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Dynamic instability of the pelvis and its relation to plantar pressures in runners

Estabilidad dinámica de la pelvis y su relación con las presiones plantares

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Keywords:

Stability, pelvic, plantar pressures, pronation, gluteus.

Abstract

Introduction: The pelvis plays an important role during running, being key to the right distribution of loads on the two legs, maintaining the stability and alignment of both the limbs and the trunk. However, little is known about the relationship between poor pelvic stability and the distal segment of the lower limb (foot). The aim of this study was therefore to assess whether dynamic pelvic instability is related to any alteration of plantar pressures.

Patients and methods: In a sample of 47 healthy male runners, the single-leg squat test was video-recorded for evaluation by a panel of 5 experts. These formed the participants into three groups: bad pelvic control (BPC) (n = 8); medium pelvic control (RPC) (n = 14); and good pelvic control (GPC) (n = 25). Plantar pressures were measured running at 3.3 m/s, using the FootScan pressure platform. Peak pressure (N/cm^2), time of peak pressure (ms), and load ratio (pressure/time, $N/cm^2 \cdot s$) were determined in ten zones of the foot.

Results: The results showed the greatest peak pressures under the first (BPC = 14.7 N/cm^2, RPC = 10.7 N/cm^2, GPC = 7.9 N/cm^2; p = 0.003) and second metatarsals (BPC = 16.8 N/cm^2, RPC = 14.8 N/cm^2, GPC = 10.3 N/cm^2; p = 0.008). Also, there were significant differences in load ratio for the first metatarsal (BPC = 0.31 $N/cm^2 \cdot s$, RPC = 0.23 $N/cm^2 \cdot s$, and GPC = 0.18 $N/cm^2 \cdot s$; p = 0.049).

Conclusions: Dynamic pelvic instability leads to greater pressures and load ratios in the medial area of the forefoot (first and second metatarsals), wich is usually related to pronation on the foot.

Palabras clave:

Estabilidad, pelvis, presiones plantares, pronación, glúteo.

Resumen

Introducción: La pelvis juega un papel importante durante la carrera, siendo la clave en la correcta distribución de la carga entre las dos extremidades y manteniendo la estabilidad y el alineamiento entre las extremidades inferiores y el tronco. Sin embargo, poco se conoce sobre la relación de una pobre estabilidad pélvica en el segmento inferior distal (pie). Por ello, el objetivo de este estudio fue valorar si hay una relación entre la inestabilidad dinámica de la pelvis con una alteración de las presiones plantares.

Pacientes y métodos: En una muestra de 47 corredores sanos, se realizó el Single Leg Squat Test y fueron grabados en vídeo corriendo, siendo evaluados por un comité de cinco expertos. Se realizaron tres grupos: a) mal control pélvico (MPC) (n = 8); b) buen control pélvico (BCP) (n = 25); y c) control pélvico regular (RCP) (n = 14). Las presiones plantares se tomaron a 3.3 m/s con la plataforma de presiones FootScan. El pico de presión (N/cm^2), tiempo de máxima presión (ms) y ratio de carga ($N/cm^2/s$) fueron valorados en 10 regiones de interés.

Resultados: Los resultados obtenidos fueron máxima presión en primera (MCP = 14.7 N/cm^2, RCP = 10.7 N/cm^2, BCP = 7.9 N/cm^2; p = 0.003) y segunda cabeza metatarsal (MCP = 16.8 N/cm^2, RCP = 14.8 N/cm^2 y BCP = 10.3 N/cm^2, p = 0.008). También el ratio de carga (presión/tiempo) mostró diferencias significativas en la primera cabeza metatarsal (BCP = 0.31 $N/cm^2/s$, RCP = 0.23 $N/cm^2/s$ y BCP= 0.18 $N/cm^2/s$; p = 0.04).

Conclusiones: La inestabilidad dinámica de la pelvis produce mayor presión y ratio de carga en la región medial del antepié (primera y segunda cabeza metatarsal), lo que está normalmente relacionado con una mayor pronación del pie.

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INTRODUCTION

The pelvis plays an important role during running by distributing the loads between the two legs as well as maintaining leg/trunk stability and alignment[1-3]. Pelvic instability can occur for various reasons: malalignment[4], strength deficits in (a) hip abduction muscles[5], (b) core[6], (c) hip flexors-extensors[7], and (d) external hip rotators[8], or (e) inefficiency in neuromuscular control[9], especially in the hip abductors[10]. This instability can lead to compensation, as in the case of "pelvic drop"[11], which is usually produced by alteration of the hip abductor musculature, and is accompanied by a hip adduction[12] with or without internal rotation of the femur[13]. In this sense, the greater the pelvic drop, the greater the loading of the medial compartment of the knee[14]. Poor dynamic stabilization of the pelvis may be provoked by other muscle groups, such as the hip external rotators[14], thus triggering dynamic knee valgus[15] which is a medial adduction of the knee in the body's frontal plane, and internal rotation[16] in the horizontal plane with internal or external rotation of the tibia[17]. This pelvic instability is associated with such pathologies of the knee[18] as patellofemoral syndrome[19] and iliotibial band, with mechanisms of injury of the knee's anterior cruciate ligament[20], and with ankle sprains[21] and Achilles tendinopathy[22].

The "single leg squat" is a reliable and reproducible clinical test[23] that helps to locate patients who have dynamic instability of the pelvis and dynamic knee valgus[24]. Due to the influence of dynamic instability in distal joints such as the knee or the ankle, there may be alteration of certain kinetic or kinematic variables in a pelvic-drop positive population. The objective of the present study was therefore to see whether the plantar pressure pattern is altered in runners who have different degrees of pelvic control.

PATIENTS AND METHODS

Characteristics of the sample

The sample comprised 47 participants, all men, mean age 27.8 ± 9.9 years, mean height 1.7 ± 0.07 m, mean weight 75.2 ± 9.1 kg, and mean BMI 23.7 ± 2.4 kg/m². Inclusion criteria included runners capable 1) to perform a minimum of 3 training sessions per week and 2) run at minimum pace of 12 km/h. The runners of the sample were practicing running 3 times a week for at least 2 years. The two exclusion criteria were a lower limb injury during the past 6 months, and lower limb surgery in the preceding 3 years.

All the subjects gave their written consent before participating in the tests. The study was conducted in accordance with international ethical standards and approved by the university's ethics committee (Id: UEX 100/2015).

Test conditions and experimental design

The runners were classified into three groups on the basis of their performance of three attempts at the single-leg squat test (Figure 1a). These attempts were video-recorded (Gopro hero 3 black edition, 720p and 120fps) at 3 metres distance and with focus on the pelvis. The test was performed with the arms crossed over the chest, bending the knee at 60° and descending for 2 seconds, performing 5 repetitions without the contralateral foot touching the ground[25]. The videos were analysed by a group of 5 experts (2 in podiatry, 2 in physiotherapy, and 1 in sports science). The experts used a scoring questionnaire (Table I) to classify each runner into three groups; 1- good (Figure 1b), 2- regular, and 3- bad pelvic stabilization (Figure 1c), replicating the procedure used by Crossley et al.[25]. For the good pelvic control group (GPC, Figures 1b and 2a), 0 or 1 poor item scores were allowed (Table I), 2 or 3 poor items for the regular pelvic control group (RPC), and 4 or 5 poor items meant assignment to the bad pelvic control group (BPC, Figures 1c and 2b).

Baropodometry

All the runners performed the dynamic tests with their own sports shoes[26-30]. The test was carried out at a speed of

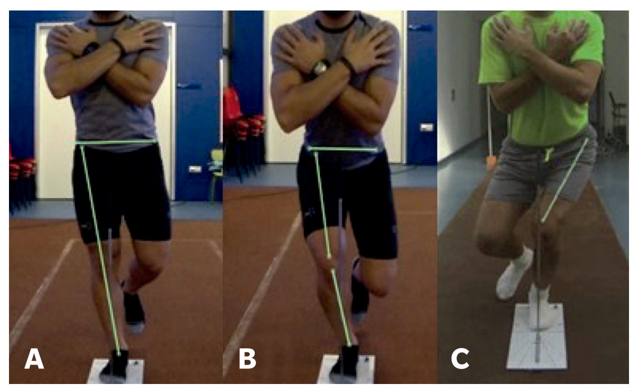

Figure 1. A. Pre-test Single Leg Squat (SLS). B. Good Pelvic Control. C. Bad Pelvic Control.

Figure 2. Single Leg Squat (SLS) with compensatory inclination of the trunk. A. Good Pelvic Control. B. Bad Pelvic Control.

Table I. Modified evaluation questionnaire for the single leg squat.

Single-leg-squat evaluation questionnaire	
Overall impression of the 5 repetitions	One poorly scored item is allowed for good control
Ability to maintain balance Movements of the person Squat depth Squat speed	
Trunk posture	One poorly scored item is allowed for good control
Lateral displacement or deviation of the trunk Trunk rotation Lateral trunk flexion Anterior trunk flexion (Figure 2)	
Pelvic position	One poorly scored item is allowed for good control
Pelvic wobble or lateral deviation Pelvic rotation Pelvic tilt	
Hip joint	No poorly scored item is allowed
Hip adduction Femoral internal rotation	
Knee and foot articulation	No poorly scored item is allowed
Evident knee valgus Knee position relative to the foot	

12 km/h (3.3 m/s) along a 50-metre analysis corridor. The pressure platform (Footscan®, Rsscan International, Olen, Belgium) and the photocells were placed halfway along this corridor (Chronojump Boscosystems®, Spain). A tolerance of 3.3 m/s ± 10 % was established for the baropodometry data to be taken as valid. Finally, 3 valid steps were analysed for each foot, using the software Footscan 7.97, dividing the image into 10 regions of interest (medial heel, lateral heel, midfoot, 1st, 2nd, 3rd, 4th, and 5th metatarsal heads –MTH-, hallux, and lesser toes). Footscan® platform that has shown good reliability[31]. The following variables were determined (each being the mean of the respective measurements corresponding to the three valid steps): peak pressure (N/cm²), time of peak pressure (ms), and load ratio (N/cm²·s).

Statistical analysis

In order to maintain the independence of the data[32] for the statistical tests, only one foot of each one (selected at random, 25 right, 22 left) were considered. The statistical analysis was carried out using the SPSS program package (SPSS Inc., Chicago, IL, USA, campus license UEX v 19.0). To establish the relationship between the plantar pressure values with each of the 3 groups (good, regular, and bad control), the following statistical tests were performed: (a) t-test for independent samples to determine the pressures between the right and left feet; (b) analysis of variance (ANOVA) inter- and intra-group for the 3 groups; and (c) Tukey post-hoc test in cases where there was significance of the variance. The results are presented as mean ± standard deviation (SD), and the statistical significance level was set at $p < 0.05$.

RESULTS

In the overall sample of runners, the maximum pressure (Table II) was under the second metatarsal head (12.7 N/cm²), followed by the third metatarsal head (10.6 N/cm²).

The analysis of variance (ANOVA) indicated that there were significant differences between the three groups of runners

Table II. Descriptive analysis of plantar pressure distribution.

Zone	Peak pressure (N/cm²)
Medial heel	6.9
Lateral heel	6.8
Midfoot	6.1
MTH1	9.7
MTH2	12.7
MTH3	10.6
MTH4	9.1
MTH5	6.0
Hallux	7.6
Lesser toes	4.9

Table III. ANOVA Tukey's post-hoc test, Peak Pressure at *1st and 2nd metatarsal heads (MTH)*.

	1st MTH N/cm²	2nd MTH N/cm²
Good (n = 25)	7.9	10.3
Regular (n = 14)	10.7	14.8
Bad (n = 8)	14.7	16.8
p	0.003	0.008

Table IV. ANOVA Tukey's post-hoc test, load ratio of the 1st MTH.

	Load Ratio 1s MTH N/cm²·s
Good (n = 25)	0.18
Regular (n = 14)	0.23
Bad (n = 8)	0.31
p	0.049

(good, regular, and bad control) in the plantar pressures under the first and second metatarsal heads ($p = 0.003$ and $p = 0.008$, respectively). The rest of the zones did not present any differences between the three groups ($p > 0.05$ in all cases). Tukey's post-hoc test showed that there were differences in peak pressure between the good and bad single leg squat groups under 1st MTH ($p = 0.003$) and 2nd MTH ($p = 0.008$). The mean pressure for Group 1 (good) under 1st MTH was 7.9 N/cm², while for the bad group it was 14.7 N/cm². Under 2nd MTH, the good group pressure was 10.3 N/cm², while for the bad group it was 16.8 N/cm², $p = 0.008$ (Table III).

The ANOVA showed that there were significant differences among the three groups of runners for the load ratio corresponding to the first metatarsal ($p = 0.049$). Tukey's post-hoc test showed that these differences for the first metatarsal were between the good and the bad single leg squat groups, being the mean 1st MTH load ratio for Group 1 (good) was 0.18 N/cm²·s, and for Group 3 (bad) was 0.31 N/cm²·s (Table IV).

The ANOVA did not show any significant differences in the time of peak pressure between the three groups of runners ($p > 0.05$ in all cases).

DISCUSSION

At the plantar level, the foot is the union between the ground and the rest of the body in the support phase of gait. Therefore, any alteration at the proximal level, such as pelvic instability, could impact the pattern of plantar pressures.

During running, the peak pressures were located under the 2nd metatarsal, followed by the 3rd, 1st, and the hallux (Table II) in that order. These results are similar to those found in the literature, where greater pressure is also reported in 2nd MTH and 3rd MTH than in 1st MTH, in addition to following the same order[31,33,34].

Bryant et al.[35] analysed the same baropodometric variables as we did, but barefoot and walking, founding their peak pressure results are greater than ours possible due to the different pressure platform used (EMED system). Their results showed that it is the second metatarsal that supports the greatest peak pressure. Also, the peak pressure difference they found between 1st MTH and 2nd MTH (1st 29 N/cm²; 2nd MTH: 42 N/cm²) is much greater than in our study (1st 9.7 N/cm²; 2nd 12.7 N/cm²), which may be a reflection of a greater load on the first metatarsal in our case.

When a runner presents some pelvic instability, there is a significant increase in pressure on the first and second metatarsals of the right foot. Thus, the greater the difference between good and poor pelvic control in running, the greater the difference in plantar pressures in the medial column of the foot (first and second metatarsals). Greater pressures under the first and second metatarsals are usually associated with a medialization of the subtalar joint axis due to adduction, anteriorization, and plantar flexion of the talus[36]. A consequence is sagging of the foot's internal longitudinal arch and a greater load on the medial zone of the forefoot (greater reactive forces from the ground on 1st MTH and 2nd MTH)[37].

As well as finding increased pressure in the medial zone of the forefoot in runners who developed lesions, Stacoff et al.[37] also analysed pronation excursion in 3D. They found that this was greater in feet with greater medial forefoot plantar pressure. This supports our hypothesis that the greater pressure on 1st MTH and 2nd MTH in the greatest pelvic instability group is associated with alterations in the entire kinetic chain, and that its final link, the pronation of the foot, leads to medialization of the subtalar axis, thereby increasing the loads on the medial column of the forefoot. In this study, the runners were shod, and the plantar pressures were not separated by points but into broader zones (medial, central, and lateral forefoot).

The greater 1st MTH and 2nd MTH pressures in the bad dynamic pelvic control group might be a predisposing factor for overuse injuries[37,38] although there is very little literature on the issue, and a particular lack of homogeneity in the methods and variables used[39].

Plantar pressures have also been used to try to find injuries related to running. However, no clear pattern has been identified relating plantar pressures with actual injuries. This may be because the variables analysed might not have been the most appropriate. A prospective study by Rice et al.[38] provided evidence that a more medial concentration of plantar pressures may be a risk factor for injury in runners. It also found greater peak pressures under 1st MTH and a more medial loading (1st MTH-2nd MTH) in the group that developed an injury.

In our study the dominant foot of the participants was not recorded, and could be a little bias of the results. In their review, Sadeghi et al.[40] analysed this selective alteration of kinematic values. They reported that the foot of the dominant leg is used for manipulative actions such as kicking a ball, and the foot of the non-dominant leg for stabilization and maintenance of posture. Niu et al.[41] describe the dominant ankle as being at greater risk of injury than the non-dominant ankle since they found greater peaks in angular velocity and a reduction in the electromyography of the ankle flexors. In support of this theory, Knight & Weimar[42] also concluded that the non-dominant leg functions more efficiently than the dominant leg during posture and stabilization tasks, affording better protection against ankle injuries. This greater involvement of the dominant foot could explain some of the pathologies that occur unilaterally, such as ankle sprains[41-43].

Another hypothesis is that the body tends to compensate any alteration in stability or alignment occurring in the pelvis and lower limb in the dominant leg, and this, through the neuromuscular system, will lead to muscular adjustments that will change, among other factors, articular rigidity[44,45]. Also, there are frequently asymmetries in walking and running[46-48], and the performance of the preferred limb may differ from that of the contralateral limb[49].

The main limitation to extrapolate results of this study is that the type of foot (i.e with the foot posture measurement) was not assessed. It is possible that intrinsic factors of the foot could also contribute to these distribution of plantar pressures, such as a pronated or valgus foot.

In conclusion, when a runner manifests some form of dynamic pelvic instability, there occur changes in lower limb kinetics that lead to a greater load on 1st MTH and 2nd MTH. Data on this issue may be useful for the prevention or treatment of foot injuries.

CONFLICT OF INTERESTS

Authors do not have any conflict of interests regarding the present study.

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