



Research article

Hallux valgus assessment on X-ray and Magnetic resonance Imaging (MRI): Correlation with qualitative soft tissue and internal derangement findings on MRI[☆]



Jed Hummel^a, Justin Skweres^a, Nathan Heineman^{a,b}, Riham Dessouky^c, Yin Xi^a, Lihua Zhang^d, Dane K. Wukich^b, Avneesh Chhabra^{a,b,*,1}

^a Radiology, UT Southwestern Medical Center, Dallas, TX, USA

^b Orthopaedic Surgery, UT Southwestern Medical Center, Dallas, TX, USA

^c Radiology, Faculty of Medicine, Zagazig University, Zagazig, Egypt

^d Peking University Third Hospital, China

ARTICLE INFO

Keywords:

Hallux valgus
Radiograph
MRI
Derangement
Sesamoid

ABSTRACT

Aim: Radiographs (X-rays) are used for the preoperative assessment of hallux valgus (HV). Our purpose was to determine how well quantitative measurements of HV on radiographs and MRI correlate with the qualitative soft tissue and internal derangement findings on MRI.

Materials and methods: After IRB approval, 56 consecutive patients with MRI and radiographs of the foot were retrospectively reviewed. Two trained readers independently evaluated radiographs, measuring hallux valgus angle (HVA) and intermetatarsal angle (IMA). Two separate readers assessed qualitative MRI data by evaluating 21 different soft tissue and bony features. Statistical analysis included inter-reader reliability (IRR) and correlation of quantitative and qualitative findings.

Results: Excellent IRR (ICC = 0.89–0.96) was observed for radiograph and MRI measurements of the hallux valgus severity. For qualitative assessments on MRI, IRR was good to excellent for all features (ICC = 0.63–0.9). No significant difference was found for HVA or IMA between normal and abnormal qualitative MRI features. No statistically significant correlation between the severity of hallux valgus and injury to hallux joints and supporting structures was found.

Conclusion: Hallux valgus measurements are reliable on x-rays and MRI and qualitative findings of 1st MTP joint show good to excellent inter-reader agreement on MRI. No statistically significant correlations exist between the severity of hallux valgus and qualitative MRI findings.

1. Introduction

Hallux valgus is a common condition, affecting approximately 25% of adults aged 18 to 65 and 36% of adults over the age of 65 in the United States [1]. The first ray is subject to substantial forces during gait, however it serves a key role in maintaining the structure of the medial arch, acting as the main load-bearing structure [2,3]. The first metatarsophalangeal (MTP) joint is inherently unstable and relies on balanced static and dynamic restraints. Hallux valgus can result from failure anywhere along the first ray, from the distal phalanx to the talonavicular joint [2]. Predisposing factors to failure include both inherent and acquired biomechanical abnormalities [2]. No

musculotendinous structures attach to the metatarsal head. The primary static stabilizers on the medial side of the joint are the capsule, collateral ligament, and medial sesamoid ligament. Insufficiency of these structures is key to development of the deformity and are considered one of the early and essential lesions [2,4]. Failure of the medial static stabilizers allows the metatarsal head to drift medially, slipping off the sesamoid apparatus. The proximal phalanx remains tethered at its base by the sesamoids, the plantar plate, and the adductor hallucis tendon. As the metatarsal drifts medially, the tethered proximal phalanx shifts into valgus with the biomechanical consequence of increased lateral muscle pull and thus progression of the deformity [5]. The medially shifted metatarsal head may bear increased contact between

[☆] Institute from which the work originated: UT Southwestern Medical Center – Radiology Department.

* Corresponding author at: Musculoskeletal Radiology, UT Southwestern Medical Center, 5323 Harry Hines Blvd, Dallas, TX 75390-9178, USA.

E-mail address: avneesh.chhabra@utsouthwestern.edu (A. Chhabra).

¹ Adjunct Faculty, Johns Hopkins University.

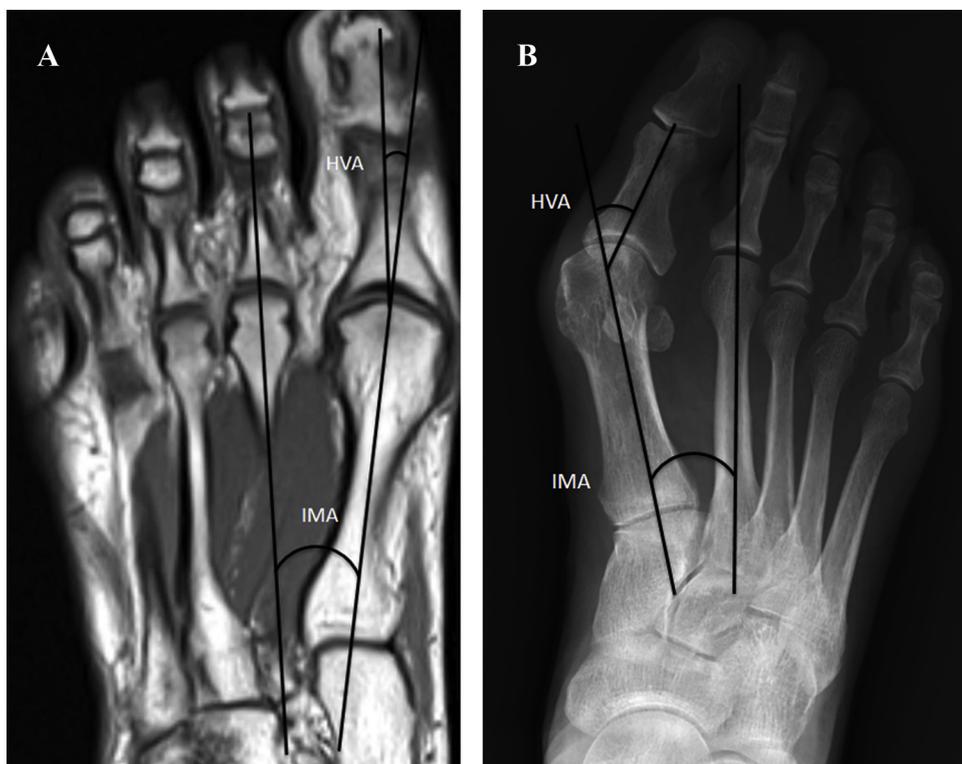


Fig. 1. Examples of HVA and IMA measurements on MRI and x-ray. IMA is the angle created between lines drawn through the midpoints of the first metatarsal head and base and midpoints of the second metatarsal head and base. HVA is the angle created between lines drawn through the midpoints of the first metatarsal head and base and midpoints of the first proximal phalanx head and base.

the medial sesamoid and crista resulting in cartilage and osseous erosions [2].

Radiography is the initial imaging study for the evaluation of hallux valgus. Radiographic measurements are essential parameters for assessing the severity of hallux valgus and are used to select surgical procedures and evaluate the results of surgical treatment [6]. Many measurements have been described to assess the severity of hallux valgus. The hallux valgus angle (HVA) and the intermetatarsal angle (IMA) have been shown to correlate best with the magnitude of deformity [7].

Evaluation of injuries of the 1st MTP joint static and dynamic stabilizers can be done with MRI. However, MRI is expensive and may not be easily available for all patients; radiography is typically more easily accessible and of lower cost. If radiographic hallux measurements are able to predict findings of internal derangement of the 1st MTP joint, MRI may be used more selectively. However, correlation of these radiographic measurements with specific injuries of the metatarsophalangeal (MTP) joint, hallux sesamoid complex, and supporting structures including cartilage, collateral ligaments, and the plantar plate on MRI is not known. Our purpose was to determine how well the quantitative measurements for assessing the severity of hallux valgus on radiographs and MRI correlate with the qualitative soft tissue findings on MRI.

2. Materials and methods

2.1. Study sample

Institutional IRB approval was obtained for this retrospective study, and informed consent was waived. We used Primordial[®] software to retrospectively query the institution's patient database and found 90 consecutive patients who had MRI of the forefoot and midfoot performed between April 27, 2015 and March 9, 2016. Inclusion criteria was patients between the ages of 18 and 100 years who had weight-bearing x-rays (AP and lateral) and MRI of the same foot with both studies obtained within 3 months of each other. Exclusion criteria included recent foot trauma, tumors, infections, or orthopedic hardware

(19 exams) and poor quality of the images (15 exams). The final sample was 56 patients who met both inclusion and exclusion criteria.

2.2. Imaging technique

Anteroposterior and lateral views of the foot in the weight-bearing position were available in all patients. The MR imaging was obtained using standardized institutional protocol on 1.5 T and 3 T scanners employing a boot coil. Short axis (axial), horizontal long axis (coronal) and sagittal images from both fat suppressed and non-fat suppressed intermediate weighted sequences were available in all cases as the MRI machines undergo ACR accreditation for foot protocols on a regular basis.

2.3. Image analysis

For every patient, the HVA and IMA were measured on x-ray by two trained readers (NH, a medical student and LZ, a radiologist- Readers 1, and 2) and MRI images were evaluated for qualitative findings by two musculoskeletal radiology fellows (JS and JH- Readers 3 and 4) who were trained on an initial set of 6 cases from the sample under the direction of a senior radiologist with more than 20 years of radiology experience.

2.4. Radiographic analysis

The HVA is defined as the angle formed by the axis of the first metatarsal and the axis of the first proximal phalanx (Fig. 1). The IMA is defined as the angle formed by the axis of the first metatarsal and the axis of the second metatarsal (Fig. 1). The longitudinal axis (midline) was determined by connecting the centers of the bones as described by Miller (traditional method) [8]. Previous literature has described multiple methods for obtaining the axis of the first metatarsal (by Hawkins, Venning, Mitchell, Miller, and Nestor et al.) [9], with the Miller method connecting the centers of the head and base of the metatarsal being the most popular and widely used. Recently, a point-method connecting the medial most point points of the bones across MTP joint has also been

Table 1
Structured evaluation of the 1st MTP joint qualitative findings on MRI.

Coronal plane evaluation									
MTP	Median Eminence			Capsule					
Normal, partial, full	Normal, partial, full	Present or absent	Present or absent	Present or absent	Present or absent	Present or absent	Normal, thickened, torn	Normal, thickened, torn	Normal, thickened, torn
Metatarsal Cartilage Erosion	Phalanx Cartilage Erosion	Osteophytes	Median Eminence Cystic Change	Median Eminence Bony Hypertrophy	Subchondral Bone Marrow	Capsule - Tibial Collateral	Capsule - Fibular Collateral		
Axial plane evaluation									
Capsule									
Present or absent	Normal, partial, full	Normal or abnormal	Present or absent	Present or absent	Present or absent	Present or absent	Normal, torn, tendinosis	Normal or fatty atrophy	Normal or fatty atrophy
Crista Erosion	Sesamoid Cartilage Erosion	Fibular Sesamoid Bone Marrow	Tibial Sesamoid Bone Marrow	Fibular Sesamoid Osteophyte	Tibial Sesamoid Osteophyte	Metatarsal Edema/sclerosis	Flexor Hallucis Longus	Flexor Hallucis Brevis Medial Head	Flexor Hallucis Brevis Lateral Head
Sagittal plane evaluation									
MTP									
Present or absent	Plantar Plate	Plantar Plate	Plantar Plate	Plantar Plate	Plantar Plate	Plantar Plate	Measure thickness (mm)	Measure thickness (mm)	Measure thickness (mm)
Joint Effusion	Plantar Plate	Plantar Plate	Plantar Plate	Plantar Plate	Plantar Plate	Plantar Plate	Proximal Plantar Plate Thickness	Distal Plantar Plate Thickness	Distal Plantar Plate Thickness

Table 2
Definitions of qualitative MRI findings of 1st MTP joint.

Term	Definitions
Metatarsal Cartilage Erosion	Partial = loss of cartilage that is not through the full thickness of cartilage at any point Full = complete loss of cartilage (even if only focal loss)
Phalanx or MT Cartilage Erosion	Partial = loss of cartilage that is not through the full thickness of cartilage at any point Full = complete loss of cartilage (even if only focal loss)
Osteophytes	Present = angled bony projections from the surface of the bone across the joint space
Median Eminence Edema	Present = fluid signal within the median eminence of the 1 st metatarsal
Median Eminence Cystic Change	Present = cysts and erosions on the distal end of the 1 st metatarsal at tibial collateral ligament attachment
Median Eminence Bony Hypertrophy	Present = abnormal angulated enlargement of the medial aspect of the median eminence of the 1 st metatarsal
Subchondral Bone Marrow	Abnormal = presence of sclerosis, cysts, or edema at joint surface of MT head
Capsule - Tibial Collateral	Torn = full or partial thickness defect in the tibial collateral ligament Thickened = abnormal thickening of the ligament
Capsule - Fibular Collateral	Torn = full or partial thickness defect in the fibular collateral ligament Thickened = abnormal thickening of the ligament
Crista Erosion	Present = blunting of the point of the inter-sesamoid crista
Sesamoid Cartilage	Partial = loss of cartilage that is not through the full thickness of cartilage at any point Full = complete loss of cartilage (even if only focal loss)
Fibular Sesamoid Bone Marrow	Abnormal = presence of sclerosis, cysts, or edema
Tibial Sesamoid Bone Marrow	Abnormal = presence of sclerosis, cysts, or edema
Fibular Sesamoid Osteophyte	Present = bony projections from the surface of the bone at MT-sesamoid articulation
Tibial Sesamoid Osteophyte	Present = bony projections from the surface of the bone at MT-sesamoid articulation
Metatarsal Edema	Present = fluid signal within the 1 st metatarsal at MT-sesamoid articulation
Metatarsal Sclerosis	Present = hypointense signal on T1 at MT-sesamoid articulation
Flexor Hallucis Longus	Torn = full thickness defect Tendinosis = thickening and increase in signal of tendon
Flexor Hallucis Brevis Medial Head	Fatty atrophy = presence of fat signal interspersed throughout muscle belly with or without loss of volume
Flexor Hallucis Brevis Lateral Head	Fatty atrophy = presence of fat signal interspersed throughout muscle belly with or without loss of volume
Joint Effusion	Present = increased fluid signal in joint space with distention of dorsal or lateral recesses
Plantar Plate	Torn = full thickness defect or retraction; Degenerative = fraying, thinning or increasing signal
Proximal Plantar Plate Thickness	Thickness of the plantar plate at the most prominent proximal area
Distal Plantar Plate Thickness	Thickness of the plantar plate at the most prominent distal area

Table 3
Study cohort characteristics (N = 56).

	N patients (%)
Sex	
Male	16 (28.6%)
Female	40 (71.4%)
Foot	
Left	30 (53.6%)
Right	26 (46.4 %)
BMI (kg/m²)	28.7 ± 7.0
Normal or Underweight (< 25)	19 (33.9%)
Overweight (25-30)	15 (26.8%)
Obese (> 30)	20 (35.7%)
N/A	2 (3.6%)
Age (years)	54.2 ± 15.4
< 65	41 (73.2%)
> 65	15 (26.8%)

proposed but the traditional (Miller) method has been the most validated and was used for this study [10,11]. The HVA and IMA were also used on MRI. MRI measurements were found to be reliable with small differences from X-ray measurements, as it was reported in our previous work [12].

2.5. Qualitative MRI analysis

Both musculoskeletal radiology fellows in second half of their training year assessed the MRI exams for qualitative data looking at 21 different soft tissue and bony features (Table 1) using a standard set of definitions (Table 2) after reviewing 10% of cases in consensus with the senior radiologist.

2.6. Statistical analysis

Inter reader reliability (IRR) was assessed using kappa for binary variables and weighted kappa for ordinal variables. The highest-grade diagnosis from the 2 readers was used for analysis. The distributions of HVA and IMA were right skewed, therefore medians and IQRs were reported and Wilcoxon-Mann-Whitney rank sum tests were used. Bland-

Altman plots were generated for HVA and IMA. Bland-Altman plot reviews potential bias, heteroscedasticity, skewness, and shifts in the agreements between two measurements. P values < 0.05 were considered statistically significant.

3. Results

3.1. Patient demographics

The mean age of the study group was 54.2 ± 15.4 years. The mean BMI was 28.7 ± 7.1 kg/m², and 71.4% (40/56) were females. 53.6% (30/56) of the patients had imaging of the left foot and 46.4% (26/56) had imaging of the right foot (Table 3).

3.2. Qualitative MRI findings

A total of 1176 qualitative features were evaluated on MRI. 446 and 451 qualitative abnormalities were found (by readers 3 and 4, respectively) among 56 patients. The most common soft tissue finding among both readers was plantar plate tear (in 33 and 37 patients respectively), followed by partial metatarsal cartilage erosion (in 29 and 30 patients respectively), phalangeal cartilage erosion (26 and 29 patients respectively), and flexor hallucis tendinosis (27 and 18 patients respectively). Table 4 demonstrates frequencies of individual qualitative findings in both readers.

3.3. Inter-reader agreements

Excellent inter-reader reliability (ICC = 0.89–0.96) was observed for radiograph measurements of severity (HVA and IMA), (Table 5A). For qualitative assessments on MRI, inter-reader reliability was good to excellent for all features (Table 5B, Figs. 2–5). Bland-Altman plots demonstrated most measurements of HVA/IMA within 2 standard deviations of the mean (Figs. 6 and 7).

Table 4
Frequency of abnormalities for each qualitative MRI finding.

		Reader 3	Reader 4
Metatarsal Cartilage Erosion	Normal	7	11
	Partial	29	30
	Full	20	15
Phalanx Cartilage Erosion	Normal	19	15
	Partial	26	29
	Full	11	12
Osteophytes	Absent	37	36
	Present	19	20
Median Eminence Edema	Absent	45	47
	Present	11	9
Median Eminence Cystic Change	Absent	42	44
	Present	14	12
Median Eminence Bony Hypertrophy	Absent	40	47
	Present	16	9
Subchondral Bone Marrow	Normal	43	44
	Abnormal	13	12
Capsule - Tibial Collateral	Normal	30	32
	Thickened	24	22
	Torn	2	2
Capsule - Fibular Collateral	Normal	44	36
	Thickened	8	13
	Torn	4	7
Crista Erosion	Absent	40	43
	Present	16	13
Sesamoid Cartilage	Normal	11	12
	Partial	23	26
	Full	22	18
Fibular Sesamoid Bone Marrow	Normal	42	43
	Abnormal	14	13
Tibial Sesamoid Bone Marrow	Normal	39	41
	Abnormal	17	15
Fibular Sesamoid Osteophyte	Normal	49	48
	Abnormal	7	8
Tibial Sesamoid Osteophyte	Normal	52	51
	Abnormal	4	5
Metatarsal Edema/sclerosis	Normal	34	34
	Abnormal	22	22
Flexor Hallucis Longus	Normal	28	36
	Tendinosis	27	18
	Torn	1	2
Flexor Hallucis Brevis Medial Head	Normal	46	43
	Fatty atrophy	10	13
Flexor Hallucis Brevis Lateral Head	Normal	45	41
	Fatty atrophy	11	15
Joint Effusion	Absent	31	35
	Present	25	21
Plantar Plate	Normal	6	4
	Degenerative	7	15
	Torn	33	37
All quantitative findings	Total	1176	1176

Table 5A
Inter-reader Reliability on radiographs.

Angle	Reader 1 vs. Reader 2
HVA	0.96 (95% CI 0.94,0.98)
IMA	0.89 (95% CI 0.8,0.95)

3.4. Correlations of radiographic measurements and MRI qualitative findings of 1st MTP joint derangements

No significant difference was found for HVA or IMA between normal and abnormal qualitative MRI features (p > 0.05) (Table 6). No statistically significant correlation existed between the severity of hallux valgus and injury to the hallux joints and supporting structures.

4. Discussion

Radiographic measurements are essential parameters for assessing

Table 5B
Inter-reader Reliability on MRI.

Measurements	Kappa (95% CI) *weighted kappa
Metatarsal Cartilage Erosion	*0.77 (0.62, 0.92)
Phalanx Cartilage Erosion	*0.74 (0.59, 0.88)
Osteophytes	0.88 (0.75, 1)
Median Eminence Edema	0.88 (0.71, 1)
Median Eminence Cystic Change	0.9 (0.76, 1)
Median Eminence Bony Hypertrophy	0.7 (0.49, 0.92)
Subchondral Bone Marrow	0.74 (0.53, 0.96)
Capsule - Tibial Collateral	0.71 (0.53, 0.9)
Capsule - Fibular Collateral	0.66 (0.45, 0.86)
Crista Erosion	0.77 (0.58, 0.96)
Sesamoid Cartilage	*0.75 (0.61, 0.89)
Fibular Sesamoid Bone Marrow	0.66 (0.43, 0.89)
Tibial Sesamoid Bone Marrow	0.74 (0.54, 0.93)
Fibular Sesamoid Osteophyte	0.77 (0.52, 1)
Tibial Sesamoid Osteophyte	0.64 (0.26, 1)
Metatarsal Edema/sclerosis	0.7 (0.51, 0.89)
Flexor Hallucis Longus	*0.63 (0.44, 0.82)
Flexor Hallucis Brevis Medial Head	0.84 (0.66, 1)
Flexor Hallucis Brevis Lateral Head	0.8 (0.62, 0.99)
Joint Effusion	0.71 (0.52, 0.89)
Plantar Plate	*0.67 (0.46, 0.88)

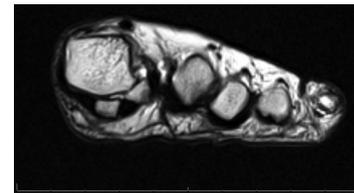


Fig. 2. Erosion of the crista. Both readers agreed on this finding.

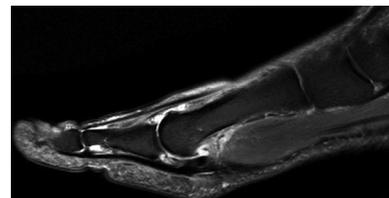


Fig. 3. Torn great toe plantar plate. Both readers agreed on this finding.

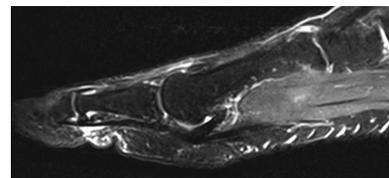


Fig. 4. Plantar plate pathology. One reader classified as torn and one reader classified as degenerated.

the severity of hallux valgus and are used to select surgical procedures and evaluate the results of surgical treatment [6,13]. Previous studies have shown HVA and IMA to be strongly correlated with severity of hallux valgus [7,13]. Relative normal values for HVA and IMA vary in the literature, but generally accepted values are as follows: Normal HVA less than 15°, IMA approximately 9° [14] and severe HV defined as having an HVA of greater than 40° and IMA greater than 15–16° [14,15]. Recently, we have also found that radiographic HVA and IMA measurements can also be used in quantification of HV on MRI [12].

Currently, HV is considered a three dimensional deformity with rotational components, such as pronation of 1st metatarsal and lateral displacement of the sesamoids, possibly limiting current 2D



Fig. 5. Thickening of the tibial collateral ligament and full-thickness cartilage loss on metatarsal head. Both readers agreed on these findings.

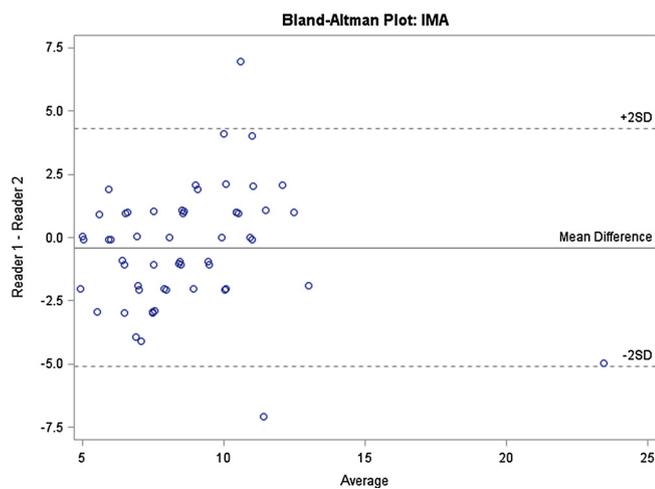


Fig. 6. Bland-Altman plot of IMA measurements.

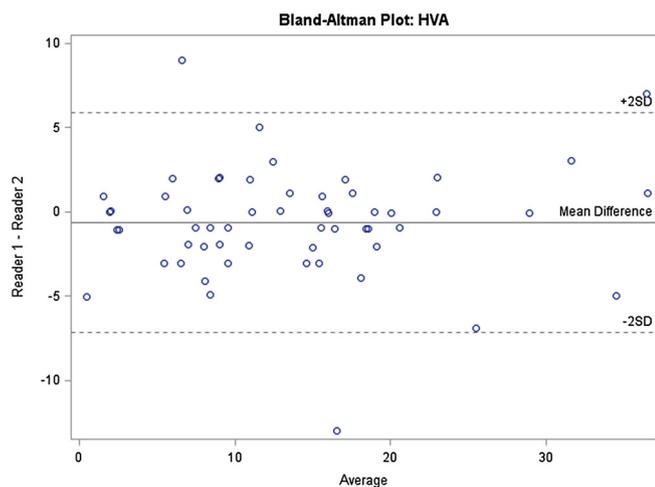


Fig. 7. Bland-Altman plot of HVA measurement.

radiographic technique [16]. Ultimately, the surgical treatment is decided based on a combination of clinical symptoms and severity of the hallux valgus. The surgical failure rate is 5–20% with persistent metatarsalgia, and it might be related to underlying internal derangement including plantar plate tear, cartilage loss, bone marrow edema/erosion, etc. apart from the surgical complications, e.g. undercorrection, overcorrection, avascular necrosis, etc. While MRI can be

used for evaluation of internal derangement findings, and few limited studies have evaluated qualitative features of HV on MRI [17–19], it is still not clear whether there is any correlation of such qualitative findings with X-ray measurements used for surgical planning. To the best of our knowledge, this is the first and largest study performed to assess the correlations of various osseous, ligamentous and tendinous MRI findings of with severity of HV.

In our study, the most common qualitative finding among both readers was plantar plate tear. Other common findings included metatarsal cartilage erosion, phalangeal cartilage erosion, and flexor hallucis tendinosis. These are novel findings and have not been previously reported, mainly due to lack of assessment and better MR capabilities than that of previous studies [17,18]. A Previous study by Schweitzer et al. has described the most frequent findings observed being the presence of median eminence hypertrophy, sesamoid proliferation, adventitial bursitis, MTP osteophytes, geodes, and marrow edema, however, patients with HV only represented 4.1% of evaluated patients [17]. Another study by Eustace et al. evaluated correlation of tendon shift with HV, and although all patients had clinical and radiographic features of HV, no quantitative measurement of tendon shift was performed to allow reproducibility and study sample was very small (20 patients) to draw conclusive results [18]. We also found good to excellent inter-reader agreement for qualitative findings on MRI with excellent agreements on assessment for metatarsal cartilage, MTP osteophytes, median eminence edema, median eminence cystic change, crista erosion, fibular sesamoid osteophyte, and atrophy of the flexor hallucis brevis muscle. To the best of our knowledge, this has not been previously assessed and highlights the importance of MRI as a reproducible modality in evaluation of soft tissue derangements of HV.

Other important findings were excellent inter-reader reliabilities for radiographic measurements of HV severity (HVA and IMA ICC = 0.89–0.96). This agreed with a previous studies by Lee et al. and Saro et al. [7,20], thus, severity measurements are highly reproducible and are therefore, prudently used for clinical decision making. No statistically significant correlations were found between the severity of hallux valgus and qualitative MRI findings. We therefore advice against use of expensive modality, i.e. MRI for primary evaluation of hallux valgus.

Some limitations deserve mention. We did not perform intra-reader agreements for the measurements. There was no surgical correlation available for MRI findings. However, few of the MRI findings would have presented surgical issues and we wanted to assess the full spectrum of findings as they relate to the varying severity of the hallux valgus. In some cases MRI image quality may have resulted in difficulty in distinguishing between minor differences in severity of a finding for example, partial from full thickness cartilage loss. We also did not correlate the imaging findings with the clinical symptoms due to the retrospective nature of the study and small sample size. Sample was small since only patients with x-ray and MRI exams obtained concurrently within three months were evaluated to avoid confounding the results due to the introduction of new pathology. In addition, the patients did not present primarily for great toe pain. A prospective study with functional foot scores evaluation may resolve these limitations, however, since we found no statistical correlations, it might not be necessary.

In conclusion, Hallux valgus measurements are reliable on x-rays and the evaluation of qualitative findings of great toe MTP joint shows good to excellent inter-reader agreement on MRI. No statistically significant correlations existed between the radiographic determinants of severity of hallux valgus and the described qualitative MRI findings and thus, MRI may not be needed to determine clinical treatment decisions.

Funding

No funding was received.

Table 6
Correlations of hallux valgus measurements on X-rays and qualitative foot MRI findings.

		HVA	p-value	IMA	p-value
Metatarsal Cartilage Erosion	Normal	14.75, (8– 18.5), 34	0.4	7.75, (6.5 - 10), 34	0.23
	Partial/full	10.25, (6.5 –18), 18		9, (7 - 10.5), 18	
Phalanx Cartilage Erosion	Normal	14, (7.25–18.25), 40	0.78	7.75, (6.5 - 10), 40	0.05
	Partial/full	10.25, (7.5–17.75), 12		9.75, (8.5 - 11), 12	
Osteophytes	Absent	11.5, (6.5– 19), 19	0.75	9, (7.5 - 11), 19	0.14
	Present	12.5, (7.5 – 17.5), 33		8, (6.5 - 10), 33	
Median Eminence Edema	Absent	15, (6.5 - 16.5), 11	0.9	8.5, (7.5 - 9), 11	0.97
	Present	11, (7.5 - 18.5), 41		8, (6.5 - 10.5), 41	
Median Eminence Cystic Change	Absent	15.5, (9.5 - 18.5), 13	0.32	9, (8.5 - 9.5), 13	0.11
	Present	11, (7 - 17.5), 39		7.5, (6.5 - 10.5), 39	
Median Eminence Bony Hypertrophy	Absent	10.5, (6.5 - 16.5), 14	0.47	8.75, (7 - 9.5), 14	0.97
	Present	13, (8 - 18.5), 38		8, (7 - 10.5), 38	
Subchondral Bone Marrow	Normal	11, (6 - 16.5), 14	0.56	8.75, (7 - 11), 14	0.32
	Abnormal	14.75, (7.5 - 18.5), 38		8, (7 - 10), 38	
Capsule – Tibial Collateral	Normal	13.5, (7 - 18), 27	0.87	7.5, (6.5 - 9.5), 27	0.2
	Thickened/torn	11, (8 - 18.5), 25		8.5, (7.5 - 10.5), 25	
Capsule – Fibular Collateral	Normal	12.5, (7.5 - 20.5), 18	0.62	8.5, (7 - 9.5), 18	0.69
	Thickened/torn	11.75, (7 - 17.5), 34		8.25, (7 - 9.5), 34	
Crista Erosion	Absent	14.5, (6.5 - 19), 17	0.65	8.5, (7 - 9.5), 17	0.99
	Present	11, (8 - 17.5), 35		8, (7 - 10.5), 35	
Sesamoid Cartilage	Normal	11, (8.5 - 17.5), 29	0.88	8.5, (7.5 - 10.5), 29	0.47
	Partial/full	12.5, (6.5 - 20.5), 23		8, (6.5 - 9.5), 23	
Fibular Sesamoid Bone Marrow	Normal	15.5, (6.5 - 25.5), 15	0.21	8, (7 - 9.5), 15	0.9
	Abnormal	11, (7.5 - 16.5), 37		8.5, (7 - 10.5), 37	
Tibial Sesamoid Bone Marrow	Normal	14.5, (2.5 - 20.5), 17	0.92	7.5, (6.5 - 10.5), 17	0.51
	Abnormal	11.5, (8 - 17.5), 35		8.5, (7 - 10), 35	
Fibular Sesamoid Osteophyte	Normal	11.25, (4 - 19.75), 8	0.78	8.25, (6.5 - 9), 8	0.53
	Abnormal	13, (7.75 - 17.75), 44		8.5, (7 - 10.5), 44	
Tibial Sesamoid Osteophyte	Normal	17, (11.5 - 20.5), 6	0.26	9, (8.5 - 9), 6	0.56
	Abnormal	11, (7 - 17.5), 46		8, (7 - 10.5), 46	
Metatarsal Edema/sclerosis	Normal	12.5, (6.5 - 19), 25	0.99	8.5, (7 - 10.5), 25	0.48
	Abnormal	11.5, (8 - 16.5), 27		8, (6.5 - 10), 27	
Flexor Hallucis Longus	Normal	14, (8.5 - 20.5), 26	0.07	8.5, (7 - 10.5), 26	0.35
	Torn/tendinosis	11, (6 - 16), 26		8, (6.5 - 9.5), 26	
Flexor Hallucis Brevis Medial Head	Normal	11.5, (11–18.5), 11	0.8	9, (6.5 - 10.5), 11	0.9
	Fatty atrophy	12.5, (7–18), 41		8, (7 - 10), 41	
Flexor Hallucis Brevis Lateral Head	Normal	11.5, (7.5–18.5), 15	0.75	8.5, (6.5 - 9.5), 15	0.58
	Fatty atrophy	12.5, (7–17.5), 37		8, (7 - 10.5), 37	
Joint Effusion	Absent	11.25, (7.5–16.25), 24	0.73	7.75, (6.75 - 10), 24	0.25
	Present	13.5, (7.25–18.75), 28		8.5, (7–10.75), 28	
Plantar Plate	Normal/torn	11.25, (7 - 16.5), 34	0.58	7.75, (6.5 - 9.5), 34	0.17
	degenerative	14, (8.5 - 19), 18		9.25, (7.5 - 11), 18	

Conflict of interest

The authors report no conflict of interest.

Disclosures

AC serves as a consultant to ICON Medical. AC receives royalties from Jaypee and Wolters.

Acknowledgements

None.

References

[1] S. Nix, M. Smith, B. Vicenzino, Prevalence of hallux valgus in the general population: a systematic review and meta-analysis, *J. Foot Ankle Res.* 3 (21) (2010), <https://doi.org/10.1186/1757-1146-3-21>.

[2] A.M. Perera, L. Mason, M.M. Stephens, The pathogenesis of hallux valgus, *J. Bone Joint Surg. – Ser. A* 93 (2011) 1650–1661, <https://doi.org/10.2106/JBJS.H.01630>.

[3] D.J. Morton, Structural factors in static disorders of the foot, *Am. J. Surg.* 9 (1930) 315–328, [https://doi.org/10.1016/S0002-9610\(30\)91100-2](https://doi.org/10.1016/S0002-9610(30)91100-2).

[4] D.W. Wilson, Treatment of hallux valgus and bunions, *Br. J. Hosp. Med.* 24 (1980) 548–549 <https://www.ncbi.nlm.nih.gov/pubmed/7272540>.

[5] A. Deenik, N. Guldemond, Validity of hallux valgus angle measurement using plantar pressure measurement: a pilot study, *Hallux Valgus* (2015) 69, <https://doi.org/10.1063/1.4810597>.

[6] H. Shima, R. Okuda, T. Yasuda, T. Jotoku, N. Kitano, M. Kinoshita, Radiographic measurements in patients with hallux valgus before and after proximal crescentic osteotomy, *J. Bone Joint Surg. – Ser. A* 91 (2009) 1369–1376, <https://doi.org/10.2106/JBJS.H.00483>.

[7] K.M. Lee, S. Ahn, C.Y. Chung, K.H. Sung, M.S. Park, Reliability and relationship of radiographic measurements in hallux valgus foot and ankle, *Clin. Orthop. Relat. Res.* 470 (2012) 2613–2621, <https://doi.org/10.1007/s11999-012-2368-6>.

[8] J.W. Miller, Distal first metatarsal displacement osteotomy. Its place in the schema of bunion surgery, *J. Bone Joint Surg. – Ser. A* 56 (1974) 923–931, <https://doi.org/10.2106/00004623-197456050-00005>.

[9] S. Srivastava, N. Chockalingam, T. El Fakhri, Radiographic measurements of hallux angles: a review of current techniques, *Foot* 20 (2010) 27–31, <https://doi.org/10.1016/j.foot.2009.12.002>.

[10] J.H. Seo, J.Y. Ahn, D. Boedijono, Point-connecting measurements of the hallux valgus deformity: a new measurement and its clinical application, *Yonsei Med. J.* 57 (2016) 741–747, <https://doi.org/10.3349/ymj.2016.57.3.741>.

[11] N. Heineman, A. Chhabra, L. Zhang, R. Dessouky, D. Wukich, Point vs. traditional method evaluation of hallux valgus: interreader reliability and intermethod performance using X-ray and MRI, *Skeletal Radiol.* (2018) 1–7, <https://doi.org/10.1007/s00256-018-3022-5>.

[12] N. Heineman, Y. Xi, L. Zhang, R. Dessouky, J. Hummel, J. Skweres, D. Wukich, A. Chhabra, Hallux valgus evaluation on MRI: can measurements validated on radiographs be used? *J. Foot Ankle Surg.* 57 (2018) 305–308, <https://doi.org/10.1053/j.jfas.2017.10.009>.

[13] T.S. Roukis, et al., A prospective comparison of clinical, radiographic, and intraoperative features of hallux rigidus, *J. Foot Ankle Surg.* 41 (2) (2002) p.

[14] M.J. Coughlin, C.L. Saltzman, R.B. Anderson, Mann's Surgery of the Foot and Ankle, (2014), <https://doi.org/10.1016/B978-0-323-07242-7.00051-6>.

[15] P.F. Rippstein, Y.U. Park, F.D. Naal, Combination of first metatarsophalangeal joint arthrodesis and proximal correction for severe hallux valgus deformity, *Foot Ankle Int.* 33 (2012) 400–405, <https://doi.org/10.3113/FAL.2012.0400>.

[16] M.J. Welck, N. Al-Khudairi, Imaging of hallux valgus: how to approach the deformity, *Foot Ankle Clin.* 23 (2018) 183–192, <https://doi.org/10.1016/j.fcl.2018.01.002>.

- [17] M.E. Schweitzer, S. Maheshwari, N. Shabshin, Hallux valgus and hallux rigidus: MRI findings, *Clin. Imaging* 23 (1999) 397–402, [https://doi.org/10.1016/S0899-7071\(00\)00167-4](https://doi.org/10.1016/S0899-7071(00)00167-4).
- [18] S. Eustace, D. Williamson, M. Wilson, J. O'Byrne, L. Bussolari, M. Thomas, M. Stephens, J. Stack, B. Weissman, Tendon shift in hallux valgus: observations at MR imaging, *Skeletal Radiol.* 25 (1996) 519–524, <https://doi.org/10.1007/s002560050128>.
- [19] A.P. Sanders, R.E. Weijers, C.J. Snijders, L.C. Schon, Three-dimensional reconstruction of magnetic resonance images of a displaced flexor hallucis longus tendon in hallux valgus, *J. Am. Podiatr. Med. Assoc.* 95 (2005) 401–404, <https://doi.org/10.7547/0950401>.
- [20] C. Saro, D.N. Johnson, J. Martinez De Aragón, U. Lindgren, L. Felländer-Tsai, Reliability of radiological and cosmetic measurements in hallux valgus, *Acta Radiol.* 46 (2005) 843–851 <http://www.ncbi.nlm.nih.gov/pubmed/16392609>.