Acta Orthopaedica et Traumatologica Turcica 53 (2019) 145–149

Contents lists available at ScienceDirect

Acta Orthopaedica et Traumatologica Turcica

journal homepage: https://www.elsevier.com/locate/aott

Association of quadriceps angle with plantar pressure distribution, navicular height and calcaneo-tibial angle

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ARTICLE INFO

Article history:
Received 9 February 2018
Received in revised form
2 October 2018
Accepted 21 December 2018
Available online 9 January 2019

Keywords:
Quadriceps angle
Plantar pressure
Navicular height
Calcaneo-tibial angle
Lower extremity alignment

ABSTRACT

Objective: The aim of study was to analyze the association between Quadriceps Angle (QA) and plantar pressure, navicular height (NH), and calcaneo-tibial angle (CTA).
Methods: A total of 64 volunteers (mean age: 22.25 ± 2.54 (range:19–33)) participated in this cross sectional study. EMED-m (Novel GmbH, Germany) electronic pedobarograph was employed for dynamic plantar pressure measurement using two step protocol. The angle between the vertical axis of calcaneus and the long axis of Achilles tendon for CTA. The height of navicular tubercle from the ground was measured while the subject was standing on both feet for NH. QA was measured while the subject was standing in a relaxed posture where both feet bearing equal weight.
Results: There were significant negative correlations between QA and maximum force (MxF) under the 4th. metatarsal head (MH4). The QA was also significantly correlated with MxF and force-time integral (FTI) under the bigtoe (BT). FTI under the 3rd. metatarsal head (MH3), MH4 and 5th. metatarsal head (MH5) were significantly negatively correlated with QA. Pressure-time integral (PTI) under the MH4 and MH5 were found to be significantly negatively correlated with QA. A significant correlation was also found between QA and NH ($p < 0.0001$), whilst there was no correlation between QA and CTA. Regression analysis showed that NH was appeared as the major contributor for the QA ($\beta = -0.49$, $p < 0.001$) in the dynamic condition, followed by BT-FTI ($\beta = 0.37$, $p < 0.001$) and MH5-MxF ($\beta = -0.21$, $p < 0.037$).
Conclusion: These findings may imply that the NH which can at least be controlled by appropriate shoe inserts may affect QA. This way, loading pattern of both plantar region and whole lower extremity may be altered.
Level of evidence: Level III, Diagnostic Study.

Introduction

The overall understanding of lower extremity alignment is one of the key points to predict how body weight is transferred to the ground. The created force vector depending on this alignment is used as a surrogate measure of the load in magnitude and estimate its location under the foot. Lower extremity is defined as an overlapping column, therefore it is thought that if a segment of lower extremity deviates from normal, this also affects the other parts of lower extremity.[1] It has been suggested that the change in axial loading in lower extremity joints may be responsible for degenerative disorders as a predisposing factor.[2] Due to the lack of a gold standard diagnostic tool, studies have been using a set of tests to obtain data for axial alignment of the lower extremity such as Quadriceps angle (QA), navicular height (NH) and calcaneo-tibial angle (CTA), which all are commonly used tools in a clinical setting.[1,3,4]

QA is a common measure of the angle between the lines from anterior iliac spine (ASIS) to center of patella, and from center of patella to tibial tuberosity.[5] Although there is no consensus on the normal range of the QA, American Orthopedic Association considers it to be 10°. As it has been reported by several authors, any change in QA beyond normal range may result in a decreased medial longitudinal arch height, or an abnormal dynamic response to calcaneo-tibial joint position in which the foot is pronated or supinated.[6] This malalignment of the rear foot may cause tibial rotation that if it is tibial internal rotation, there may be an increase

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Peer review under responsibility of Turkish Association of Orthopaedics and Traumatology.

https://doi.org/10.1016/j.aott.2018.12.008

in QA.[7] Thus, as Wilson and Kitsell concluded, QA value should be considered as a variable rather than a constant one.[8]

Segmental alignment of the foot in the kinetic chain were shown to be influencing factors affecting proximal segments such as patella-femoral joints.[9] Excessive foot pronation decreases the tibial external rotation in midstance phase of gait. Decreased external tibial rotation is compensated by excessive internal rotation of the femur that results in increased QA.[10]

Femoral adduction caused by excessive valgus moment leads to increased QA that results in the subtalar joint pronation.[11] Rearfoot eversion may cause abnormal stress in medial femoral condyle, patello-femoral pain syndrome and plantar fasciitis.[12–14] It also decreases the medial longitudinal arch height and leads to medially shifted axial load on the foot.[14] This could result in altered plantar pressure values. It may, therefore, be assumed that axial alignment of the lower extremity would associate with plantar pressure distribution pattern. However, Braz et al concluded that, there was no association between plantar pressure distribution and QA.[15] To our knowledge, this is the only study investigating the relations between QA and plantar pressure. It has also been reported that participants of the study were among football players. In studies investigating the possible effects of alignment problems on plantar pressure values, affecting parameters were limited to only one segment. For the first time knee joint was also assessed in addition to ankle joint and was investigated the relations between other parameters in our study.

Regarding to the above mentioned assumptions, it would be worthwhile to investigate the association between QA and plantar pressure, NH, and CTA to understand how these variables of the foot alignment affect the QA. Thus, it was hypothesized that QA, NH and CTA are interrelated and affect plantar pressure distribution. With this knowledge in hand one may be able to determine underlying causes of malalignment, and the impact of interventions such as foot orthotics and footwear modifications on knee pain.

Materials and methods

Participants

Power analysis performed according to values taken as follows; effect size (f^2) = 0.2, $\alpha = 0.05$, power: 80%, and thus the total number of required participants was found to be 52. By adding another 20% more individuals for possible drop-outs a total of 64 (33 males and 31 females) volunteers ages between 18 and 25 years old, without trauma and/or surgical history, as well as a gross deformity and pain related to their lower limb participated in this cross sectional study. Following a brief explanation about the study, all participants signed the informed consent form. The study was approved by the Research Ethics Committee of the University.

Procedure

Plantar Pressure Measurement

EMED-m (Novel GmbH, Germany) electronic pedobarograph was employed for dynamic plantar pressure measurement using two step protocol.[16] Numerical data was obtained for variables of maximal Force (MxF), peak pressure (N/m^2), pressure-time integral ((N/m^2) × s) and force-time integral (N × s).

Calcaneo-Tibial Angle Measurement

This assessment was performed by measuring the angle between the vertical axis of calcaneus and the long axis of Achilles tendon while the participant was in standing position.[17,18]

Navicular Height

The height of navicular tubercle from the ground was recorded in millimeters while the subject was standing and distributing his/her body weight evenly to both feet.[17,19]

Quadriceps Angle Measurement

QA was measured in a relaxed, standing posture where both feet bearing equal weight. The axis between ASIS and center of patella and the axis between center of patella and tibial tubercle were marked.[3]

The CTA, NH and QA measurements were performed and average values were recorded.

Data analysis

Both feet of the 64 participants were pooled into 128 samples. However, avoiding violation of independency, 64 feet out of 128 were randomly selected for the statistical analysis.[20] The data were normally distributed and therefore parametric analyses were used. Bivariate Pearson correlation coefficients were calculated between QA, NH and CTA and plantar pressure variables. The variables those of significantly correlated with QA (dependent variable) were input as independent variables into a multiple linear regression analysis to find major contributors to the QA. The regression analysis was run following the backward stepwise elimination procedure based on the probability of F determined as a stepping method criteria. A significance level of $p < 0.05$ was required for entry into the model, and $p > 0.6$ was the criterion for removal.[21,22] The maximum value of variance inflation factor (VIF) was determined as 5.0 for multicollinearity. The significance level was set at 5% ($p < 0.05$). All statistical analysis was performed using IBM SPSS software version 20.0 (IBM Corporation, Armonk, NY, USA).

Results

Demographics features of the participants are shown in Table 1. Correlation coefficients analysis showed that there were significant negative correlations between QA and MxF under the MH4 ($p = 0.004$) and MH5 ($p = 0.001$). QA was also significantly correlated with MxF under the BT ($p = 0.001$) (Table 2). Measured FTI under the MH3 ($p = 0.006$), MH4 ($p = 0.003$) and MH5 ($p = 0.002$) were found to be significantly negatively correlated with QA, whilst there was significant correlation between BT-FTI value and QA (0.001) There was no correlation between PP under any region of plantar surface and QA. However, PTI under the MH4 and MH5 were found to be negatively correlated with QA. A significant correlation was also found between QA and NH ($p < 0.0001$), whilst there was no correlation between QA and CTA (Table 2).

Total of 10 plantar pressure variables that significantly correlated with QA were put in the multiple regression analysis and narrowed down to two (MH4-FTI and BT-FTI) based on a significance level of $p < 0.05$ to enter the model and a p=<0.06 was criterion for the removal. The resulting two-variable model ($F = 12.13$, $p < 0.0001$) had an $r = 0.53$ and $r^2 = 0.29$ and VIF <2.0 (Table 3).

Table 1
Demographic features of the participants.

(n = 64)	Minimum	Maximum	Mean	Std. Dev.
Age, y	19.00	33.00	22.25	2.54
Body Height, cm	152.00	190.00	171.56	7.92
Body Mass, kg	45.00	108.0	67.58	14.4
Body Mass Index	16.14	33.96	22.83	3.58

Table 2
Correlation coefficients between quadriceps angle and plantar pressure variables, navicular height and calcaneo-tibial angle.

	QA	
	r	p
NH	−.523**	.000
CTA	.195	.122
TF-MxF	−.035	.782
HF-MxF	−.013	.919
MF-MxF	−.036	.775
MH1-MxF	−.074	.560
MH2-MxF	−.024	.850
MH3-MxF	−.053	.679
MH4-MxF	−.358**	.004
MH5-MxF	−.390**	.001
BT-MxF	.409**	.001
ST-MxF	.144	.256
T345-MxF	.146	.251
TF-PP	.173	.172
HF-PP	−.059	.644
MF-PP	−.126	.322
MH1-PP	.090	.477
MH2-PP	.034	.787
MH3-PP	.088	.491
MH4-PP	−.017	.896
MH5-PP	−.142	.263
B-PP	.180	.154
ST-PP	.063	.619
T345-PP	.068	.595
TF-FTI	−.195	.122
HF-FTI	−.005	.971
MF-FTI	−.217	.085
MH1-FTI	−.080	.532
MH2-FTI	−.218	.084
MH3-FTI	−.338**	.006
MH4-FTI	−.369**	.003
MH5-FTI	−.375**	.002
BT-FTI	.418**	.001
ST-FTI	.208	.100
T345-FTI	.109	.391
TF-PTI	.136	.283
HF-PTI	.190	.132
MF-PTI	.060	.637
MH1-PTI	.034	.789
MH2-PTI	−.094	.462
MH3-PTI	−.132	.300
MH4-PTI	−.266*	.034
MH5-PTI	−.307*	.013
BT-PTI	.263*	.035
ST-PTI	.185	.143
T345-PTI	.212	.093

*$P < 0.05$, **$p < 0.01$.
Total foot (TF); hindfoot (HF); midfoot (MF); metatarsal head (MH); big toe (BT); second toe (ST); toes345 (T345); maximum force (MxF); force-time integral (FTI); peak pressure (PP); pressure-time integral (PTI); quadriceps angle (QA); navicular height (NH); calcaneo-tibial angle (CTA).

Regression coefficient was significant for only MH4-FTI ($\beta = -0.333$, $p = 0.003$) and BT-FTI ($\beta = 0.386$, $p = 0.001$) (Table 3).

When we have added NH and CTA into the regression, MH5-MxF and BT-FTI, and NH remained as independent variables in the final model ($F = 19.19$, $r = 0.70$, $p < 0.0001$, $r^2 = 0.49$) (Table 4). NH was appeared as the major contributor for the greatest negative change in QA ($\beta = -0.49$, $p < 0.001$) in the dynamic condition, followed by BT-FTI ($\beta = 0.37$, $p < 0.001$) and MH5-MxF ($\beta = -0.21$, $p < 0.037$) Table 4). The QA was found to be decreased with the higher NH and lower FTI under the BT.

Discussion

The aim of this study was to investigate the relation between QA and plantar pressure values. It was identified that increased QA may also increase the load on the medial column of the foot. Additionally, the relations investigated between QA, NH and CTA indicated that NH is a significant contributor to QA.

The results of the present study indicated that as the FTI and MxF increased under the MH3-5 and MH4-5 respectively, and decreased under the BT, the QA was decreased. As Nguyen et al hypothesized, the decrease in NH could also results in the increase of QA (Table 2) due to patellar medial displacement and lateral displacement of tibial tuberosity owing to rotational change caused by foot pronation.[1] Although MH4-FTI and BT-FTI were the only plantar pressure variables remained in the regression model (Table 3), and explaining −33% and 39% variance in the QA respectively, MH4-FTI was replaced by MH5-MxF when we have included NH in the final model. Hence, NH was found to explain the −49% variance in the QA values, whilst BT-FTI and MH5-MxF contributed 37% and −21% change in QA respectively (Table 4). It was reported that lower QA values may possibly result in supinated foot posture. Inversely, QA also decreases as the foot posture changes from pronation to supination.[23,24] Therefore, NH was the most significant contributor for QA putting the foot posture in the excessive supination or pronation that could alter plantar pressure distribution as we have found under the MH4 and BT. The load under the MTH3, 4 and 5 and BT were only variables among the ten plantar regions significantly associated with QA, this was probably due to the greater ground reaction force affects the forefoot region during the push-off phase of the gait. That could indicate the dynamic link between the knee and foot.

In a normal gait, the subtalar joint moves into pronation after heel contact until the end of the foot flat. In the push-off phase, it begins to move towards supination and converts the foot into a rigid lever arm for propulsion.[24] In people with pronated foot, subtalar joint cannot move into supination on the time during the push-off phase[25], and is not sufficient for completing the push-off during gait.[26] An excessive pronation of the foot is generally associated to excessive or prolonged tibial rotation and larger QA because of the coupling movement between inversion/eversion and tibial rotation via subtalar joint.[27] When plantar pressure variables modulated by shoe, insole or terrain, or different posture of the foot such as pes planus or pes cavus, the subtalar joint could also be placed in a supinated or pronated position that might lead externally or internally rotated tibia. This rotation alters the position of the tibial tubercle results in change of QA.[1]

In an asymptomatic condition, the load on the medial compartment of the knee joint increases with higher adductor moment caused by lower QA, loading line may be located laterally

Table 3
Multiple regression between Quadriceps Angle and plantar pressure variables remained in the final model ($F = 12.13$, $r = 0.53$, $p < 0.0001$, $r^2 = 0.29$).

Independent Variables	B	Std. Error	β	t	p	95.0% CI for B		VIF
						Lower Bound	Upper Bound	
(Constant)	12.062	1.553		7.768	.000	8.957	15.168	
MH4-FTI	−.088	.029	−.333	−3.062	.003	−.145	−.030	1.009
BT-FTI	.093	.026	.387	3.556	.001	.041	.146	1.009

Table 4
Multiple regression for Quadriceps Angle after adding navicular height variable ($F = 19.19$, $r = 0.70$, $p < 0.0001$, $r^2 = 0.49$).

Independent Variables	B	Std. Error	β	t	p	95.0% CI for B		VIF
						Lower Bound	Upper Bound	
(Constant)	23.39	2.62		8.92	.000	18.143	28.637	
MH5-MxF	−.04	.02	−.21	−2.14	.037	−.076	−.002	1.110
BT-FTI	.09	.02	.37	3.84	.000	.043	.135	1.073
Nheight	−2.79	.54	−.49	−5.19	.000	−3.867	−1.716	1.037

in the supinated foot to reduce this adduction moment. Contrary to this, medially located loading line in the pronated foot increases the adduction moment at the knee joint that could be reduced with larger QA.[26] Although, patello-femoral joint, on the other hand, could be overloaded with increased QA, both mechanisms could work in equilibrium in the dynamic condition to minimize risks of knee pathology.

Previously, Braz et al used a similar approach in soccer players.[15] The main methodological difference between the two studies were the technique related to QA measurements which, in Braz et al.'s, study were taken with the help of a reflector supported by a firmware. Braz et al reported that there were no association between QA and plantar pressure values. However, the players with reduced QA had higher forefoot mean peak pressures. Their feet were more likely to be supinators with varus malalignment. Braz et al study is not comparable with this current study for three reasons.[15] First, the sample in their study were consisted of both soccer players and non-players. Secondly, the statistical approach to the data is different. In addition to correlation statistics we have also conducted multiple regression analysis to determine the most influencing factors. Lastly, in our study, not all but some standard measurements related to foot alignment were taken into consideration to analyze their relation with QA.

Whilst there is no data whether calcaneal position has an influence on QA in asymptomatic individuals, it was still contrary to our expectations. The CTA, which has natural relation with tibial rotational alignment was expected to be correlated with QA. This expectation may originate from the studies previously demonstrating the relationship between rearfoot position and QA in conditions like patellofemoral pain syndrome.[28] In the current study with asymptomatic participants, however, the CTA was surprisingly not represented in the final regression model either alone or in combination with other predictors. It seems that CTA is more likely related to the torsion of the distal tibia compensating the proximal, thus disconnecting a possible positional link between calcaneus and QA in asymptomatic conditions. Assessing CTA may be used to help identifying possible effects of tibial torsion on ankle and foot. Interestingly, our findings were consistent with other studies indicating no association between rearfoot movement and tibial rotation during walking for the asymptomatic group.[7,22,29] Barton et al (2012) also concluded that it was unclear whether the apparent relationship between rearfoot position and tibial rotation found in the people with patello-femoral pain syndrome (PFPS). Another reason for this finding may partially be due to the multiple anatomical factors that may influence the effect size of CTA on QA. It has been suggested that the QA is a composite measure of pelvic position, hip rotation, tibial rotation, patella position, and foot position. However, this may be a major limitation of the current study as we have not measured the effects of pelvic position, hip and tibial rotation, which could greatly affect QA. Second limitation of our study was that we were not able to eliminate the activation of quadriceps muscle during measurement of QA, since activation of quadriceps muscle might decrease QA.

Conclusion

NH was the most significant contributor for QA aligning the foot posture into supination or pronation that could alter plantar pressure distribution. The results of the present study also indicated that the load increased under the lateral aspect of the forefoot was associated with decreased QA. In contrast, the load was found to be higher under the medial aspect of the forefoot with larger QA. It is well known that, laterally shifted loading line in the supinated foot seems to reduce adduction moment, whilst medially located loading line in the pronated foot increases the adduction moment at the knee joint that could only be reduced with larger QA. These findings may imply that the NH which can at least be controlled by appropriate shoe inserts may affect QA. This way, loading pattern of both plantar region and whole lower extremity may be altered. Thus, in addition to QA, navicular drop test should be conducted in individuals with alignment problems related to lower limbs. However, the relation between CTA and QA with respect to natural alignment of lower extremity may still be considered as obscured, especially in asymptomatic individuals.

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