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Windlass mechanism in individuals with diabetes mellitus, peripheral neuropathy and low medial longitudinal arch height

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Abstract

Background—The windlass mechanism, acting through the plantar fascia, stabilizes the arches of the foot during stance phase of gait. The purpose of this study was to compare changes in radiographic measurements of the medial longitudinal arch (MLA) between toe-flat and -extended positions in participants with and without diabetes mellitus (DM), peripheral neuropathy (PN) and a low MLA.

Methods—Twelve participants with DMPN and low MLA and 12 controls received weightbearing radiographs in a toe-flat and toe-extended position. DMPN participants were subcategorized from radiographs into DMPN severe, evidence of severe joint changes, and DMPN low, absence of joint changes. Primary measurements of MLA were determined in each position and included Meary's angle, talar declination angle, first metatarsal declination angle, and navicular height.

Results—The DMPN severe group had no difference between toe-flat and -extended positions for Meary's, talar declination and first metatarsal declination angles ($p>0.35$) while navicular height elevated ($p<0.05$). The DMPN low group had no difference between toe-flat and -extended positions for talar declination angle ($p=0.38$), while Meary's angle, first metatarsal declination angle **and** navicular height elevated ($p<0.05$). All measurements in the control group changed, consistent with arch height elevation, **when toes were extended** ($p<0.05$).

Conclusion—The DMPN severe and low groups showed impaired ability to raise the arch from the toe-flat to -extended position. Further research is needed to examine the contribution of

specific windlass mechanism components (i.e. plantar fascia, ligament, foot joint integrity and mobility) as they relate to progressive foot deformity in adults with DMPN.

Keywords

Foot; Deformity; Radiograph

INTRODUCTION

The disability associated with acquired neuropathic foot deformities in individuals with diabetes mellitus is high. Diabetic peripheral neuropathy (DMPN), peripheral vascular disease, foot deformity and previous foot ulceration or amputations have all been cited as risk factors for new and recurrent lower extremity ulceration and amputation. Foot deformities in individuals with DMPN frequently occur along the medial longitudinal arch (MLA), which is formed by the calcaneus, talus, navicular, cuneiform and metatarsals one through three.²⁸ Little is known about the development of initial deformity or markers of deformity progression.^{2,21}

In addition to bone geometry, the MLA is maintained by several soft tissues, in particular the plantar fascia.^{16,22} The plantar fascia accounts for much of the functional stability of the MLA, especially when the metatarsal phalangeal joints are extended.^{15,16,30} The plantar fascia originates at the medial tubercle of the calcaneus and extends distally toward the forefoot, attaching to the toe flexor tendons, metatarsal heads, transverse head of adductor hallucis muscle and the deep transverse ligament, and also continues distally to insert at the plantar aspect of the base of the proximal phalanges.³ Tension through the plantar fascia as the toes extend contributes to first metatarsal plantarflexion and subtalar joint inversion, helping to transform the midfoot (transatarsal) joints into a rigid lever that is efficient in transmitting plantar flexor force during the stance phase of gait.^{9,20,25} This phenomenon of dynamic elevation or stabilization resulting from metatarsophalangeal joint extension is known as the windlass mechanism and is thought to be particularly important for MLA support during the toe-off phase of walking.^{15,19}

The plantar fascia and the windlass mechanism undergo changes in individuals with DM and PN. A number of researchers have reported an increase in plantar fascia thickness in those with DMPN.^{4,8,10} Chuter and Payne examined the windlass mechanism in individuals with DMPN with and without Charcot neuroarthropathy of the midfoot joints using Jack's test.⁷ To complete Jack's test, the individual being tested stands with weight on both feet and the tester passively maximally dorsiflexes the great toe while performing a visual assessment of MLA elevation.^{7,17} Chuter and Payne found that participants with Charcot neuroarthropathy did not have visible arch elevation when the toes were extended and that toe extension range of motion was decreased. These authors concluded that the presence of Charcot neuroarthropathy at the midfoot was associated with a loss of plantar fascia function and that loss of toe extension range of motion may contribute to the loss of function.⁷ In addition to changes in the plantar fascia and metatarsophalangeal joint mobility, joint limitations in the midfoot and hind foot could also contribute to impaired windlass mechanism function.²⁶ To our knowledge, no study has used radiographic measures to quantify changes in bony

alignment of the MLA during Jack's test in individuals with DMPN and low MLA or healthy control participants.

The purpose of this study was to compare windlass mechanism function by assessing change in radiographic measurement of the MLA's bony alignment during Jack's test in participants with diabetes, peripheral neuropathy and clinical measurements of low MLA to control participants without DM, PN or clinical measurements of low MLA. We hypothesized that radiographic measures of alignment in a toe-extended position would demonstrate MLA elevation compared to a toe-flat position and participants with DMPN would demonstrate less MLA elevation than controls.

MATERIALS AND METHODS

Participants

Twenty-four participants were recruited for this case control study between May 2010 and May 2012: a group with DM, PN and a low medial longitudinal arch (DMPN, n=12) and an age-, and weight-matched control group (n=12). Participants were included in the DMPN group by meeting the following criteria: 1. Type 1 or 2 diabetes mellitus, 2. Peripheral neuropathy, and 3. Clinical (non-radiographic) measurements of a low MLA. Participants were excluded if they had lower extremity amputations that included more than their toes, current plantar ulcers, unable to complete the testing required for study participation, weighed >180 kgs or had metal implants/pacemakers. Height and weight were measured, and BMI was calculated [weight (kg)/ height (m)²]. Presence of diabetes mellitus was confirmed by participant report of medical history and a hemoglobin A1c value >6%, (laboratory measure of the percent of glycated hemoglobin in serum). Peripheral neuropathy was defined as a loss of protective sensation and was determined by the inability to sense a 5.07 Semmes-Weinstein monofilament on at least one location on the plantar foot.²⁹ Clinical measurements of low MLA required that the individual meet at least two of the following four criteria (Figure 1): navicular height less than 24 mm (measured from the inferior surface of the navicular to the floor)²⁰; arch index (dorsal foot height/truncated foot length) less than 0.263⁶; longitudinal arch angle less than 130 degrees (angle formed by the medial malleolus, inferior portion of the navicular, and the first metatarsal head)¹⁸; and calcaneal eversion greater than 5 degrees while standing on both feet (angle between bisection of the calcaneus and the bisection of the lower leg in resting stance).¹⁸

Foot radiographs, described in detail below, were obtained. A foot and ankle fellowship trained orthopaedic surgeon (initials removed for blinding) subcategorized all DMPN participants into two groups; Individuals with radiographic evidence of severe tarsal joint changes (n=4) or 1st tarsal metatarsal joint changes (n=1) that would prevent midfoot joint motion or limit ability to engage the windlass mechanism (DMPN severe, n=5) and individuals without such joint changes (DMPN low, n=7). Each control participant had one foot designated as their involved foot. In the DMPN severe and DMPN low groups, if both feet met the criteria for low MLA, the foot that demonstrated lower MLA was used in our analysis. In general, the foot studied for the control group was selected to match the foot studied for the DMPN+ group. This study was approved by the Institutional Review Board at [blinded]. Informed consent was obtained for all participants.

Foot Radiographs

Weightbearing, lateral foot radiographs were taken in a toe-flat and toe-extended position with a board fixed at a 60-degree angle. A single member of the research team followed a clinical protocol and aligned the feet to standardize the foot positions for the radiographs.

The x-ray source was aligned parallel to the floor at the level of the foot—A radiopaque ruler, calibrated in millimeters (mm), was placed relative to the foot and used to adjust for magnification error. Radiographs were measured using iSite® Picture Archiving and Communication Systems (PACS) software (Philips Healthcare Informatics, Foster City, CA), which provided length measurements to the nearest 0.1 mm and angle measurements to the nearest degree. The following radiographic measurements were chosen because they provided a comprehensive examination of medial and lateral longitudinal arch alignment and tibial and first metatarsophalangeal joint position: ankle dorsiflexion angle, toe extension angle, Meary's angle, talar declination angle, first metatarsal declination angle, navicular height, calcaneal inclination angle, and cuboid height (Table 1 and Figure 2). Radiographs were measured by a single rater (initials removed for blinding), who was blinded to the group assignment. The rater completed a computer-based training session and demonstrated reliability compared to a foot and ankle fellowship trained orthopedic surgeon using sample radiographs and previously determined precision criteria¹⁴ prior to performing measurements.

Data analysis

Group differences in participant characteristics (age, height, and weight), tibial alignment in toe-flat position, tibial alignment and first metatarsophalangeal extension in the toe-extended position were compared using a one-way analysis of variance (ANOVA). A Chi-square was used to examine group differences for discrete variables (sex, race). A 3×2 (Group $\times$ Position) repeated measures ANOVA was used to examine the radiographic measures. Because we had particular interest in group differences for each position and in change in alignment between toe-flat and -extended positions, we report comparisons in that format. SPSS Statistics version 19 was used for all statistical analyses (SPSS Statistics Inc., Chicago, USA). A p value of <0.05 was considered significant for all comparisons.

RESULTS

Group demographics

The three groups did not differ in age, height, weight, or BMI; however the control group hemoglobin A1c values were significantly lower than the DMPN low group (Table 2). Average age was 57 ± 13 years in the DMPN low group, 63 ± 12 years in the DMPN severe group and 57 ± 14 years in the control group. All groups were classified as Class II obese, with DMPN low BMI $37 \pm 9 \text{ kg/m}^2$, DMPN severe BMI $40 \pm 8 \text{ kg/m}^2$ and control BMI $35 \pm 8 \text{ kg/m}^2$.

Tibia and hallux alignment

There was no difference in the tibia alignment relative to the floor between groups in the toe-flat and -extended positions. The amount of toe extension was not different between groups in the toe extended position (Table 3).

Toe-flat position

In the toe-flat position (Table 4), the DMPN severe group demonstrated lower Meary's angle, navicular height, calcaneal inclination angle and cuboid height **and greater talar declination angle** than controls ($p<0.05$). Alignment was lower in the DMPN severe compared to the DMPN low group for calcaneal inclination and cuboid height ($p<0.05$). The DMPN low group demonstrated a lower navicular height relative to the control group ($p<0.05$).

Toe-Extended Position

In the toe-extended position (Table 4), the DMPN severe group demonstrated a lower Meary's angle, navicular height, calcaneal inclination angle and cuboid height **and greater talar declination angle** relative to the control group ($p<0.05$). Alignment in the DMPN severe group was significantly lower for Meary's angle, calcaneal inclination angle and cuboid height **and higher for talar declination angle** compared to the DMPN low group ($p<0.05$). The DMPN low group demonstrated a lower Meary's angle and navicular height **and a greater talar declination angle** relative to the control group ($p<0.05$).

Within Group Comparison of Toe-flat to Toe-extended Position

Navicular height, calcaneal inclination and cuboid height were different between the toe-flat and -extended positions for each group (Table 4). Meary's angle and first metatarsal declination angle were higher in the toe-extended position compared to toe-flat position in the control group and the DMPN low group ($p<0.05$) but not different in the DMPN severe group. Talar declination angle was less (arch elevation) in the toe-extended position compared to toe-flat for the control group ($p<0.05$), but there was no difference between positions for either DMPN group.

Between Group Comparison of the Amount of Change Between Positions

The DMPN severe group demonstrated a smaller amount of change between toe-flat and toe-extended compared to controls for Meary's angle and navicular height ($p<0.05$, Table 4). The DMPN low group also had less change in calcaneal inclination compared to controls ($p<0.05$). There were no differences in amount of change across positions between DMPN low and DMPN severe groups. Note that these results are consistent with the finding of significant Group x Position interactions in the ANOVAs ($p<0.01$) for Meary's angle and navicular height. A representative participant from each group is shown in Figure 3.

DISCUSSION

This is the first study to examine the windlass mechanism using radiographic measurements of MLA alignment and height during passive toe extension in individuals with DMPN and a

low MLA and age- and weight-matched controls. Across groups, our data provides evidence of progressive loss of windlass mechanism function during passive toe extension. The control group demonstrated a change in alignment with the toe-extended position consistent with an arch rise across all **six** radiographic measures, compared to **five** of the **six** measures in the DMPN low group, and **three** of the **six** measures in the DMPN severe group. In light of these findings, we suspect that the windlass mechanism is intact but impaired in the DMPN low group, and is further impaired in the DMPN severe group.

Meary's angle

Meary's angle represents the angle formed between the head and neck of the talus and the shaft of the first metatarsal. A positive angle represents an arch where the apex is located dorsally, while a more negative angle represents an arch whose apex is plantar. Initial alignment of Meary's angle in DMPN low (−17 degrees), DMPN severe (−23 **degrees**), and control (−11 degrees) groups was markedly lower than the normative value of −4 to +4 degrees.¹¹ Although radiographic evidence is mixed,^{31,32} obesity has been associated with measures of lower arch height in adults¹ and children³¹ and could be the reason for the lower toe-flat Meary's angle in all groups.

Dynamic arch elevation requires normal midfoot and tarso-metatarsal joint mobility and a functional plantar fascia. The DMPN severe group in our study had a **one** degree change of Meary's angle during passive toe extension compared to **six** degrees of change in the DMPN low group and 10 degrees in the control group. During dynamic arch elevation, Meary's angle is expected to become less negative and may become positive.¹⁵ Meary's angle in the DMPN severe group remained at −22 degrees and DMPN low remained at −11 degrees even in the toe-extended position, compared to 0 degrees in the control group. Smaller rise and maintenance of a negative Meary's angle during toe extension in the DMPN groups indicates that the windlass mechanism is impaired. Future research is needed to assess the association of Meary's angle to arch stability and deformity progression.

Talar declination angle and first metatarsal declination angle

Talar declination and first metatarsal declination angles make up the hindfoot and the forefoot components of Meary's angle (Figure 2). We measured talar declination and first metatarsal declination angles individually to gain a regional understanding of arch elevation. The talar declination angle and the first metatarsal declination angle were both measured in relation to a common reference line to allow for direct comparison of the changes under each condition in both groups of participants. The starting talar declination angle was greater (more declined) and it did not change between toe-flat and -extended positions in the DMPN severe and DMPN low groups, while talar declination angle decreased (distal aspect of the talus became less declined) with passive toe extension in the control group. First metatarsal declination angle, in contrast, elevated similarly in all groups when the windlass mechanism was engaged.

Inability of the talus to incline during toe extension in the DMPN groups was an intriguing finding. Initial weightbearing talar alignment may be a potential contributing factor to decreased rise of talar declination angle in individuals with DMPN. A low initial

weightbearing talar alignment reflects compromised passive restraints, in particular the spring ligament, which are critical in maintaining the MLA in static standing¹⁶ and in force transmission as the toes are extended. Jack et al noted that a talo-navicular break (increased talar declination without changes in navicular, medial cuneiform and first metatarsal alignment) would not have sufficient leverage to elevate the arch during toe extension.¹⁷ However, we did not find a relationship between severity of talar declination and amount of talar rise during toe extension. Interestingly, three individuals with the greatest talar declination (average of 49 ± 1 degree) had elevation of the talus during toe extension comparable to the control group (-5 ± 3 degrees). This evidence, in conjunction with previous work finding worsening of Charcot deformity beyond the typical period of immobilization,¹³ suggests what were once thought to be fixed deformities are in fact mobile and at risk for progression.

Given that both groups with DMPN demonstrated limited rise in the talus during toe extension, we believe the cause may be the systemic effects of advanced glycation end-products. Advanced glycation end-products are thought to accumulate in tissues (i.e., extra cellular matrix, connective tissue, skin, and tendons) making them thicker, stiffer and weaker.^{5,27} Achilles tendon pathology and limited dorsiflexion range of motion in individuals with DMPN is common and could affect talar movement by preventing calcaneal inclination and related hind foot movement.^{10,23} To the best of our knowledge, there are no previous studies determining the association between joint and soft tissue mobility limitations and windlass mechanism function. Future effort towards development of a reliable and valid strategy to measure midfoot mobility is warranted. Such a tool would provide critical information toward understanding the location, chronology, and degree of progression in this susceptible population.

Navicular height

Navicular height mirrored Meary's angle findings; the control group demonstrated the highest starting height and greatest elevation between toe-flat and toe-extended positions, followed by DMPN low group and the DMPN severe group. Menz found a mean navicular height of 31.1 ± 6.5 mm in a sample of 95 older individuals using radiographs in a toe-flat position, which is comparable to our control group [30.1 ± 6.8 mm] and larger than the DMPN low group [22.8 ± 6.1 mm] and DMPN severe group [20.9 ± 9.8 mm].²⁰ Standard navicular height in a toe-extended position is unknown. One benefit of using navicular height as a measurement criteria is that it can be measured clinically as well as radiographically.²⁴ Hicks depicted the rise of the navicular in his initial descriptions of the windlass mechanism.¹⁵ Future research examining clinical measurements of navicular height in toe-flat versus toe-extended positions is warranted, as it may be a clinically feasible way to screen for initial onset of impairment in the windlass mechanism and a risk of developing medial column deformity.

Lateral longitudinal arch and lateral column of the foot

The bones of the lateral column of the foot include calcaneus, cuboid and metatarsals four and five. We used cuboid height as our radiographic measure of lateral column alignment and change in lateral longitudinal arch height. We found that although the starting alignment

of the cuboid was significantly lower in the DMPN severe group [-1.5 ± 11.2 mm] compared to the DMPN low group [7.2 ± 2.7 mm] and the control group [11.7 ± 3.5 mm], the amount of elevation of the lateral longitudinal arch with passive toe extension was comparable between groups. In general, the effect of passive toe extension on lateral column elevation (DMPN severe 2.3 mm, DMPN low 2.5 mm and controls 1.7 mm) was smaller than its effect on medial column (navicular) elevation (DMPN severe 3.9 mm, DMPN low 7.1 mm and controls 10.1 mm). While lateral column deformity was not the intended scope of this study, it could be another important component in gaining a better understanding about onset and progression of diabetic, neuropathic midfoot deformity since many ulcerations occur beneath the cuboid and base of the fifth metatarsal.

Limitations

This study does not assist us in understanding the reason for diminished MLA elevation when the toes are passively extended. Changes that occur in the plantar fascia and soft tissues affecting the foot and ankle joints as a result of advanced glycation end-products, as well as more severe Charcot joint disruption causing joint ankylosis are all potential factors that can contribute to an impaired windlass mechanism, and thus all may be important **components** in progressive midfoot deformity in the DMPN population. If progressive impairment of the windlass mechanism contributes to midfoot deformity, then further research about the timing and relationship of tissue changes relative to arch function is warranted, with a goal of targeted intervention and prevention. Given that midfoot deformity is progressive in nature, it will be necessary to capture a larger study sample and follow participants longitudinally, as well as track changes in individual components critical to a functional arch rise, including forefoot, midfoot and hindfoot joint integrity and flexibility and plantar fascia function.

Our groups' inclusion and exclusion criteria limit generalizations of the study findings. Individuals with low arches were excluded from the control group, so comparisons of windlass mechanism function between individuals with a DMPN pes planus and non-DMPN pes planus population cannot be made. Likewise, low MLA in the DMPN group was defined by clinical measurements. Thus the DMPN groups may include individuals with diabetes and peripheral neuropathy who had a pre-existing pes planus foot structure. In addition, we did not include a non-obese, low arch control group; therefore our findings may not reflect the alignment and behavior of the foot in a normal weight population. Given the many variables that could contribute to changes in foot function, an important next step would be to make similar comparisons in normal weight individuals who exhibit normal arch height compared to low MLA height.

We also acknowledge the limitations of our measurement techniques. Our radiographic measurements were restricted to the sagittal plane in the toe-flat and -extended position, therefore our data may not fully describe any bony rotation or translation that may be occurring out of the plane of the x-ray or between positions. Future research using techniques that would allow simultaneous measurement of all bones along multiple planes and time points would give more detailed insight into the mechanics of MLA elevation in this population.¹²

CONCLUSION

Participants with DMPN and low MLA with and without severe joint changes demonstrate less arch elevation radiographically than non-diabetic age- and weight-matched controls when passive toe extension is used to engage the windlass mechanism. Specific causes behind the impaired windlass mechanism are still unknown, and further research is needed to understand the multi-factorial nature of a functional windlass mechanism (plantar fascia integrity, foot joint mobility) in adults with diabetes and peripheral neuropathy who are at risk for progressive acquired neuropathic foot deformity.

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Figure 1.

To qualify as low medial longitudinal arch height, the individual had to meet at least two of the following clinical (non-radiographic) measurements: navicular height (NH) less than 24 mm; arch index (dorsal foot height(DFH)/truncated foot length(TFL)) less than 0.263; longitudinal arch angle (LAA, in black) less than 130 degrees; and calcaneal eversion (CE) greater than 5 degrees (angle between bisection of the calcaneus and the bisection of the lower leg in resting stance). Dorsal foot height (DFH) is the height of the foot at 50% of foot length (FL)

Figure 2.

Radiographic foot measurements. Figure 2A demonstrates a toe-extended radiograph, with tibia to floor angle (T) and toe extension angle (TE). Figure 2B demonstrates all other angular and height measurements. Height measurements are in white, angular measurements in black, and reference line is indicated by thick black dotted line. Measurements include Meary's angle (M), first metatarsal declination angle (MD), talar declination angle (TD), navicular height (N), cuboid height (C) and calcaneal inclination angle (CI).

Figure 3.

A wide range of foot deformity was measured. Depicted in this figure are A) a control subject, B) an individual with DMPN who has low MLA, C) an individual with DMPN who has low MLA and severe deformity. Meary's angle takes into account both the position of the hind foot (talus) and the forefoot (first metatarsal). With passive toe extension, all Meary's angles moved in a positive direction, indicating arch rising. However, Meary's angle for participants B and C remain negative.

Table 1

Description of radiographic measurements

Measurement	Description
Tibia angle (T)(Fig 2A)	Angle between the long axis of the tibia and the weightbearing surface.
Toe extension (TE) (Fig 2A)	Angle between the long axis of the first metatarsal and the long axis of the first proximal phalanx.
Meary's angle (M)(Fig 2B)	Angle between the long axis of the talus and the first metatarsal.
Talar declination angle (TD) (Fig 2B)	Angle between the long axis of the talus and the reference* line.
First metatarsal declination angle (MD) (Fig 2B)	Angle between the long axis of the first metatarsal and the reference* line.
Navicular height (N) (Fig 2B)	Perpendicular distance to the inferior aspect of the navicular from the reference* line.
Calcaneal inclination angle (CI) (Fig 2B)	Angle between a line from the plantar most aspect of the calcaneus to its distal articulation with the cuboid, and the reference* line.
Cuboid height (C) (Fig 2B)	Perpendicular distance to the inferior aspect of the cuboid from the reference* line.
*Reference line (Fig 2B)	Straight line between the plantar most aspect of the calcaneus and the inferior aspect of the fifth metatarsal head.

Table 2

Group differences in participant characteristic

	DMPN Severe	DMPN with low MLA	Control	p-value
Age(yr)	63 (12)	57 (13)	57 (14)	1.0
Sex (Male/Female)	3/2	4/3	8/4	0.67
Height (m)	1.70 (0.09)	1.70 (0.09)	1.74 (0.11)	1.0
Weight (kg)	114 (26)	107 (25)	108 (30)	1.0
Body Mass Index (m/kg ²)	40 (8)	37 (9)	35 (8)	1.0
Duration of DM	13 (11)	21 (11)		0.30
HbA1c(%)	6.7 (1.2)	9.1 (2.9)	5.2 (1.7)	<0.01 (DMPN low MLA vs Control)

Table 3

Tibia and Hallux alignment

	DMPN Severe	DMPN with low MLA	Control	p-value
Tibia to floor angle (degrees) Toe flat	84 (4)	87 (6)	84 (4)	0.46
Tibia to floor angle (degrees) Toe extended	86 (4)	89 (5)	87 (4)	0.80
Great toe extension (degrees)	60 (20)	58 (13)	60 (10)	1.0

Table 4

All comparisons (within group and between group)

	Toe flat position: Between group comparison				Toe extended position: Between group comparison			Within group comparisons between positions				Between group comparison in amount of change between positions		
	DMPN Severe deformity n=5		DMPN with low MLA n=7		Control n=12		DMPN severe deformity	DMPN with low MLA		Control	p-value	DMPN severe deformity	DMPN with low MLA	Control
Meary's (degrees)	-23 ^a (16)	-17 (6)	-11 (5)	-22 ^a ^b (11)	-11 ^c (6)	0 (6)	.52	<0.01	<0.01	<0.01		1 ^a (8)	6 (5)	10 (3)
Talar declination (degrees)	39 ^a (15)	32 (5)	27 (4)	38 ^a ^b (10)	30 ^c (5)	22 (5)	.63	0.38	<0.01	<0.01		-1 (6)	-2 (5)	-6 (4)
First metatarsal declination (degrees)	15 (2)	15 (4)	17 (3)	17 (4)	19 (5)	21 (4)	.35	<0.01	<0.01	<0.01		1 (3)	4 (3)	4 (2)
Navicular height (mm)	20.9 ^a (9.8)	22.8 ^c (6.1)	30.1 (6.8)	24.8 ^a (11.4)	29.9 ^c (5.8)	40.3 (6.2)	.03	<0.01	<0.01	<0.01		3.9 ^a (3.5)	7.1 (4.3)	10.1 (3.5)
Calcaneal inclination (degrees)	6 ^a ^b (9)	14 (3)	18 (6)	8 ^a ^b (8)	17 (4)	20 (6)	<.01	<0.01	<0.01	<0.01		2 (1)	3 ^c (1)	2 (2)
Cuboid height (mm)	-1.5 ^a ^b (11.2)	7.2 (2.7)	11.7 (3.5)	0.9 ^a ^b (9.9)	9.6 (3.0)	13.3 (3.3)	<.01	<0.01	<0.01	<0.01		2.3 (2.1)	2.5 (1.2)	1.7 (0.8)

All comparisons (within group and between group)

^aDMPN severe deformity is different than Controls (p<0.05)
^bDMPN severe deformity is different than DMPN with low MLA (p<0.05)
^cDMPN with low MLA is different than Controls (p<0.05)