Title: Peak Pressure under the forefoot in classical ballet.

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Abstract

Ballet dancers are significantly predisposed to foot and ankle stress related injuries. Chronic and acute injuries relate primarily to repetitive loading of the foot and ankle during pointe work, which forms the basis of the technique in classical ballet. This study determined the differences in the peak pressure distributed under the forefoot in flat foot and in pointe position. Additionally, the study evaluated the affect of the application of gel modalities in the form of a gel toe sock and gel toe wedges, determining their ability to alleviate pressure under the forefoot. Fifteen female dancers aged between 18 and 25 (mean age 19 years) were examined, and local loading of the forefoot was assessed under three conditions: a) in the absence of any pressure reducing modality, b) wearing the gel toe sock and c) wearing the gel wedges. The results revealed a significant increase in peak pressure (kPa) under the forefoot in pointe stance for the three conditions of the study. The major trend in the mean peak pressure was a decrease in peak pressure under the forefoot in pointe position when each of the gel modalities were utilised, namely the toe sock and gel wedges. According to this trend, the gel modalities tested were effective in decreasing pressure under the forefoot. The statistical analysis (one way ANOVA: $p=0.05$) did not show that this trend was statistically significant, thus the efficiency of the gel modalities are inconclusive.

Introduction

The physical demands of classical ballet place the dancer at risk of injuries related to stress and impact loading of the bony and soft tissue structures of the foot and ankle. Factors commonly associated with the injuries observed in this dance discipline include poor anatomical structure, improper technique, hard floor surface, increased body mass index and muscle imbalance (Harrington & Orichton, 1993). A significant causative factor, however, is the technique shoe used in classical ballet and the technical nature of this dance discipline involving the application of pointe work (Stone & Fu, 2001).

The mechanics involved in the execution of pointe technique incorporate the *releve* motion of the foot from a flat foot to a plantar foot position, for which the heels are lifted off the floor and weight is maintained over the metatarsal heads (Miller & Paulos, 1990). In this pointe position, the centre of gravity is positioned over the metatarsals and there is increased weight distributed through the first and second metatarsal (Miller & Paulos, 1990). This pattern of weight distribution is often associated with post traumatic changes in the forefoot resulting in conditions such as metatarsal shaft fractures, avascular necrosis of the metatarsal heads, and stress fractures at the base of the second metatarsal (Harrington & Orichton, 1993). Weight is also borne through the posterior aspect of the ankle joint so that in the presence of a bony anatomical variant in the ankle joint, excessive compression can occur in the bone or soft tissue at the posterior ankle joint (Denton, 1997). Subsequently, weight borne through the posterior ankle may give rise to conditions such as talar spurring and some soft tissue injuries (Harrington & Orichton, 1993).

The research to date includes work by researchers such as Miller & Paulos (1990) who examined the pressure under the forefoot in classical ballet using the pressure plate analysis. Their research investigated whether the pressure across the foot could be more evenly distributed by wearing various modified technique shoes padded with Spenco or Sorbathane. The pressure plate was used to record pressure at the first, second metatarsal heads, medial and lateral arches and the heel of the foot (Miller & Paulos, 1990). In contrast, the procedures used for our study, incorporated the use of the F-Scan system to measure the peak pressure under the forefoot (Tekscan, Boston, USA). The F-Scan system is an accurate and reliable pressure measuring system for the monitoring of local loading of the foot inside the shoe (Ahron & Boyko, 1998). The pressure plate analysis, however, does not measure

local loading inside the shoe. This study was a pilot study, providing further opportunity for the investigation of peak pressure under the forefoot in classical ballet using the F-Scan system.

Various modalities have been used by dancers in attempt to alleviate pressure and decrease friction over the metatarsal joints, especially during pointe technique in classical ballet. It has been postulated by the manufacturer that a non-silicon polymer may be used to protect areas of the foot prone to friction and trauma (Online-Internet, Bunheads Dance Accessories), whereby the construction of a fabric covered gel pad is worn over the forefoot to cover the five metatarsal joints. This innovation has been thought to decrease pressure and friction over these metatarsal joints. Similarly, the application of toe gel wedges which are placed between the first two toes, aligning the first two metatarsal joints, have also been implicated to reduce any pressure which may involve these joints.

The objective of the research was to determine the difference in the local loading of the forefoot (kPa) in pointe position and flat foot stance. Additionally, the study aimed to evaluate whether the pressure could be reduced under the forefoot by the implementation of gel devices worn to protect the forefoot structures (gel sock or gel wedges). Each modality was tested independently to examine whether pressure under the forefoot structures was alleviated. This study was designed as a pilot study to examine pressure under the forefoot using the F-Scan system.

Method

Sample

This study was performed at the Victoria University Biomechanics Laboratory. Fifteen female dance students at the Victorian College of the Arts volunteered to be tested. This sample comprised elite classical dance students of an advanced level, aged between 18-25 years (mean age 19 years), with a background of at least 12 years of classical dance training, and who were involved in a minimum of 10 hours of tuition a week. Consent forms were completed prior to commencement of the study.

Pre-test

An adequate warm up of the foot and ankle and lower limb was performed prior to testing so as to minimize the risk of injury. The warm up comprised a series of stretches involving the dorsiflexor and plantar flexor muscles of the lower limb. Additionally each dancer was screened and assessed for any acute or chronic injury of the foot or ankle on the day of testing. To reduce sample bias, injured dancers were excluded from the study. Prior to testing, practice trials of the study were also conducted so the participants could familiarise themselves with the equipment and requirements of the study, including the specific requirements of the execution of pointe position and flat foot position at particular stages of the study.

Instrumentation

The equipment required for the study included pointe shoes (no more than three months old) supplied by each dancer. The two types of gel modalities required for assessment included a pair of gel wedges and a gel sock that were composed of a non-silicon polymer formulated with medical grade mineral oils (manufacturer and brand name: Bunheads). One pair of each type of gel modality was obtained from the manufacturer 'Bunheads Dance Accessories' (New York, USA). The gel sock was designed so the plantar and dorsal surfaces of the forefoot were covered, protecting the entire length of each of the five metatarsals. A pair of gel wedges was designed to insert between the first and second metatarsal, effectively contacting the medial and lateral surfaces of the first two metatarsals. Each modality was tested independently to determine which design, if any, was effective at alleviating pressure under the forefoot in pointe position.

The F-Scan system was used as the measuring device to measure the local loading of the foot inside the shoe. The F-Scan system assessed the local loading of the forefoot for two independent variables, namely the flat foot and pointe position variable. The flat foot and the pointe position variables were examined for three different testing conditions – no gel implement, implementation of the gel sock and implementation of the gel wedges. The F-Scan system involved the application of a plantar sensory device that was worn inside the shoe of the participant. The specially designed shoe insert covered the entire plantar surface of the foot and contained sensors that measured pressure distribution in kPa. The plantar insert was connected to the F-Scan software and the pressure measurements obtained were recorded on the software.

Testing protocol

The participants were tested in three conditions. The first condition involved the participant wearing pointe shoes without a gel modality, the second involved the participant wearing the gel toe sock whilst wearing pointe shoes, and the third involved the participant wearing gel wedges between the first two toes whilst wearing pointe shoes. For each of the three conditions each participant stood in flat foot position and also in pointe position. There were rest intervals between each reading of approximately 5 minutes. This allowed for a recovery period between tests to eliminate any bias between the different conditions.

Statistical Analysis:

The statistical analysis incorporated descriptive statistics (means and standard deviation) and repeated measures t-test calculations. A one way analysis of Variance (ANOVA) for repeated measures was used to detect differences in pressure distribution. The ANOVA compared the subject in pointe position under three testing conditions: a) in the absence of any pressure reducing modality, b) wearing the gel sock and c) wearing the gel wedge. The effect size was also calculated.

Results

Evaluation of the descriptive statistics revealed a mean peak pressure value of 943.67kPa under the forefoot in pointe position, in the absence of any gel modality. Under the gel sock and gel wedge condition, the mean pressure values were 655 kPa and 700kPa respectively (refer to table 1). The major trend observed from these mean pressure values was consistent with a decrease in peak pressure at the forefoot when the gel sock and gel wedges were utilised. The mean peak pressure decreased by 288.67kPa when the gel sock was tested and 243.67kPa when the gel wedge was tested (refer to table 1). The mean peak pressure values obtained for the application of the toe sock displayed a slightly greater decrease in peak pressure in comparison to the gel wedge. These trends, however, were not supported by the ANOVA analysis that revealed that the mean peak pressure values were not significantly different.

The repeated measures t-test indicated a significant difference in pressure under the forefoot in pointe position compared to flat foot position. The increase in pressure from flat to pointe position was significant in each of the different testing conditions (no gel modality p=0.009, with the gel sock, p=0.002 and with the gel wedge, p=0.002). This data statistically confirmed an increase in peak pressure under the forefoot in pointe position.

Interpretation of ANOVA output: An examination of the F ratio indicated that the results were not significant for the flat foot variable, when using the new degrees of freedom. The F score for the flat foot variable was 2.413 for a significance level of p=0.133. This result revealed that when comparing the flat foot variable under the three different conditions, no significant difference in the pressure recorded under the forefoot was detected. An examination of the F ratio indicated that the results were not significant for the pointe position variant using the new value for degrees of freedom, F score=2.190, p=0.161.

While the ANOVA data showed that the results were not statistically significant, there was however a major trend observed in the mean peak pressure values that indicated that the modalities were able to decrease pressure under the forefoot. The peak mean pressure for the forefoot in pointe position with no gel implement was 943.67kPa which decreased to a peak pressure of 655kPa when the toe sock was utilised and a peak pressure of 700kPa in pointe position when the gel wedge was utilised (see table 1). An effect size of 0.51 was calculated from the data which suggests the result trends represent substantial strength and reliability.

Discussion

The ballet dancer is suceptible to a wide range of foot conditions, including calluses, corns, first metatarsal osteoarthritis, stress fracture and sprained ligaments. The fundamentals of pointe technique rely on the execution of *releve* motion with a plantar flexed position of the foot. While factors such as anatomy, training regime and poor technique can influence the type of injuries seen in this type of dance, the technical nature of this dance discipline and the construction of the pointe shoe contribute significantly to the injuries observed (Wiesler & Hunter, 1996). The forefoot structures, namely the long axis of the first and second metatarsals are exposed to the most stress and pressure, as the two metatarsals bear most of the body weight in pointe (Denton,1997).

Studying the dancer in pointe position as well as flat foot position, provided comprehensive insight to the increased peak pressure that is distributed through the forefoot structures in pointe position. The results consistently revealed that in all conditions of pointe stance there was an increase in peak pressure directed through the forefoot region. This fact was highlighted by the repeated measures t-test which indicated a significant difference in pressure under the forefoot in pointe position compared to flat foot position. The increase in pressure from flat foot to pointe position produced significant results in each of the testing conditions (no gel modality $p=0.009$, with the gel sock $p=0.002$ and with the gel wedge $p=0.002$).

Dancers suffer an array of foot injuries. Post traumatic changes in the mid and forefoot in dancers include talar spurring, metatarsal shaft fractures, avascular necrosis of the metatarsal heads, osteoarthritis, stress injuries at the base of the second metatarsal and acquired pes planus. Studies conducted by Harrington & Crichton (1993) and Miller & Paulos (1990) confirm that the mechanism of injury associated with these conditions can be linked to the use of pointe shoes and the fundamentals of pointe technique.

The application of the gel modalities was proposed to act to absorb and alleviate some of the pressure under the forefoot structures in pointe ballet. The significance of assessing such modalities was for the purpose of injury prevention and alleviation of pressure at the forefoot. According to the general trends in the results, the utilisation of the gel modalities, namely the gel toe sock and gel wedge, proved effective in the alleviation of peak pressure under the forefoot.

While the results were not statistically significant according to the ANOVA analysis, there were some major trends observed in the mean peak pressure results. The mean peak pressure values decreased when either the gel sock or gel wedge were utilised compared to when no modality was implemented. According to the results, the mean peak pressure measured at the forefoot in pointe position with no gel implementation was 943.67kPa and decreased to a peak pressure of 655kPa when the toe sock was utilised. The mean peak pressure decreased to 700kPa in pointe position when the gel wedge was utilised. Two very distinctive trends can be observed from this data. The first trend is that both modalities decrease pressure under the forefoot in pointe position. This trend is supported by an effect size value of 0.51 (medium effect size). The second trend is that the gel sock is slightly more effective at reducing pressure under the forefoot as opposed to the gel wedge. This observation may be accounted for the larger surface area that the toe sock covered, thus making it more effective at absorbing the pressure forces under the forefoot.

For the purpose of data analysis it should be stated that the results obtained may have been negatively affected by the sensitive nature of the plantar inserts. These plantar inserts were highly sensitive to creasing which was associated with a false increase in the peak pressure measured. Subsequently this may have predisposed the peak pressure readings to some degree of inaccuracy. When the dancer was in pointe position the small amount of foot movement that occurred in the shoe may have caused bending and creasing of the insert, thus affecting the accuracy of the results.

The study comprised a sample size of fifteen dancers thus the study had a low power. This sample size may not have been sufficient to exclude individual differences between each dancer in terms of foot technique. Differences in foot technique may have had implications in relation to different degrees of movement and positioning of the foot, so that different degrees of inversion and eversion may have been attained at the subtalar joint. Consequently, differences in foot technique may have had an affect on the pressure distributed at the different structures of the forefoot, thus influencing the accuracy of the results.

In hindsight, in order for more significant results to have been obtained, additional readings for each peak pressure should have been taken for each testing variable. Three readings may have been more appropriate to eliminate experimental error when obtaining the pressure readings. Additionally, some more consideration may have been needed for the design of each gel modality so as they would have been

more effective at absorbing pressure under the forefoot. The toe sock design may have been more effective if it incorporated a larger surface area that covered a greater proportion of the forefoot. Additionally the gel density of the toe sock may have been increased so that it was thicker and denser to allow for a greater absorption of shock. The gel wedge design may have also been more effective if it incorporated a larger contact surface, covering the two metatarsal heads. These particular design modifications may have served in providing greater absorption of stress and impact, thus aiding to alleviate more pressure through the long axis of the metatarsals. These factors may be applied to future investigations in this area of study.

Overall the research analysis revealed a major trend, showing that the gel sock and gel wedges are able to alleviate some pressure under the forefoot. There was, however, no statistical significance associated with the findings of this research so therefore the results are inconclusive.

Conclusion

The data support the hypothesis that pressure increased under the forefoot in pointe position. The research reveals that the gel sock and gel wedge are effective at reducing pressure under the forefoot. The data, however, is not statistically significant and thus the efficiency of the gel modalities is inconclusive. The results of the study provide further opportunity for extended work in this area of study, to determine effective modalities that will have a positive impact on reducing pressure under the forefoot in pointe ballet. This information may be important in the application of injury prevention in classical ballet because the pointe position subjects the dancers' forefoot to markedly increased pressure.

Table 1: Means and Standard Deviations of Measured Variables.

Foot position	**Mean & SD: No implement**	**Mean & SD : Gel Sock**	**Mean & SD: Gel Wedge**	**Mean diff b/w no implement & gel sock**	**Mean diff b/w no implement & gel wedge**
Flat foot	232.60 (SD 93.446)	278.13 (SD 96.390)	259.20 (SD 99.854)	45.53	26.6
Pointe position	943.67 (SD 895.636)	655.00 (SD 403.234)	700.00 (SD 447.148)	288.67	243.67

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