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Effects of Running Intensity on Forefoot Plantar Pressure Elevation

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Abstract

Running had been known producing a posterior muscle tightness in lower extremity, particularly calf muscles, resulting in a relative equinus deformity. Numerous study reported the association between equinus deformity and foot pain, partially due to the increased plantar pressure of forefoot. This study was directed to find a relation between running intensity and increased forefoot plantar pressure. Subjects were divided into two groups according to running intensity as classified as runner or non-runner. Forefoot plantar pressures data were obtained using a foot imprinter and analyzed into numerical values. Ankle maximum dorsiflexion was also examined in an extended knee to detect the calf tightness. Mean forefoot plantar pressure value was Grau 2.89 (range 2-4) in runner group, and Grau 2.15 (range 1-4) in non-runner group (p=0.004). Ankle maximum dorsiflexion was also limited in runner group (16.05±1.98°) compared with 19.30±1.38° in non-runner group (p<0.001). There was an association found between running intensity and plantar pressure elevation. Considering the potential damaging effects to the foot, it is recommended for runners or treating physician to look into this problem as well as to make sure that regular calf stretching is advocated.

Keywords: *equinus, forefoot, plantar pressure, runner*

Introduction

Running became more and more popular recently, and has proven benefits for health. It is easy to perform, relatively inexpensive, and has a social component (Ooms, Veenhof, & de Bakker, 2013; Junior, Pillay, Mechelen, & Verhagen, 2015). In the face of these benefits, running-related musculoskeletal problems are common among runners (Lopes, Junior, Yeung, & Costa, 2012; Kakouris, Yener, & Fong, 2021). Although acute injuries are common, a majority of running injuries can be classified as cumulative micro-trauma injuries and several identifiable factors may predict who is at risk (Ferber, Hreljac, & Kendall, 2009).

Wang et al had concluded that long distance runners appear to have posterior muscle tightness in the lower extremity (Wang, Whitney, Burdett, & Janosky, 1993). Compared with regular walking activity, the average values of gastrocnemius heads were higher during running or jogging in treadmill test (Tsuji, Ishida, Oba, Ueki, & Fujihashi, 2015). It is also known that force exerted on the Achilles tendon during running may exceeds 12-fold the weight of the runner (Hreljac, 1995). Various pathophysiology has been associated to the increased calf muscle tightness in people doing exercise regularly. Equinus deformity, in which the ankle joint dorsiflexion is decreased, one at a time has been thought to be one of the source of excessive strain throughout the foot, thus causing pain (Maskill, Bohay, & Anderson, 2010).

Metatarsalgia is one of the common causes of plantar foot pain that related to gastrocnemius muscle contracture that overload the foot (Cortina, Morris, & Vopat, 2018). Numerous study had reported the association between equinus deformity and foot pain, or between running activity and lower limb musculoskeletal alterations (Van Gils & Roeder, 2002; Amis, 2016; van Oeveren, de Ruiter, Beek, & van Dieen, 2021).

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However, there were prior studies focused on forefoot plantar pressure analysis related to running intensity. This study was directed to find a relation between running activity and increased forefoot plantar pressure as a compensatory result to give additional insight for diagnosis and treatment algorithm.

Material and methods

This was a cross sectional study comprised of thirty-nine subjects aged between eighteen years old to forty-five years old, aiming to compare the plantar pressure distribution between two groups with different running intensity.

Participants

Group 1 consisted of nineteen subjects who had running habit minimum three times a week, not less than three kilometers on each occasion, continuously for at least one year prior to the data collection. This criteria was based on a definition of runner introduced by Clement et al (Clement, Taunton, Smart, & McNicol, 1981). Group 2 consisted of twenty healthy active subjects with no regular running habit, or maximum frequency one occasion per week. Mean age of Group 1 was 26.52±5.12 years old and Group 2 was 29.65±6.08 years old. Sex was not equally distributed (thirteen male and six female subjects in Group 1; fourteen male and six female subjects in Group 2) as seen in Table 1.

Exclusion criteria were as follows: (1) any fixed foot deformity such as pes planovalgus or cavovarus, (2) history of having any significant scar wound or surgical wound on ankle and foot region, (3) known comorbidity that affected musculotendineous contractility such as diabetes or inflammatory arthritis. This study was approved and registered by Universitas Padjadjaran Institutional Review Board No. 650/UN6.KEP/EC/2022 before commenced.

Measurements

Plantar pressure data were obtained at the subjects' running field or workplace (Fig.1), utilizing a Harris Mat foot imprinter, Podiascan scanner and converter software (Diabetik Foot Care Pvt Ltd, Tamil Nadu, India). Footprint were taken from dominant foot from a stance phase of a pace, on natural stride length and comfortable speed. Pressure load of forefoot areas particularly first and second metatarsal head region was classified according to numerical values based on the study by Silvino, Evanski, and Waugh as shown in figure 2 (Cisneros, Fonseca, & Abreu, 2010; Silvino, Evanski, & Waugh, 1980). The highest values of forefoot area plantar pressure from each subject were collected and agreed by two examiners, as illustrated in figure 3. All subjects were also examined for ankle joint maximum dorsiflexion measured by a goniometer, with and without knee flexed.

FIGURE 1. Footprint taking using Harris Mat.

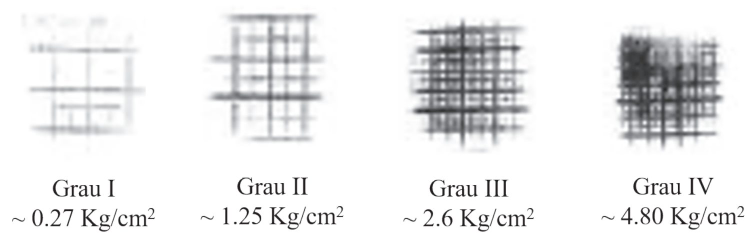

FIGURE 2. Plantar pressure patterns classification based on study by Silvino, Evanski, and Waugh.

Statistics

Data were documented and statistically analyzed to indicate the differences between two independent groups by Mann Whitney U test (Table 1) using IBM SPSS Statistics for Windows, Version 28.0 (Armonk, NY: IBM Corp) software. $P<0.005$ was considered significant.

Results

Mean forefoot plantar pressure value was Grau 2.89 (range 2-4) in group 1 and 2.15 (range 1-4) in group 2. Mean ankle joint maximum dorsiflexion in group 1 was 16.05 ± 1.98^0 (range 14^0-22^0) in flexed knee and 12.73 ± 1.32^0 (range 10^0-15^0) in extended knee, while in group 2 was 19.30 ± 1.38^0 (range 17^0-

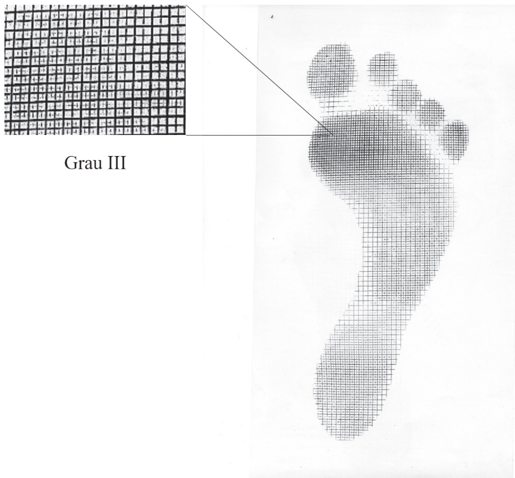

FIGURE 3. Illustration of a footprint depicting Grau 3.

22⁰) in flexed knee and 15.8±1.38⁰ (range 13⁰-18⁰) in extended knee. There was significant difference between groups obtained from Mann Whitney U test in terms of forefoot plantar pressure mean (p=0.004) and ankle maximum dorsiflexion mean (p<0.001), while ankle maximum dorsiflexion in flexed knee was not significantly different between two groups (p=0.977).

Table 1. Comparative results between groups.

	Group 1	Group 2	p-value
Age (years)	26.52±5.12	29.65±6.08	
Sex (n)			
Male	13	14	
Female	9	6	
Forefoot plantar pressure mean (Grau)	2.89	2.15	0.004
Ankle maximum dorsiflexion mean (degree)			
With knee flexed	16.05±1.98	19.30±1.38	0.977
With knee extended	12.73±1.32	15.8±1.38	<0.001

Discussion

Foot pain during walking is associated with high plantar pressures generated during gait (Mickle, Munro, Lord, Menz, & Steele, 2010). The results of this study was in concordance with prior studies noticing higher peak plantar pressures in people with equinus foot more than those without the deformity (Lavery, Armstrong, Boulton, & Diabetex Research Group, 2002) as well as the association between running exercise and calf hypertrophy (Ozaki, Loenneke, Thiebaud, Stager, & Abe, 2013; van Oeveren et al., 2021). Equinus deformity was stated if the ankle dorsiflexion was less than 10⁰ with the knee flexed that it may occur from bony deformity or from soft tissue contracture, particularly triceps surae muscles or Achilles tendon. Tendon imbalance between bulky posterior muscles and thinner anterior side musculatures in lower leg may result in relative equinus, which in turn will increased stress in forefoot. More than merely pain, ankle equinus contributes to many other foot problems, such as deformities and ulceration. Inadequate ankle dorsiflexion requires compensation within the foot which requires subtalar joint and midtarsal joint to be altered. These abnormal compensatory motion will result in further damage as well (Van Gils & Roeder, 2002).

It is understood that long period of physical exercise such as walking or running can increase leg muscle size even though the investigation of its effect on muscle morphology is still controversial. This study showed that the plantar pressure was significantly higher in runners (Group 1) compared with non regular runners. Particularly, this was attributable to tight calf muscles that decrease the excursion resulted in increased forefoot pressure. Running, walking, and hiking are known as excellent calf-strengthening exercises, especially in inclinations (Ozaki et al., 2013; Chang, Li, Wang, & Zhang, 2020; van Oeveren et al., 2021). Acceleration or agility training in sports that include run, jump, and push off will be beneficial too for toning the calf muscles. Evaluation of maximum ankle joint dorsiflexion between groups presented different comparison regarding whether the knee joint was flexed or extended. Mean of ankle joint range of motion was significantly different with knee extended, but not in flexion. This examination adapted the Silfverskiold test that used to identify isolated gastrocnemius contracture. It was noticeable that the different plantar pressure values between groups was due to gastrocnemius contracture and not Achilles tendon, while bony deformity as a possible cause had been excluded from initial subject selection. This finding confirmed that the limited ankle joint motion was attributable to calf muscle hypertrophy. However, the Achilles tendinopathy as one of the viable sources of contracture was not ruled out at this point.

Non-neuromuscular isolated gastrocnemius contracture deformity among healthy individuals is often subtle or silent. There is a theory namely the split second effect that describing a critical time span during terminal midstance, where damaging forces are produced along the whole tension chain, that explained why a silent equinus contracture can gradually cause significant harm when left untreated (Amis, 2016). Routine gastrocnemius stretching is advisable for athletes. Prior studies reported a significant higher ankle dorsiflexion flexibility measurements in athletes undergoing routine gastrocnemius stretching compared with control group (Macklin, Healy, & Chockalingam, 2011; Knapik, La Tulip, Salata, Voos, & Liu, 2019). The training regiments included keeping the knee of the stretched leg straight with the heel flat on the ground while bending the front knee and pushing the hips toward a wall. This exercise was held for 10 seconds, repeated 20 times 3 times daily (Knapik et al., 2019). Different result was reported by Searle et al, noticing no meaningful effect of static calf muscle stretching on ankle range of motion, or plantar pressure, in people with diabetes and ankle equinus (Searle, Spink, Oldmeadow, Chiu, & Chuter, 2019).

This study has three main limitations. The most obvious limitation was the design and the sample size. A randomized study involving more cases is necessary to verify the validity of this result. Second limitation is multiple confounding factors that may contribute to the contracture development, such as vascular status, blood glucose level, and smoking habit were not objectively analyzed. Third, the subjects were not categorized according to running types. In fact, calf muscle exercise will be different among sprint, endurance, or recreational running. However, this study may provide framework to define the diagnostic and treatment algorithm regarding foot problems in runners.

Conclusion

There was an association found between running intensity and plantar pressure elevation. This is attributable to the gastrocnemius tightness resulted from long time exercise particularly on calf muscles. Other than metatarsalgia due to increased forefoot pressure, this condition may be harmful to other parts of the foot as well. Isolated gastrocnemius contracture, even though asymptomatic, must be addressed to prevent further damage. It is recommended for runners or treating physician to look into this problem and to make sure that regular calf stretching is advocated.

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Conflict of Interest
The author declares that there is no conflict of interest.

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