DR. MARIE-LYNE NAULT (Orcid ID : 0000-0002-8024-0527)

Article type : Original Article

Plantar pressure analysis: identifying risk of foot and ankle injury in soccer players

Presented by:

Anne-Laure Ménard[1,2,3], anne-laure.menard@polymtl.ca

Mickaël Begon[1,2], mickaelbegon@gmail.com

Justin Barrette [1], jbarrette2@bell.net

Benjamin Green[1], benjamin.green@umontreal.ca

Laurent Ballaz[2,4], laurent.ballaz@gmail.com

Marie-Lyne Nault[1,2] timinet@hotmail.com

1. Université de Montréal, 2900 boul. Edouard-Montpetit, Montréal, QC, Canada, H3T 1J4
2. CHU Sainte-Justine, 7905-3175 Côte Ste-Catherine, Montréal, QC. Canada, H3T 1C
3. Hopital du Sacré-Cœur de Montreal, 5400 boul. Gouin O., Montreal, QC, Canada, H4J 1C5
4. Department of Physical Activity Sciences, UQAM, Montréal, Canada, H2L 2C4

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1002/TSM2.253

Corresponding author

Marie-Lyne Nault, CHU Sainte-Justine, 7905-3175 Côte Ste-Catherine, Montréal, QC. Canada, H3T 1C5. Tel: 514-345-6672. E-mail: timinet@hotmail,com

Conflict of interest statement: The authors do not have any conflict of interest related to this work.

Ethics committee approval: CHU Sainte-Justine CER #2019-1980

Data availability statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Abstract

Introduction: The aim of this study was to determine if risk factors for foot or ankle injuries could be identified using quantitative foot measurements.

Methods: Male and female soccer players of all levels, from 9 to 40 years old were included in this cross-sectional study. Soccer history, foot and ankle function and injury history were investigated. Foot symmetry, length and arch height flexibility and plantar pressure captured with a mat were measured. All variables showing a significant correlation ($p \leq 0.05$) and the presence of at least one foot or ankle injury, were integrated into a multivariate logistic regression model using forward stepwise selection.

Results: We recruited 277 players (196 males) and 79 participants had sustained at least one foot or ankle soccer-related injury. The significant variables were: age, gender, pressure on the lateral heel and on the fourth and fifth metatarsals. Based on the model, the area under the ROC curve was 81.2%. To achieve a specificity of 80%, the corresponding sensitivity was 72.2%.

Conclusions: Plantar pressure measurements can objectively assess foot alignment. Increased pressure on the lateral heel and fourth and fifth metatarsal cavovarus foot type, represent a risk factor for foot and ankle injuries in soccer.

Level of evidence: IV

Keywords: Cavovarus foot; cavus foot; soccer; foot or ankle injury; injury prevention; plantar pressure**.**

Introduction

Soccer injuries are common in both the recreational and competitive settings, resulting in a high socioeconomic impact that can exceed US$30 billion per year[1,2]. Ankles and feet are among the most common sites for injury in soccer players[1], with ankle sprains making up 76-80% of all soccer foot/ankle injuries. The injury mechanism is an abrupt inversion/supination motion with the foot in plantarflexion in 85% of cases[1].

In order to prevent these foot and ankle injuries, it is important to identify the related risk factors[1,3]. Increased age[1,4], being female[2,5], having less experience with greater skill[6], playing level[5] and the number of previous ankle injuries[1,7,8] have been highlighted as intrinsic risk factors. Foot type is another intrinsic risk factor, but its direct involvement remains unclear, mainly because foot deformity is often measured subjectively and its severity varies from one study to another[7,9]. The cavovarus foot, one of the most frequent types of foot deformity, is defined by a high medial longitudinal arch, usually accompanied with a hindfoot varus[10-12]. The cavovarus foot type, even in its subtle form, increases the load on the lateral side of the foot, resulting in an increased risk of inversion injury. These individuals are prone to lateral ankle sprains and eventually chronic lateral ankle instability[13]. Although the gold standard to diagnose cavovarus foot has not been determined, it is generally accepted that plantar pressure measurements during static standing can objectively identify a cavovarus foot type[10]. People with pes cavus foot have a higher pressure-time integral and peak pressure in the lateral forefoot and rearfoot regions, along with decreased midfoot loading[10,14] On the lateral side of a cavovarus foot, most of the pressure will be located and excessive under the lateral calcaneus, as well as the fourth and fifth metatarsal bones[15,16].

Soccer players are of particular interest as they have a higher prevalence of cavovarus foot compared to other athletes[17] and are also at high risk of lateral ankle sprains[18]. Current foot evaluation methods, such as the simplified foot posture index FPI-6[19], are reliable and regularly used in clinical practice[14,21]. However, FPI-6 categories are too broad to detect differences within similar categories. Studies have shown that specific foot types, namely flat, normal and cavus arched feet defined by FPI-6 scores, display typical plantar pressure patterns[14,15]. Thus, quantitative pressures provide objective and sensitive measures of foot pressure distribution that are related to foot type. Within this framework, various pressure-sensing systems to assess injury risk in soccer players can be used: pressure mat technology an EMED-AT platform for dynamic pressure evaluation[21] or a plate type Twin Gravicoder with a MD-1000 device [22,23]. Azevedo et al. found plantar pressure asymmetries, with increased pressure on the hallux and fifth metatarsal and reduced pressure on the medial rearfoot of the non-preferred leg, in a cohort of young soccer players compared to their control non-athlete counterparts[22]. These findings concur with reported injury sites among soccer players[22]. Conversely, both Matsuda et al. and Hetsroni et al. did not find significant plantar pressure differences between players with and without a history of fifth metatarsal stress fractures[21,23]. However, both studies only looked into one specific soccer-related injury and little information was known about the injury mechanism.

Our hypothesis was that plantar pressure measurements could help predict the risk of foot and ankle injury in soccer players. The primary aim of this cross-sectional cohort study was to identify measurable and modifiable risk factors for foot and ankle injury in soccer.

Material and methods

Cross-sectional study participants

Male and female soccer players from amateur to semi-professional levels were recruited. Inclusion criteria were soccer players aged between 9 to 40 years old at the time of data collection. Young soccer players were voluntarily included to provide a baseline for foot types. Exclusion criteria consisted of congenital foot deformities (e.g. clubfoot) and active injury three months prior and during data collection. The Institutional Ethics committee approved this study and all participants and their parents, when participants were under 18 years old, provided written consent.

Data collection

Data was collected from June to September 2019 in a dozen soccer clubs and academies to recruit players of varying ages and levels. Subjects completed a soccer-related questionnaire, which included previous injuries (side, year of injury) and soccer history (number of years of practice, highest level played). Memory bias was assumed to affect all players and thus not significantly impair nor change the conclusions drawn from our results. Soccer levels were divided into six categories from beginner to professional, as follows: 1- beginner, 2- A, 3- AA, 4- AAA, 5- semi-professional and 6- professional. Body mass and foot length were measured. Arch height flexibility was calculated as the difference between standing and sitting heights measured with a caliper at the midfoot, normalized to body mass[24].

Plantar pressure measurements

A pressure-sensing mat (MatScan™, Tekscan®, Boston, MA, USA) was used to measure the participants' plantar pressure distribution under both feet, as described in the study by Azevedo et al.[22]. Subjects were asked to stand still on the mat with their head straight for 10 seconds while distributing their body mass equally on each foot, this was assessed visually, while their foot pressure was recorded.

Pressure data analysis

The foot was divided into 12 areas corresponding to specific anatomical landmarks. The heel was split into medial and lateral zones. One zone was defined for the midfoot, five zones were located under each metatarsal bone, and four zones for the toes, fourth and fifth toes being grouped together. All pressure values were reported in kPa and expressed as percentages of the total foot pressure to compare distribution patterns.

Sample size

Participant recruitment was estimated at 280 based on the data collection period, soccer team availability and the number of players in each team. Injury prevalence calculated from our data was 28.5%. With a ratio of one to ten between an explanatory variable and data from an injured soccer player, the predictive logistic regression model could include up to eight variables.

Statistical analyses

The participants' descriptive statistics consisted of gender, age, body mass, and highest level played. Foot-related data included foot length, arch height flexibility and plantar pressure under each zone of the foot. Nominal variables were expressed as percentages and continuous variables as mean and standard deviation. Sociodemographic characteristics associated with injury were assessed using univariate odds ratios and 95% confidence intervals.

For each variable, T-tests for paired data were computed to evaluate if there was a significant difference between feet. Upon lack of significance, the right foot was selected[25].

Univariate logistic regressions were performed for each pre-selected candidate variable separately and odds ratios reported along with 95% confidence intervals and p-values.

All variables with a $p \leq 0.05$ were included into a multivariate logistic regression model with forward stepwise selection based on the likelihood ratio. Three variables were retained in the model: age, gender and fourth metatarsal pressure. For clinical purposes, lateral heel and fifth metatarsal pressures were added to the model. The ROC curve based on the predicted probability of injury was produced. The area under the curve as well as the 95% confidence interval were reported. A sensitivity corresponding to a specificity of 80% was reported, along with their respective 95% confidence intervals. Data was analyzed using IBM SPSS Statistics version 25 (IBM Corp., Armonk, N.Y., USA) at a significance level of 0.05.

Results

Sample description

The cohort included a total of 277 participants, of which 196 were males, with 97 players having reached a more advanced level (AAA or higher) (Table 1). Age distribution was bimodal, ranging from 9 to 40 years of age and highly correlated with both body mass (Spearman correlation of 0.846) and foot length (Spearman correlation of 0.735). In the cohort, 79 players (28.5%) sustained at least one soccer-related foot and ankle injury (Table 1).

Plantar pressure values

Players with a history of injury had significantly higher plantar pressure values on their ipsilateral heel, their second, third, fourth and fifth metatarsals, as well as on their second and third toes (Table 2).

Logistic regression model

In the final multivariate logistic regression model, gender and age were highly correlated to injury (Table 3). Females were found to be 3.2 times more at risk of injury compared to males, taken as the reference category. Age was also associated with an increased risk of injury, up by 1.14 per added year, equivalent to a 1.93 times greater injury risk over 5-years. The only significant pressure variable was pressure under the fourth metatarsal, while lateral heel pressure and fifth metatarsal pressure did not show any significant correlation. The logistic regression model had an area under the curve of 81.2% with 95% confidence interval (lower and upper boundaries of 75.4% and 87.1% respectively). Finally, the ROC curve showed that in order to meet the specificity criteria of 80.3% ($CI_{95\%}$ = [73.9 – 85.5]), a sensitivity of 72.2% ($CI_{95\%}$ = [60.8 – 81.4]) was reached (Figure 1).

Discussion

This cross-sectional study compared never injured soccer players, with soccer players who sustained at least one foot and ankle injury. Our cohort of soccer players included young children and adults of different ages and levels, ranging from beginner to professional. A logistic regression model was built with gender, age, plantar pressure of the lateral heel, and the fourth and fifth metatarsals, and reached over 70% sensitivity for a specificity of at least 80%. Specificity was given priority over sensitivity to better target prevention interventions for players at higher risk of injury.

Non-modifiable risk factors (gender and age) included in the logistic regression model

Known risk factors for foot and ankle injuries in this study were female gender and increased age, in agreement with previously conducted research[1,2,4,5]. Faude et al.[4] found that the incidence of game injuries increased with age among children and adolescent soccer players and that those aged 17-19 had injury rates similar to adult players[4]. This can be explained by the increased muscle tightness and decreased flexibility observed in older and more elite soccer players[3]. Wong and Hong[5] also report a higher injury rate in female players than in males, overall and during training. Professional players had a higher percentage of injury (number of injured players divided by total players) compared to adolescent players[5].

Increased plantar pressures on specific zones as risk factors for soccer injuries

Plantar pressure has already been used in studies with soccer players[22,23]. In Matsuda et al, no specific plantar pattern could be associated to injury but their cohort only included 29 injured players[23] (*versus* 79 in our cohort). However, Azevedo et al. (n = 15 non-injured soccer players)[22] found that plantar pressure asymmetries in young soccer players could explain the high incidence of fifth metatarsal fractures. Our study also identified an increased pressure on the fifth metatarsal bone as a risk factor. Interestingly, the increased plantar pressure zones that were significantly correlated to injuries were similar to those observed in the cavovarus foot type[14,15].

Plantar pressure analysis as a prevention tool

This study is clinically relevant because the quantitative foot evaluation described is made with a portable plantar pressure platform that can be used by soccer clubs or in clinical practice. Since it does not rely on the evaluator's experience, it is more objective than the gold standard FPI-6 to assess foot type. Instrumented, plantar pressure analysis is also more accurate in its ability to predict injury[22]. Training activity and younger age were associated with decreased postural stability, and a resulting increase in peak pressure. In another study, younger players were also found to have an asymmetrical plantar pressure distribution, likely due to decreased postural control[26]. These plantar pressure distribution asymmetries, or increased load in specific areas of the foot, could be detected and acted upon. In the long term, foot orthotics can be used in order to prevent foot and ankle injuries by correcting the alignment of the foot and bring about a more neutral distribution of plantar pressure.

Study limitations and future work

This study has some limitations. Firstly, this was a cross-sectional study, with a memory bias in terms of injury history and whether these injuries were soccer-related or the result of other sports activities. This bias might be more frequent in the younger, less experienced players who are less dedicated to soccer and tend to practice various other high intensity activities, leading to a greater risk of overload injuries. Furthermore, the area specifically affected, the type of injury and injury mechanism – to discriminate between contact and non-contact injuries – were not specified, as the authors focused on ankle and foot injuries. However, this study was exploratory and aimed to determine the potential of plantar pressure for the medical assessment and follow up of cavus feet to prevent soccer-related injuries. Consequently, we chose technology that was readily available and gathered information directly from soccer players. More information on injury mechanisms could be relevant in prospective studies where players keep track of their injuries. Another limitation was the static plantar pressure analysis; although a relevant first step, it does not entirely reflect the on-field behavior of foot loading characteristics during soccer. A dynamic plantar pressure analysis could be used in future studies to identify asymmetries, potential weaknesses and injury risk factors.

Conclusion

This study provided a logistic regression model to identify injury risk in soccer players based on age, gender and plantar pressure. More specifically, pressure on the lateral heel and the fourth and fifth metatarsals were identified as foot-ankle risk factors. Interestingly, this higher injury risk pressure pattern shares similar characteristics with the cavovarus foot type. Future studies are required to develop and test conservative preventive strategies such as orthoses.

Perspective

Soccer injuries are very common, and more than three quarters of soccer-related injuries affect the foot and ankle area. Moreover, soccer players are more likely to have a cavovarus foot type, which is characterized by increased pressure on the lateral part of the foot. This study is the first to propose a multivariate model to assess injury risk for soccer players based on quantitative plantar pressure. This model could be used in clinical practice to identify players potentially at risk of injury. Our results show that increased pressure on the lateral heel as well as on the fourth and fifth metatarsals are risk factors for foot and ankle injury in soccer. This is a first step towards a strategy to target soccer players at risk and to develop protocols or material for prevention.

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Figure legends

Figure 1 – ROC curve showing a sensitivity of 72.2% at a specificity of 80.3%. The value of the area under the curve (AUC) and its 95% confidence interval are also indicated.

Table 1 – Descriptive statistics

	All soccer players (n = 277)	**Healthy (n = 198)**	**Injured (n = 79)**	**Odds Ratios [95% CI]**
Gender: ***Male***	*196 (70.8%)*	*150 (75.8%)*	*46 (58.2%)*	2.30** [1.32 – 4.01]
Female	81 (29.2%)	48 (24.2%)	33 (41.8%)	
Level: ***below AA***	*180 (65.0%)*	*145 (73.2%)*	*35 (44.3%)*	0.29** [0.17 – 0.50]
over AAA	97 (35.0%)	53 (26.8%)	44 (55.7%)	
Age [years old]	16.9 ± 7.5	14.8 ± 6.2	22.1 ± 8.0	1.15** [1.10 – 1.20]
Body mass [kg]	54.8 ± 19.7	49.9 ± 18.4	67.1 ± 17.7	1.05** [1.03 – 1.07]
Foot length [cm]	24.2 ± 2.2	23.9 ± 2.3	25.0 ± 1.8	1.24** [1.10 – 1.40]
Arch height flexibility [mm/kN]	18.5 ± 15.7	19.5 ± 17.4	16.1 ± 9.7	0.99 [0.97 – 1.00]

Note: The reference categories are indicated in italics for categorical variables. Nominal variables were reported as percentages and continuous variables as mean ± standard deviation (SD). Odds Ratios were added with 95% confidence intervals (CI) at $*p < 0.05$, $**p < 0.01$.

Table 2 – Plantar pressure values (mean ± standard deviation) expressed in kPa and percentages of total foot pressure in brackets.

	All players	**Healthy**	**Injured**	**Odds Ratio with [95% CI]**
Total Foot	*161 ± 61 (100%)*	*162 ± 66 (100%)*	*159 ± 46 (100%)*	*0.99 [0.99 – 1.00]*
Medial Heel	153 ± 63 (95%)	156 ± 68 (96%)	147 ± 48 (92%)	0.99 [0.99 – 1.00]
Lateral Heel	103 ± 35 (64%)	100 ± 35 (62%)	112 ± 34 (70%)	1.01* [1.00 – 1.02]
Total Heel	*154 ± 63 (96%)*	*156 ± 68 (96%)*	*148 ± 48 (93%)*	*0.99 [0.99 – 1.00]*
Midfoot	54 ± 24 (34%)	54 ± 23 (33%)	54 ± 26 (34%)	0.99 [0.99 – 1.01]
Metatarsal 1	75 ± 36 (47%)	74 ± 34 (46%)	77 ± 39 (48%)	1.00 [0.99 – 1.01]
Metatarsal 2	67 ± 26 (42%)	64 ± 24 (40%)	76 ± 28 (48%)	1.02** [1.01 – 1.03]
Metatarsal 3	65 ± 26 (40%)	61 ± 23 (38%)	76 ± 30 (48%)	1.02** [1.01 – 1.03]
Metatarsal 4	56 ± 25 (35%)	51 ± 19 (31%)	68 ± 32 (43%)	1.03** [1.02 – 1.04]
Metatarsal 5	41 ± 25 (25%)	39 ± 23 (24%)	48 ± 28 (30%)	1.015** [1.005 – 1.03]
Total Metatarsals	*90 ± 36 (56%)*	*85 ± 33 (52%)*	*103 ± 41 (65%)*	*1.01** [1.01 – 1.02]*
Toe 1	48 ± 45 (30%)	48 ± 46 (30%)	48 ± 41 (30%)	1.00 [0.99 – 1.01]
Toe 2	20 ± 24 (12%)	17 ± 24 (10%)	25 ± 22 (16%)	1.01* [1.00 – 1.02]
Toe 3	11 ± 18 (7%)	8 ± 16 (5%)	17 ± 22 (11%)	1.03** [1.01 – 1.04]
Toes 4 - 5	1.5 ± 8 (1%)	1 ± 7 (1%)	2 ± 10 (1%)	1.01 [0.98 – 1.04]

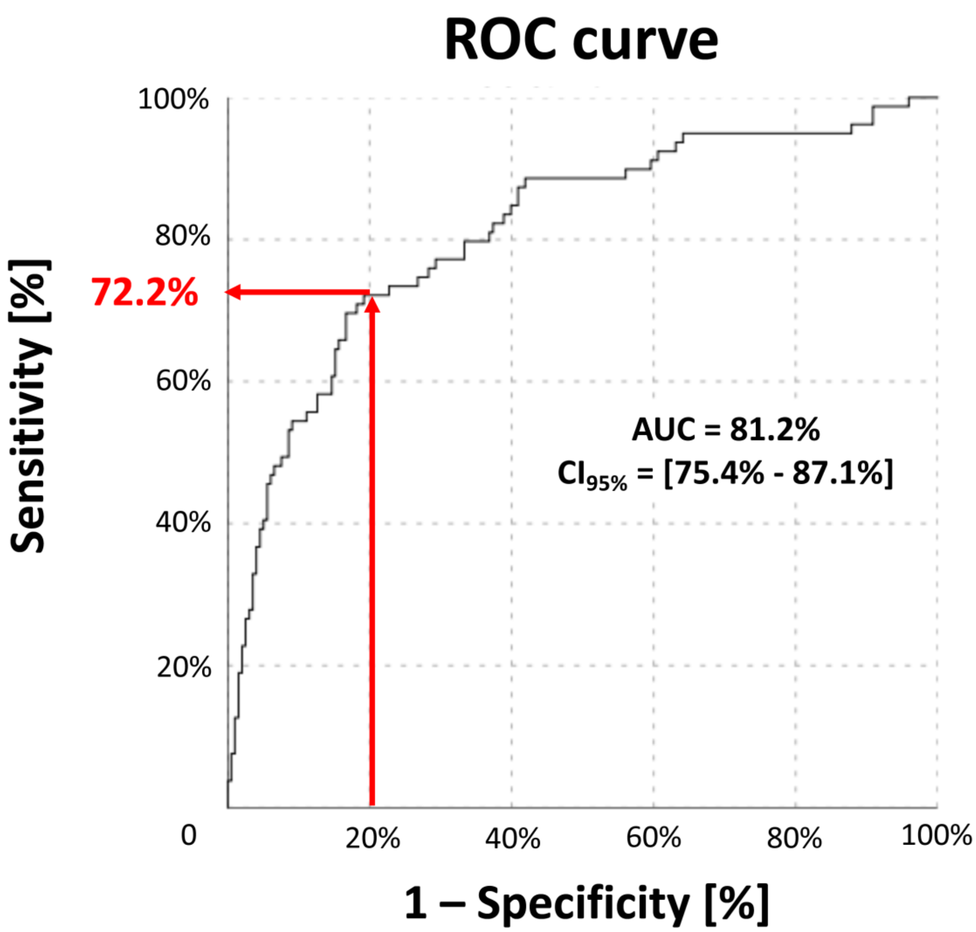
Total Toes	*49 ± 44 (30%)*	*49 ± 46 (30%)*	*50 ± 41 (31%)*	*1.00 [0.99 – 1.01]*

Note: Odds Ratios were added with 95% confidence intervals (CI) at *p < 0.05, **p < 0.01.

Table 3 – Final model with adjusted odds ratios (OR) and its 95% confidence interval (CI) lower and upper boundaries in square brackets, as well as adjusted p-value. The reference category for gender is indicated in italics and bold.

	Adjusted OR	95% CI	Adjusted p-value
Gender [Female/***Male***]	3.2	[1.66 – 6.15]	< 0.001**
Age [years]	1.14	[1.08 – 1.19]	< 0.001**
Pressure: lateral heel [%]	1.0	[0.99 – 1.01]	0.942
Pressure: M4 [%]	1.02	[1.00 – 1.04]	0.012*
Pressure: M5 [%]	1.002	[0.99 – 1.02]	0.792

Note: Male was chosen as the reference category



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