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# Off-axis view radiographs for assessing hallux valgus interphalangeus in hallux valgus deformity: A comparison with the traditional anteroposterior standing radiographs

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ABSTRACT

*Background:* The newly described anteroposterior “off-axis view” (OAV) radiograph might help detect a hallux valgus interphalangeus (HVI) deformity more precisely compared to anteroposterior standing radiographs.
*Methods:* A radiographic assessment of HVI angles was performed using preoperative standing anteroposterior and OAV radiographs for 67 ft. Intra- and interobserver agreement for all angles and their correlation with HV severity were analyzed.
*Results:* The proximal-to-distal phalangeal articular angle showed less intra- and interobserver variance (intraclass correlation coefficient: 0.825) than did the other angles. OAV radiographs showed less interobserver reliability than did standing radiographs. HVI was underestimated significantly, by up to 5°, on standing radiographs compared to OAV radiographs ($p < 0.001$). The mean differences between OAV and standing radiographs were 3.7° and 5.0° for the proximal-to-distal phalangeal articular and hallux interphalangeal angles, respectively, and were more pronounced for moderate-to-severe HV deformities.
*Conclusion:* Angular measurements of HVI on traditional anteroposterior standing radiographs are significantly smaller than on OAV radiographs. Furthermore, angular measurements on OAV radiographs are associated with higher interobserver reliability. The most precise angle representing an HVI deformity might be the proximal-to-distal phalangeal articular angle.
*Clinical Relevance:* Our findings may facilitate preoperative decision-making for additional akin osteotomy in HV correction.
*Level of Evidence:* Level II.


## 1. Introduction

Hallux valgus (HV) is a multidimensional deformity of the forefoot, characterized by adduction of the first metatarsal at the site of the tarsometatarsal joint and a valgus position of the greater toe at the first metatarsophalangeal joint, resulting in an incongruent joint with lateralization of the sesamoids. Surgical correction of HV is one of the most frequently performed surgical interventions of the foot [1,2]. Multiple surgical techniques for HV correction have been presented so far, each with its specific advantages and limitations [3–5]. The surgical correction of HV usually consists of a metatarsal osteotomy and a soft-tissue procedure for the greater toe joint to achieve a lateral release. The aim of every HV correction is the achievement of a congruent joint and sesamoid reduction as well as to ensure a satisfactory cosmetic appearance.

In HV a HV interphalangeus (HVI) as well as a phalangeal hyperpronational deformity can be found frequently. Although the neglect of HVI is considered a causative factor for recurrent HV, the need for an additional phalangeal osteotomy remains controversial [5]. Recently, better results were reported in cases of combined

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metatarsal and phalangeal correction [6,7]. In several studies, HV recurrence was reported in cases in which an additional HVI deformity was not addressed [8–10].

The need for additional phalangeal osteotomies of the greater toe to correct concomitant HVI is commonly based on the preoperative radiographic assessment of HVI. On traditional anteroposterior standing radiographs, HVI is likely to be underestimated due to a pronational deformity of the greater toe, resulting in a changed projection of the phalangeal bones on anteroposterior views. This may influence the radiographic measurements and result in missing the need for a phalangeal correction, especially in borderline cases. Furthermore, an increase in HVI has been observed postoperatively after isolated metatarsal correction of HV and might be a consequence of a changed projection of the phalangeal bone on standing radiographs [8,11].

In light of the uncertainties mentioned above, the aim of our study was to compare the different radiographic angular measurements of HVI between traditional anteroposterior standing radiographs and a newly described anteroposterior radiograph obtained by complete reduction of the pronation of the greater toe, a so-called "off-axis view" (OAV) radiograph. We hypothesized that HVI is underestimated on traditional anteroposterior standing radiographs compared to OAV radiographs (hypothesis 1). We also hypothesized was that the detected differences between standardized and OAV radiographs correlate with the severity of HV (hypothesis 2).

## 2. Material and methods

The study was approved by the ethics committee of the local medical university (institutional review board identifier: 1100/2019) and is registered with ClinicalTrials.gov (identifier: NCT04284618). Informed consent was obtained from all individual participants included in the study. Data were gathered from a consecutive series of patients who underwent surgery for HV or HVI by open or minimally invasive percutaneous HV correction at the Orthopedic and Foot Center Innsbruck between November 2018 and February 2019. All patients with isolated HV and/or HVI were assigned and asked for participation in this study. Sixty-seven feet of 46 among 48 patients who had undergone hallux surgery in this time period were included in this study. HV was defined as an intermetatarsal 1/2 angle (IMA) greater than 10° and an HV angle (HVA) greater than 15°.

The exclusion criteria were as follows: [1] metatarsal osteotomy due to reasons other than HV [2]; age of less than 18 years, so as to exclude effects of congenital deformities [3]; previous HV surgery on the same foot; and [4] neurologial patients with cognitive disorders. Table 1 presents the demographic data of our study cohort.

### 2.1. Radiological evaluations

A radiological analysis was performed using standardized standing anteroposterior radiographs of the foot with full weightbearing. The second set of radiographs used for the analysis were OAV radiographs of the greater toe. These radiographs were

**Table 1**
Patient demographics.

| | | Range |
|---|---|---|
| Number of patients | 46 | |
| Number of feet | 67 | |
| Age (yr) | 60.0 ± 15.6 | 20.5–86.4 |
| Female (%) | 88.1 | |
| Right foot (%) | 47.8 | |
| BMI | 23.7 ± 3.7 | 17.2–33.0 |

Abbreviations: BMI—bodymass index; yr—years.

obtained by equalizing the hyperpronation of the greater toe. The OAV radiograph is a modification of the standardized anteroposterior radiograph with the beam positioned perpendicular to the nail plate. Toe nails are variable structures and the determination of the plane of the nail plate seems challenging. In an unpublished preliminary analysis of 40 feet, the transversal plane of the greater toe was represented by the nail plate consistently, irrespective of the shape of the nail. The plane of the nail plate is defined by the medial and lateral edge of the greater toe nail (Fig. 1). The angle produced by the nail plate and the floor in standing radiographs, named the nail-floor angle, has been described previously [12]. OAV radiographs were obtained by aligning the nail plate of the greater toe parallel to the detector (x-ray beam perpendicular to the nail plate of the greater toe), thereby correcting the hyperpronation of the greater toe and counterbalancing the nail-floor angle. The positioning of the greater toe can be facilitated using radiolucent wedges of the appropriate height by elevating the medial arch of the foot. We have developed 5, 10, 15, 20, and 30 mm insole-like wedges. Using these wedges, OAV radiographs can be obtained in the same way as weightbearing radiographs (Fig. 1b).

The radiological evaluation was performed in a digital manner by using specific angles to define the deformity of the phalangeal bone as well as classical angles for defining HV. For each patient, all angles were measured thrice each at different time points by three different reviewers (603 measurements). An interval of at least 24 h was maintained between the measurements to achieve reliable results. The investigators were blinded to the clinical results and did not participate in the surgical process. All investigators were orthopedic surgeons who were not involved in patient care and had undergone specific training for performing the measurements.

The following radiographic outcome measures for HVI have been used most consistently in the literature so far and were used for our study as well (Fig. 2) [13]: (1) The hallux interphalangeal angle (HIA), which is the angle between the midshaft axis of the proximal and the distal phalanx of the greater toe. (2) The proximal to distal phalangeal articular angle (PDPAA), which is the angle formed by tangential lines to the proximal and distal phalangeal articular surfaces of the proximal phalanx of the greater toe. (3) The proximal phalangeal articular angle (PPAA) or distal articular set angle, which is formed by a line perpendicular to the midshaft axis of the proximal phalanx and a line running through the edges of the proximal articular surface of the proximal phalanx of the greater toe. (4) The distal phalangeal articular angle (DPAA), which is formed by a line perpendicular to the midshaft axis of the proximal phalanx and the line running through the edges of the distal articular surface of the proximal phalanx of the greater toe. Additional evaluation of the two classical angles for hallux valgus deformity was performed for (5) the HVA and (6) the IMA, which have been described previously [1].

At present, a HIA greater than 10° serves as the most frequently used definition of HVI. which is formed by a line perpendicular to the midshaft axis of the proximal phalanx and the line running through the edges of the distal articular surface of the proximal phalanx of the greater toe. Therefore, the PDPAA might describe HVI deformity more precisely and reliably than does the HIA [13–15]. In contrast, the PPAA and the DPAA describe parts of the phalangeal deformity only.

### 2.2. Statistics

An a priori sample size analysis (two-sided paired t-test, target: minimal power of 0.80, Cohen's d of 1 revealing large effects, assumed mean difference and standard deviation of 5°, type 1 error of 1.25% Bonferroni adjusted) suggested that 48 participants were necessary. Therefore, an optimal sampling size of more than 50 feet was chosen to reveal large-scale effects with sufficient power.

**Fig. 1.** (a) Clinical picture of HV deformity with severe pronation of the greater toe. (b) Foot positioning for OAV of the foot. (c) Preoperative anteroposterior weightbearing radiograph of the foot. (d) OAV of the foot.

The HIA, PDPAA, PPAA, and DPAA were selected as primary outcome parameters. Secondary dependent variables included the HVA and the IMA. Statistical analysis was performed using the current version of the software SPSS Statistics (version number 22-2014, IBM, Armonk, New York, USA). The primary variables were analyzed in a confirmatory manner, while all secondary variables were analyzed in a purely descriptive way.

Radiographic measurement parameters of the primary endpoint were compared by using the two-sided paired Wilcoxon test with Bonferroni correction for multiple testing ($\alpha$ = 1.25). Intraobserver agreement was analyzed by one-way random, single-measure, absolute-agreement intraclass correlation coefficients (ICCs). Interobserver agreement was analyzed by two-way random, single-measure, absolute-agreement ICCs with the mean of all (three) measurements. Based on the 95% confidence interval of the ICC estimates, values less than 0.5, values between 0.5 and 0.75, values between 0.75 and 0.90, and values greater than 0.90 indicated poor, moderate, good, and excellent reliability, respectively [16]. Normality was assessed by using Kolmogorov-Smirnov tests and histograms. Mild and moderate/severe HV groups were compared with the non-parametric Mann-Whitney U as well as with a parametric Student *t*-test. An IMA of less or equal to/greater than 13° was chosen to distinguish between mild or moderate/severe HV deformity. On the basis of the definition of a HV deformity, an IMA below 10° was used as the cut-off value for HV deformity. To facilitate analyses of a possible correlation with the grade of the HV deformity, feet without an HV deformity (less than 10° IMA) were excluded (7 ft). A multivariate, binary logistic

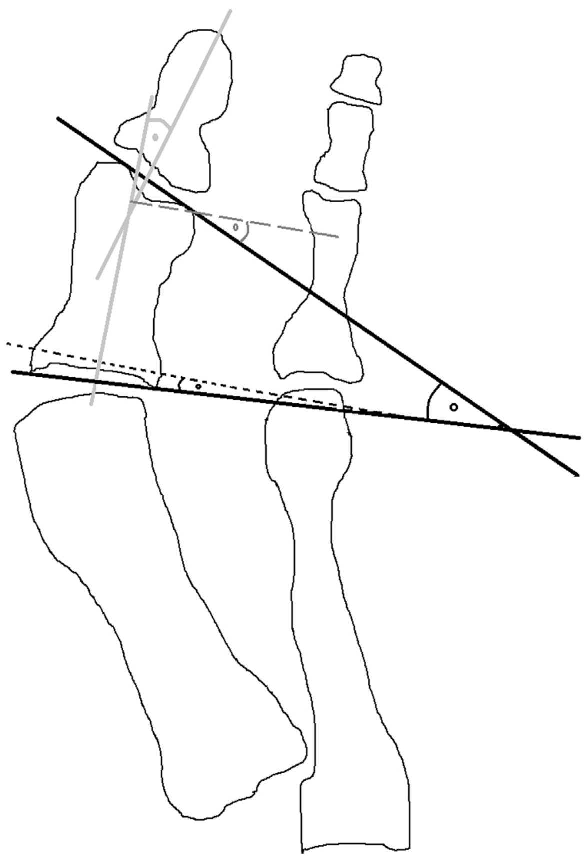

**Fig. 2.** Diagram illustrating the radiological angles HIA (gray lines), PDPAA (black lines), PPAA (dotted black lines) and DMAA (chained gray lines).

regression analysis was performed to identify the significant factors (differences of radiographic angles) associated with the severity of the HV deformity (mild and moderate/severe).

## 3. Results

Sixty-seven feet (46 patients) could be included for analysis. In the first step, intra- and interobserver agreements for all HVI angles were assessed: From the used HVI angles, PDPAA showed the highest intra- and interobserver reliability. Intraobserver reliability was good to excellent for HVA, IMA, HIA, HIAoav, PDPAA, PDPAAoav, PPAA, and PPAAoav, while it was moderate for DPAA and DPAAoav only (Table 2). Interobserver reliability was excellent for HVA only, whereas it was good for IMA, HIA, PDPAA, PDPAAoav, and PPAAoav, only moderate for HIAoav, PPAA and DPAAoav and poor for DPAA (Table 3).

In assessments for the two hypotheses of this study, namely that HVI deformity is underestimated on traditional anteroposterior standing radiographs compared to OAV (hypothesis 1) and that the differences between the anteroposterior standing and OAV radiographs correlate with the severity of the HV deformity (hypothesis 2), the following findings were obtained:

All tested HVI angles (except the DPAA) showed significantly lower values in the standing anteroposterior radiographs compared to OAV (hypothesis 1, $p < 0.001$). More specifically, HIA and PDPAA differed by more than 4°, whereas differences of PPAA and DPAA were less pronounced (Table 4). The value of the HVI angles did not correlate with the severity of the HV deformity (Table 4). However, analysis of the angular differences of the HVI angles between the traditional and the OAV radiographs showed a dependency to the severity of the HV deformity for all measured HVI angles (Table 5, Fig. 3). Correlation testing showed a significant difference in PDPAA measurement deviations ($p < 0.04$) between the two groups, but not for HIA ($p = 0.322$), PPAA ($p = 0.520$), and DPAA ($p = 0.877$) (Table 5). Similarly, the results of a multivariate, binary logistic regression analysis indicated that for PDPAA the measured differences were associated with the severity of HV deformity ($p = 0.038$).

## 4. Discussion

In this study, we focused on the radiographic assessment of a newly described anteroposterior OAV radiograph in comparison to the traditional anteroposterior standing radiographs. In the first step, we assessed the intra- and interobserver reliability of various HVI angles. PDPAA showed the highest intra- and interobserver reliability in comparison to HIA, PPAA, DPAA. In detail, good to excellent intraobserver reliability for all angles, except the DPAA, and good interobserver reliability for PDPAA could be found on both radiographs. Therefore, PDPAA might be the most precise angle for measuring HVI.

The main finding of our study was the underestimation of the HVI deformity on anteroposterior standing radiographs compared to OAV radiographs. We regard the hyperpronation of the greater toe in HV patients to be the cause of this finding. On closer examination, the detected differences between the traditional anteroposterior radiographs and the OAV were lower for DPAA and PPAA than for HIA and PDPAA. This finding can be explained by the fact that DPAA and PPAA only describe parts of the HVI deformity, whereas HIA and PDPAA represent the HVI deformity as a whole.

**Table 2**
Intraobserver reliability of hallux valgus and hallux valgus interphalangeus angle measurements.

| | Observer 1 | | Observer 2 | | Observer 3 | |
|---|---|---|---|---|---|---|
| | ICC | 95% CI | ICC | 95% CI | ICC | 95% CI |
| HVA | 0.985 | [0.978–0.990] | 0.975 | [0.963–0.984] | 0.986 | [0.979–0.991] |
| IMA | 0.956 | [0.936–0.972] | 0.823 | [0.750–0.881] | 0.856 | [0.794–0.904] |
| HIA | 0.922 | [0.886–0.948] | 0.951 | [0.927–0.968] | 0.925 | [0.890–0.951] |
| $HIA^{oav}$ | 0.879 | [0.826–0.920] | 0.854 | [0.792–0.902] | 0.843 | [0.776–0.894] |
| PDPAA | 0.899 | [0.853–0.933] | 0.934 | [0.903–0.957] | 0.912 | [0.872–0.942] |
| $PDPAA^{oav}$ | 0.976 | [0.964–0.984] | 0.945 | [0.919–0.964] | 0.892 | [0.844–0.928] |
| PPAA | 0.867 | [0.808–0.911] | 0.879 | [0.826–0.919] | 0.820 | [0.746–0.878] |
| $PPAA^{oav}$ | 0.936 | [0.906–0.958] | 0.823 | [0.750–0.881] | 0.834 | [0.764–0.888] |
| DPAA | 0.763 | [0.671–0.838] | 0.697 | [0.588–0.789] | 0.776 | [0.688–0.847] |
| $DPAA^{oav}$ | 0.771 | [0.681–0.843] | 0.745 | [0.648–0.825] | 0.672 | [0.557–0.770] |

$^{oav}$off axis view.
Abbreviations: HVA–hallux valgus angle; IMA—intermetatarsal angle; HIA—hallux interphalangeus angle; PDPA—Aproximal to distal phalangeal articular angle; PPA—Aproximal phalangeal articular angle; DPAA—distal phalangeal articular angle; SD—standard deviation; oav—off axis view; CI—confidence interval.

**Table 3**
Interobserver reliability of hallux valgus and hallux valgus interphalangeus angle measurements.

| | Observer 1/2/3 | | Observer 1/2 | | Observer 1/3 | | Observer 2/3 | |
|---|---|---|---|---|---|---|---|---|
| | ICC | 95% CI | ICC | 95% CI | ICC | 95% CI | ICC | 95% CI |
| HVA | 0.973 | [0.959–0.982] | 0.964 | [0.943–0.978] | 0.965 | [0.943–0.978] | 0.989 | [0.982–0.993] |
| IMA | 0.878 | [0.813–0.922] | 0.840 | [0.694–0.911] | 0.917 | [0.843–0.954] | 0.877 | [0.808–0.923] |
| HIA | 0.751 | [0.620–0.840] | 0.681 | [0.397–0.824] | 0.691 | [0.493–0.811] | 0.879 | [0.810–0.924] |
| HIA[oav] | 0.632 | [0.450–0.761] | 0.598 | [0.162–0.797] | 0.533 | [0.277–0.706] | 0.765 | [0.645–0.849] |
| PDPAA | 0.766 | [0.666–0.842] | 0.690 | [0.504–0.807] | 0.716 | [0.573–0.815] | 0.902 | [0.839–0.941] |
| PDPAA[oav] | 0.825 | [0.739–0.886] | 0.778 | [0.625–0.867] | 0.770 | [0.621–0.860] | 0.946 | [0.914–0.967] |
| PPAA | 0.618 | [0.492–0.729] | 0.542 | [0.347–0.691] | 0.507 | [0.305–0.665] | 0.828 | [0.734–0.891] |
| PPAA[oav] | 0.751 | [0.655–0.829] | 0.775 | [0.658–0.855] | 0.651 | [0.487–0.770] | 0.841 | [0.753–0.899] |
| DPAA | 0.423 | [0.274–0.568] | 0.264 | [0.040–0.467] | 0.344 | [0.121–0.535] | 0.717 | [0.576–0.816] |
| DPAA[oav] | 0.558 | [0.393–0.694] | 0.554 | [0.319–0.715] | 0.448 | [0.173–0.644] | 0.730 | [0.595–0.825] |

[oav]off axis view.
Abbreviations: HVA—hallux valgus angle; IMA—intermetatarsal angle; HIA—hallux interphalangeus angle; PDPA—Aproximal to distal phalangeal articular angle; PPA—Aproximal phalangeal articular angle; DPAA—distal phalangeal articular angle; SD—standard deviation; oav—off axis view; CI—confidence interval.

**Table 4**
Overall measurements (N = 603, 67 feet, 3 observer, 3 measurements/observer) and after grouping in mild (N = 261) and moderate/severe hallux valgus deformity (N = 279).

| | | Standard view | | | | Off axis view | | | | Difference | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean ± SD | Min | Max | Rg[a] | Mean ± SD | Min | Max | Rg[a] | Diff[b] | P-value |
| Overall | HVA | 27.2 ± 9.5 | 8.8 | 55.4 | 46.6 | | | | | | |
| | IMA | 12.2 ± 3.9 | 0.0 | 23.7 | 23.7 | | | | | | |
| | HIA | 10.7 ± 6.0 | 0.0 | 26.7 | 26.7 | 13.7 ± 4.9 | 0.5 | 28.7 | 28.2 | 5.0 | <0.001[c] |
| | PDPAA | 6.6 ± 5.0 | 0.0 | 30.2 | 30.2 | 9.4 ± 4.9 | 0.0 | 28.0 | 28.0 | 4.1 | <0.001[c] |
| | PPAA | 4.6 ± 3.6 | −4.0 | 21.2 | 25.2 | 6.7 ± 3.9 | 0.0 | 22.9 | 22.9 | 3.3 | <0.001[c] |
| | DPAA | 2.8 ± 3.0 | −7.8 | 11.4 | 19.2 | 3.2 ± 2.5 | −3.9 | 12.7 | 16.6 | 2.5 | <0.001[c] |
| Mild hallux valgus (IMA < 13°) | HVA | 23.6 ± 7.1 | 8.8 | 39.2 | 30.4 | | | | | | |
| | IMA | 9.9 ± 3.2 | 0.0 | 21.1 | 21.1 | | | | | | |
| | HIA | 11.5 ± 5.9 | 0.1 | 26.7 | 26.6 | 14.1 ± 5.0 | 0.5 | 28.7 | 28.2 | 5.0 | <0.001[c] |
| | PDPAA | 7.2 ± 4.4 | 0.2 | 20.1 | 19.9 | 9.8 ± 5.0 | 0.1 | 22.3 | 22.2 | 3.7 | <0.001[c] |
| | PPAA | 4.9 ± 3.1 | 0.0 | 13.9 | 13.9 | 6.9 ± 4.0 | 0.0 | 18.2 | 18.2 | 3.2 | <0.001[c] |
| | DPAA | 2.9 ± 2.5 | −4.6 | 10.2 | 14.8 | 3.5 ± 2.6 | 0.0 | 10.5 | 10.5 | 2.2 | 0.001[c] |
| Moderate / severe hallux valgus (IMA ≥ 13°) | HVA | 32.6 ± 9.2 | 14.4 | 55.4 | 41.0 | | | | | | |
| | IMA | 15.0 ± 2.7 | 3.0 | 23.7 | 20.7 | | | | | | |
| | HIA | 8.7 ± 5.2 | 0.0 | 24.4 | 24.4 | 13.0 ± 4.8 | 1.5 | 26.2 | 24.7 | 5.0 | <0.001[c] |
| | PDPAA | 5.0 ± 4.1 | 0.0 | 21.1 | 21.1 | 8.8 ± 4.1 | 0.0 | 25.8 | 25.8 | 4.7 | <0.001[c] |
| | PPAA | 3.7 ± 3.0 | −4.0 | 13.2 | 17.2 | 6.1 ± 3.1 | 0.1 | 16.5 | 16.4 | 3.4 | <0.001[c] |
| | DPAA | 2.3 ± 3.2 | −7.8 | 11.4 | 19.2 | 2.9 ± 2.3 | −3.9 | 11.0 | 14.9 | 2.5 | 0.002[c] |

Abbreviations: HVA—hallux valgus angle; IMA—intermetatarsal angle; HIA—hallux interphalangeus angle; PDPA—Aproximal to distal phalangeal articular angle; PPA—Aproximal phalangeal articular angle; DPAA—distal phalangeal articular angle; SD—standard deviation; Diff—difference.
[a] Range.
[b] Differences were calculated based on the absolute differences of the single measurements, e.g. $|HIAoffaxis_i\text{-}HIA_i| = |2.9-7.6| = |-4.7| = 4.7$.
[c] Off axis view measurements were compared using the (paired) Student-t-test.

**Table 5**
Comparison of differences between measurements of HVI between preoperative traditional anteroposterior standing radiographs and OAV (mean of 3 measurements from 3 observer).

| | Mild hallux valgus (IMA < 13°, N = 29) | | | | Moderate / severe hallux valgus (IMA ≥ 13°, N = 31) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Absolute difference | Mean ± SD | Min | Max | Rg | Mean ± SD | Min | Max | Rg | p-value |
| \|HIAoa-HIA\|\|PDPAAoa-PDPAA\|\|PPAAoa-PPAA\|\|DPAAoa-DPAA\| | 3.6 ± 2.9 | 0.1 | 10.9 | 10.7 | 4.4 ± 3.5 | 0.0 | 12.7 | 12.7 | 0.322[a] |
| | 3.2 ± 2.3 | 0.1 | 8.0 | 7.8 | 4.4 ± 2.2 | 0.8 | 9.2 | 8.4 | 0.04[a] |
| | 5.1 ± 3.3 | 0.4 | 12.8 | 12.4 | 5.4 ± 2.9 | 0.8 | 12.5 | 11.7 | 0.520[a] |
| | 1.5 ± 1.3 | 0.0 | 4.1 | 4.1 | 1.6 ± 1.5 | 0.2 | 5.2 | 5.0 | 0.877[a] |

Abbreviations: CI—confidence interval; HIA—hallux interphalangeus angle; PDPA—Aproximal to distal phalangeal articular angle; PPAA—proximal phalangeal articular angle; DPAA—distal phalangeal articular angle; IMA—intermetatarsal angle; Oa—off axis; SD—standard deviation.
[a] Mean absolute value of the measurement differences in traditional radiographs and OAV radiographs were compared using the non-parametric Mann–Whitney-U test as the data were not normally distributed (Kolmogorov–Smirnov test).

All HVI angles showed higher values on the OAV radiographs, but a significant correlation with the severity of the HV could not be found. However, the angular differences between OAV and traditional radiographs correlated significantly with the severity of the HV deformity. In other words, the severity of the HV deformity resulted in a higher mismatch of the measured HVI angles but not in increased HVI levels. Therefore, underestimation of the HVI on traditional anteroposterior radiographs seems to be more likely in moderate to severe HV deformity. Underestimation of HVI has been shown previously [8,11,13] and can be explained by a rotational phalangeal deformity in patients with moderate to severe HV. OAV radiographs represent the true HVI deformity more precisely in HV and are therefore recommended, especially in moderate to severe HV cases.

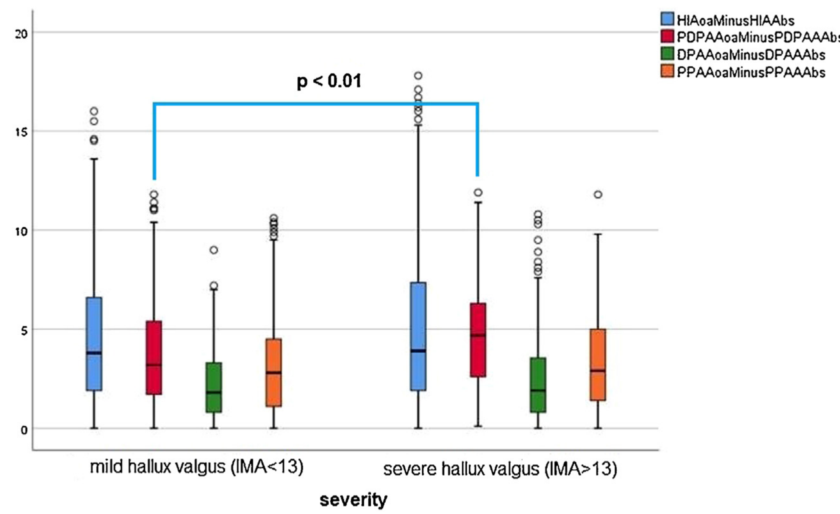


**Fig. 3.** Boxplot showing the differences in the assessed angles between the traditional anteroposterior standing radiograph and the OAV.

HV recurrence is frequently observed after HV correction, and several reasons for HV recurrence are discussed in the literature [17]. Loss of correction has been shown to correlate with preoperative deformity in terms of IMA, HVA, DMAA, and sesamoid position [18,19]. On the other hand, incomplete correction of HV deformity predisposes patients to loss of correction as well [20,21]. At present, HV is regarded as a three-dimensional pathology caused by forefoot and sometimes mid- or hindfoot deformity. In order to achieve recurrence-free and successful outcomes, correction of all pathology causing factors is necessary. Finally, persistent HVI is meant to be a major cause of HV recurrence and might result from the following reasons: Non-detection or underestimation of HVI on preoperative radiographs due to malprojection of the phalangeal deformity; poor reliability of certain radiographic angular measures resulting in HVI neglection; undefined threshold values determining the need for additional HVI correction; and insufficient operative correction of HVI. Park et al. could outline the incidence of intraoperative HVI after correction of the HV deformity and explained this finding with underestimation of the HIA on the preoperative radiographs [11]. Similarly, Dixon et al. found a deterioration of 6° of HIA and 2° of PDPAA postoperatively after different types of bunion correction without akin osteotomy [8]. In accordance with these studies, we believe that correction of a pathological HVI is mandatory for successful operative bunion correction. Therefore, preoperative assessment of an HVI should be performed precisely to facilitate accurate planning and deformity correction.

The decision to perform an additional phalangeal osteotomy is currently based on the radiographic measurement of HVI on preoperative anteroposterior radiographs. A precise threshold value making phalangeal osteotomy mandatory is missing so far. Nevertheless, Arnold et al. presented data with recommendations for akin osteotomy with an HIA of more than 10° [22]. Recently the threshold value for additional akin osteotomy in HV correction was determined to be 8° [6,7]. As a consequence of our findings, we recommend using OAV radiographs for determining the need for additional phalangeal osteotomy in HV correction, especially in uncertain cases. With the use of defined radiolucent wedges, taking an OAV radiograph is a standardized quick and simple diagnostic step. In particular, for a moderate to severe HV deformity, this radiograph allows for accurate measurement of the HVI deformity and timely surgical decision-making for an additional akin osteotomy. However, future studies should be conducted to investigate the reproducibility of OAV and to evaluate its effect on surgical decision-making in HV recurrence.

We acknowledge that the variability of the greater toenail may have influenced our findings. Nevertheless, the nail plane may be used as an indicator for the phalangeal pronation. The plane is defined by the lateral and medial edges of the nail. Recently the nail plane in relation to the base line has been described as nail-floor-angle in standing radiographs [12].

## 5. Limitations

A major limitation of our study stems from the monocentric character of this study and the small study cohort. Another limitation is attributable to the toenail anatomy, which could lead to errors in the OAV projection. A third limitation may be the fact that all radiographs, including the OAV radiographs, were obtained once. Acquisition of repeated OAV radiographs for every foot would have been beneficial to prove reliability but cannot be performed due to ethical reasons.

## 6. Conclusion

Angular measurements of HVI on traditional preoperative anteroposterior standing radiographs are significantly smaller than on OAV. Angular measurements on OAV radiographs show higher interobserver reliability. The most precise angle representing a HVI deformity might be the PDPAA.

## Ethics approval and consent to participate

This study has been approved by the local ethical committee of the Medical University of Innsbruck (IRB identifier: 1100/2019) and is registered with ClinicalTrials.gov (identifier: NCT04284618).

Due to the retrospective nature of this study and its limitation to a radiological analysis no consent to participate was obtained.

Research has been performed in accordance with the Declaration of Helsinki and was approved by the local ethics committee of the Medical University of Innsbruck.

## Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

## Consent for publication

Not applicable.

## Availability of data and material

All data generated or analysed during this study are included in this published article. This study or contents of this study have not been published or submitted for publication elsewhere.

## Conflict of interests

The authors declare that they have neither financial nor non-financial competing interests.

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## Author's contributions

- G.K. conceived of the study, generated its design, carried out parts of the measurements and acts as corresponding author.
- M.S. carried out parts of the measurements and acts as co-author.
- M.H. carried out parts of the measurements and acts as co-author.
- L.M. helped to draft the manuscript and acts as co-author.
- P.H. performed the statistical analysis and acts as co-author.
- B.M. drafted the manuscript and acts as senior author.

All authors read and approved the final manuscript.

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