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The Frequency of Subtalar Joint Instability in Adult Patients Who Underwent Surgical Correction of First Metatarsophalangeal Joint Surgery-a Retrospective Radiographic Evaluation

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Abstract

Objective: Subtalar joint instability creates misalignment of talus on the calcaneus. The loss of talar alignment and stability leads to a prolonged period of foot pronation during the stance phase of the gait cycle. Over or hyperpronation is known as a contributing factor to the progression of hallux valgus (HV) and hallux limitus/rigidus (HL/R). The purpose of this retrospective radiographic study is to evaluate the number of adult patients (feet) diagnosed with HV and HL/R who underwent surgical correction within a one year period.

Methods: Pre-operative weightbearing radiographs for one-hundred five feet, that met the inclusion criteria, were retrospectively analyzed. Both transverse (talar second metatarsal (T2M)) and sagittal (talar declination (TD)) plane angular measurements were independently calculated and compared to normal values based on literature.

Results: In this study, 97 (92.38%) of 105 feet with HV and HL/R had values above normal for at least one of the T2M and/or TD angle indicating an abnormal talar alignment. The mean T2M was 21.88 ± 7.95 (range 1.13 to 50.58 degrees) and the mean TD was 23.45 ± 3.94 (range 14.75 to 34.24 degrees). Forty (38.1%) feet exhibited a single plane deformity and 57 (54.28%) comprised of a both transverse and sagittal plane deformities.

Conclusion: This supports the hypothesis that a correlation between subtalar joint instability and HV or HL/R exists. This hind foot deformity should be considered as a contributing factor in the progression of 1st MPJ pathology.

Keywords: Hallux valgus; Hallux limitus; Hallux rigidus; Subtalar joint instability; Hyperpronation; Radiographic measurements

Introduction

Hallux valgus (HV) and hallux limitus/rigidus (HL/R) are some of the most commonly reported chronic foot disorders. [1,2]. Prescribed treatment options vary based on the severity of symptoms and the degree of structural pathology [3]. Most options focus on correcting the local pathomechanic issue at the 1st metatarsophalangeal joint (1st MPJ) and alleviating the associated pain. The prevalence of 1st MPJ disorders has been increasing and is expected to increase in the future with the aging society.

Pronation of the subtalar joint creates an "unlocking" of the joints of the hind and mid foot, whereas supination creates a "locking" or stiffness of those same joints. A loss of stability of the talus on the calcaneus and/or navicular (tarsal mechanism) can lead to a prolonged period of pronation during the stance phase of the gait cycle [4,5]. A primary factor for the progression of both HV and HL/R is over-pronation [6-9]. The excessive subtalar joint pronation can also lead to increased forces on the 1st MPJ and/or the 1st metatarsocuneiform joint (1st MCJ) [10-16].

The purpose of this retrospective study is to evaluate the possible association between pathologic subtalar joint alignment and HV and HL/R. The presence of higher than accepted normal (≥ 17 degrees) weightbearing talar-second metatarsal (T2M) and/or talar declination (TD) angles (≥ 22 degrees) in patients diagnosed with HV and HL/R can be considered an indication of abnormal hindfoot alignment [17].

Patients and Methods

After receiving institution review board approval, the weight bearing relaxed stance position (RSP) dorsoplantar (DP) and lateral radiographs of a total of 105 feet from adults, 18 years of age and older, were specifically diagnosed with 1st MPJ pathology, HV and HL/R. A diagnosis of HV and hallux limitus-rigidus (HL/R) was made via clinical and radiographic examination. Specifically, the diagnosis of HV was based on DP X-ray measurements of the 1st intermetatarsal angle, >9 degrees, and hallux abductus angle >25 degrees [18-20]. Only the feet of patients who underwent surgical correction and met the inclusion criteria, were analyzed. The consecutive patient selection was based on ICD 9 (International Classification of Diseases, World Health Organization, Geneva, Switzerland) (735.0, 735.2) and CPT® (Current Procedural Terminology, American Medical Association, Chicago, IL) (28290, 28293, 28296) codes at the Louis Stokes Cleveland VA Medical Center (Cleveland, OH) from 01/2011 to 12/2011.

The radiographs were then collected and independently evaluated (HMK). Only the patients (feet) who had no history of an acute trauma

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to their 1st MPJ or previous foot surgery were included. Patients were excluded if they had trauma to their 1st MPJ or previous foot surgery. A total of one-hundred-and-five feet met the inclusion criteria.

Determination of radiographic angles

The talar declination (TD) and talar-second metatarsal (T2M) angles were used to determine subtalar joint alignment (Figures 1 and 2). These angles were selected because they provide an accurate representation of sagittal and transverse plane alignment of the subtalar joint. The T2M angle was measured from the DP preoperative radiographs (transverse plane) and the TD angle was measured from the lateral preoperative radiographs (sagittal plane). Both angles were independently measured using software that is part of the VistA Computerized Patient Record System, version 1.0.28.24 by a single individual (HMK) (Table 1, Table 1, Figures 3-5).

Data analysis

The angles calculated from the radiographs for patients in both groups were compared to the normal values based on literature [21-25]. A T2M angle ≤ 16° and the TD angle ≤ 21° would be considered "normal". Thus, T2M angles greater than ≥ 17° and/or TD angles higher than ≥ 21° may indicate the presence of subtalar joint instability. While a clinical determination of a pathologic angle that is 1 degree difference between normal and abnormal will not alter the treatment, however a "line in the sand" must be made for determining normal and abnormal. For the patient population, the percentage of occurrence of values higher than the normal values in at least one view (DP or lateral) was calculated.

Once a total percentage was calculated, the presence of the deformity was further analyzed with respect to the plane of dominance, if any. Pathologic values of the T2M angle indicates deformity in the transverse plane while pathologic values of the TD angle indicates deformity in the sagittal plane [21-25]. Transverse plane dominance was identified when the radiographs for a single patient showed a higher than normal T2M angle and a TD angle within the normal range. Alternatively, sagittal plane dominance was identified with only a higher TD angle coupled with a normal T2M angle. Pathologic T2M and TD angles together indicate deformity in both planes.

Statistical Analysis

The data was tested for normality using the Kolmogorov-Smirnov test to determine distribution of the sample population. For normally distributed data, a t-test was used to determine the statistically significant difference between angle values higher than normal and values less than or equal to normal within a group of patients. The Mann-Whitney Rank Sum test was used for data that was not normally distributed. Statistical analysis was conducted using SigmaStat Software, version 3.5 (Systat, Chicago, Illinois) (JS). Statistical significance was defined at the 5% ($p \leq 0.05$) level.

Figure 1: Weight bearing lateral radiograph of the foot. The method for measuring the talar declination angle is shown.

Figure 2: Weightbearing dorsoplantar radiograph of the foot. The method for measuring the talar second metatarsal angle is shown.

Results

Frequency of occurrence

Ninety-two (88%) of the 105 feet diagnosed with HV or HL/R had one or more pathologic angle and only 13 (12%) feet had normal T2M and TD angles (Table 2 and Figure 6). The mean T2M was 22 ± 8 (range 5 to 51 degrees) and the mean TD was 23 ± 4 (range 15 to 34 degrees). The radiographic angles were separated into two sub-groups; pathologic and acceptable normal values. The T2M angle was higher than the normal values in 76 (73%) feet and the TD angle was abnormal in 69 (64%) feet. The number of feet with pathologic and normal values were compared to obtain the frequency of occurrence of these values for feet diagnosed with a HV and HL/R (Table 3 and Figure 7). Forty (38%) of the feet had a single plane involvement and 52 (50%) feet exhibited both transverse and sagittal plane deformities (Table 4 and Figure 8).

Statistical significance

An equal number of feet were considered to test statistical correlation between pathologic radiographic angles and acceptable values. The mean values for T2M and TD angles were calculated. It was seen that there was a statistically significant difference between the normal T2M values (≤ 16 degrees) and the abnormal T2M values (≥ 17 degrees) for both groups of feet. Moreover, the abnormal TD angle values were statistically different than the normal TD angles. This test helps to further validate the data results.

Planar dominance

Planar dominance was also analyzed for abnormal transverse and

Foot #	Talo-2nd Met	Talar declination	Foot #	Talo-2nd Met	Talar declination	Foot #	Talo-2nd Met	Talar declination
1	28	18	36	23	20	71	14	21.74
2	18	24	37	14	18	72	51	14.75
3	19	24	38	15	23	73	47	17.74
4	22	24	39	12	27	74	20	27.24
5	26	24	40	35	24	75	18	28.01
6	26	26	41	37	21	76	24	17.03
7	16	20	42	14	17	77	29	24.67
8	24	24	43	16	21	78	32	21.58
9	19	22	44	27	18	79	19	19.75
10	29	19	45	31	16	80	18	20.9
11	23	20	46	24	22	81	22	24.15
12	11	19	47	27	23	82	22	25.85
13	11	20	48	18	32	83	32	23.59
14	17	21	49	18	25	84	25	26.51
15	7	22	50	27	23	85	29	24.91
16	37	26	51	24	30	86	30	24.1
17	27	23	52	30	32	87	24	22.34
18	25	24	53	34	27	88	26	19.25
19	15	30	54	24	26	89	16	16.18
20	15	30	55	27	25	90	14	21.25
21	22	21	56	23	22	91	13	21.28
22	22	26	57	1	25	92	5	22.6
23	25	31	58	5	27	93	28	18.85
24	29	21	59	22	30	94	29	20.49
25	29	22	60	25	23	95	29	22.07
26	23	18	61	12	24	96	23	32
27	15	26	62	11	21	97	28	34.24
28	19	22	63	22	28	98	20	24
29	19	32	64	26	24	99	24	25.57
30	25	26	65	23	23	100	24	28.54
31	10	23	66	11	23	101	12	28.72
32	23	27	67	21	20.88	102	16	27.81
33	26	26	68	25	27.65	103	13	20.69
34	16	19	69	15	22.76	104	20	21.45
35	16	20	70	21	19.93	105	21	22.03
						Mean	22	23
						Standard deviation	8	4

Table 1: Radiographic measurements.

sagittal plane deformities (Table 5 and Figure 9). Of the 92 (88%) feet that exhibited abnormal radiographic angle, 40 (38%) exhibited a single plane deformity and 52 (50%) comprised of a both transverse and sagittal plane deformity. A trend was identified in feet diagnosed with a HV and HL/R. Twenty-five (24%) feet showed only a transverse plane displacement and a sagittal plane deformity was seen in 15 (14%) feet. Finally, 52 (50%) feet showed evidence of a subtalar joint misalignment in both the transverse and sagittal planes.

Discussion

The talotarsal joint (TTJ) is formed by the articular surfaces of the talus with both the calcaneus and navicular. This complex mechanism is responsible for the redistribution of the proximal vertical forces posteriorly and anteriorly [26-27]. A second function of the TTJ is the locking-stabilizing supinatory and unlocking-weakening pronatory motions. There are specific periods during the gait cycle when the TTJ should be pronated and other times supinated [28-30]. The stability of the TTJ will therefore determine the amount of supination or pronation, as well as the redistribution of the vertical forces posteriorly and anteriorly.

The sinus tarsi, a canal formed by the talus and calcaneus, acts as dividing landmark or fulcrum point for the posterior and anterior joint forces. It has been estimated that approximately 52% of the vertical forces, in a stable-aligned TTJ, should pass through the body of the talus onto the posterior talocalcaneal joint, at heel strike and the remaining 48% of the forces should pass anteriorly [31].

Subtalar joint instability leads to the dynamic displacement of the talus on the calcaneus and/or navicular. During the gait cycle a reloading of joint forces occurs when the talus resupinates on the tarsal mechanism. The excessive subtalar joint motion will occur immediately after heel strike. The talus loses its normal stability and alignment on the tarsal mechanism (Figure 10). It will remain in an unlocked pronated position longer than it should during the weight bearing portion of the gait cycle. This leads to increased forces acting anteriorly [32]. The soft and osseous foot structures will be forced to compensate for the result-

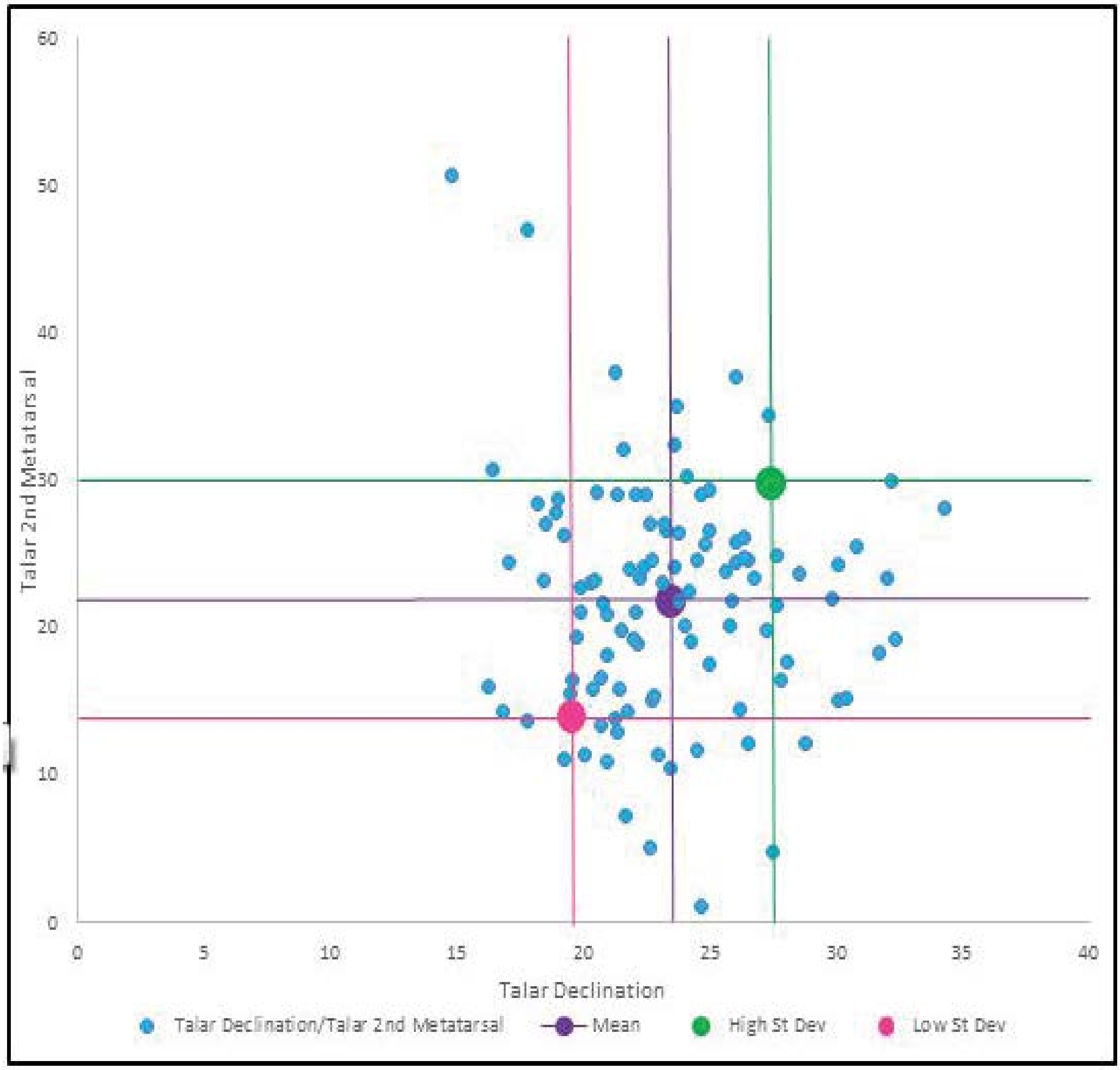

Figure 3: Scatter plot of values per foot (talar 2nd metatarsal and talar declination).

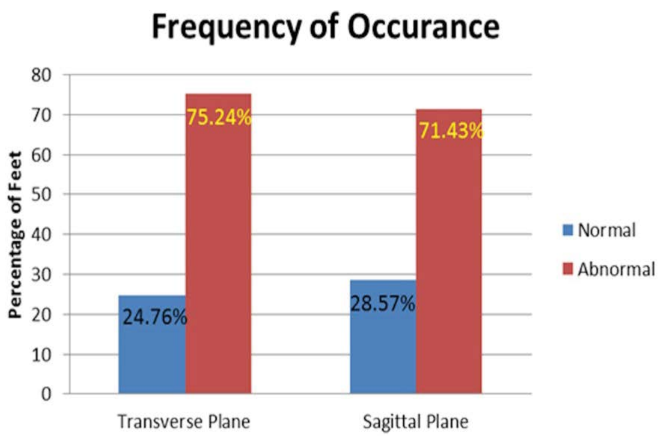

Figure 4: Graphical presentation of Table 1.

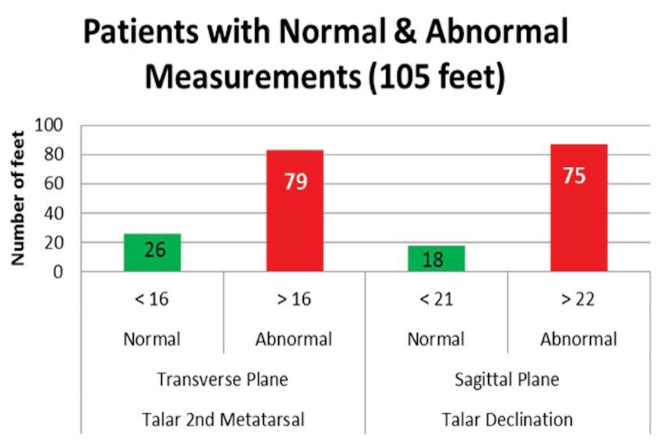

Figure 5: Graphical presentation of Figure 3.

Comparison of Normal to Abnormal Measurements	n	
Normal T2M and TD Angles	13	12%
Abnormal T2M and/or TD Angle	92	88%

Table 2: Number and percentage of feet exhibited normal or abnormal radiographic measurements.

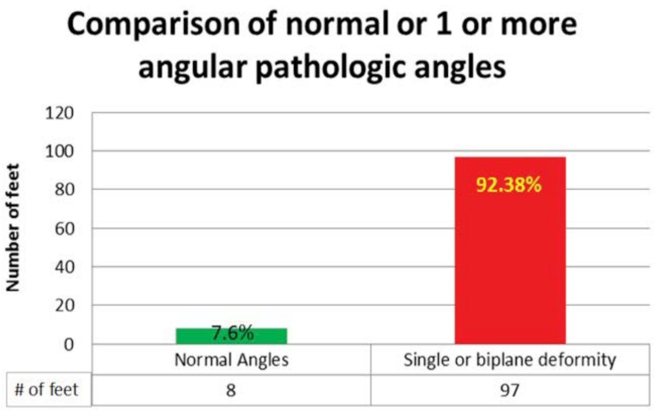

Figure 6: Graphical presentation of Table 2.

Frequency of Occurrence	n	
Transverse Plane		
Normal (≤ 16°)	29	27%
Abnormal (≥ 17°)	76	73%
Sagittal Plane		
Normal (≤ 21°)	36	36%
Abnormal (≥ 21°)	69	64%

Table 3: The frequency of transverse and sagital plane abnormal findings.

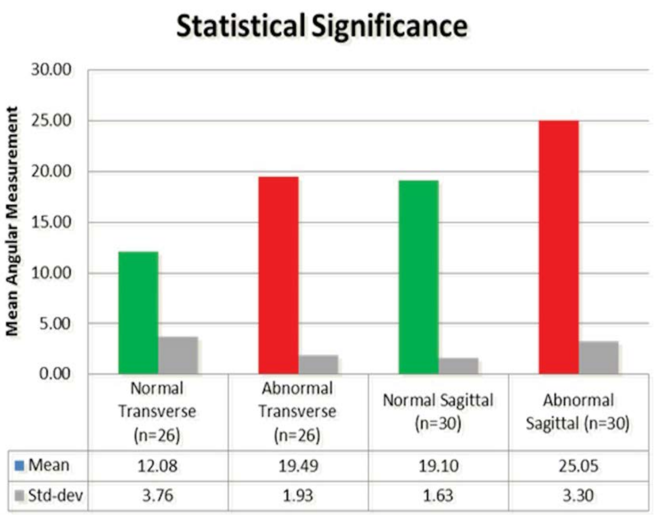

Figure 7: Graphical presentation of Table 3.

Frequency of Normal Verse Plane(s) of Deformity	n	
Normal	13	12%
Single plane deformity	40	38%
Biplane deformity	52	50%

Table 4: Number and percentage of normal, or planar dominace of abnormal radiographic findings.

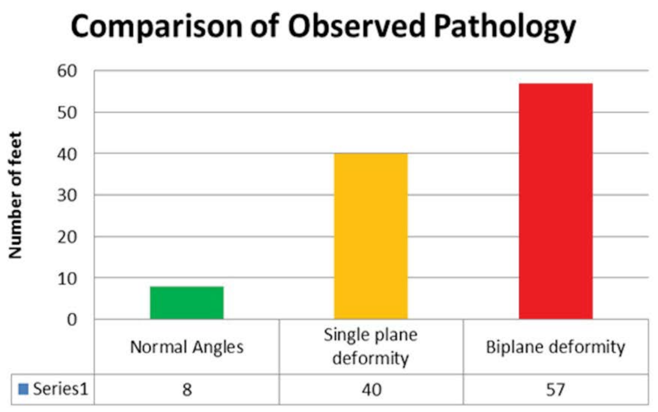

Figure 8: Graphical presentation of Table 4.

Planar Dominance	n	
Transverse only	25	24%
Sagittal only	15	14%
Both Transverse and Sagittal	52	50%

Table 5: Number and percentage of single or biplane plane(s) of deformity.

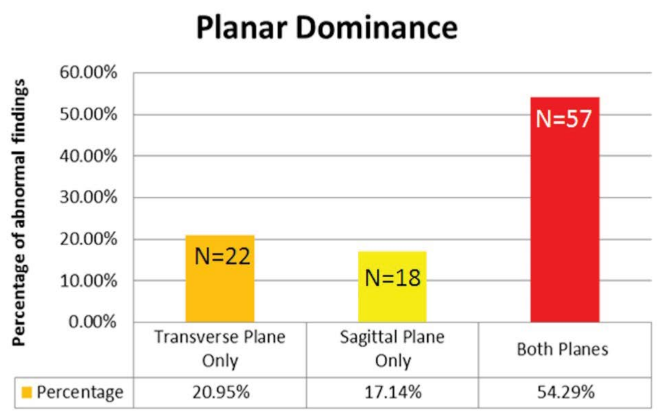

Figure 9: Graphical presentation of Table 5.

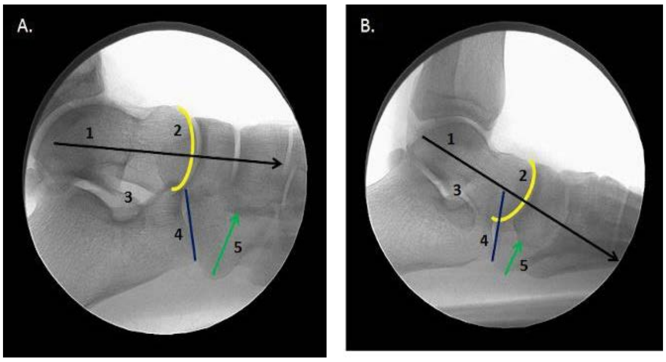

Figure 10: Lateral weightbearing fluoroscopic image. (A) Simulating heel strike: Talus is aligned on the calcaneus, 1. Bisection of the talus, 2. Anterior head of the talus used to compare to the 4. Anterior end of the calcaneus. 5. Indicated the plantar aspect of the navicular to the plantar aspect of the cuboid (3). Sinus tarsi. (B) Mid-stance full weightbearing image 1. Pathologic increase of the talar declination (> 21 degrees), 2. anterior deviation of the talus compared to 4. anterior end of the calcaneus. 5. Plantar sag of the navicular. The sinus tarsi space is obliterated (3).

ing excessive forces in an attempt to resupinate the talus for heel lift [33,34].

The determination of subtalar joint stability and alignment can be assessed by non-weightbearing and weight bearing examination. However, it is difficult to quantify the degree of deformity from observer to observer. For that reason, the diagnosis of subtalar joint instability should be confirmed with standardized and validated weight bearing radiographic analysis. The dorsoplantar (DP) talar second metatarsal (T2M) angle is formed between the longitudinal bisection of the second metatarsal and the bisection of the talus. The T2M angle is a reliable measurement to determine rear- to forefoot alignment. Values > 16 degrees are considered a pathologic transverse plane deformity. This indicates an abnormal adduction of the talus and abduction of the forefoot [21,23].

The lateral weightbearing radiograph determines a sagittal plane component. The sinus tarsi space should be present or "open" in a foot with an aligned TTJ. There are no specific quantifiable measurements, but a partially obliterated sinus tarsi can be an indication of a misaligned subtalar joint. The talar declination angle (TD) is a quantifiable measurement formed by the bisection of the longitudinal axis of the talus and the plane of support. The accepted value for the TD angle is ≤ 21° [21,24,27]. Any value >21 degrees was considered abnormal.

Hallux valgus (HV) is a pathologic condition where there is a valgus rotation and abduction of the hallux on the first metatarsal. It is usually described as a deformity acquired by abnormal biomechanics at the first metatarsophalangeal joint (MPJ) [35]. HV is often believed to be caused by the use of improper or fashionable footwear [36]. However, this cannot be targeted as the primary reason as the deformity is not necessarily seen in all the population wearing such footwear. It has also been suggested that there exists a relationship between collapse of the medial longitudinal arch and development of HV [37]. It is further believed that intrinsic factors like pes planus, equinus, flexible or rigid pes planovalgus, rigid or flexible forefoot varus, hypermobility of the first metatarsal or a short first metatarsal can be some of the contributing factors that may lead to or exacerbate HV [9,38-41].

There exists much controversy as to the ideal "bunion" treatment [42]. The current HV treatment paradigm has been called into question due to a diversity of mid- and long-term outcomes [43,44]. This is due to the variability of post-treatment results. One of the potential complications of HV surgery is recurrence that is associated with the most common bunion correction techniques [45,46]. It has been said that there are so many different methods described to fix HV because there is lack of agreement on the correction of choice.

The primary goal of hallux valgus surgery is the realignment of the hallux and the 1st metatarsal. However, little attention is given to addressing any underlying or co-existing hindfoot pathology, such as subtalar joint instability. A connection between subtalar or TTJ instability and forefoot pathology has been identified [47]. Coskun et al. also found that "increasing HV angle and pathomechanical changes in the rear foot are correlated, resulting in increasing pain and thus decreasing functional status as well as decreasing quality of life" [48].

Functional hallux limitus and rigidus (HL/R) is 1st MPJ disorder also linked to pathologic hindfoot position/motion [49]. There is an impaction of the head of the first metatarsal into the base of the proximal phalanx resulting in joint spacing narrowing. This 1st MPJ disease is often reported as an osteoarthritis condition. The tissue destruction is due to the years of "wear-and-tear" on the 1st MPJ due to excessive joint forces.

The data from this study helps to establish a connection that abnormal subtalar joint alignment is found in a majority of patients diagnosed with 1st MPJ pathology. Ninety-two (88%) feet with HV and HL/R had higher than the normal values of at least one of the two measured angles. It stands to reason that hind foot instability leads to a prolonged period of instability of the joints of the mid and forefoot and can increase the forces acting on the 1st MPJ during the gait cycle.

In a cadaver study by Graham et al, it was shown that stabilization of the subtalar joint led to a reduction of excessive abnormal forces acting on the middle and anterior talocalcaneal joint [31]. This should also lead to decreased strain on the osseous structures and soft tissues of the medial column of the foot. Arangio et al. showed 37% load under the 1st MPJ in a "flat foot" compared to 12% load for a normal foot [34]. Thus, reduction in pathologic forces acting on the medial column should lead to a reduction in secondary deformities associated with the medial column. The majority of the patient's in this study had some form of talotarsal joint pathologic measurement indicating an excessive pronating subtalar joint. As Gould concluded in his study "Hyperpronation may exist without pes planus but, pes planus rarely is present without some degree of hyperpronation". Not all patients with a hyperpronating subtalar joint will have a lower than normal arch. That is because it is possible to have subtalar joint pronation without the navicular dropping and a normal or higher than normal calcaneal inclination angle [50].

It has been the author's experience that the use of a sinus tarsi stent to stabilize the hind foot has had a positive effect in reducing mild increases the 1st intermetatarsal angle. Other times, it is possible to perform the sinus tarsi stent insertion, observe a reduction of the 1st intermetatarsal angle. If there is not a reduction, then an appropriate form of surgical correction can be performed as a staged procedure. Finally, there are other situations where a semi-rigid or fixed deformity of 1st metatarsocuneiform joint requires surgical intervention at the same surgical setting.

A similar approach to hallux limitus can be offered to a patient. This depends on the degree of the deformity. Hind foot stabilization with a sinus tarsi stent should have a positive effect to the 1st MPJ range of motion. More research is required to substantiate this claim, but the biomechanics make sense as the talus shifts distally ultimate force the head of the 1st metatarsal into the base of the proximal phalanx. Again, a semi-rigid or rigid loss of motion at the 1st MPJ would require additional surgical intervention.

A limitation of this study was that only weight bearing radiographs were evaluated and clinical observations were not available. The clinical range of motion measurements taken would be purely subjective rather than the objective data from standardized weight bearing radiographs and therefore non-contributory to the study. Clinical grading of the severity of the HV and HL/R was not taken into consideration. Yet, the patient's symptoms and 1st MPJ deformity was such that surgical intervention was desired for all participants in the study.

This study did not evaluate the presence or absence an equinus component, but that was not the purpose of this study. Further research is needed to evaluate the role, if equinus would contribute to 1st MPJ pathology. Another limitation was the failure to exclude acute traumatic episode that contributed to the 1st MPJ disease. It cannot be assumed that all of the feet had atraumatic induced 1st MPJ deformity. None of the patients included had a specific recollection of a traumatic episode that led to their 1st MPJ deformity.

The body-mass-index (BMI) is another factor that can be taken into consideration. The greater the BMI, the greater the forces acting on the 1st MPJ. This data was not factored into this study but would be interesting to note. One would assume that a greater BMI would result in an increase force acting on the anterior rather than the posterior joint facets in a patient with subtalar joint instability.

Conclusion

The data from this study supports the hypothesis that a significant number of feet diagnosed with HV and HL/R also have subtalar joint instability. While the exact nature of any clinical significance is to be determined, there is an argument to be made that the "hindfoot controls the forefoot" and it is possible that excessive hindfoot motion could lead to increased forces acting on the 1st MPJ. These increased forces could play a role in the progression of a pre-existing 1st MPJ misalignment and reduction of those excessive forces should be a consideration in the treatment of 1st MPJ disease.

Availability of data and materials

The data that supports the findings of this study is included in the article.

Author contributions

Conception: MEG; Design of the study: MEG, LK, HK; Analysis and interpretation of data: LK; Literature search: MEG, LK; All authors contributed to the drafting the article and revising it critically for important intellectual content.

Consent for publication

The participants consented to the utilization of their data for the purposes of this scientific study.

Role of the funding source

There was no funding for this manuscript.

Competing interests

The authors declare that they have no competing interests.

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