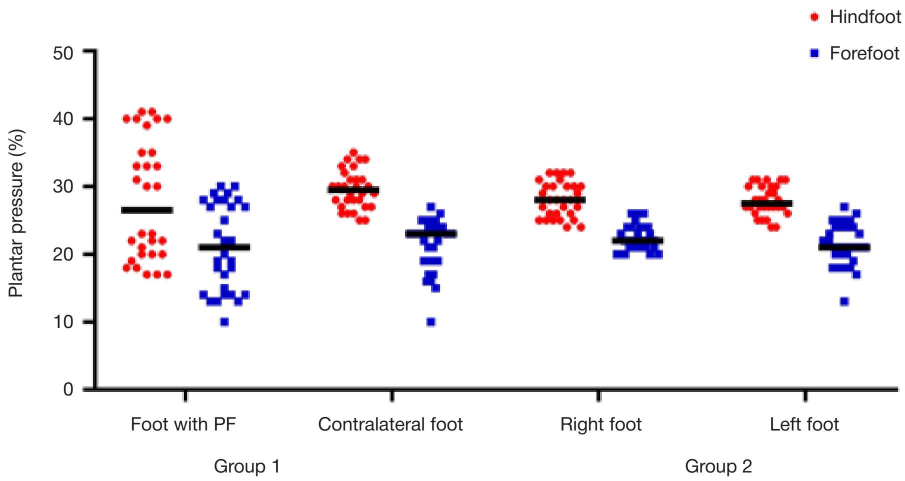

Fig. 2. Plantar pressure distribution in the studied groups based on the results of baropodometric examination in the static test

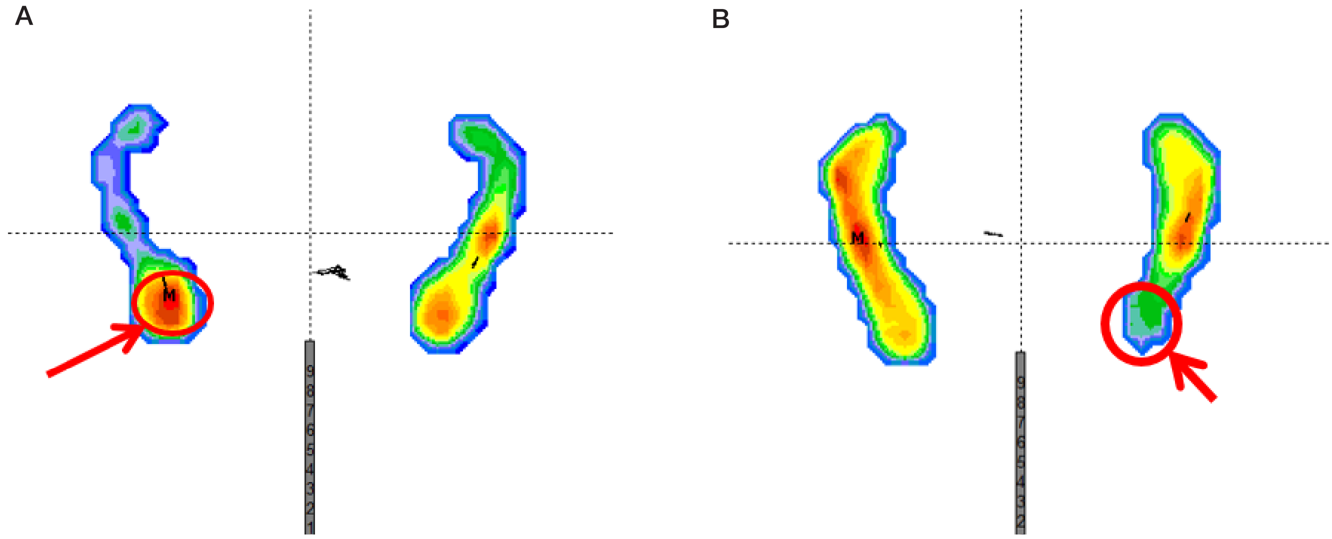

Fig. 3. Plantar pressure distribution in athletes with PF in the static test. The heel of the athlete with PF is highlighted in *red*. **A**. Excess plantar pressure in the affected foot. **B**. Plantar pressure deficit

and Y axes were more significant in group 1, than in group 2 ($p < 0.01$) (Fig. 6).

DISCUSSION

In the study, several baropodometric patterns clearly traceable in athletes with PF were revealed. In static tests, these were represented by deficit of support or overload in the affected area, depending on pain severity; in dynamic tests, these were represented by deformation of GPV in the projection of the most painful area with the reduced pressure in the forefoot. It is likely that degenerative changes of the plantar aponeurosis result from the increased load on the latter that can be associated with the overlying impairment of the lower limb biomechanics in general, which is manifested by the increased plantar pressure in the heel. Further prolongation of excess load on the plantar fascia leads to pain contributing to the emergence of the plantar pressure deficit area in the heel, depending on pain severity. The findings are generally consistent with the data obtained by various authors in the general population of patients. Thus, the group of researchers found that in patients with PF the maximum pressure in the hindfoot and the contact area were significantly lower in the affected foot compared to the contralateral foot [8]. Other researchers obtained similar results and noted that patients with PF showed decreased plantar pressure in the medial part of the forefoot when undergoing dynamic tests, as reported in our study [9]. The plantar pressure deficit in the anteromedial part of the foot wore off in cases of successful therapy [9]. In our study, it was pointed out that plantar pressure in the hindfoot was inversely proportional to pain severity, which had not been previously reported in the literature. Our study revealed GPV deformation in the most painful area in patients with PF when conducting dynamic tests. This is in line with the data, according to which the anteromedial shift of the plantar pressure load is observed in patients with PF [10]. The authors also reported that heel pain occurred in the foot with normal arch in 59% of cases [10]. However, in the above studies, the dynamic test involved plantar pressure estimation during walking, while our study involved the use of a broader range of the dynamic testing methods, which had not been previously reported in the literature. Furthermore, the tests reported in the study are to the greater extent consistent with the essence of the medical and biological support of sports, since these make it possible to detect even minimal functional disorders impeding intense movement. Similar results were obtained by the researchers, who detected deficit in the initial contact phase only when performing dynamic tests. Furthermore, the reported changes were usually bilateral [11]. We usually observed no imbalance of pressure distribution under the foot on both sides in patients with the confirmed diagnosis of combined flat foot having no PF. Furthermore, no local deformation of the pressure vector under the feet was reported in this group of athletes. It is likely that the GPV changes observed in athletes with PF can be partially explained by postural disorders associated with functional insufficiency of the overlying muscles (particularly, gluteal muscles).

The hypothesis explaining the presence of the zones of excess pressure in the sole we have detected by muscular imbalance seems to be rather logical. Many studies have shown that the decrease in the strength and response time of the plantar flexors is observed in patients with PF [12–14]. It has been assumed that it is these muscles that absorb most of load, and their incorrect functioning can result in the multiple increase of the load on the plantar aponeurosis [15–17]. Furthermore, in 83% of cases PF was associated with the calf muscle shortening [18], which resulted in the ankle dorsiflexion limitation, excess pronation in the rolling phase, and, as a result, the increase in the distance between the heel tubercle and the toes [16, 19]. The reported impossibility of ankle dorsiflexion

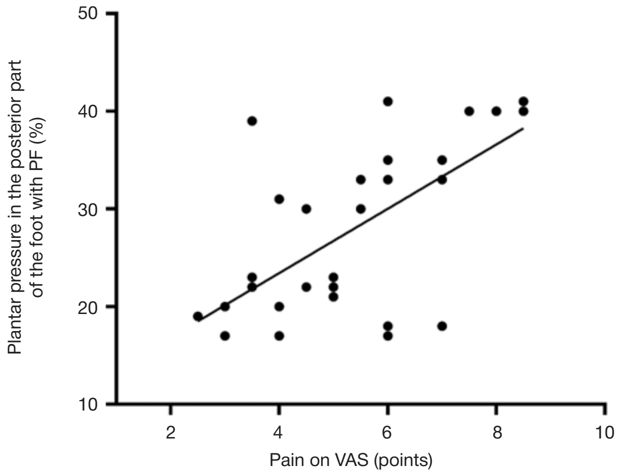

Fig. 4. Relationship between plantar pressure in the posterior part of the foot with PF and pain severity in athletes with PF

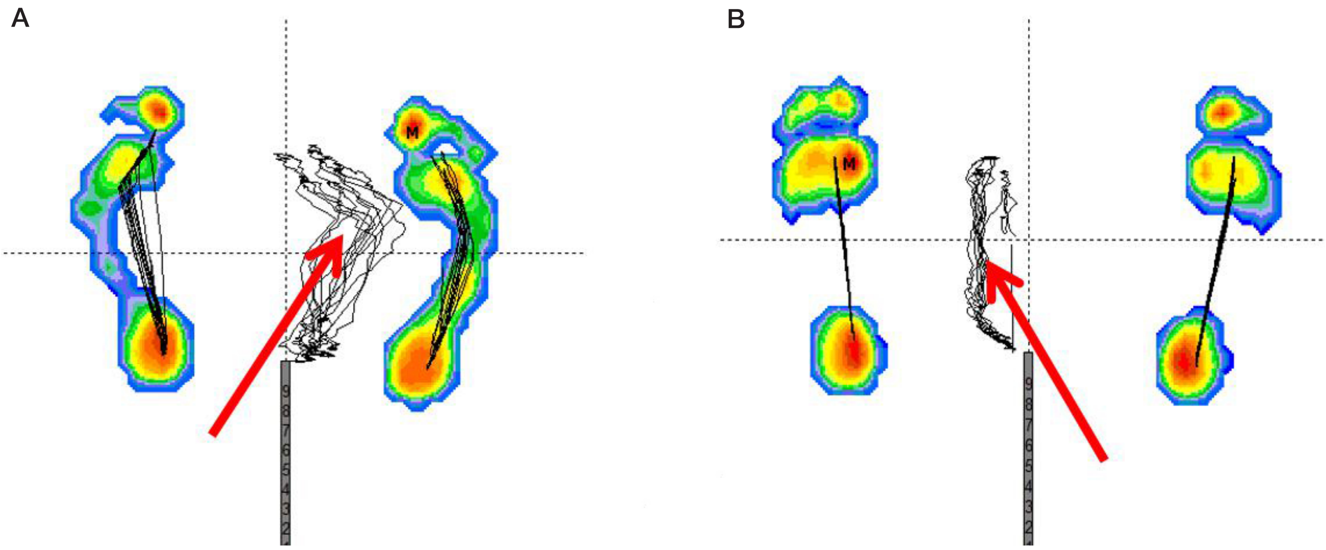

Fig. 5. Plantar pressure distribution in athletes with PF in the sagittal dynamic test. The GPV shift towards healthy side relative to the central axis is marked with *red arrow*. **A**. Left plantar fasciitis. **B**. Right foot is affected

23-fold increases the risk of PF [20]. However, it is still unclear, whether the above changes are primary or secondary relative to other, probably overlying, disorders. Therefore, further research is required.

In this regard, the study reporting a possible relationship between weakness of the hip abductor muscles and the PF development seems to be interesting [21]. The authors described the case of long-term PF refractory to the majority of treatment options. It was inclusion of exercises for the hip abductor muscles that made it possible to achieve clinical improvement and redistribution of the pressure zones in the foot based on the baropodometric data [21]. Similar cases were also reported by other authors [17, 22, 23]. It is likely that PF can be a more complex and multifactorial issue than previously thought.

In our study, PF was slightly more common in females, than in males, which was generally consistent with the literature data [2, 24]. As expected, BMI is not a risk factor of PF in athletes, in accordance with the previously reported data [5]. Higher prevalence of PF among football players and track-and-field athletes is explained by high running load in these sports; impaired biomechanics of running is likely to be the key to understanding the PF pathogenesis in athletes [6, 16]. Furthermore, high prevalence of hammertoe deformity among athletes with plantar aponeurosis inflammation was revealed. Some researchers report that there is a strong correlation between flat foot and the PF development [25]. Previously, the possible contribution of forefoot abnormalities to the PF development was separately reported [26].

Considering the results obtained in our study and the literature data, it seems feasible to include the methods estimating pressure distribution across the sole surface in the PF diagnosis programs. This will make it possible to improve accuracy of the diagnostic measures themselves and the dynamic control of treatment methods for PF in cases of suspected PF and allow us to get closer to understanding biomechanical problems underlying the PF development, especially in the athletic cohort.

CONCLUSIONS

Plantar fasciitis (PF) is an urgent and common issue, including in elite sports, which is still poorly understood. Baropodometric examination of athletes with PF represents an important phase of assessment and detection of pressure distribution abnormalities in the sole that makes it possible to determine impaired biomechanical patterns and, therefore, improve treatment outcomes.

Common baropodometric pattern changes were revealed in athletes with PF during the study. These are deficit of support or overload of the affected area in the static test, depending on pain severity, and deformation of the general pressure vector in projection of the most painful area with the reduced pressure in the forefoot in dynamic tests. It seems important to consider biomechanical changes associated with such baropodometric pattern in order to more adequately select corrective interventions and, as a result, reduce the duration of treatment and rehabilitation of athletes having the discussed disorder.

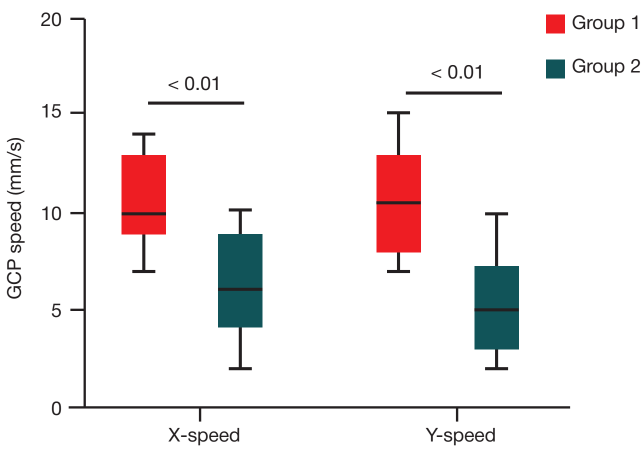

Fig. 6. Comparison of changes in GCP speed in groups 1 and 2

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