# Comparison of fore- and midfoot angles using 3DCT in standard weightbearing and sesamoid view position in feet with hallux valgus

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## Aims

To evaluate how fore- and midfoot coronal plane alignment differs in feet with hallux valgus (HV), using 3DCT when measured in standard weightbearing (SWB) versus sesamoid view (SV) position, and to determine whether first metatarsophalangeal (MTP) dorsiflexion affects the relationship between the first metatarsal (M1) head and the sesamoid bones.

## Methods

A consecutive series of 34 feet that underwent 3DCT in SWB and SV positions for symptomatic HV was assessed, of which four feet were excluded for distorted or incomplete images. Two foot and ankle clinicians independently digitized a series of points, and measured a series of angles according to a pre-defined protocol. Measurements include navicular pronation angle, M1 head (Saltzman angle), and metatarsosesamoid rotation angle (MSRA).

## Results

The mean age of the 30 patients was 57.5 years (SD 13.4). The mean navicular pronation angle was significantly smaller in the SV position (9.6° (SD 4.4°)) compared to the SWB position (16.4° (SD 5.8°); $p < 0.001$). There was a difference in MSRA between the SWB and SV positions, revealing an increase in MSRA in 22 patients, while there was a decrease in eight patients. In patients where the MSRA increased, the mean Saltzman angle was 2.5° (SD 5.7°) lower in the SV position versus the SWB position, while in patients where MSRA decreased, the mean Saltzman angle was 3.4° (SD 3.6°) greater in the SV position versus the SWB position.

## Conclusion

MTP dorsiflexion causes supination of the navicular, while other first ray parameters remain unchanged, and has a greater influence on the M1 head coronal alignment than on the sesamoids. MTP dorsiflexion induces axial rotations of M1, which vary in direction and magnitude from one patient to another.


## Article focus

- To allow complete assessment of the coronal alignment in the fore- and midfoot.
- To evaluate how fore- and midfoot coronal plane angles differ when measured in standard weightbearing (SWB) versus sesamoid view (SV) position in hallux valgus patients.

## Key messages

- The most important findings of this study are that there is a greater influence of metatarsophalangeal (MTP) dorsiflexion on rotation of the M1 head, indicated by

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the Saltzman angle, than on the rotation of the sesamoids.

- Surgeons should be aware that preoperative planning and assessment of routine angles in the sesamoid view position may lead to inaccurate intraoperative corrections, as MTP dorsiflexion induces rotations of M1 in the coronal plane, which vary in direction and magnitude from one patient to another.

## Strengths and limitations

- This is a retrospective case series of 30 patients, comparing fore- and midfoot angles in two positions. A larger cohort size could have provided more representative population proportions for the subgroup analysis, and would have allowed the authors to perform uni- and multivariable regression analyses.
- Including a control group may have identified adaptations caused by the patients' natural foot morphology, rather than the deformity.
- To the authors' knowledge, this is the first study that compared SWB position to the SV position using 3DCT, which revealed that MTP dorsiflexion induces a rotation of the M1 head over the sesamoids, rather than a rotation of the sesamoids under the M1 head, as demonstrated by the significant difference in the Saltzman angle when comparing patients with an increase versus decrease of the metatarsosesamoid subluxation (MSRA).

## Introduction

Radiological imaging has been used as the gold standard for the 2D assessment and visualization of hallux valgus (HV),[1] and is adequate to measure the intermetatarsal angle (IMA) and the hallux valgus angle (HVA). Further assessment of the first ray in the coronal plane, however, is difficult when using x-rays, due to the superimposition of the distal bones. This was partly resolved by dorsiflexing the toes when using the sesamoid view (SV) (Figure 1b), also known as Guntz view or tangential view, which allowed coronal plane assessment of the sesamoid bones, and the head of the first metatarsal (M1) due to the metatarso-phalangeal (MTP) dorsiflexion, but did not allow complete assessment of the coronal alignment in the fore- and midfoot.

Due to the emergence of new imaging methods such as 3DCT, it is now possible to analyze the HV deformity more accurately, and therefore provide better treatment.[2-8] Several studies have investigated the correlations between coronal plane rotation angles, assessed on 3DCT, and dorsoplantar angles assessed on standard weightbearing (SWB) radiographs.[5,9-14] To the authors' knowledge, however, none have compared the SWB position and the SV position, using 3DCT, which could mask or exacerbate deformities of the fore- and midfoot angles,[15–17] including the sesamoid rotation angle (SRA), M1 head pronation (Saltzman angle), metatarsosesamoid complex rotation angle (MSRA), or even a navicular pronation, caused by the distal and dorsal pull of the sesamoids due to MTP dorsiflexion.

The primary purpose of the present study was to evaluate how fore- and midfoot coronal plane angles differ when measured in SWB versus SV position in HV patients. The secondary purpose was to determine whether MTP dorsiflexion affects the relationship between the M1 head and the sesamoid bones.

## Methods

The authors retrospectively assessed a consecutive series of 34 patients (34 feet) who underwent 3DCT for symptomatic hallux valgus (HV), with no surgical antecedents. Upon preliminary assessment, the authors excluded four feet that had distorted (e.g. poor resolution due to artefacts) or incomplete images (e.g. distal part of the phalanx not visible). All patients provided informed consent, and the study was approved by the local ethics committee (IRB: 201912144). The study was conducted following the STROBE guidelines (Supplementary Material).

The 30 patients had a mean age of 57.5 years (SD 13.4), with a BMI of 24.4 kg/m$^2$ (SD 3), and comprised 22 females (73%) (Table I). The right foot was measured in 21 patients (70%).

### Image collection

Each patient underwent two 3DCT assessments. Patients were first assessed in the standard weightbearing (SWB) position, with the foot flat on the ground (Figure 1a). They were then assessed in the sesamoid view (SV) position, with the toes in dorsiflexion (Figure 1b).

### Landmark annotation

All scans were acquired using a 3DCT scanner (Curvebeam Pedcat, USA) with slice thickness of 0.5 mm. The Digital Imaging and Communication in Medicine (DICOM) scans were imported into the image processing software OsiriX (Pixmeo; Switzerland) in standard resolution. This imaging software enabled simultaneous visualization of 3DCT cross-sections in the coronal, sagittal, and axial planes. For each patient, the age, sex, side, and BMI were noted, and two foot and ankle clinicians (MT, PB) independently digitized a series of points according to a pre-defined measurement protocol (Supplementary Material): 30 points in the SWB position, and 27 points in the SV position.

### Angle calculations

For each CT scan, the Cartesian coordinates of the digitized points were exported as comma-separated variables (CSV) files, which were then imported into a spreadsheet using Excel (Microsoft, USA), and represented as an array for each foot, in each position, after which the landmarks were projected onto the planes of interest to calculate the following angles (Supplementary Material), as previously described in the literature: metatarsophalangeal (MTP) dorsiflexion,[18] SRA,[19] Saltzman angle (coronal plane rotation of the M1 head),[20] MSRA (assessing the metatarsosesamoid subluxation),[21] navicular pronation angle,[22] IMA,[23] HVA,[23] phalangeal pronation angle,[24] M1 base pronation angle,[25] and the foot and ankle offset (FAO)[26] in the SWB position only. Positive angles were considered as pronation, while negative angles were considered as supination.

### Inter- and intraobserver reliability

To calculate interobserver reliability, two observers (MT, PB) performed measurements on all 30 feet, in SWB position and in SV position. To calculate intraobserver reliability, the same

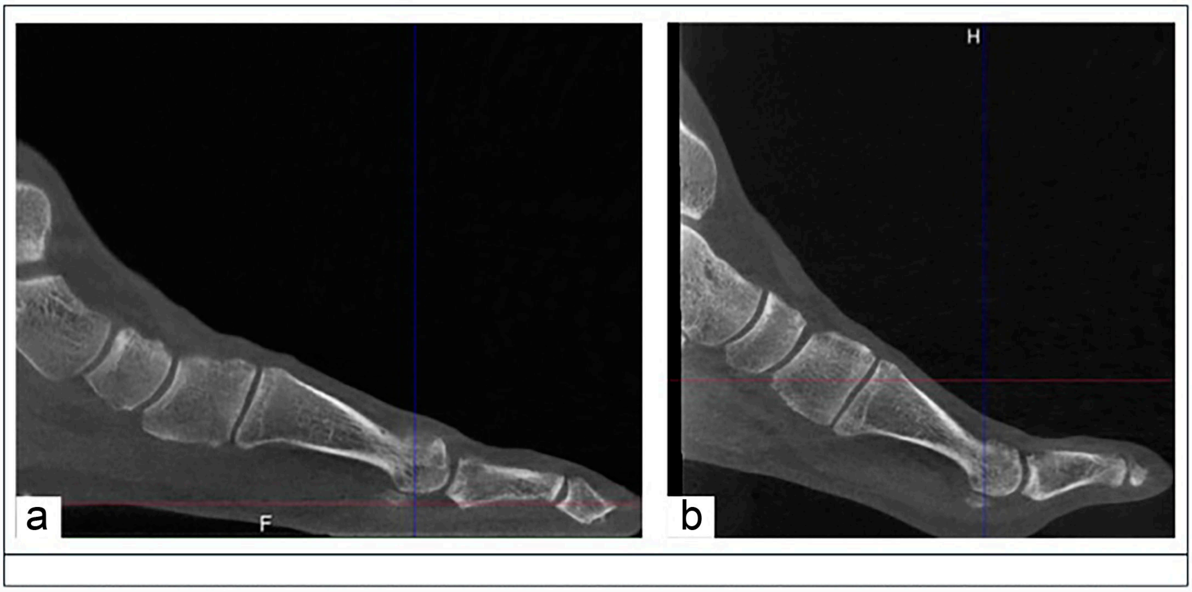


**Fig. 1**
a) Foot positioned in the standard weightbearing (SWB) position. b) Foot positioned in the sesamoid view (SV) position, with the toes in dorsiflexion.

**Table I.** Patient demographic data.

| Characteristic | Value |
|---|---|
| Mean age, yrs (SD, range) | 57.5 (13.4, 22.0 to 77.0) |
| Mean BMI, kg/m$^2$ (SD, range) | 24.4 (3.0, 18.7 to 30.8) |
| Sex, n (%) (male/female) | 8 (27)/22 (73) |
| Side, n (%) (left/right) | 9 (30)/21 (70) |

two observers repeated the measurements on a set of seven feet, one month from first assessment.

### Statistical analysis

Descriptive statistics were used to summarize the findings, and Shapiro-Wilk tests were used to assess the normality of data distributions. For Gaussian distributed continuous data, differences between groups were evaluated using independent-samples *t*-tests. For non-Gaussian continuous data, differences between groups were evaluated using Mann-Whitney U test. Agreement between the two observers was calculated using intraclass correlation coefficients (ICCs), which can be interpreted as follows: < 0.40, poor; 0.41 to 0.59, fair; 0.60 to 0.74, good; and 0.75 to 1.00, excellent.[27] Correlations between all radiological measurements were determined using Kendall's correlation coefficients and were interpreted as follows: < 0.1 or > -0.1 very weak; +/- 0.1 to 0.19 weak; +/- 0.2 to 0.29 moderate; and > 0.3 or < -0.3 strong. Statistical analyses were performed using R version 4.2.3 (R Foundation for Statistical Computing, Austria).

## Results

### Inter- and intraobserver reliability

Interobserver reliability was excellent for all measurements, but only good for sesamoid subluxation in SWB position. Intraobserver reliability was excellent for all measurements, but only good for navicular pronation angle and IMA in SWB position, and only fair for MTP dorsiflexion in SWB position (Table II).

### Angle measurements

The mean MTP dorsiflexion angle was significantly greater in the SV position (48.0° (SD 7.5°)) compared to the SWB position (15.8° (SD 4.3°); $p < 0.001$) (Table III). In contrast, the mean navicular pronation angle was significantly smaller in the SV position (9.6° (SD 4.4°)) compared to the SWB position (16.4° (SD 5.8°); $p < 0.001$). There were no other significant differences observed between the SV and SWB positions, for the SRA ($p = 0.350$), Saltzman angle ($p = 0.582$), MSRA ($p = 0.314$), sesamoid subluxation ($p = 0.109$), IMA ($p = 0.278$), HVA ($p = 0.146$), phalangeal pronation angle ($p = 0.854$), and M1 base pronation angle ($p = 0.117$).

### Fore- and midfoot angle changes during MTP dorsiflexion

The mean difference of the SRA between SWB and SV positions was 2.8° (SD 4.8°), of which three patients had a difference ≥ 4°, while 14 patients had a difference ≤ -4°. The mean difference of the Saltzman angle between SWB and SV positions was -0.9° (SD 5.8°), of which eight patients had a difference ≥ 4°, while six patients had a difference ≤ -4°. The mean difference of the navicular pronation angle between SWB and SV positions was 6.8° (SD 5.3°), of which 22 patients had a difference ≥ 4°, while one patient had a difference ≤ -4°. The mean difference of the MSRA between SWB and SV positions was 3.2° (SD 6.0°), of which two patients had a difference ≥ 4°, while 13 patients had a difference ≤ -4°.

Further analysis of the difference in MSRA between SWB and SV positions revealed an increase in MSRA in 22 patients, while there was a decrease in eight patients. In patients where the MSRA increased, the mean Saltzman angle was 2.5° (SD 5.7°) lower in the SV position versus the SWB

**Table II.** Inter- and intraobserver reliability. All p-values were calculated using intraclass correlation coefficients.

| Variable | Observer 1 (n = 7) | | | Observer 2 (n = 7) | | | Interobserver (n = 30) | | |
|---|---|---|---|---|---|---|---|---|---|
| | ICC | 95% CI | p-value | ICC | 95% CI | p-value | ICC | 95% CI | p-value |
| **SWB** | | | | | | | | | |
| MTP dorsiflexion | 0.54 | -0.01 to 0.80 | < 0.001 | 0.83 | 0.36 to 0.97 | 0.005 | 0.77 | 0.59 to 0.87 | < 0.001 |
| SRA | 0.98 | 0.97 to 0.99 | < 0.001 | 0.94 | 0.73 to 0.99 | < 0.001 | 0.97 | 0.94 to 0.98 | < 0.001 |
| Saltzman angle/M1 head | 0.96 | 0.91 to 0.98 | < 0.001 | 0.90 | 0.59 to 0.98 | 0.001 | 0.80 | 0.57 to 0.90 | < 0.001 |
| MSRA | 0.96 | 0.91 to 0.98 | < 0.001 | 0.78 | 0.22 to 0.96 | 0.011 | 0.87 | 0.78 to 0.93 | < 0.001 |
| Sesamoid subluxation | 0.98 | 0.78 to 0.99 | < 0.001 | 0.85 | 0.40 to 0.97 | 0.004 | 0.74 | 0.52 to 0.87 | < 0.001 |
| Navicular pronation | 0.73 | 0.50 to 0.86 | < 0.001 | 0.60 | -0.06 to 0.91 | 0.032 | 0.85 | 0.73 to 0.91 | < 0.001 |
| IMA | 0.74 | 0.52 to 0.87 | < 0.001 | 0.92 | 0.65 to 0.99 | 0.001 | 0.84 | 0.72 to 0.91 | < 0.001 |
| HVA | 0.94 | 0.94 to 0.97 | < 0.001 | 0.97 | 0.87 to 1.00 | < 0.001 | 0.96 | 0.89 to 0.98 | < 0.001 |
| Phalangeal pronation | 0.93 | 0.75 to 0.97 | < 0.001 | 0.83 | 0.35 to 0.97 | 0.005 | 0.95 | 0.90 to 0.97 | < 0.001 |
| M1 base pronation | 0.96 | 0.92 to 0.98 | < 0.001 | 0.92 | 0.15 to 0.99 | < 0.001 | 0.91 | 0.83 to 0.95 | < 0.001 |
| Foot and ankle offset | 0.99 | 0.94 to 1.00 | < 0.001 | 0.96 | 0.67 to 0.99 | < 0.001 | 0.99 | 0.98 to 1.00 | < 0.001 |
| **SV** | | | | | | | | | |
| MTP dorsiflexion | 0.90 | 0.69 to 0.96 | < 0.001 | 0.96 | 0.82 to 0.99 | < 0.001 | 0.93 | 0.88 to 0.96 | < 0.001 |
| SRA | 0.95 | 0.90 to 0.97 | < 0.001 | 0.97 | 0.83 to 0.99 | < 0.001 | 0.91 | 0.84 to 0.85 | < 0.001 |
| Saltzman angle/M1 head | 0.94 | 0.87 to 0.97 | < 0.001 | 0.74 | 0.12 to 0.95 | 0.019 | 0.88 | 0.75 to 0.94 | < 0.001 |
| MSRA | 0.87 | 0.74 to 0.93 | < 0.001 | 0.81 | 0.29 to 0.96 | 0.004 | 0.88 | 0.79 to 0.93 | < 0.001 |
| Sesamoid subluxation | 0.99 | 0.97 to 0.99 | < 0.001 | 0.97 | 0.84 to 0.99 | < 0.001 | 0.86 | 0.76 to 0.92 | < 0.001 |
| Navicular pronation | 0.89 | 0.79 to 0.95 | < 0.001 | 0.60 | -0.09 to 0.91 | 0.020 | 0.80 | 0.65 to 0.88 | < 0.001 |
| IMA | 0.92 | 0.84 to 0.96 | < 0.001 | 0.94 | 0.71 to 0.99 | < 0.001 | 0.75 | 0.57 to 0.85 | < 0.001 |
| HVA | 0.98 | 0.95 to 0.99 | < 0.001 | 0.97 | 0.83 to 0.99 | < 0.001 | 0.94 | 0.81 to 0.97 | < 0.001 |
| Phalangeal pronation | 0.97 | 0.94 to 0.99 | < 0.001 | 0.91 | 0.61 to 0.98 | 0.001 | 0.95 | 0.91 to 0.97 | < 0.001 |
| M1 base pronation | 0.97 | 0.97 to 0.99 | < 0.001 | 0.95 | 0.77 to 0.99 | < 0.001 | 0.89 | 0.81 to 0.94 | < 0.001 |

ICC: poor: < 0.40; fair: 0.41 to 0.59; good: 0.60 to 0.74; excellent: 0.75 to 1.00.
HVA, hallux valgus angle; ICC, intraclass correlation coefficient; IMA, inter-metatarsal angle; MSRA, metatarsosesamoid complex rotation angle; MTP, metatarsophalangeal; SRA, sesamoid rotation angle; SV, sesamoid view position; SWB, standard weightbearing position.

position, while in patients where the MSRA decreased, the mean Saltzman angle was 3.4° (SD 3.6°) greater in the SV position versus the SWB position (Table IV).

## Discussion

The most important findings of this study are that passing from SWB position to SV position causes significant supination of the navicular, while other first ray parameters remain unchanged, reflecting adaptations within the fore- and midfoot. Conversely, there was a significant difference in the Saltzman angle when comparing patients with an increase versus decrease of the MSRA. These findings indicate a greater influence of MTP dorsiflexion on rotation of the M1 head (indicated by the Saltzman angle) than on the rotation of the sesamoids. Surgeons should be aware that preoperative planning and assessment of routine angles in the SV position may lead to inaccurate intraoperative corrections, as MTP dorsiflexion induces rotations of M1 in the coronal plane, which vary in direction and magnitude from one patient to another.

Standard radiological assessment for patients with HV focuses on the HVA and IMA, which are angles of the axial plane. However, HV is associated with a pronation of M1, an intrinsic torsion of M1, and a subluxation of the sesamoids which are deformities of the coronal alignment.[5,8,28,29] Assessment of the coronal plane should not be overlooked, as recurrence rates for HV are notoriously high, and could be linked to the inadequate treatment of concomitant deformities.[3–7,30,31] Using radiographs, the only coronal plane assessment possible in the SV position would be of the sesamoids and M1 head, as MTP dorsiflexion grants visibility of the sesamoids and the inferior edge of M1. Dorsiflexion, however, could hide or alter deformities, such as the presence of an M1 pronation, or alteration of the sesamoid subluxation caused by the action of the flexor hallucis brevis.[32] Assessment of the first ray in SWB position is now possible with the emergence of new imaging methods such as 3DCT. This technological breakthrough can provide an insight into the possible internal rotation alterations of the first ray, brought by MTP dorsi-

**Table III.** Angles comparing the standard weightbearing position versus the sesamoid view position.

| Variable | SWB (n = 30) | SV (n = 30) | p-value* | MD | 95% CI |
|---|---|---|---|---|---|
| | Mean (SD, range) | Mean (SD, range) | | | |
| MTP dorsiflexion | 15.8 (4.3, 8.6 to 26.3) | 48.0 (7.5, 30.9 to 61.9) | < 0.001 | 32.23 | 29.15 to 35.32 |
| SRA | 22.4 (10.2, 3.5 to 43.3) | 25.2 (12.9, 0.0 to 51.6) | 0.350 | 2.83 | -3.05 to 8.71 |
| Saltzman angle/M1 head | 10.3 (5.0, 1.0 to 20.0) | 9.9 (7.7, 0.0 to 32.3) | 0.582 | -0.38 | -3.66 to 2.9 |
| MSRA | 12.3 (10.5, 0.1 to 37.9) | 15.5 (12.9, 0.1 to 54.3) | 0.314 | 3.2 | -2.76 to 9.16 |
| Sesamoid subluxation | 4.6 (2.6, 1.9 to 11.7) | 5.3 (2.6, 1.7 to 14.3) | 0.109 | 0.73 | -0.59 to 2.04 |
| Navicular pronation | 16.4 (5.8, 0.9 to 27.4) | 9.6 (4.4, 2.5 to 21.7) | < 0.001 | -6.79 | -9.38 to -4.21 |
| IMA | 14.1 (3.3, 5.9 to 19.7) | 13.2 (3.5, 7.0 to 21.3) | 0.278 | -0.97 | -2.7 to 0.76 |
| HVA | 28.0 (10.5, 11.7 to 61.8) | 31.1 (10.1, 15.7 to 61.6) | 0.146 | 3.04 | -2.18 to 8.25 |
| Phalangeal pronation | 22.2 (12.8, 4.2 to 61.1) | 21.6 (12.6, 0.0 to 55.5) | 0.854 | -0.57 | -6.97 to 5.84 |
| M1 base pronation | 101.9 (4.8, 92.2 to 109.9) | 104.3 (6.8, 93.7 to 115.8) | 0.117 | 2.41 | -0.56 to 5.37 |
| FAO | 2.9 (0.2, 2.7 to 3.4) | | | | |

*p-values were calculated using the Mann-Whitney U test or independent-samples *t*-test, depending on normality.
HVA, hallux valgus angle; IMA, inter-metatarsal angle; MD, mean difference; MSRA, metatarsosesamoid complex rotation angle; MTP, metatarsophalangeal; SRA, sesamoid rotation angle; SV, sesamoid view position; SWB, standard weightbearing position.

**Table IV.** Subgroup analysis of angles in patients with a metatarsosesamoid complex rotation angle increase and decrease in sesamoid view position.

| Variable | Increase in MSRA (n = 22) | Decrease in MSRA (n = 8) | p-value* | MD | 95% CI |
|---|---|---|---|---|---|
| | Mean (SD, range) | Mean (SD, range) | | | |
| **HVA** | | | | | |
| SWB | 28.6 (10.6, 11.7 to 61.8) | 26.5 (10.7, 15.6 to 40.6) | 0.696 | 2.059 | -6.579 to 10.697 |
| SV | 31.8 (9.7, 16.0 to 61.6) | 29.0 (11.7, 15.7 to 45.1) | 0.513 | 2.799 | -6.254 to 11.851 |
| Difference | 3.2 (3.5, -5.9 to 9.0) | 2.5 (2.2, -0.7 to 5.1) | 0.588 | -0.740 | -2.890 to 1.411 |
| **IMA** | | | | | |
| SWB | 14.3 (3.0, 5.9 to 18.4) | 13.7 (4.3, 6.1 to 19.7) | 0.658 | 0.622 | -2.586 to 3.830 |
| SV | 13.3 (3.4, 7.0 to 18.5) | 12.8 (4.0, 8.3 to 21.3) | 0.697 | 0.580 | -2.561 to 3.721 |
| Difference | -1.0 (2.4, -6.6 to 2.6) | -0.9 (2.9, -4.0 to 4.8) | 0.969 | 0.042 | -2.217 to 2.300 |
| **SRA** | | | | | |
| SWB | 23.2 (10.5, 5.6 to 43.3) | 20.0 (9.4, 3.5 to 31.3) | 0.458 | 3.19 | -4.66 to 11.03 |
| SV | 26.5 (13.6, 0.0 to 51.6) | 21.6 (10.8, 1.4 to 33.1) | 0.366 | 4.91 | -4.49 to 14.31 |
| Difference | 3.3 (5.2, 11.6 to 11.5) | 1.6 (3.5, -4.5 to 6.3) | 0.399 | -1.721 | -4.982 to 1.539 |
| **Saltzman angle/M1 head** | | | | | |
| SWB | 10.4 (4.9, 1.1 to 20.0) | 10.1 (5.4, 1.0 to 17.3) | 0.908 | 0.24 | -4.01 to 4.50 |
| SV | 7.8 (5.4, 0.0 to 23.5) | 13.6 (7.8, 0.8 to 22.1) | 0.030 | -5.75 | -11.62 to 0.13 |
| Difference | -2.5 (5.7, -20.0 to 7.9) | 3.4 (3.6, -2.1 to 8.1) | 0.005 | 5.992 | 2.543 to 9.441 |
| **Navicular pronation** | | | | | |
| SWB | 16.4 (6.0, 0.9 to 27.4) | 16.3 (5.6, 9.2 to 25.7) | 0.990 | 0.03 | -4.60 to 4.67 |
| SV | 8.9 (4.1, 2.5 to 18.1) | 11.5 (4.9, 7.6 to 21.7) | 0.149 | -2.62 | -6.39 to 1.16 |
| Difference | -7.5 (5.7, -22.9 to 4.1) | -4.9 (3.6, -10.0 to 1.7) | 0.231 | 2.649 | -0.784 to 6.081 |

*p-values were calculated using the Mann-Whitney U test or independent-samples *t*-test, depending on normality.
HVA, hallux valgus angle; IMA, inter-metatarsal angle; MD, mean difference; MSRA, metatarsosesamoid complex rotation angle; SRA, sesamoid rotation angle; SV, sesamoid view position; SWB, standard weightbearing position.

flexion, and therefore the validity of the SV position, when compared to SWB position.

The development of 3DCT has led to multiple studies investigating the correlations between the measurements performed on radiographs to those performed on 3DCT.[5,10-13] Siebert et al[13] found no significant difference in M1 head pronation between the SWB position on 3DCT versus the SV on radiographs, in patients with or without HV deformity. Patel et al[12] compared the SWB position on both 3DCT and radiograph, to measure the M1 head pronation. Using radiographs, the M1 head pronation was evaluated by examination of the shape of the head. Patel et al[12] concluded that there were only weak correlations between the two imaging methods, when investigating M1 head pronation in SWB. While the two studies had different conclusions on the use of radiographs for the assessment of the M1 head pronation, they agreed that using the SV position or radiograph could lead to loss of information on the true anatomy of the foot. To our knowledge, however, no studies have compared the SWB position and SV position using 3DCT.

The present study grants insights into the internal rotations of the metatarsosesamoid complex and of the midfoot, which may occur during MTP dorsiflexion when positioned in the SV position, namely the SRA, the Saltzman angle, the MSRA angle, and the navicular pronation angle. The significant difference for the navicular pronation angle found between the two positions indicates that positioning the foot in the SV position does affect the hindfoot alignment by inducing a supination of the navicular, and can therefore influence the entire first ray. The differences between the SWB and SV positions for the angles of interest show that different patients can have strong positive or negative differences for the same angle, as found notably for the Saltzman angle, which represents the M1 head pronation angle. Of the 30 patients, eight had a difference ≥ 4°, while six patients had a difference ≤ -4°, and 16 had an absolute difference of less than 4°. Differences for the SRA, MSRA, and navicular pronation angle can also be divided into a group with an increase ≥ 4° (3, 2, and 22 patients, respectively), a group with a decrease ≤ -4° (14 patients, 13 patients, and 1 patient, respectively), and a group with an absolute difference < 4°.

Understanding the dynamics of the metatarsosesamoid complex is necessary to provide adequate treatment for HV, and the present study shows that MTP dorsiflexion has varying effects on the fore- and midfoot bones for each patient. Comparing measurements of patients who showed an increase in MSRA (n = 22) to patients who showed a decrease in MSRA (n = 8) revealed a significant difference only for the Saltzman angle. An explanation for these results could be that the M1 head alone is responsible for changes of the metatarsosesamoid complex and, as such, that the HV deformity is caused by a motion of the M1 head over the sesamoids, and not a motion of the sesamoids under the head, as found by Lalevée et al[21] and Geng et al[23] when investigating the relationship between the sesamoids and M2. These results show that, with regard to the metatarsosesamoid complex, the sesamoid position should not be strongly affected by MTP dorsiflexion in the SV position compared with the M1 head pronation. More precisely, while measuring SRA or sesamoid subluxation in SV position can approximate the reality, the Saltzman angle, which is an angle that takes the ground as reference, should only be measured in the SWB position. Recent findings have shown that M1 pronation should be preoperatively assessed and intraoperatively corrected when treating HV, to improve outcomes and reduce recurrence rates.[2,33] The clinical application of the present study is that, to assess M1 pronation, the SWB position on 3DCT is preferred compared to the SV position on radiograph.

The findings of this study should be interpreted with the following limitations in mind. The study is a retrospective case series of 30 patients, comparing fore- and midfoot angles in two positions; a larger cohort size could have provided more representative population proportions for the subgroup analysis, and would have allowed the authors to perform uni- and multivariable regression analyses. Furthermore, including a control group may have identified adaptations caused by the patients' natural foot morphology, rather than the deformity.

In conclusion, the most important findings of this study are that MTP dorsiflexion causes supination of the navicular, while other first ray parameters remain unchanged, and induces a rotation of the M1 head over the sesamoids rather than a rotation of the sesamoids under the M1 head, as demonstrated by the significant difference in the Saltzman angle when comparing patients with an increase versus decrease of the MSRA. Surgeons should be aware that preoperative planning and assessment of routine angles in the SV position may lead to inaccurate intraoperative corrections, as MTP dorsiflexion induces rotations of M1 in the coronal plane, which vary in direction and magnitude from one patient to another.

## Supplementary material

STROBE checklist and measurement protocol

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## Data sharing

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