Normal Variations in Lisfranc 3D Weight-Bearing Computed Tomography Assessment and Determining a Threshold for Instability

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INTRODUCTION: Untreated Lisfranc injuries can lead to chronic pain, midfoot arthritis, and functional disability. Yet, up to one-third of Lisfranc injuries are missed on initial evaluation. This can be attributed to a lack of parameters regarding normal variations of patients without injury to the Lisfranc complex, which results in ambiguous diagnostic criteria for Lisfranc complex injury. Prior studies have underscored the utility of weight-bearing computed tomography (WBCT) in Lisfranc instability, which allows for bilateral three-dimensional (3D) evaluation under physiologic load. The first aim of this study was to identify anatomic variations of 3D WBCT measurements of the Lisfranc complex of patient with an uninjured midfoot. The second aim was to quantify appropriate diagnostic cutoff values of Lisfranc instability using 3D WBCT anatomic measurements.

METHODS:

In this retrospective case-control study, 234 adult patients with bilateral WBCT scans of the foot were included: 44 patients with Lisfranc instability and 190 patients without a history of current or prior midfoot injury. Lisfranc instability was confirmed intraoperatively or by clinical evaluation performed by the surgeon. Patients with prior midfoot surgery, Charcot arthropathy, severe midfoot arthropathy, or significantly displaced fracture of the cuneiforms or 1st, 2nd, or 3rd, metatarsal bases were excluded. The following Lisfranc joint measurements were collected bilaterally: joint volume on coronal slices (3D), area of the joint on an axial slice (2D), and diastasis between the second metatarsal and medial cuneiform on an axial slice (1D). Foot alignment was assessed using Meary's angle. Patient demographics (age, sex, weight, height, BMI) were also collected. Percent difference was used to assess volume, area, and diastasis between contralateral sides. Mann-Whitney U and Pearson correlation tests were used to assess association of demographic data and 3D WBCT Lisfranc measurements. Pearson R Chi-Square and Mann Whitney U tests were used to compare data between case and control groups. Using receiver operator curves (ROC), area under the curve (AUC) and minimum distance to the corner was used to determine optimal diagnostic cutoff values. For all statistical analysis, P<0.05 or an equivalent Bonferroni adjusted p-value was considered significant.

RESULTS: Demographic data for case and control groups is shown in Table 1. There was no association between demographic data and percent difference between contralateral feet for all three measurements (Table 2). A large standard deviation was observed for absolute measurement of volume, area, and diastasis; therefore, analysis was conducted using percent difference between contralateral feet (Table 3, Table 4). In the control group, there was a 13.3% ±1.7%, 17.6% ±2.9%, 16.4% ±2.9% difference for volume, area, and diastasis respectively. In the case group, the percent difference between contralateral feet for volume, area, and diastasis was 35.1% ±9.0%, 46.8% ±10.2%, and 57.3% ±12.8%. There was a significant difference between cases and controls for all three WBCT measurements (p<0.001). Based on ROC analysis (Figure 1), the AUC and diagnostic cutoff values were found to be 18% and 0.806 for volume, 24% and 0.827 for area, and 34% and 0.903 for diastasis.

DISCUSSION AND CONCLUSION: Absolute Lisfranc WBCT measurements demonstrated a large standard deviation, indicating a large patient-to-patient variation in Lisfranc joint complexes. Percent difference between contralateral feet is a means of normalizing the WBCT measurements to account for this variation. Percent difference of Lisfranc 3D WBCT measurements were not associated with age, sex, weight, height, or BMI, suggesting these variables do not need to be considered when assessing the Lisfranc complex with WBCT measurements. There was less than a 20% difference between contralateral feet in the control group, compared to at least a 30% difference in the Lisfranc instability group. According to AUC analysis, volume and area provide excellent diagnostic capability, and diastasis demonstrated excellent diagnostic capability, with a sensitivity of 0.774 and specificity of 0.900. Furthermore, AUC values demonstrated decreased diagnostic accuracy as the number of dimensions increased, suggesting additional dimensions are introducing noise into the measurements.

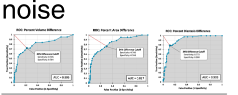

Figure 1: ROC curves for each of the WBCT measurements: volume, area, and diastasis. AUC was calculated to determine the diagnostic capability of each measurement. Minimum distance to the corner analysis was used to determine the optimal diagnostic cutoff value for each of the measurements. For each measurement, the AUC, optimal diagnostic cutoffs value and associated specificity and sensitivity is shown. Diastasis demonstrates the greatest diagnostic capability with the greatest specificity (0.900) and sensitivity (0.773).

Table 1: Demographic data for both the case and control group. For differences between groups, a p-value less than 0.05 was considered significant.

		Lisfranc Instability (n=44)	Controls (n=190)	p-value
Age (years) *		38.8 ± 17.5	45.3 ± 17.2	0.023
Sex †	Male	40.9%	38.9%	0.810
	Female	59.1%	61.1%	
BMI $\left(\frac{kg}{m^2}\right)$ *		25.8 ± 4.5	28.8 ± 6.2	0.002
Height (cm) *		173.4 ± 10.3	169.3 ± 11.1	0.027
Weight (kg) *		77.9 ± 17.3	83.1 ± 21.8	0.216

* Mann Whitney U test
† Chi-Square test

Table 2: Correlation of WBCT measurements and Meary's angle with patient demographic data. Statistical analysis was conducted for both absolute WBCT volume, area, and diastasis measurements and for percent difference in measurements between contralateral sides. Where applicable, correlation coefficients and p-value for each association are shown. Bolded values were found to be statistically significant.

Volume	Left		Right		Percent Difference	
	Correlation Coefficient	p-value	Correlation Coefficient	p-value	Correlation Coefficient	p-value
Age†	0.004	0.414	0.007	0.274	0.032	0.668
Sex*	--	**< 0.0001**	--	**< 0.0001**	--	0.115
BMI†	0.015	0.097	0.007	0.265	0.081	0.278
Height†	0.295	**< 0.0001**	0.354	**< 0.0001**	-0.044	0.552
Weight†	0.131	**< 0.0001**	0.134	**< 0.0001**	0.045	0.549
Meary's Angle†	0.001	0.724	0.001	0.812	-0.114	0.226

Area	Left		Right		Percent Difference	
	Correlation Coefficient	p-value	Correlation Coefficient	p-value	Correlation Coefficient	p-value
Age†	0.015	0.101	0.003	0.448	0.148	0.046
Sex*	--	0.010	--	**0.002**	--	0.501
BMI†	0.000	0.843	0.002	0.525	-0.010	0.894
Height†	0.027	0.028	0.038	0.009	0.022	0.769
Weight†	0.004	0.378	0.003	0.470	0.002	0.977
Meary's Angle†	0.002	0.667	0.004	0.506	0.075	0.430

Diastasis	Left		Right		Percent Difference	
	Correlation Coefficient	p-value	Correlation Coefficient	p-value	Correlation Coefficient	p-value
Age†	0.011	0.169	0.005	0.358	0.074	0.324
Sex*	--	0.052	--	0.123	--	0.042
BMI†	0.017	0.084	0.011	0.166	-0.047	0.528
Height†	0.024	0.038	0.020	0.057	0.001	0.991
Weight†	0.001	0.678	0	0.815	-0.042	0.575
Meary's Angle†	0.001	0.756	0.001	0.703	-0.011	0.905

†Pearson correlation test, Bonferroni adjusted p<0.008 was considered statistically significant
* Mann-Whitney U; Bonferroni adjusted p<0.008 was considered statistically significant.

Table 3: WBCT measurements (volume, area, and diastasis) of patient without midfoot current or prior midfoot, representative of physiologic anatomic variants. Due to large standard deviation, absolute measurements are presented as median and IQR. There is a significant difference between left and right sided measurements. The 95% confidence interval for percent difference as well as the median percent difference between contralateral sides are also shown. For all three measurements, there is less 15% difference in measurements between sides.

	Volume			Area			Diastasis		
	Left	Right	p-value	Left	Right	p-value	Left	Right	p-value
Median (IQR)	786.1 (309.8)	816.4 (347.0)	0.03*	23.9 (7.7)	24.4 (9.7)	0.08*	2.6 (0.7)	2.7 (0.9)	0.01*
Percent Difference 95% CI	13.3% ± 1.7%			17.6% ± 2.9%			16.4% ± 2.9%		
Median Percent Difference (IQR)	10.2% (13.5%)			11.8% (17.8%)			10.6% (12.6%)		

*Wilcoxon Signed-Rank test; p < 0.05 considered statistically significant

Table 4: WBCT measurements (volume, area, diastasis) of patients with confirmed Lisfranc instability. Due to large standard deviation, absolute measurements are presented as median and IQR. There is a significant difference in measurements the between injured and uninjured feet. The 95% confidence interval for percent difference as well as the median percent difference between contralateral sides are also shown. For all three measurements, there is at least a 25% difference in measurements between sides.

	Volume			Area			Diastasis		
	Injured	Uninjured	p-value	Injured	Uninjured	p-value	Injured	Uninjured	p-value
Median (IQR)	1054.0 (495.9)	834.2 (261.7)	<0.001*	32.5 (11.6)	23.5 (8.7)	<0.001*	4.25 (1.5)	2.8 (0.9)	<0.001*
Percent Difference 95% CI	35.1% ± 9.0%			46.8% ± 10.2%			57.3% ± 12.8%		
Median Percent Difference (IQR)	32.8% (28.2%)			43.9% (47.5%)			49.0% (38.2%)		

*Wilcoxon Signed-Rank test; p < 0.05 considered statistically significant