Revisiting the radiological signs for the first metatarsal pronation assessment

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Aims

The first metatarsal pronation deformity of hallux valgus feet is widely recognized. However, its assessment relies mostly on 3D standing CT scans. Two radiological signs, the first metatarsal round head (RH) and inferior tuberosity position (ITP), have been described, but are seldom used to aid in diagnosis. This study was undertaken to determine the reliability and validity of these two signs for a more convenient and affordable preoperative assessment and postoperative comparison.

Methods

A total of 200 feet were randomly selected from the radiograph archives of a foot and ankle clinic. An anteroposterior view of both feet was taken while standing on the same x-ray platform. The intermetatarsal angle (IMA), metatarsophalangeal angle (MPA), medial sesamoid position, RH, and ITP signs were assessed for statistical analysis.

Results

There were 127 feet with an IMA > 9°. Both RH and ITP severities correlated significantly with IMA severity. RH and ITP were also significantly associated with each other, and the pronation deformities of these feet are probably related to extrinsic factors. There were also feet with discrepancies between their RH and ITP severities, possibly due to intrinsic torsion of the first metatarsal.

Conclusion

Both RH and ITP are reliable first metatarsal pronation signs correlating to the metatarsus primus varus deformity of hallux valgus feet. They should be used more for preoperative and postoperative assessment.

Take home message

- Round head and inferior tuberosity position signs of preoperative and postoperative radiographs can be reliably compared for rotational correction of the first metatarsal after a particular hallux valgus corrective surgery.

Introduction

There has been much advancement in understanding the hallux valgus (HV) deformity. It is a deformity complex composed of a deformity trio of the deviated first metatarsal, hallux, and sesamoids of the forefoot's first ray. The HV deformity has long been known to be precipitated by its underlying metatarsus primus varus (MPV) deformity.[1] The first metatarsal of MPV feet is well known for its instability in the transverse and sagittal planes. However, the first metatarsal has also been found to be unstable in its frontal plane, creating its pronation deformity and resulting in the recurrence of the HV deformity if it is not addressed.[2-6]

MPV and metatarsal primus elevatus deformities can be assessed by plain radiograph examination of the foot.[7] However, the study of pronation deformity has mostly relied on 3D standing CT scans,[2,3,8-11] which may not be readily available or affordable in many parts of the world. A CT scan study for all patients may not always be necessary if there are reliable radiograph signs for assessing the first metatarsal rotation or comparing surgical results.[12]

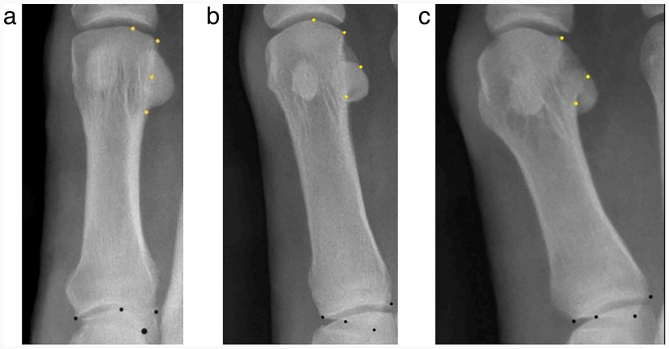

Fig. 1
Standing anteroposterior view of the first metatarsal round head sign in a 47-year-old female. a) Angular. b) Intermediate. c) Round.

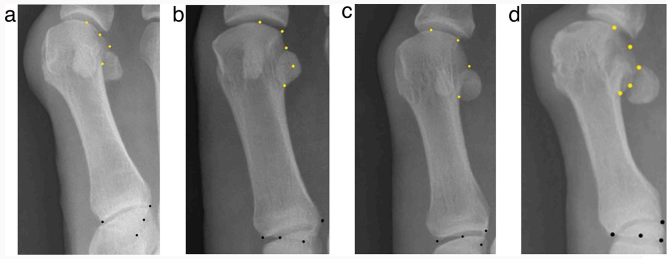

Fig. 2
Standing anteroposterior view of the first metatarsal inferior tuberosity position sign in a 55-year-old female: a) 0°, b) 10°, c) 20°, and d) 30°.

In the past, two radiological signs have been described to demonstrate the first metatarsal rotation: the round head (RH) sign of the lateral edge of the first metatarsal head,[13-15] and the first metatarsal inferior tuberosity position (ITP) sign of the first metatarsal base.[16] Normally, the lateral border of the first metatarsal head is straight in the anteroposterior (AP) view radiograph of the foot, forming an acute angle with the first metatarsal articular surface. However, it would appear round when the convexed plantar surface is rotated into view laterally in the first metatarsal pronation (Figure 1). The inferior tuberosity at the first metatarsal base may also be shifted laterally by the same rotational process (Figure 2).

The purpose of this study was to revisit the RH and ITP signs in connection with the first metatarsal pronation deformity since no other studies have tried to reproduce the same conclusions as their original investigators. We also wanted to know if there is any correlation between these signs or pronation rotation of the first metatarsal and the intermetatarsal angle (IMA), metatarsophalangeal angle (MPA), or medial sesamoid position (MSP).

Methods

We randomly chose 100 patients from the single surgeon-author's (DYW) practice: 30 patients had radiograph examinations for other foot conditions than a HV history, and 70 patients had radiographs for their unilateral or bilateral HV feet. No patients with previous foot fractures or surgery of the first ray area were accepted for this study. The left and right feet of each patient were regarded as independent samples. Hence, there were 200 feet for the study without considering the patient's age, sex, or other variants. Every patient's standing AP radiograph of both feet was taken on the same platform of a computerized digital podiatric x-ray machine (20/20 Imaging, USA). We assessed their IMA, MPA, MSP, RH, and ITP signs. Their IMA and MPA were measured with the mid-axial line method described by Hardy and Clapham.[17] The medial sesamoid position (MSP) was assessed using Hardy's seven-position method.[17] The round head sign was classified into three levels: angular, intermediate, and round, as described by Yamaguchi et al[13] (Figure 1). Also, the inferior tuberosity position was used to determine the amount of rotation as defined by Eustace et al's[16] radiograph study of cadavers: "On pronation, the inferior Tuberosity of the base of the first metatarsal moved laterally to the mid-line axis. At 10°, the Tuberosity pointed to the junction of the inner third and outer two-thirds of a line between the midpoint and lateral tubercle of the base. At 20°, it pointed to the junction of that line's inner two-thirds and outer third. At 30°, it pointed to the outer margin of the lateral third."[16] (Figure 2)

Radiographs of the 100 pairs of feet included in the study were submitted with their IMA and MPA measured in one film and round head and ITP borders traced with dots in another film for online review and reference (Supplementary Table i). The raw data (Supplementary Table ii) and statistical analysis results (Supplementary Material 3) are also available as supplementary material.

Statistical analysis

The data were analyzed using SPSS Statistics v. 28.0.1.0 (IBM, USA). One-way analysis of variance (ANOVA) was used to test for differences in means among independent groups. The Mantel-Haenszel (exact) test for trend was used to test for a linear association between two ordinal variables. A p-value < 0.05 was considered statistically significant.

Results

There were 73 feet with IMA ≤ 9° and 127 feet with IMA > 9°. The mean IMA was 10.9° (1.6° to 25°). The average MPA was 21.4° (1° to 62.9°). The mean MSP was 3.9 (0 to 7) (Supplementary Table ii).

The variable of roundness has three levels: angular (no rotation), intermediate (slightly round), and round (greatest rotation). The means of each of the three measures, namely IMA, MPA, and MSP, are significantly different with regard to the three levels of roundness. The means of the three measures increase with the level of rotation. By comparing the means of the three levels using a one-way ANOVA model, we obtained a p-value less than 0.001 (Supplementary Material 3) for all three measures, indicating that a higher level of rotations is strongly associated with a larger value of IMA, MPA, and MSP. Therefore, their measurements and level of rotations are significantly correlated to the round head sign.

The variable ITP has four levels: 0°, 10°, 20°, and 30° of rotation, as defined by Eustace et al.[16] The mean IMA and the mean MSP measurements tend to increase with the level of tuberosity rotation, resulting in larger measurements due to a higher tuberosity rotation level. The results are also statistically

significant, with respective p-values of 0.013 and 0.005, both less than the 0.05 significance level (Supplementary Material 3).

The mean MPA for the four levels also exhibits an increasing trend with the level of tuberosity rotation, but is statistically insignificant with a p-value of 0.197, greater than the 0.05 significance level (Supplementary Material 3).

The cohort was also divided into subgroups of IMA ≤ 9°, IMA > 9° but ≤ 15°, and IMA > 15° for further analysis. The Mantel-Haenszel exact test for linear trend was employed to examine the potential linear association between two ordinal variables. The findings of the analysis can be found in Supplementary Table iv. The results of the Mantel-Haenszel test revealed statistically significant linear trends among three ordinal variables: IMA, roundness, and tuberosity. Specifically, the analysis demonstrated a significant linear relationship between IMA and both roundness ($p < 0.001$) and tuberosity ($p = 0.021$), indicating that higher levels of IMA are associated with increased levels of roundness and/or tuberosity. Additionally, roundness and tuberosity exhibited a significant positive trend, suggesting that elevated roundness is linked to higher levels of tuberosity ($p = 0.022$).

Discussion

The first metatarsal of HV feet can be displaced in its horizontal, sagittal, and frontal planes. Any residual deformity in these three planes can be a risk factor for HV deformity recurrence postoperatively.[12] While the first metatarsal displacement in the horizontal and sagittal planes is mostly assessed by plain radiograph examinations, the pronation deformity in the frontal plane has mostly been evaluated by standing CT scans. Even though radiological RH and ITP signs have long been described, they are seldom used for the first metatarsal pronation deformity assessment.

Our study of 200 normal and HV feet confirmed that both the metatarsal head roundness and ITP signs could be reliably used to indicate first metatarsal pronation deformity, and their severity also has a significant correlation with the severity of MPV and MSP deformities. The roundness sign was also significantly related to the severity of MPA. Although the ITP sign was not significantly associated with the MPA, there was still a significant statistical trend.

While there is consensus on the first metatarsal pronation deformity,[9,18] there are different opinions about its anatomical origin. Some studies have found it was intrinsic due to torsion of the first metatarsal shaft,[2,19,20] and others believed it was extrinsic due entirely to rotation of the first metatarsal itself through the metatarsocuneiform joint by external forces in walking.[3,19] Lalevée et al[21] thought it was due to a combination of intrinsic and extrinsic factors. Ota et al[2] found that the weightbearing of the normal foot would impart a pronation force to the first metatarsal. Our study demonstrated that the roundness and tuberosity signs showed a significant positive association, indicating that a high level of roundness is associated with a high tuberosity level. This dependence relationship indicated the first metatarsal rotation was due mostly to the rotation of the entire first metatarsal by extrinsic factors. However, others probably had intrinsic rotation deformity of the first metatarsal itself to account for a more severe RH sign than expected of a milder ITP sign, and vice versa. The crosstab table (Supplementary Material 3) revealed that 12 feet had a RH sign but a low-level ITP sign (Figure 2a) and, conversely, 22 feet had a high-level ITP sign but an angular head shape (Figure 1a). The different degrees of severity between the two signs possibly indicate a combination of extrinsic and intrinsic factors. We believe that both radiological rotation signs of the first metatarsal are reliable for assessing the presence and severity of distal and proximal rotations. The surgical indication of the first metatarsal rotation with similar distal and proximal rotation severity is a technique that can rotate the entire first metatarsal (Figure 2d), such as the Lapidus procedure, which is more appropriate for its correction. Otherwise, for first metatarsals with notable distal and proximal rotation severity discrepancies (Figures 1a and 2a) indicating the existence of intrinsic torsion deformity, the first metatarsal osteotomy procedures should be considered instead.

We believe changes in RH and ITP signs are quantifiable for detecting rotational correction for research. For comparison between preoperative and postoperative findings, we recommend the RH sign because it is suitable for both osteotomy and Lapidus procedures, while the latter can disfigure the ITP sign. Statistically, the RH sign also had a stronger relationship with MPV, HV, and MSP parameters than the ITP sign.

This study is limited by the lack of a means to quantify the RH and ITP signs precisely, and the fact that first metatarsal sagittal plane deformity and foot pronation were not accounted for. It is, however, strengthened by the standardized and consistent radiological technique in full weightbearing, and the large study cohort.

We did not conduct a comparative study between the radiological and CT scan methods because this study aimed to show that RH and ITP signs are statistically significant in correlation to the MPV (IMA) deformity and a reliable method to detect changes in first metatarsal rotation.

The RH and ITP are reliable radiological signs for assessing first metatarsal rotation, which can be due to intrinsic and extrinsic factors. They are significantly correlated and associated with MPV deformity. The RH sign is probably more useful and appropriate for postoperative assessment and surgical technique comparison than the ITP sign.

Supplementary material

Excel tables and radiographs of all studied feet.

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D. Y. Wu: Conceptualization, Data curation, Investigation, Methodology, Resources, Visualization, Writing – original draft, Writing – review & editing.
E. K. F. Lam: Data curation, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing.

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Data sharing

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