Journal of Science and Medicine in Sport 22 (2019) 392–396

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

How does ballet training alter ankle tendinous morphology and hemodynamics in asymptomatic pre-professional dancers? An ultrasonographic study

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A R T I C L E I N F O

Article history:
Received 27 December 2017
Received in revised form 18 August 2018
Accepted 20 September 2018
Available online 28 September 2018

Keywords:
Posterior tibial artery
Flexor hallucis longus
En pointe
Duplex ultrasonography
Adolescent
Dance

A B S T R A C T

Objectives: Among symptomatic dancers, sonographic abnormalities are common. Whether asymptomatic dancers have any abnormalities remains unknown. Some dancers became cyanosis over distal feet after ballet training. The hemodynamic changes at the feet in ballet are not clearly understood.
Design: Cross-sectional study.
Methods: In 25 dancers and 14 non-dancers, B-mode ultrasonography was used to measure cross-sectional areas (CSA) of tendons of deep posterior compartment muscles. Doppler ultrasonography was used to measure peak velocity (V_{peak}) of posterior tibial artery in three ankle postures: the neutral position, passively and forced actively plantar flexion (en pointe). The big toe oxygen saturation was recorded in neutral position and during 1-min en pointe. Single-leg standing heel rise test was performed to represent the muscle function.
Results: The CSA of FHL was larger in dancers (0.26 cm^2 [0.20, 0.30] vs 0.21 cm^2 [0.17, 0.24], $p < 0.01$), while other tendons were not different (all $p > 0.05$). Higher V_{peak} was recorded in passively plantar flexion than in neutral position ($p < 0.01$, in both groups). The blood flow was undetectable during en pointe, more frequently in dancers (54.9% vs 14.3%, $p < 0.01$). Oxygen saturation decreased during en pointe more prominently in dancers (85% [80, 90] vs 94% [84, 97], $p < 0.01$). There was no significant difference in muscle function.
Conclusions: US showed the FHL tendon thickening and en pointe-related vascular compromise in pre-professional dancers, even when they are asymptomatic.

1. Introduction

In ballet, the movements largely depend on the mobility of ankle joint and the stabilisers such as ligaments and muscles. Also, ankle joint is the most frequent site of injuries in ballet dancers.[1] The mechanism of dancing injuries usually comes from overuse. One of the most common diagnosis is tenosynovitis.[1] Ultrasonography (US), with benefits of non-invasive, radiation-free and portability, can provide immediate and precise evaluation to ankle joint.

In clinical practice, sonographic abnormalities are common among dancers. However most of these dancers do not come to clinic until they have disabling symptoms. Whether asymptomatic dancers have any abnormalities under US remains unknown. Previous studies indicated that in asymptomatic ballet dancers, hypoechoic defects in Achilles and patellar tendons were observed under US.[2] There was no difference in flexor hallucis longus (FHL) tendon thickness or cross-sectional areas (CSA) between dancers and recreationally active young non-dancers.[3] As for other tendons around the ankle, the evidence was limited.

In addition, we also observed some dancers had cyanotic changes over distal feet after ballet training. It is believed that in athletes the peripheral vessels resistance is lower with enlarged luminal diameter and decreased vessel wall thickness which permits adequate blood flow during exercise.[4] However, this adaptation may be compromised in the ankles of ballet dancers. Forced plantar flexion (en pointe) is the most common movement of ankles in ballet, but the information about hemodynamic changes during en pointe is limited. Posterior tibial artery comes along deep posterior compartment of the leg and crosses the ankle joint at tarsal tunnel. Both the change of ankle joint space and the contraction of muscles within deep posterior compartment during en pointe

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https://doi.org/10.1016/j.jsams.2018.09.231

may affect the blood flow of posterior tibial artery. Therefore, we selected the posterior tibial artery as our target.

The aim of this study is to investigate tendon morphological changes and hemodynamic changes in ankles of asymptomatic pre-professional ballet dancers with B-mode and doppler US. Our hypotheses were: (1) thickening of the tendons of deep posterior compartment muscles could be seen in dancers' ankles even asymptomatic; (2) the peak velocity (V_{peak}) in posterior tibial artery, representing its resistance, was low at rest but would become higher in condition of passively plantar flexion and movement of en pointe.

2. Methods

The study was approved by the institutional review board at the National Taiwan University Hospital. Informed consent was obtained in all participants. The study was performed from July 04, 2016 to May 16, 2017.

Inclusion criteria for dancers were: (1) receiving formal dancing training system in Taipei National University of the Art (TNUA); (2) receiving ballet training at least 3 h per week for at least 5 years; (3) no acute ankle injury in recent 3 months; (4) no history of ankle surgery. All tests were performed in the daytime before the dancing courses. Inclusion criteria for non-dancer group were: (1) never receiving formal dancing training; (2) no acute ankle injury in recent 3 months; (3) no history of ankle surgery.

Participants were instructed to lie supine in relax. Both legs were tested. The range of motion (ROM) of ankle passively plantar flexion were measured by a goniometer.

Ultrasound imaging (Hitachi Noblus, Linear probe L64, Probe frequency range 18–5 MHz, Japan) was used to measure CSA within the tendon sheath of deep posterior compartment muscles including tibialis posterior (TP), flexor digitorum longus (FDL) and FHL. We also measured peroneus tendons, which have function in plantar flexion but go along the lateral side, as comparison. For TP and FDL, probe was positioned at medial retro-malleolus area, perpendicular to TP and FDL tendons. And then the probe was moved to the connective line between medial malleolus and calcaneal tuberosity, perpendicular to FHL tendon for its CSA. The peroneus tendons, including peroneus longus and brevis, were measured with the probe at the connective line between lateral malleolus and calcaneal tuberosity, perpendicular to the tendon (Fig. 1). All the CSAs were selected with elliptic selection tool. Distal TP tendon longitudinal diameters were also measured at 2 cm proximal to the insertion at navicular bone.

Doppler ultrasound was used to measure V_{peak} of posterior tibial artery in three different conditions: ankle neutral position, passively plantar flexion at terminal range and en pointe (Fig. 1). If the blood flow was undetectable in en pointe, the toes would relax slowly until the flow resumed on the monitor. The probe was put at medial retro-malleolus area to retrieve longitudinal view of posterior tibial artery. The angle of incidence was kept to <60°. All three conditions were measured three times and the average was used for analysis.

Oxygen saturation of the big toe was recorded with oximeter (Masimo, Rad-5, U.S.A) in two conditions: ankle neutral position and during 1-min en pointe. The saturation level in neutral position and the lowest level during 1-min en pointe were recorded.

Single-leg standing heel rise test (SSHT) was performed to represent the muscle function. Participants were told to rise the heel with one leg in frequency of 1 Hz in standing as many repeats as they could until fatigue. The repeats were recorded.

All data were analysed using Statistical Package for the Social Sciences software (SPSS version 20.0.0). Because a preliminary Kolmogorov–Smirnov test demonstrated that samples did not follow a normal distribution, we decided to use nonparametric Mann–Whitney test in between-group comparison and Wilcoxon signed-rank test in within-group comparison. Results were expressed as median [interquartile range]. Pearson chi-square test was used for categorical data. A p value <0.05 was considered statistically significant and confidence interval(CI) with effect size was presented in result.

Variables of between-group comparison included: passively plantar flexion ROMs, CSA of TP, FDL, FHL and peroneus tendons, TP tendon thickness at insertion, V_{peak} of posterior tibial artery in three positions, saturation in neutral position and the lowest saturation during 1-min en pointe, and repeats of single-leg standing heel rise test. Variables of within-group comparison included V_{peak} between neutral position and passively plantar flexion, and saturation between neutral position and during 1-min en pointe in both dancers and non-dancers.

3. Results

Twenty-five female dancers (50 legs) and 14 female non-dancers (28 legs) were recruited. The medians of ages were 16 [15, 18] years old in dancers and 17 [16, 18] years old in non-dancers ($p = 0.137$). The body mass index (BMI, kg/m^2) was significantly lower in dancers (18.98 [18.44, 20.13]) than in non-dancers (22.15 [19.71, 23.03], $p < 0.01$). In dancer group, the average intensity with which the participants performed the dancing practise was 16.2 ± 3.1 h per week. All dancers have performed the dancing experience for 10.7 ± 2.7 years.

In between-group comparison, the ROM of ankle passively plantar flexion in dancers were significantly larger ($p < 0.01$) than in non-dancers (Table 1).

The FHL tendon CSA was significantly larger in dancers than in non-dancers ($p < 0.01$; CI [0.02, 0.08]). There was no significant difference in CSA of TP, FDL and peroneus tendons between dancers and non-dancers (all $p > 0.05$). There was no significant difference in TP tendon thickness at insertion between two groups ($p = 0.06$) (Table 1).

V_{peak} of neutral position and passively plantar flexion were significantly lower in dancers ($p = 0.02$ and $p < 0.01$, respectively.). V_{peak} of passively plantar flexion was significantly higher than neutral position in two groups (both $p < 0.01$) (Table 2).

During en pointe, the blood flow was undetectable in 28 legs in dancers (54.9%). The same phenomenon was seen in only 4 legs in non-dancers (14.3%) with significance (Pearson chi-square, $p < 0.01$) (Table 1). The flow partially resumed if the big toe relaxed.

There was no significant difference of the oxygen saturation in neutral position between dancers and non-dancers ($p = 0.98$). The saturation during 1-min en pointe decreased significantly from neutral position in both groups (both $p < 0.01$) (Table 2). The lowest saturation level was significantly lower in dancers ($p < 0.01$) (Table 1).

In sub-group analysis in dancers, we separated dancers into two groups according to whether the blood flow in en pointe was detectable (22 legs) or not (28 legs) and compared the lowest saturation level during 1-min en pointe. There was no significant difference between two groups ($p = 0.28$).

There was no significant difference in the repeats of SSHT between dancers and non-dancers ($p = 0.29$) (Table 1).

4. Discussion

In this study, the ROM of ankle and the CSA of FHL were larger in dancers. The dancers' V_{peak} of posterior tibial artery were lower than non-dancers' in both neutral position and passively plantar flexion. In both dancers and non-dancers, the V_{peak} increased dur-

Fig. 1. Probe position in measuring cross sectional area of ankle plantar flexion tendons (A) probe position for TP, FDL, (B) probe position for FHL, (C) probe position for peroneus tendons, and three ankle conditions in measuring V_{peak} of posterior tibial artery (A) ankle neutral position (D) passively plantar flexion at terminal range, (E) en pointe (forced plantar flexion).

Table 1
Comparison between dancers and non-dancer controls.

	Dancers (50 legs)	Non-dancers (28 legs)	*p* Value
ROM			
Ankle plantar flexion ROM (degrees)	81 [78, 87]	66 [60, 70]	<0.01*
B-mode ultrasound			
TP CSA (cm^2)	0.32 [0.25, 0.4]	0.3 [0.27, 0.36]	0.56
FDL CSA (cm^2)	0.09 [0.07, 0.12]	0.09 [0.07, 0.1]	0.69
FHL CSA (cm^2)	0.26 [0.2, 0.3]	0.21 [0.17, 0.24]	<0.01*
Peroneus tendon CSA (cm^2)	0.42 [0.31, 0.52]	0.42 [0.35, 0.49]	0.81
TP thickness at insertion (cm)	0.36 [0.33, 0.4]	0.33 [0.32, 0.37]	0.06
Doppler ultrasound			
V_{peak}, neutral position (cm/s)	40.1 [30.9, 48.5]	52.4 [36.2, 64.5]	0.02*
V_{peak}, passively plantar flexion (cm/s)	53.6 [44.3, 61.9]	66.3 [49.8, 83.5]	<0.01*
Ratio of undetectable flow in en pointe	54.9% (28 legs)	14.3% (4 legs)	<0.01*
Saturation (%)			
Saturation, neutral	100 [99, 100]	100 [99, 100]	0.98
Lowest saturation, 1-min en pointe	85 [80, 90]	94 [84, 97]	<0.01*
Muscle strength (repeats)			
Single-leg standing heel rise test	29 [22, 32]	29 [23, 35]	0.29

Results were expressed as median [interquartile range].
ROM: range of motion; TP: tibialis posterior tendon; CSA: cross sectional area; FDL: flexor digitorum longus tendon; FHL: flexor hallucis longus; V_{peak}: peak velocity of posterior tibial artery. A *p* value <0.05 was considered statistically significant.

Table 2
Within-group comparison of hemodynamic parameters in different ankle postures.

	V_{peak} in neutral position (cm/s)	V_{peak} in passively plantar flexion (cm/s)	*p* Value
Dancers	40.1 [30.9, 48.5]	53.6 [44.3, 61.9]	<0.01*
Non-dancers	52.4 [36.2, 64.5]	66.3 [49.8, 83.5]	<0.01*
	Saturation in neutral position (%)	Saturation, 1 min en pointe (%)	
Dancers	100 [99, 100]	85 [80, 90]	<0.01*
Non-dancers	100 [99, 100]	94 [84, 97]	<0.01*

Results were expressed as median [interquartile range].
V_{peak}: peak velocity of posterior tibial artery. A *p* value <0.05 was considered statistically significant.

ing passively plantar flexion. In en pointe, the blood flow was found undetectable more frequently in dancers. The decrease of saturation in en pointe was more prominent in dancers. These results imply that, even asymptomatic, the tendon morphology and hemodynamics of the ankle in pre-professional dancers are different from otherwise healthy non-dancers.

The ROM of ankle planter flexion was larger in dancers, which was compatible with a prior study.[5] The differences of the CSAs of TP, FDL and peroneus tendons between dancers and non-dancers were not significant, while the CSA of FHL was significantly larger in dancers. This result may support the theory in previous studies which viewed FHL as “dancer’s Achilles tendon”.[6,7] However, Rowley et al. found no difference of the FHL tendon under ultrasound between formally-trained dancers and non-dancers.[3] This difference might be due to the method of measurement. Rowley et al. measured the CSA with polygon selection tool and placed the probe distal to the medial malleolus and found the perpendicular cut of FHL. But considering FHL goes in oblique and deep direction quickly and distally at medial malleolus, we measured the more proximal, and therefore, superficial part of FHL tendon. Also, we used the elliptic selection tool and measured the whole area within the tendon sheath, including fluid accumulation if existed.

The V_{peak} in neutral position was significantly lower in dancers, which may be associated with a lower peripheral resistance in endurance athletes in order to maintain the mean arterial pressure under high oxygen uptake and cardiac output.[4,8,9] On the other hand, the V_{peak} of posterior tibial artery increased in passively plantar flexion compared with neutral position. It indicated that even changing the ankle joint position can affect local blood flow. Possibly the posterior tibial artery was distorted during passively plantar flexion which increased the intra-arterial pressure, and therefore the V_{peak} increased. The blood flow became undetectable in some cases during en pointe and this phenomenon was found more frequently in dancers than in non-dancers. Also, we noted that in most cases, the undetectable blood flow during en pointe partially resumed if the big toe relaxed, which indicated the role of FHL contraction in affecting ankle hemodynamics. Because the only difference between passively plantar flexion and en pointe was muscles contraction, we believed that the contraction, especially FHL, has effect to the flow of posterior tibial artery, which is more obvious in dancers.

The saturation decreased in en pointe in both groups but was more prominent in dancers. We are still unable to link the relationship between the effacement of blood flow and the decrease of saturation because in sub-groups analysis, no matter whether the blood flow was detectable in en pointe, the levels of saturations were similar. It is also not sure whether the decrease of saturation can impair dancers' performance and increase the risk to injury. However, the elevation of compartment pressure following exhausting dancing work should also be considered as a deleterious factor which was not measured in our study.[10]

There was no significant difference in SSHT. It indicated the overall function of plantar flexors including gastrocnemius, soleus, peroneus, FHL, FDL and TP muscles was similar between dancer and non-dancer groups. Rowley et al.[3] found that the "toe flexor strength" was not different between dancers and non-dancers but dancers performed worse in "heel raises without toes." They proposed a possible different muscle coordination strategy with high reliance on toe flexors to stabilize the ankle and foot in dancers. The results that similar plantar flexion function via SSHT was observed between dancers and non-dancers while thicker FHL tendon was observed only in dancers may be compatible with this muscle coordination strategy.

Through this study, we found FHL thickening and higher undetectable rate of the flow of posterior tibial artery. We believe these phenomena can be indicators of dancers' training effect, in other words, the accumulation of fatigue. A cohort study to follow up the focal symptoms in dancers may provide more information about the relationship between our findings and their long-term clinical impact. In a long run, we can use ultrasonography, a non-invasive, radiation-free and portable tool to monitor asymptomatic dancer's condition and give them adequate managements in time before symptoms develop.

5. Limitations

Several limitations should be addressed. First, the BMI was inevitably lower in dancer group, considering the situation of higher physical activity demand and lower caloric intake in reality. However, it actually made the finding of enlarged FHL tendon more persuasive that it was derived from extra physical activity but not static weight loading. Second, we controlled the participants in similar age and the same sex. All dancers received the same system of dancing training in TNUA. It may limit the extrapolation, but ballet training is the basis of all dancing training system and in TNUA it is not the exception. We believe our results are still valuable in general pre-profession dancer group. Third, we did not measure the thickness of Achilles tendon, which connects the major plantar flexors (gastrocnemius and soleus muscles). Although the Achilles tendon may be important during en pointe, no predictive value of its thickness has been found for tendon-related injury in the following one year.[2] Furthermore the gastrocnemius and soleus muscles are not in the deep posterior compartment where the posterior tibial artery locates. Therefore, the Achilles tendon was not our major target. Forth, the blood flow became difficult to detect in standing. Therefore, we could not measure the blood flow in standing though dancers usually do en pointe under weight-bearing. But even without weight loading the blood flow became undetectable and prominent enough to make significance. Fifth, although the phenomenon of undetectable blood flow during en pointe was obvious under doppler ultrasound, direct evidence to explain its cause was lacked in our study and further investigation is needed.

6. Conclusion

B-mode and Doppler US showed the FHL thickening and en pointe-related vascular compromise in pre-professional dancers even when they were asymptomatic.

Practical implications

- Our study supports the previous findings that dancers highly rely on FHL.
- It also supports the hypothesis that the hypermobility in ankle and the muscle contraction, especially FHL, can decrease the blood flow of posterior tibial artery, more frequently in ballet dancers.
- This study is the first study to use doppler ultrasound exploring blood velocity change in specific dancing movement.
- The saturation decreased in en pointe more prominently in dancers. But it is not sure whether the decrease of saturation can impair dancers' performance and increase the risk to injury in a long run.

Acknowledgments

The authors thank Chiang Chiou-O and Wang Yunyu, of Taipei National University of the Art, for their support in this study. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jsams.2018.09.231.

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