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Bilateral Asymmetry of Long Arm Bones and Jugular Foramen: Implications for Handedness

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ABSTRACT: The analysis of asymmetry of the arm long bones and of the cranial jugular foramen has been used to suggest handedness in humans. However, because of the unavailability of documented skeletal material, neither criterion has been systematically tested. If both criteria are associated with handedness, they should also be intercorrelated within individuals. Data were collected from skeletal material of 125 males and 57 females to test whether this intercorrelation exists. According to Chi-square analysis, no statistically significant association was identified. After examining several hypotheses, it was concluded that until further substantiation, neither criterion is related to handedness to a degree appropriate for forensic science identification from skeletal remains.

KEYWORDS: physical anthropology, human identification, handedness, skeletal asymmetry

Physical anthropologists are playing an increasingly important role in forensic medicine as their expertise in human musculoskeletal anatomy becomes more widely known. Their contribution stems from their commitment to the identification and explanation of variability in the human skeleton. Variation applicable to forensic science issues such as gender, race, and age differences are most efficiently documented from skeletal collections about which basic demographic information on the subjects is known. Occasionally, however, hypotheses of associations between skeletal morphology and physical appearance have been proposed from observations made on large, but less well-documented skeletal collections.

This study examines one such hypothesis as it relates to handedness or hand preference (right-handed versus left-handed) ascertained from the bilateral asymmetry in the lengths of the long bones of the arms and in the size of the jugular foramen. The term asymmetry used throughout the study denotes the bilateral variety.

Background

Of the major textbooks available on forensic anthropology, only Stewart's [*1*] presents a section devoted to the determination of handedness from skeletal material. This lack of published

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data is undoubtedly the result of the paucity of skeletal material for which handedness is documented. Nevertheless, many physical anthropologists offer suggestions as to the handedness of their subjects in forensic science case reports. Since most humans are right-handed, the criterion of handedness is significant predominantly in identification cases of left-handed individuals. The most common criteria for determining handedness have been asymmetry in the length of the long bones of the arms, asymmetry in the demarcation of muscular insertions and origins on these bones, and dorsal beveling on the glenoid fossa of the scapula. The dominant (longer, more robust, or more beveled) side has been considered indicative of hand preference in each case. The basis of these criteria is the well-documented observation that right-limb dominance is known to occur for both genders and for all races at a substantially greater frequency than left-limb dominance. If long bone dominance is functionally related to increased use of one arm over the other during development, long bone asymmetry appears to be an appropriate handedness predictor.

In addition to the long bones, jugular foramen asymmetry at the base of the cranium has also been used as a criterion of handedness. Its use has been primarily restricted to forensic science cases involving solely cranial material or as a corollary measure to asymmetry in the long bones. The historical development of this criterion is not well established. Our own knowledge of the hypothesized relationship is traced back to Dr. Charles E. Snow through personal communication with one of the authors (W. M. B.). The determination of handedness by jugular foramen morphology is made according to the side that presents the larger foramen. This side is believed indicative of hand preference and is assumed to be related to the demands of blood supply. Human anatomy texts often note that right-side jugular foramen dominance is the general pattern [*2*].

It is unfortunate that a skeletal collection is unavailable from which to test the hypothesized criteria for identifying handedness. However, if each of the proposed criteria is related to handedness, it is reasonable to assume that they are intercorrelated within individuals. This latter hypothesis can be tested and is the focus of the present study in which we test for significant association between asymmetry in the lengths of the arm long bones and in the size of the jugular foramen.

Materials and Methods

The skeletal material of 125 males and 57 females of adult age were examined for jugular foramen and long bone asymmetry. The sample was taken from the Terry Collection, housed at the National Museum of Natural History.

The maximum lengths of the right and left humeri, radii, and ulnae were measured using an osteometric board according to the method defined by Bass [*3*]. Measurements were recorded to the closest 1/10 mm. All measurements were taken by a single investigator (D. M. G.), and only individuals with complete data sets were included. Long bone asymmetry was defined as the maximum length of the right bone minus the length of the left. Positive values were recorded as +1, negative values as −1, and symmetry as 0.

Initially, jugular foramen asymmetry was recorded according to a five-grade scale for each individual. Although stated in quantitative terms, the scoring was subjective and defined as:

Score −2 = Extreme left-side dominance. Left jugular foramen at least two times larger than right side.

Score −1 = Left-side dominance. Left jugular foramen larger than right side, but less than twice the size.

Score 0 = No apparent size difference in left and right foramen irrespective of varying shape differences.

Score +1 = Right-side dominance. Right jugular foramen larger than left side, but less than twice the size.

Score +2 = Extreme right-side dominance. Right jugular foramen at least two times larger than left side.

To test for intraobserver error, approximately 22% of the sampling was randomly selected for rescoring. Of these 40 specimens, only 3 were scored differently than they were initially and in each of these cases, the scores differed by no more than one classification grade. In addition, the discrepancies were between classification as extremely dominant or simply dominant for a particular side.

Asymmetry scores for all individuals were tabulated and compared as histograms describing the relative frequencies of side dominance in the jugular foramen and in the long bones of the arm. Males and females were treated separately to examine gender differences in the frequency profiles. To test the correlation between long bone and jugular foramen asymmetry, the data were subjected to Chi-square analysis. Because Chi-square is considered a liberal test of association and because a high level of correlation is necessary for meaningful consideration in forensic science application, an alpha level of 0.01 was chosen as the criterion for significance.

Results

The histogram of observed frequencies for jugular foramen asymmetry is presented in Fig. 1. Frequency for left-side dominance was low for both genders. None of the 57 females exhibited a left-side foramen that was twice the size of the right. Symmetry in jugular foramen size was identified for 34% of the male sample and 32% of the female. The largest difference in percent between genders occurred for the right-side dominance categories. Approximately 50% of the female sample exhibited right-side dominance compared to 29% for males. Conversely, males more frequently exhibited extreme right-side dominance. When the frequencies of the two categories for each side were combined (extreme left with left, and extreme right with right), the genders achieved similar frequency profiles (Fig. 2). Left-side dominance averaged 8.5%, symmetry averaged 33%, and right-side dominance averaged 58.5%. The reduction of categories from five to three does not result in any substantial loss of information relative to the present study. It does, however, remove some of the subjectivity in evaluating jugular foramen asymmetry, and serves to increase the sample size of the individual cells for Chi-square analysis.

The breakdown of long bone asymmetry into percentages of left-side dominance, symmetry, and right-side dominance is presented in Fig. 3. The frequency distribution for both genders was similar for each long bone. In addition, the pattern of distribution among the long bones was also similar. Slightly less than 20% of the males and females showed long bone dominance of the left side, approximately 15% of the observations for each long bone indicated symmetry, and the remaining approximately 65% was attributable to right-side dominance. Compared to the jugular foramen, the long bone data indicated a greater percentage of individuals exhibiting left-side dominance, a decreased percentage for symmetry, and a greater percentage exhibiting right-side dominance.

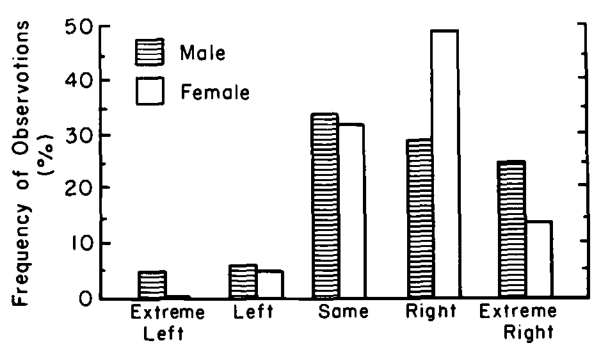

FIG. 1—*Frequency histogram for side dominance in jugular foramen size—five categories (*N *for males = 125;* N *for females = 57).*

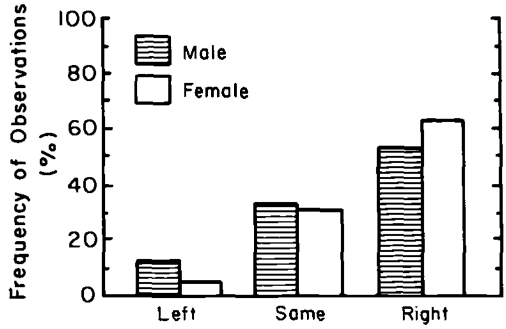

FIG. 2—*Frequency histogram for side dominance in jugular foramen size—three categories (*N *for males = 125;* N *for females = 57).*

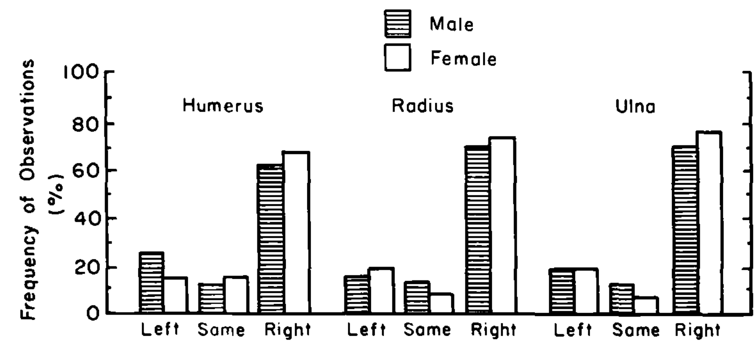

FIG. 3—*Frequency histogram for side dominance in long bone length of the humerus, radius, and ulna (*N *for males = 125;* N *for females = 57).*

Table 1 presents cross-tabulations of the observed frequencies for the three comparisons of jugular foramen and long bone asymmetry. Frequencies for jugular foramen asymmetry reflect the three-scale classification rather than the five-scale. The table reveals an inconsistent pattern in the relationship between the two asymmetry parameters. Individuals of both genders that exhibited left-side dominance of the jugular foramen did not exhibit left-side dominance of the long bones in any appreciable numbers and vice versa. For example, of the 15 males who exhibited left-side dominance of the jugular foramen, only 2 exhibited left-side dominance of the humerus, 5 exhibited left-side dominance of the radius, and 3 exhibited left-side dominance of the ulna. Similar nonrelationships were characteristic of symmetry conditions. An interpretation of nonrelationship between the asymmetry parameters was supported by the Chi-square analysis results.

Chi-square summary statistics for the cross-tabulations are presented in Table 2. In addition to testing for significant association for males and females independently, tests for a pooled sample were also included. No Chi-square values were statistically significant, indicating a lack of association among individuals for jugular foramen and long bone asymmetry.

As a corollary measure, the contingency coefficient was calculated for describing the association between the two asymmetry parameters. This statistic is similar in meaning to a correlation coefficient, yet appropriate for nonparametric data. The coefficients for all relationships did not differ significantly from zero (Table 2).

Finally, to eliminate the possibility that subjectivity in classifying individuals as symmetric

TABLE 1—*Cross-tabulations of the observed frequencies for dominant side in long bone length and in jugular foramen size.*

Jugular Foramen	Humerus				Radius				Ulna			
	Left	Same	Right	Total	Left	Same	Right	Total	Left	Same	Right	Total
					MALES							
Left	2	0	13	15	5	0	10	15	3	0	12	15
Same	9	10	24	43	3	10	30	43	7	4	32	43
Right	21	7	39	67	12	9	46	67	13	10	44	67
Total	32	17	76	125	20	19	86	125	23	14	88	125
					FEMALES							
Left	1	0	2	3	1	1	1	3	2	0	1	3
Same	3	4	11	18	3	0	15	18	2	2	14	18
Right	5	5	26	36	7	4	25	36	6	2	28	36
Total	9	9	39	57	11	5	41	57	10	4	43	57

TABLE 2—*Chi-square statistics and contingency coefficients for association between the asymmetry of jugular foramen size and of long bone length.*[a]

Test	χ^2			Contingency Coefficient		
	Male $N = 125$	Female $N = 57$	Male and Female $N = 182$	Male $N = 125$	Female $N = 57$	Male and Female $N = 182$
Jugular foramen and humerus	9.5	1.9	8.6	0.27	0.18	0.21
Jugular foramen and radius	9.4	5.2	6.4	0.26	0.29	0.18
Jugular foramen and ulna	3.3	6.1	3.6	0.16	0.19	0.14

[a]All Chi-square values not significant at $P < 0.01$ with four degrees of freedom.

for jugular foramen size was responsible for the lack of significant association between jugular foramen and long bone asymmetry, the data were reanalyzed using a two-by-two cell design. All individuals who exhibited symmetry of the jugular foramen or symmetry of the long bones were eliminated from the sample data. Therefore, only individuals with definite asymmetries for both parameters were included, thereby providing the most robust condition for measuring association. Once again, no Chi-square values were statistically significant.

Discussion

The nonsignificant association of jugular foramen and long bone asymmetry compels us to consider three hypotheses concerning the relation of either form of asymmetry to hand preference:

1. Long bone asymmetry is related to handedness, but jugular foramen asymmetry is not.
2. Jugular foramen asymmetry is related to handedness, but long bone asymmetry is not.
3. Neither jugular foramen nor long bone asymmetry is related to handedness.

The first hypothesis is questioned on multiple bases. The frequency of left-side dominant long bones (approximately 20% of the cases in this study) greatly exceeds the number of individuals considered to be left-handed in modern populations [*1,4*]. (Although estimates vary, they generally range from 3 to 10%). In addition, it has been shown recently that bone length and cortical thickness of the second metacarpal tend to be longer and thicker on the right hand relative to the left regardless of hand dominance [*5-6*]. Finally, over 50 years ago Schultz [*7,8*] advanced his doubts that preferential use of one hand over the other could be held directly responsible for the common frequencies of arm long bone asymmetry in adults. His conclusion was based on observations of long bone asymmetry in human fetuses. From a sample of 100 fetuses, Schultz [*7*] reported asymmetry percentages for the humerus as 52% right-side dominant; 27% symmetric; and 21% left-side dominant. These frequencies approximate the frequency distribution identified for adults in this study and therefore cast doubt on a developmental relationship.

The second hypothesis, a positive relationship between handedness and jugular foramen asymmetry, also raises some questions. Unlike the first hypothesis, however, the frequency of individuals exhibiting left-side dominance of the jugular foramen is more consistent with the average number of left-handed individuals. We suggest that the major problem with this hypothesis concerns the functional model from which it is drawn. The size of the foramen is related, in part, to the size of the internal jugular vein that passes through it, whose function is to receive blood drainage from the brain and superficial parts of the neck and face. The vein exits the cranium, passes down the neck, and joins with the subclavian vein to form the brachiocephalic vein, terminating at the superior vena cava. The proposed relation of the internal jugular vein to handedness demands further demonstration. The internal jugular vein has no functional relationship to blood drainage of the limbs. Furthermore, an argument for increased hemispheric blood flow of one side of the brain over the other for increased demands from muscular activity in the limbs would necessitate the hypothesis that left-arm dominance is the common pattern, consistent with the contralateral control of the left side of the body by the right hemisphere of the brain and vice versa.

The final hypothesis appears the most reasonable from the standpoint of forensic investigation. A strong correlation between skeletal morphology and physical appearance, or behavior such as handedness, must be documented to be relevant for human identification. Even though both long bone and jugular foramen asymmetry may be related in some way to handedness, the best evidence indicates that the relationship is speculative and minor. We suggest, based on the evidence presented, that handedness be considered in forensic science identification of skeletal materials only with extreme caution. Until further work has been done with documented skeletal material, and until further evaluation of other criteria such as the dorsal beveling on the glenoid fossa have been completed, the determination of handedness from skeletal morphology remains difficult for the forensic anthropologist.

Conclusions

The statistical association of bilateral asymmetry of the arm long bones to bilateral asymmetry of the jugular foramen has been shown nonsignificant. Thus, only one or neither can be considered an accurate determinant of right or left handedness. The evidence suggests that neither criterion is related to handedness to a degree appropriate for forensic science identification from skeletal remains.

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