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Clavicle Length and Hand Dominance – Does Asymmetry Exist and What are the Clinical Implications of this?

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Abstract

The assumption of symmetry regarding clavicular length has previously been found unreliable. With the decision to surgically fix clavicle fractures often being based on the degree of shortening, this assumption if untrue may change clinical practice. We hypothesized that asymmetry exists with clavicles on the dominant side being significantly shorter. Two individuals clinically measured 508 pairs of Asian clavicles. Length was defined as the distance between either the sternoclavicular joint (SCJ) and acromioclavicular joint (ACJ) or suprasternal notch (SSN) and ACJ. Both individuals measured these in both clavicles twice and in each volunteer twice to determine the extent or lack of symmetry and intra- and inter- observer reliability. Other parameters recorded included age, sex, race, occupation and hand dominance. Dominant clavicles were found to be significantly shorter by an average of 7mm and a maximum of 31mm. Intra- and inter-observer reliability were both excellent. Even if osteometric measurements are standardized using bony landmarks, we strongly advocate not applying this technique to clavicle measurements in view of the inaccuracy and unreliability, especially if this is going to determine the necessity for surgery in patients with fractures of the clavicle and what is thought to be shortening. Clavicle length is also likely related to hand dominance with clavicles of the dominant arm being shorter. Both these facts have significant implications on the clinical measurement of clavicular length post-fracture and its use as a determinant for surgery, something all orthopaedic surgeons should be made aware of.

Keywords: Clavicle anatomy; Clavicle asymmetry; Clavicle fracture; Clavicle length; Clavicle shortening; Clavicle symmetry

Level of Evidence: I (Study of Diagnostic Test).

Introduction

Clavicle length can be ascertained by a number of methods. Two common ways used include clinical measurements where surgeons measure the distance between either the sternoclavicular joint (SCJ) and acromioclavicular joint (ACJ) or suprasternal notch (SSN) and ACJ. Other methods involve radiographic measurements using x-rays or computerized tomography (CT), the latter considered by the senior author to be far more accurate but rarely performed. With it long being suggested that a standardized method of measurement is essential to determine shortening in clavicle fractures [1], the decision for surgical fixation of a clavicle fracture is often based on the amount of shortening with 20mm or greater accepted internationally as an indication for surgical fixation [2,3]. This parameter is most often determined clinically or on radiographs and rarely on CT. While a recent study proved a high inconsistency between practitioners in terms of establishing measurements of not only the clavicle but also scapula, ulna, femur and tibia [4], previous work conducted by our lead author showed a significant inherent difference in clavicular length between sides [5,6], thus questioning the assumption of symmetry with regard to clavicular length and finding it to be unreliable as well as hypothesizing a correlation between hand dominance and clavicular length. However, these studies were small and did not involve Asians, a patient population known to have varying bony size and shape geometry compared to their Western counterparts. Other authors have also previously questioned the assumption of symmetry and proven it to be unreliable [7]. The purpose of this study was to test our hypothesis that asymmetry exists with clavicles on the dominant side being significantly shorter. With the decision to surgically fix clavicle fractures often being based on the degree of shortening, our hypothesis if true, may change clinical practice for those surgeons who base their decision for surgery on shortening determined by clinical measurements.

Methods

Subject Recruitment

Institutional review board approval was not applicable for this study. Study participants were recruited directly from the community. An information sheet, containing the background and purpose of the study was given to all potential subjects with signed consent obtained from all who volunteered to participate. Subjects were recruited within the Singapore population. Healthy subjects were recruited if they were aged 21 years or over. Exclusion criteria included people with a previous upper limb fracture or chronic upper limb pathology.

Data Collection

Length was defined as the distance between either the SCJ and ACJ or SSN and ACJ. Two investigators were trained in the measurement technique by the lead author, who was an experienced orthopaedic surgeon. Using a standard measuring tape with increments in millimetres, both measured each of these lengths on both clavicles for each subject. Each investigator made these measurements twice on the same subject, while every subject had their measurements taken by both investigators, who were blinded to each other. The same measuring tape was used for all measurements. Measurements were taken before asking the participant for their hand dominance. Other data recorded included age, sex, race and occupation. Subjects' occupations were further categorized into whether they involved physical labour, office work and being unemployed/retired.

Statistical Analysis

Data within our sample was first tested for its conformity to a normal distribution, mainly through graphical means in the form of histograms and Q-Q plots. These tests for normality of data were done for the data sample as a whole as well as calculated mean differences for relevant matched pairs of data. Two reliability measures were calculated and recorded in this study. Intra-rater reliability was used to quantify reliability of repeated measures for single raters, while inter-rater reliability was used to characterize the level of agreement between raters. Both measures were calculated using intra-rater correlation coefficients (ICC) but were calculated using different statistical models [8-10]. For intra-rater reliability a 2-way mixed model was used as random effects would likely have come from the measured variable (clavicle length) while the effect from judges making the measurements would have been a fixed effect as the test only looks at test-retest situations involving one judge alone whose variability is likely to be predictable. A 2-way random effects model was used to test inter-rater reliability as variability between the judges could be seen as a random effect as the measurement methodology employed in this study could be taught to anyone. In this study the average measured ICC value was used both for intra- and inter-rater reliability analysis.

Analysis of the data collected occurred in two stages. The first stage involved univariate analysis in which various potential factors were tested to see if they could potentially have significant predictive power for clavicle length. Previous research suggests that left clavicles tend to be longer then right clavicles while males tended to have longer clavicles then females [5,6]. These were two factors that were therefore investigated in the univariate analysis. As hand dominance has been suggested as a possible predictive factor [5,6] although never tested before, this was also tested. Other potential variables that were considered for this study included age, race and employment type. Univariate analysis was conducted with all clavicles pooled together, for a total of 918 clavicles, or in the form or independent group analyses comparing either right clavicle vs. left clavicles, dominant arm vs. non-dominant arm etc.

Once univariate analysis had been complete, variables that were found to have potential predictive power for clavicle length were then placed into a multivariate linear regression model. Six assumptions required for the multivariate linear regression model to be valid were checked before final analysis, and included:

i. Adequate sample size – Generally, samples should be 15 times larger than the number of predictive variables that are in the model [11]. We can therefore assume that this study's sample size is more than adequate.

ii. Normally distributed data – Via inspection of histograms and P-P plots of the model's residuals.

iii. Adequate linearity between the predictors and the final model – Via inspection of scatter plots and graphs.

iv. Lack of collinearity – Via inspection of correlations between predictors.

v. Lack of homoscedasticity – Via inspection of residual plots.

vi. Lack of outliers – Confirmed by inspecting the number of residuals that lied more than four standard deviations from the mean. Cook's distances of all residuals of the model were also inspected with obvious outliers eliminated from further analysis.

All variables that were shown to be significant within univariate testing were entered into the regression model using the 'Enter' method. Any variables that were shown not to be significant predictors were eliminated and a further model generated without it. Significance for elimination from the regression model was set at p>.10. Once assumptions were verified for the regression model to be valid, further analysis was then carried out to establish its significance in terms of its ability to predict clavicle length by inspecting the F statistic. R2 statistics were obtained to work out how much variability in clavicle length could be explained by the model. Finally, the standardized β-coefficients were then recorded to estimate the

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relative predictive power of the variables that were in the final regression model. All statistical analyses were done using SPSS Version 21.0 (IBM Corp 2012). Once normal distributions of all data had been established, statistical tests during univariate analysis included the matched pairs t-test when related pairs of data were being tested (e.g. right clavicle length vs. left clavicle length). Independent t-test was used for unmatched pairs of data (e.g. lengths in males vs. females), with equality of variance checked using Levene's test. 1-way ANOVA tests were used for categorical variables with more than two groupings (e.g. race and job type). Correlations were used to for continuous predictive variable (e.g. age) with the Welch test used in cases of an absence of homogeneity of variance and Scheffe tests used post-hoc in cases of statistical significance upon initial ANOVA analysis. Effect sizes were also assessed by obtaining Eta2 values. All statistical tests performed in this study were 2- tailed with significance set at p<.05 apart from the linear regression analysis where it was set at <.10. Multiple regression analyses were all done on a data set comprising the pooled number of clavicles (n=918). All statistical analyses described were done separately for both measurement methods.

Results

Subjects

A total of 459 eligible subjects agreed to take part in this study, leading to a total of 918 clavicles. The median age of the whole group was 27 years (range 21 – 86). Figure 1 illustrates the age distribution. Table 1 summarizes some more of the group's descriptive statistics.

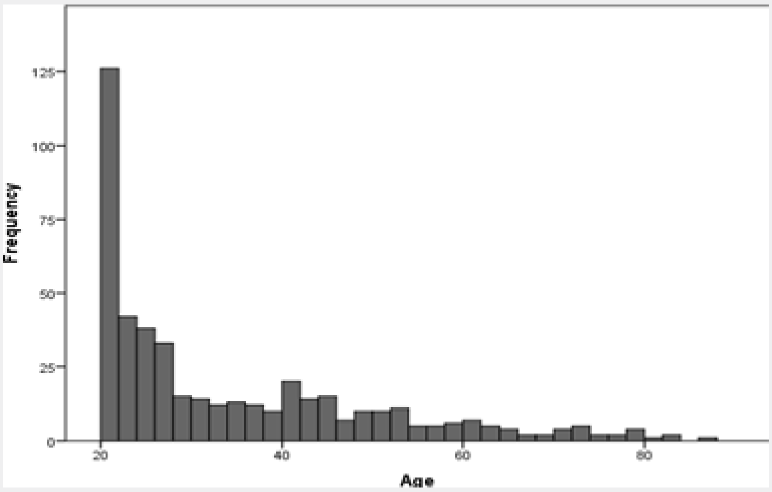

Figure 1: Histogram illustrating age distribution within whole sample.

Table 1: Summary of categorical data for all subjects.

Variable	Frequency	%
Sex		
Female	**234**	**51.0**
Male	**225**	**49.0**
Race		
Chinese	**246**	**53.6**
Malay	**54**	**11.8**
Indian	**156**	**34.0**
Others	**3**	**0.7**
Hand Dominance		
Left	**47**	**10.2**
Right	**412**	**89.8**

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Reliability Analysis

Intra-rater reliability proved to be similar for both raters. Both also proved to have excellent consistency regardless of the landmarks used to measure clavicle length. The first rater's intra-rater ICC ranged from .977-.983 (p<.0001). The second rater's ICC values ranged from .970-.987 (p<.0001). The full breakdown of every individual ICC achieved by the raters in this study can be seen in Table 2. Int

ra-rater reliability also proved to be excellent regardless of what side was measured and through what method. The range seen in this part of the study was from. 948-.973, seen as an excellent correlation in Table 3.

Table 2: Intra-rater ICCs for all measurement methods.

ICCs for Each Rater (95% CI)		
	Rater 1	Rater 2
Left Notch-ACJ	**.981 (.976-.984)**	**.985 (.982-.988)**
Right Notch-ACJ	**.983 (.980-.986)**	**.987 (.984-.989)**
Left SCJ-ACJ	**.977 (.973-.981)**	**.984 (.981-.987)**
Right SCJ-ACJ	**.978 (.974-.982)**	**.983 (.980-.986)**

Table 3: Inter-rater ICCs for all measurement methods.

	ICC	95% CI
Left Notch-ACJ	**.973**	**.962-.980**
Right Notch-ACJ	**.970**	**.961-.976**
Left SCJ-ACJ	**.954**	**.942-.962**
Right SCJ-ACJ	**.948**	**.934-.959**

Univariate Analysis

Univariate analysis was done on six potential predictors of clavicle length, namely:

i. Left-sided vs. right-sided

ii. Whether the clavicle was on the subject's dominant side or not.

iii. Gender

iv. Race

v. Employment type

vi. Age

To test factors 1 and 2, the matched pairs t-test was used. For all subjects, when measuring the SSN to ACJ distance the left clavicles were found to be significantly longer than right clavicles by 5.5mm (17.04cm vs. 16.50cm; t 19.74; df 458; p<0.0001). The same trend could be seen when measuring the SCJ to ACJ distance where left clavicles were 6.1mm longer than right clavicles (15.02cm vs. 14.42cm; t 23.87; df 458; p<.0001). When changing the analysis, so that clavicles from each subject's dominant side, in terms of handedness, was compared to their non-dominant side it was found, when measuring the SSN to ACJ distance, that non-dominant-sided clavicles were longer than dominant-sided clavicles by 6.3mm (17.09cm vs. 16.55cm; t 27.42; df 458; p<.0001). The same trend could be seen for clavicles measured via the SCJ to ACJ distance with a difference of 6.5mm (15.05cm vs. 14.39cm; t 28.68; df 458; p<.0001). This showed that differences in clavicle lengths were larger when a subject's dominant side was compared to its non- dominant side compared to when its left side was compared to its right side. Details of the matched pairs analysis are summarized in Table 4.

To further characterize the relationship between handedness and clavicle length, separate analyses were then performed between the right handers (n=412) and the left handers (n=47). When the righter handers had their clavicles measured between the SSN and ACJ, the left clavicles were found to be significantly longer by 6.6mm (17.10cm vs. 16.44cm; t29.24; df 411; p<.0001). Left clavicles were also significantly longer by 7.0mm when distance was measured between the SCJ and ACJ (15.08cm vs. 14.38cm; t 32.68; df 411; p<.0001). In left handers the opposite trend tended to be true. Right clavicles were found to be significantly longer when measured between the SSN and ACJ by 4.3mm (16.54cm vs. 16.97cm; t -4.04; df 46; p<.0001). When distance was measured between the SCJ and ACJ, right clavicles were significantly longer by 2.3mm (14.54cm vs. 14.77cm; t -2.28; df 46; p=0.028). These results add strength to

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the suggestion that clavicle length is more heavily influenced by what side the clavicle is in relation to the dominant side of an individual's body rather than just on whether the clavicle is on the right or left. Summaries of the analyses on the sample's right and left handers can be seen in Tables 5 & 6 respectively. Sex is a predictor that has been investigated in previous studies that have looked at clavicular measurements [5,6]. In this study 225 males (450 clavicles) and 234 females (468 clavicles) were compared. Overall, the male clavicle was significantly larger than its female counterpart by 2.25cm (17.92cm vs.15.67cm; t 20.93; df 916; p<.0001) and 2.11cm (15.79cm vs. 13.69cm; t 22.40; df 916; p<.0001) when measured by the SSN to ACJ and SCJ to ACJ methods respectively. When the clavicle sample was split into left and right groups as well as dominant or non- dominant groups the results were similar with mean differences recorded between 2.23cm to 2.26cm (t 14.44-15.64; df 404.67-436.80; p<.0001) for the SSN to ACJ method and between 2.10cm to 2.11cm (t 15.95-16.43; df 413.39-439.43; p<.0001) for the SCJ to ACJ method. Table 7 summarizes the findings comparing male and female clavicles in this study.

Table 4: Paired t-tests comparing opposite sided clavicles within the whole sample.

	Mean 1 (cm)	Mean 2 (cm)	Mean Difference (cm)	95% CI (cm)	t	df	p-value
1. Left Notch-ACJ Average – 2. Right Notch-ACJ Average	17.04	16.50	.55	.49-.60	19.74	458	.000
1. Left SCJ-ACJ Average – 2. Right SCJ-ACJ Average	15.02	14.42	.61	.56-.66	23.87	458	.000
1. Non-Dominant Notch-ACJ Average – 2. Dominant Notch-ACJ Average	17.09	16.55	.63	.59-.68	27.42	458	.000
1. Non-Dominant SCJ-ACJ Average – 2. Dominant SCJ-ACJ Average	15.05	14.39	.65	.61-.70	28.68	458	.000

Table 5: Paired t-tests comparing opposite sided clavicles within right handers (n=412).

	Mean 1 (cm)	Mean 2 (cm)	Mean Difference (cm)	95% CI (cm)	t	df	p-value
1. Left Notch-ACJ Average – 2. Right Notch-ACJ Average	17.10	16.44	.66	.61-.70	29.24	411	.000
1. Left SCJ-ACJ Average – 2. Right SCJ-ACJ Average	15.08	14.38	.70	.66-.74	32.68	411	.000

Table 6: Paired t-tests comparing opposite sided clavicles within left handers (n=47).

	Mean 1 (cm)	Mean 2 (cm)	Mean Difference (cm)	95% CI (cm)	t	df	p-value
Left Notch-ACJ Average – 2 Right Notch-ACJ Average	16.54	16.97	-.43	-.65- -.22	-4.04	46	.000
Left SCJ-ACJ Average – 2 Right SCJ-ACJ Average	-14.54	14.77	-.23	-.43- -03	-2.28	46	.028

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Table 7: Independent sample t-tests for males vs females.

Mean Measurement (cm)					95% confidence Interval of the Difference (cm)				
	Male	**Female**	**Mean Difference (cm)**	**Std. Error Difference (cm)**	**Lower**	**Upper**	**T**	**df**	**p-value**
All Notch-ACJ Distance	**17.92**	**15.67**	**2.25**	**.11**	2.04	**2.46**	**20.94**	916	**.000**
All SCJ-ACJ Distance	**15.79**	**13.69**	**2.11**	**.09**	**1.92**	**2.29**	**22.40**	**916**	.000
Left Notch-ACJ Distance	**18.20**	**15.94**	**2.26**	**.15**	**1.97**	**2.56**	**14.99**	**404.67**	**.000**
Left SCJ-ACJ Distances	**16.10**	13.99	**2.11**	**.13**	**1.85**	**2.36**	**16.09**	**413.83**	**.000**
Right Notch-ACJ Distances	**17.64**	**15.40**	**2.23**	**.15**	**1.94**	**2.53**	**14.87**	**436.80**	**.000**
Right SCJ-ACJ Distances	**15.49**	**13.39**	**2.10**	.13	**1.85**	**2.36**	**16.16**	**438.46**	.000
Dominant Notch-ACJ Distances	**17.61**	**15.35**	**2.26**	**.14**	**1.97**	**2.54**	**15.64**	**429.42**	**.000**
Dominant SCJ-ACJ Distances	**15.46**	**13.37**	**2.10**	**.13**	**1.85**	**2.35**	**16.43**	**439.43**	**.000**
Non-Dominant Notch-ACJ Distances	**18.23**	**15.99**	**2.24**	**.16**	**1.93**	**2.54**	**14.44**	**412.71**	**.000**
Non-Dominant SCJ-ACJ Distances	**16.12**	**14.01**	**2.11**	**.13**	**1.85**	**2.37**	**15.95**	**413.39**	**.000**

Table 8: Summary of post-hoc ANOVA testing for race.

					95% Confidence Interval (cm)		
Dependent Variable	**(I) Race**	**(J) Race**	**Mean Difference (I-J, cm)**	**Std. Error (cm)**	**Lower Bound**	**Upper Bound**	**p-value**
Notch-ACJ Distance	Chinese	**Malay**	**1.57**	**.19**	**1.10**	**2.04**	**.000**
		Indian	**1.48**	**.13**	**1.15**	**1.80**	**.000**
	Malay	**Chinese**	**-1.57**	**.19**	-2.04	**-1.10**	**.000**
		Indian	**-.10**	**.20**	**-.59**	**.40**	**.893**
	Indian	**Chinese**	**-1.47**	**.13**	**-1.80**	**-1.15**	**.000**
		Malay	**.10**	**.20**	**-.40**	**.59**	**.893**
SCJ-ACJ Distance	Chinese	**Malay**	**.98**	.18	**.54**	**1.42**	**.000**
		Indian	.95	.12	**.65**	**1.25**	**.000**
	Malay	**Chinese**	-.98	.18	-1.42	**-.54**	**.000**
		Indian	-.03	.19	**-.50**	**.43**	**.986**
	Indian	**Chinese**	**-.95**	**.12**	**-1.25**	**-.65**	**.000**
	Malay	**.03**	**.19**	**-.43**	**.50**	**.986**	

Univariate testing for race and employment type were done using 1-way ANOVA as they were both categorical variables whose data proved to show normal distribution. To begin with, three cases had to be excluded from the ANOVA dataset as the individuals concerned were not assigned a specific race. This therefore left the total number of subjects to be 456 and the number of clavicles

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to be 912. Running the analysis, we revealed 246 Chinese subjects, 54 Malay and 156 Indians. When analyzing the variables on all clavicles combined it was revealed that Chinese participants had the longest clavicles overall with both the SSN to ACJ (17.44cm vs. 15.87cm vs. 16.75cm) and SCJ to ACJ methods (15.14cm vs. 14.16cm vs. 14.19cm). Initial ANOVA analysis revealed significant Welch statistics of 83.19 and 38.61 respectively (p<.0001). Post-hoc testing revealed the Chinese clavicles to be significantly longer than their Malay and Indian counterparts (p<.0001), while there were no significant differences between Indian or Malay clavicles (p=0.893 and 0.986 respectively), from both measurement methods. Eta2 values noted for the whole clavicle sample were .146 and .073 for the two respective measurement methods suggesting that the variable could be responsible for 14.6% or 7.3%, respectively, of the variability in clavicle size. Table 8 summarizes the post-hoc testing just described. Chinese clavicles were also found to be significantly larger then Indian and Malay clavicles in all independent group analyses, regardless of measurement method. Figure 2 shows a typical graph illustrating the significant increase in length of the Chinese clavicle when compared to its Malay and Indian counterparts in this study.

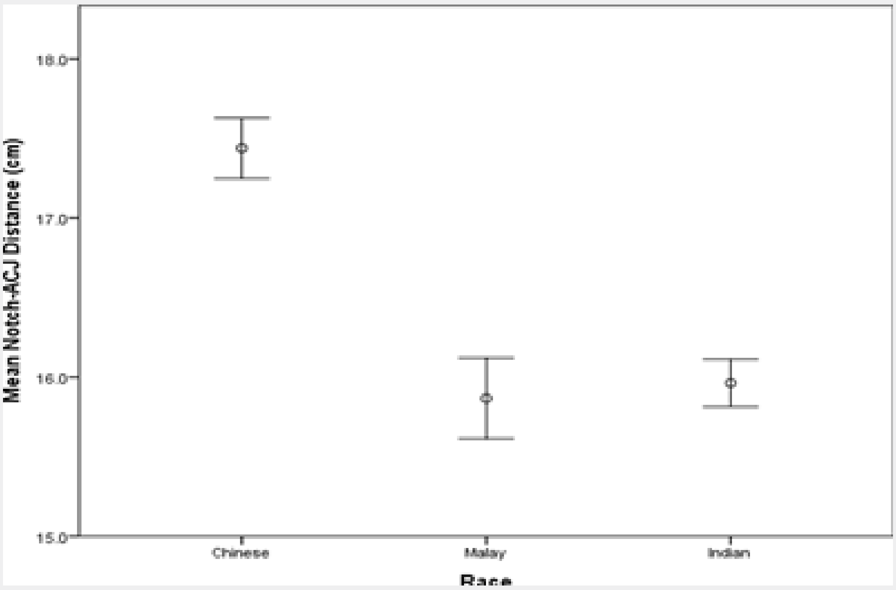

Figure 2: Graph illustrating Chinese clavicles compared to their Malay and Indian counterparts.

During recruitment each participant's job status was recorded and then categorized into three employment types. These were chosen for an easier and more objective analysis and included:

a. Physical laborers/workers.

b. Deskbound workers.

c. Unemployed/unable to work.

ANOVA analysis was performed much the same as it was for the race variable. On inspection of descriptive statistics, it could be seen that the 'Unemployed' group had noticeably smaller clavicles than the other two groups when measured by the SSN to ACJ (17.09cm vs. 17.29cm vs. 15.59) and SCJ to ACJ methods (15.06 vs. 15.08cm vs. 13.74cm). Initial ANOVA revealed significant Welch statistics of 101.60 and 95.80 respectively (p<.0001). Post-hoc testing confirmed the finding (p<.0001) while there was no such relationship between the 'Physical' and 'Deskbound' groups (p=.396-.991 respectively). This analysis is summarized in Figure 3 which illustrates the differences in means graphically. For the whole sample Eta2 values were .132 and .110 respectively. This pattern was also replicated in the independent group analyses. Age was the continuous variable that was investigated as a possible predictor for clavicle length. Figure 1 illustrates how the distribution of ages within this study is skewed and therefore does not demonstrate a normal distribution. Therefore, a nonparametric test was chosen, in the form of Spearman's Rank. Results of this analysis revealed that age had only a weak negative correlation with clavicle length when all clavicles were analyzed. This was true for the SSN to ACJ (r -.248; p<.0001) and SCJ to ACJ measurements (r -.202; p<.0001). This pattern was replicated within the grouped analyses as well (r -.186- -.264; p<.0001).

Multivariate Analysis

After univariate analysis had been concluded it was noted that within the 'race' and 'employment type' variables the 'Chinese' and 'employment status' (i.e. Employed vs. Unemployed) were likely most responsible for the levels of variability seen from their respective variables which were subsequently changed to the

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'Chinese' and 'Unemployed' variables respectively. The final list of potential predictors for clavicle length, from either method, to be considered for multivariate analysis were 'hand dominance', 'gender', 'Chinese' and 'unemployed'. Age was not included in further analysis due to its non- normal distribution and the fact that it only correlated weakly with clavicle length and therefore unlikely to contribute significantly to the prediction of clavicular length. Using the pooled group of 918 clavicles each variable was placed into the model via the 'Enter mode' Table 9.

Table 9: Summary of post-hoc ANOVA testing for employment type.

					95% Confidence Interval (cm)		
Dependent Variable	**(I) Occupation Type**	**(J) Occupation Type**	**Mean Difference (I-J, cm)**	**Std. Error (cm)**	**Lower Bound**	**Upper Bound**	**p-value**
Notch-ACJ Distance	Physical	Deskbound	**-.19**	**.14**	**-.54**	**.16**	**.396**
		Unemployed/Retired	**1.51**	**.16**	**1.11**	**1.90**	**.000**
	Deskbound	Physical	**.19**	**.14**	**-.16**	**.54**	**.396**
		Unemployed/Retired	**1.70**	**.15**	**1.33**	**2.07**	**.000**
	Unemployed/Retired	Physical	**-1.51**	**.16**	**-1.90**	**-1.12**	**.000**
		Deskbound	**-1.70**	**.15**	**-2.07**	**-1.33**	**.000**
SCJ-ACJ Distance	Physical	Deskbound	**-.02**	**.13**	**-.34**	**.30**	**.991**
		Unemployed/Retired	**1.32**	**.14**	**.97**	**1.67**	**.000**
	Deskbound	Physical	**.02**	**.13**	**-.30**	**.34**	**.991**
		Unemployed/Retired	**1.34**	**.14**	**1.00**	**1.68**	**.000**
	Unemployed/Retired	Physical	**-1.32**	**.14**	**-1.67**	**-.97**	**.000**
		Deskbound	**-1.34**	**.14**	**-1.68**	**-1.00**	**.000**

Figure 3: Graph illustrating comparison between clavicles of the unemployed and employed.

Upon verifying the assumptions for the linear regression models to work it was already established that the sample numbers were more than adequate. Normality of data was also evident in the shape of both models' histograms and P-P plots as seen in Figures 4 & 5. Collinearity was not an issue within the model as there were no two variables which correlated highly with each other, nor were the Condition Indexes high. Visual inspection of residual plots revealed no evidence of homoscedasticity and there were no outliers that were in danger of overly influencing the model. Cook's distances were no larger than 0.02. Overall, both models

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showed that all four predictors inputted into them had significant effects on its ability to predict a clavicle's length (p<.0001). From what can be seen in Tables 10 & 11 the most influential factor that determined clavicle length from either measurement method would be the sex of the subject. As discussed before, this study did seem to show evidence that an individual is likely to show shortening of his or her non- dominant shoulder compared to the opposite one. Standardized β-coefficients for hand dominance were .16 for the SSN to ACJ model and 0.18 for the SCJ to ACJ measurement. Chinese clavicles also seemed to be quite influential in shaping both models' functions with standardized β-coefficients of .29 and .18 respectively. Employment status was the least influential predictor with respective standardized β-coefficients of .12 and .11. R2 values for both models were reasonably high suggesting that the models themselves would be able to explain a large amount of the dependent variable's variability. For the SSN to ACJ measurements the R2 value was .465 while for the SCJ to ACJ measurements it was .443. These two numbers suggest a good predictive power of the models that created them as they suggest that 46.5% and 44.3% of the dependent variable's variability can be explained by the model.

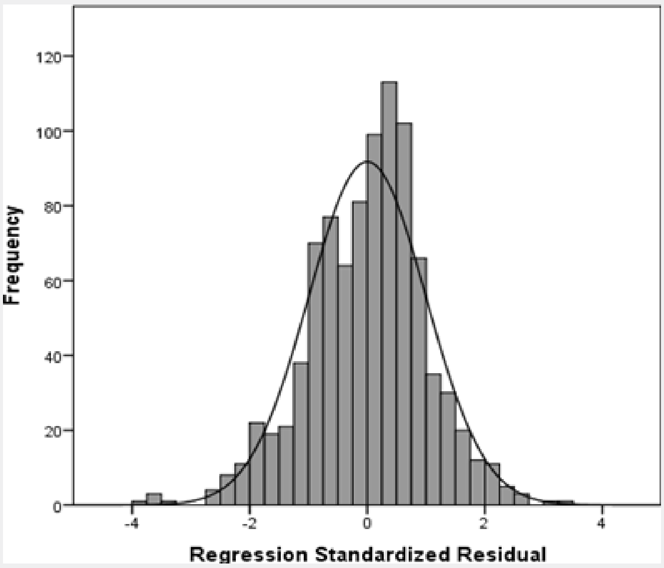

Figure 4: Histogram plotting frequencies of regression standardized residuals for clavicles measured by the SSN to ACJ method.

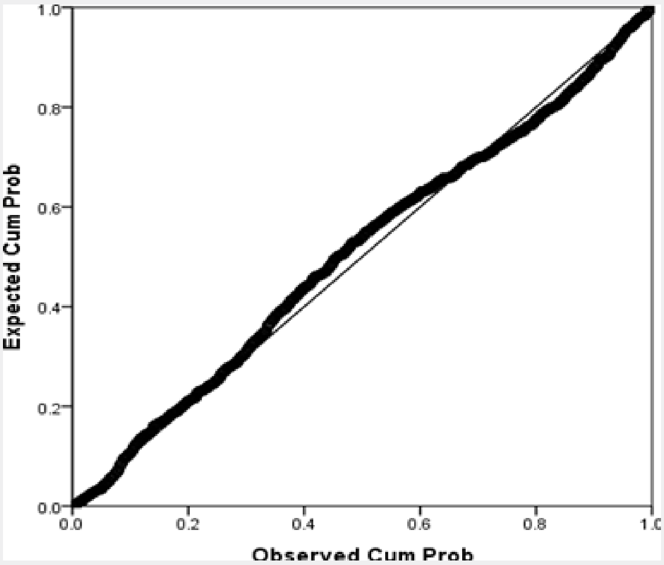

Figure 5: P-P plot of regression standardized residual against observed values for data from clavicles measured by the SSN to ACJ method.

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Table 10: Summary statistics from regression model for SSN to ACJ measurements.

			95% confident Interval		
	Unstandardized β-Coefficients	Lower Bound	Upper Bound	Standardized β-Coefficients	p-value
Employment Status	.52	.30	.76	.12	.000
Dominant or Non-Dominant Side	.64	.45	.82	.16	.000
Chinese	1.14	.95	1.34	.29	.000
Gender	2.03	1.83	2.23	.51	.000

Table 11: Summary statistics from regression model for SSN to ACJ measurements.

Unstandardized β-Coefficients		Lower Bound	Upper Bound	Standardized β-Coefficients	p-value
Employment Status	.52	.30	.76	.12	.000
Dominant or Non-Dominant Side	.64	.45	.82	.16	.000
Chinese	1.14	.95	1.34	.29	.000
Gender	2.03	1.83	2.23	.51	.000

Discussion

We only recruited subjects who were 21 years and over (459 subjects, 918 clavicles) as ossification of the medial clavicle is shown to not be completed until at least that age [12]. From an anatomic and non-clinical point of view, there have been a number of studies over the years analyzing clavicular size and shape [13]. However, few have taken into consideration the asymmetry that our study shows exists [5-7], nor have they produced a predictive model as extensive as this present study. This is also the first study to suggest clearly, that discrepancies in clavicle length are likely to be due to an individual's handedness as opposed to other studies that have just suggested the right clavicle to be shorter than the left [7]. A more recent study stated that clavicular length correlates with the midpoint cortical diameter and with the radius of medial curvature [14]. Results of this as well as all other studies on clavicular anatomy should now raise the question as to whether their findings and conclusions can be applied generically or may in fact be side- specific, hence requiring re-evaluation and in turn having potential clinical implications.

Clinically, even if osteometric measurements are standardized using bony landmarks, we strongly advocate not applying this technique to clavicle measurements in view of its inaccuracy and unreliability, especially if this is going to be used to determine the necessity for surgery in patients with fractures of the clavicle and what is thought to be shortening. It should also be noted that clavicle length is likely related to hand dominance with clavicles of the dominant arm being shorter.

Conclusion

Our hypothesis that asymmetry exists with clavicles on the dominant side being significantly shorter was found to hold true with significant clavicular asymmetry existing in terms of length. This has significant implications on the clinical measurement of clavicular length post-fracture being used as a determinant for surgery, something all orthopaedic and upper limb surgeons should be made aware of. More importantly, these findings should be taken into consideration before a decision to operate is made based on clinical measurements alone, currently a common practice. With the mean inherent clavicular length difference between dominant and non-dominant sides being nearly 7mm and with our maximum observed difference being 31mm, perhaps before offering surgery based on an assumed shortening of at least 20mm we should consider a change in clinical practice and in the words of Hippocrates, “First do no harm.”

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Author Contributions

All authors made substantial contributions to all of the following:

i. Conception and design of the study, acquisition, analysis and interpretation of data.

ii. Drafting the article or revising it critically for important

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intellectual content.

iii. Final approval of the version to be submitted.

Amritpal Singh – Role of lead author involved in the literature review and drafting of manuscript.

Sumon S Huq – Co-author and statistician who analyzed and interpreted the data.

Siya Dayal – Co-author instrumental in acquiring the data.

Pooja D Shah – Co-author instrumental in acquiring the data.

Diarmuid P Murphy – Role of co-author who supervised the study, interpreted the data and input important intellectual content.

Zubin J Daruwalla – Role of senior author and person who put forth the hypothesis and conceptualized the study as well as analyzed and interpreted the data.

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