

Reconstruction of humeral length from measurements of its proximal and distal fragments

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Abstract

The aim of the present study was to estimate the length of humeri from measurements of their proximal and distal fragments. This information is important in archaeological studies and forensic investigations, particularly when fragmented material is examined. Forty humerus of adults individuals, sex-aggregated, of the Departamento de Anatomia/UFRJ collection were selected to analysis (right = 20; left = 20). Maximum length and measures of 12 fragments of the humerus (proximal = 7; distal = 5), named P1-P7 and D1-D5, were obtained by means an osteometrical board and an analogical caliper. Simple and multiple linear regressions ($p < 0.01$) were made to correlate each fragment with total length of the humerus. In right humeri, best estimates were observed with P1, P4, P6, P7 (proximal fragments) and D1, D2, D3, and D4 (distal fragments). In left side, P1, P6 (proximal fragments) and D1, D2, D3 (distal fragments) showed best results. Multiple regressions did not show significant increase in estimates of the humeral length. Regressions formulae were obtained to define these estimative. In conclusion, our study demonstrated that length of the humerus can be estimated from measures of proximal or distal fragments.

Keywords: forensic anthropology, fragmentary humerus, morphometry.

1 Introduction

Reconstructions of life from human skeletal remains have been a challenge among bioanthropologists. Measurements of long bones play an important role in the estimative of stature of individuals in paleoanthropology and forensic investigations (UBELAKER, 1989; SJØVOLD, 1990; CUENCA, 1994; FORMICOLA and FRANCESCHI, 1996; HOPPA and GRUSPIER, 1996; KOZAK, 1996; DEMENDONÇA, 2000; MALL, HUBIG, BUTTNER et al., 2001; NATH and BADKUR, 2002; RADOINOVA, TENEKEDJIEV and YORDANOV, 2002; PELIN, 2003; PETERSEN, 2005; CELBIS and AGRITMIS, 2006; RAXTER, AUERBACH and RUFF, 2006).

Living stature prediction, from lengths of the limb bones, is one of the oldest problems in the history of anthropology (HOPPA and GRUSPIER, 1996; KOZAK, 1996). For many years, anthropologists examining forensic and archaeological remains have considered human body size, including stature, as a parameter of human biodemography (STEWART, 1979; KROGMAN and ISCAN, 1986). Researchers have pioneered stature estimation early in the 19th and 20th centuries (PEARSON, 1899; TROTTER, 1970). In the last quarter of the last century such studies were expanded to large populations (SANGVICHIAN, SRISURIN and WATTANAYINGSAKUL, 1985; SHAO, 1989).

In archaeological approach, statures estimated from human skeletal remains is a essential step in assessing health, sexual dimorphism, and general body size trends among past populations (HOPPA and GRUSPIER, 1996; RAXTER, AUERBACH and RUFF, 2006). The length of long bones

is still employed to normalize data about robusticity of the upper and lower limbs, adjusting absolute values to size and shape of the body, because differences intra- and interpopulational, as well as, between male and female individuals inside of a same group (RUFF, TRINKAUS, WALKER et al., 1993; PEARSON, 2000; RUFF, 2000; LEDGER, HOLTZHAUSEN, CONSTANT et al., 2000; STOCK and PFEIFFER, 2001; RHODES and KNUSEL, 2005; WEISS, 2005; MARCHI, SPARACELO, HOLT et al., 2006; STOCK, 2006). In this context, length of the humerus have been employed to standardize cross-sectional area of the cortical bone or geometric properties of humerus' shaft, solving questions relative to hypertrophy of cortical bone as a response to mechanical stress promoted by daily tasks (RUFF, TRINKAUS, WALKER et al., 1993; TRINKAUS, 1997; LEDGER, HOLTZHAUSEN, CONSTANT et al., 2000; RUFF, 2000; STOCK and PFEIFFER, 2001; WEISS, 2003; WEISS, 2005; RHODES and KNUSEL, 2005; MARCHI, SPARACELO, HOLT et al., 2006; STOCK, 2006; STOCK and SHAW, 2007; WANNER, SOSA, ALT et al., 2007).

Height of individuals is also vital to medico-legal investigations. Thus, in forensic anthropology, projection of the stature from bones plays an important role in the identification of missing persons (ROSS and KONIGSBERG, 2002; WRIGHT and VÁSQUEZ, 2003; ÖZASLAN, SERMET, INCI et al., 2006; KRISHAN, 2007; PETROVECKI, MAYER, SLAUS et al., 2007).

Estimative of living stature can be done from the humeral length, in the absence of more appropriated long bones, as femur or tibia (STEELE and McKERN, 1969; KATE and MAJUMDAR, 1976; SJØVOLD, 1990; MALL, HUBIG, BUTTNER et al., 2001). Individually and collectively, the femur and tibia are the most important components of height. Therefore, the best assessment of height is obtained from regression formulae derived from femoral and tibial lengths. Despite arm bone will not be as accurate as one from the leg, it may be the only part found in burial (CUENCA, 1994; DeMENDONÇA, 2000; MALL, HUBIG, BUTTNER et al., 2001; RADOINOVA, TENEKEDJIEV and YORDANOV, 2002; AKMAN, KARAKAP and BOZKIR, 2006; PETROVECKI, MAYER, SLAUS et al., 2007).

While some attention has been given to the estimation of living stature from long bone length in ancient populations, few studies have been accomplished with modern human groups. For this reason, there are few available data regarding estimating of living height in actual human groups (MALL, HUBIG, BUTTNER et al., 2001; WRIGHT and VÁSQUEZ, 2003; ÖZASLAN, SERMET, INCI et al., 2006; PETROVECKI, MAYER, SLAUS et al., 2007).

Developing of data set involving modern populations are essential as support to the forensic investigations. Forensic analysis performed in modern individuals, particularly involving linear measurements, cannot be based on formulae obtained from ancient populations. Meadows and Jants, (1995); Kozak (1996) and Celbis and Agritmis (2006) have suggested that, because diachronic secular changes in limbs proportion, formulae obtained from ancient groups are inappropriate for modern forensic cases and, for this reason, they need readjustment. To this respect, Iscan (2005) has considered that stature estimation is becoming more and more difficult because the height of human being is rapidly increasing and, thus, regression equations need to be adjusted when we consider populations no contemporary.

The updating of these data to modern population is a challenge of the forensic investigations. Additionally, comparisons between ancient and modern populations, about limbs proportions and stature, are important in analysis of temporal trends in body shape and size.

However, in most of studies involving exhumed skeletons, these estimates need to be accomplished from long bones fragments, because the difficulties to finding complete bones samples (JACOBS, 1992). Steele and McKern (1969) made the first attempt at estimating stature from fragments of the femur, using five landmarks from which four segments were delineated. They derived regression equations for the estimation of maximum length of the femur from each of the segments and combinations of these segments, using prehistoric American femora obtained from three different sites in Mississippi, EUA.

Studies have also been developed on the usefulness of fragments of long bones in the estimate of stature on humerus (WRIGHT and VÁSQUEZ, 2003) radius and femur (STEELE and McKERN, 1969; MYSOREKAR, VERRMA and NANDEDKAR, 1980), femur and tibia (STEELE and McKERN, 1969), ulna and tibia (MYSOREKAR, NANDEDKAR and SARMA, 1984), and tibia (HOLLAND, 1992; INTRONA Jr., STASI and DRAGONE, 2003; CHIBBA and BIDMOS, 2007).

Our aim is to correlate measures of some fragments of the proximal and distal epiphyses of the humerus with its total length, in the attempt of obtaining regression equations that allow us to estimate the humeral length from these fragments. It also serve as guidelines to the contemporary research trend in the field of forensic anthropology as compared with those that have been carried out in the last decade, and, still, to shed light to the anthropological issue of human variation.

2 Material and methods

Forty humeri from adult individuals were measured (right = 20; left = 20). Information about sex was not available, considering that material belongs to the didactic collection of the Department of Anatomy of Universidade Federal do Rio de Janeiro. For the same reason, humeri were unmatched relative to right and left sides.

For the measurements of the humeral length, an osteometrical board (Figure 1) was used (precision = 0.1 cm). The measurements of the proximal and distal segments were made by means a Mitutoyo caliper (Figure 2), with a similar precision = 0.1 cm.

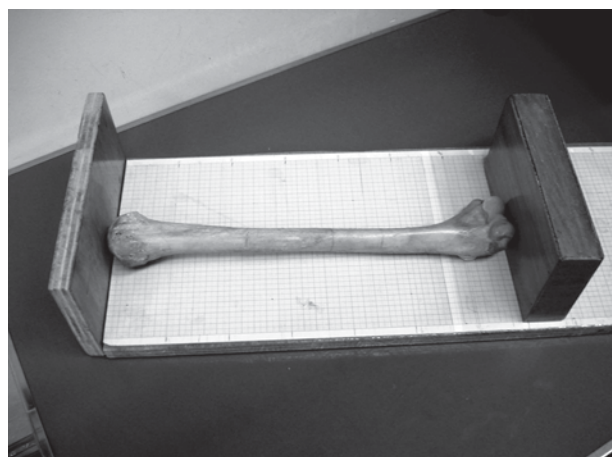


Figure 1. Osteometrical board. Departamento de Anatomia/ICB/UFRJ.

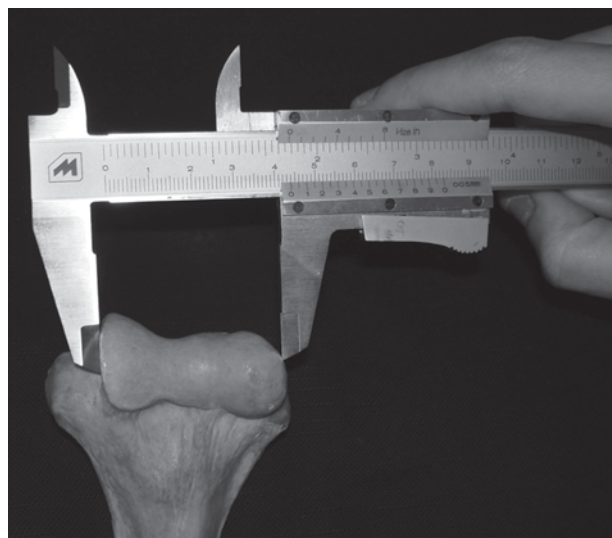


Figure 2. Analogical Caliper Mitutoyo. Departamento de Anatomia/ICB/UFRJ.

Each humerus was positioned with helping of plastic material to permit that its shaft axis was aligned with the horizontal plane of the board. Humeral length was obtained through the vertical distance from tip of the humeral head to the horizontal line passing in the apex of the trochlea.

Seven proximal (P) and five distal (D) fragments were considered in this study (Figure 3). Each measure was made three times by the same examiner and the mean value was considered.

Initially, a simple linear regression was applied, using Microsoft® Excel 2002 software. This regression was made considering the right and left humeri, separately. Soon afterwards we employed multiple regression by means Statistica for Windows® software. In this method, the incorporation of variables was made through stepwise regression. In all statistical procedures the significance level was $<1\%$ ($p < 0.01$).

3 Results

3.1 Descriptive statistics

Table 1 shows mean values of maximum length of the humerus (MHL), proximal and distal fragments (right and left sides). No statistical test to analysis of differences between right and left sides was accomplished, because right and left humeri do not belong to same individuals.

3.2 Simple linear regression

Tables 2 and 3 show the results of simple linear regression, involving proximal and distal segments, respectively.

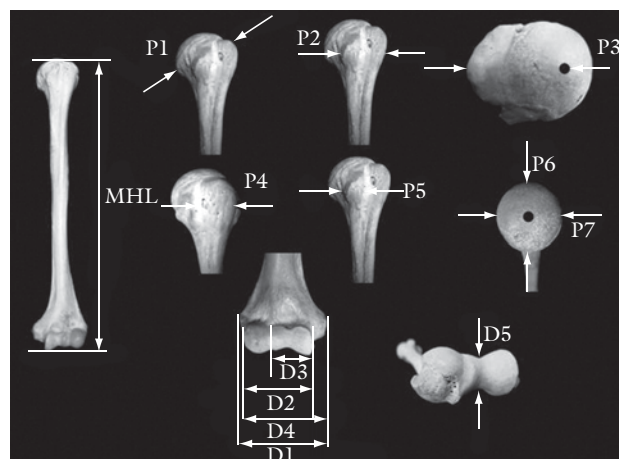


Figure 3. Measurements of Maximum Humeral Length (MHL), and Proximal (P) and Distal (D) Fragments. The black circle indicates the medium point of the humeral head. Departamento de Anatomia/ICB/UFRJ.

Analyzing results of simple regression, it was possible to observe that best estimative were obtained in right side. Greater differences about side were registered in the proximal epiphyses of the humerus. Considering proximal region of the right humeri, the best results were seen with P7, P6, P1 and P4 (decreasing order). Examining left humeri, the best results were obtained with P1 and P6 (decreasing order). In distal region of right humeri, greater regression coefficients were seen in D3, D2, D4 and D1 (decreasing order). On the other hand, in left humeri best results were observed in D3, D2 and D1 (decreasing order).

3.3 Simple regression formulae

Table 4 shows regression formulae to estimative of humerus' length from proximal and distal segments, considering in each case the standard error of estimate:

3.4 Multiple linear regression

Results of multiple regression is shown in Table 5.

Analyzing determination coefficient we could observe that association of two segments (P7 + P6) increases 2% in estimative of humeral length in right side ($r^2 = 0.62$), comparing with P7 alone ($r^2 = 0.60$). In left side, however, the use of P1 + P6 does not increase the estimative of humeral length. In distal segments, D3 + D2 (right side), increase 3% in estimative of humeral length ($r^2 = 0.72$), contrasting with D3 alone ($r^2 = 0.69$). In the left side, D3 + D2 cause an increase of 1% in estimative of humerus' length ($r^2 = 0.56$), comparing with D3, taken separately ($r^2 = 0.55$). Thus, no significant increase was found by the use of multiple regression.

4 Conclusion

The major problem of the present study is the small number of specimen for which maximum length of the humerus was estimated from fragments. It would be desirable to provide estimates on a larger sample than the one used in this study. However, authors (TAL and TAU, 1983; SIMMONS, JANTZ, BASS, 1990; ISCAN, 1990; CUENCA, 1994; ISCAN, 2005; PETERSEN, 2005) have considered that, in most studies, only a small number of skeletons is available for analysis. Thus, it is necessary to accomplish new studies on similar population for a better characterization of these relationships.

Regression analysis is a more appropriated method to define relationships between length of long bones and living height of individuals, and between length of measurements of long bones fragments and their maximum length (KROGMAN and ISCAN, 1986; NATH and BADKUR, 2002; ISCAN, 2005). This statistical method has been used in the estimation of stature from intact long bones of the upper and lower limbs in different populations as Americans

Table 1. Mean values (standard deviation in parentheses) of maximum humeral length (MHL), and proximal and distal segments of the humerus (right and left sides).

	MHL	P1	P2	P3	P4	P5	P6	P7	D1	D2	D3	D4	D5
Right	31.3 (2.3)	4.9 (0.5)	4.3 (0.6)	3.8 (0.4)	3.1 (0.4)	2.0 (0.2)	4.4 (0.4)	4.0 (0.4)	5.8 (0.6)	4.0 (0.4)	2.4 (0.3)	5.8 (0.5)	1.6 (0.2)
Left	30.5 (1.6)	4.8 (0.4)	3.9 (0.4)	3.7 (0.3)	3.1 (0.3)	1.9 (0.3)	4.2 (0.3)	3.9 (0.3)	5.7 (0.4)	3.9 (0.4)	2.4 (0.2)	5.6 (0.4)	1.6 (0.1)

Table 2. Simple linear regression coefficients (Pearson) in the correlation between humeral length and proximal segments (right and left sides).

	P1	P2	P3	P4	P5	P6	P7
Right	0.71 (p = 0.00)	0.29 (p = 0.21)	0.46 (p = 0.04)	0.64 (p = 0.00)	0.59 (p = 0.01)	0.77 (p = 0.00)	0.77 (p = 0.00)
Left	0.69 (p = 0.00)	0.46 (p = 0.04)	0.59 (p = 0.01)	0.42 (p = 0.01)	0.25 (p = 0.28)	0.65 (p = 0.00)	0.57 (p = 0.01)

Significant level: p < 0.01.

Table 3. Simple linear regression coefficients (Pearson) in the correlation between humeral length and distal segments (right and left sides).

	D1	D2	D3	D4	D5
Right	0.69 (p = 0.00)	0.79 (p = 0.00)	0.83 (p = 0.00)	0.77 (p = 0.00)	0.38 (p = 0.10)
Left	0.63 (p = 0.00)	0.73 (p = 0.00)	0.74 (p = 0.00)	0.48 (p = 0.03)	0.25 (p = 0.28)

Significant level: p < 0.01.

Table 4. Simple regression formulae relative to proximal and distal segments (right and left humeri).

	Right humerus	Left humerus
Proximal segments	MHL = 14.1 + 3.49P1 ± 1.60 MHL = 19.6 + 3.78P4 ± 1.73 MHL = 14.1 + 3.94P6 ± 1.46 MHL = 12.9 + 4.61P7 ± 1.44	MHL = 16.0 + 3.03P1 ± 1.20 MHL = 15.4 + 3.55P6 ± 1.26
Distal segments	MHL = 14.8 + 2.84D1 ± 1.64 MHL = 14.0 + 4.28D2 ± 1.39 MHL = 16.9 + 5.96D3 ± 1.27 MHL = 12.2 + 3.30D4 ± 1.46	MHL = 16.8 + 2.39D1 ± 1.28 MHL = 19.8 + 2.72D2 ± 1.13 MHL = 17.2 + 5.63D3 ± 1.11

MHL = maximum humeral length.

Table 5. Pearson coefficients (p-values in parentheses), considering multiple correlations between measures of the total humerus' length and proximal and distal fragments (right and left humeri).

Right humerus		Left humerus	
P7 + P6	D3 + D2	P1 + P6	D3 + D2
r = 0.78	r = 0.85	r = 0.69	r = 0.75
(0.00)	(0.00)	(0.00)	(0.00)

(TROTTER and GLESER, 1952; TROTTER and GLESER, 1958) British and East Africans (ALLBROOK, 1961), South Africans (LUNDY, 1983; LUNDY and FELDESMAN, 1987), Portuguese (DeMENDONÇA, 2000), German (MALL, HUBIG, BUTTNER et al., 2001), Bulgarians (RADOINOVA, TENEKEDJIEV and YORDANOV, 2002), and Turkish (CELBIS and AGRITMIS, 2006)

Data have shown that estimating of living height of individuals could be influenced by ethnicity. Ross and Konigsberg (2002) have admitted that prediction formulae developed from American Whites may be inappropriate for European populations. Systematic use of regression formulae obtained in a specific population can under- or overestimate stature, when applied in another population. Thus, authors have recommended that regression formulas obtained in a

certain population should not be applied the other (ZVEREV and CHISI, 2005; KRISHAN, 2007).

Despite our material to be more appropriate to forensic investigations - assuming that skeletal remains from Brazilian population are characterized by high degrees of genetic mixture and morphological variability - our results can be tested on skeletal remains of ancient human groups, looking for existence of more stable segments that could be involved in indirect estimating of living stature.

In forensic and archeological studies, the mean value of total humerus length gives important evidence to indicate the characteristic features of a population (MALL, HUBIG, BUTTNER et al., 2001; WRIGHT and VÁSQUEZ, 2003). Relationships between living stature and long bones length are dependent of genetic and environmental factors, also considering sexual dimorphism (intra-population) a secular trend of human groups (inter-population). However, as there are no definitive data about population differences involving the relationships between length of the long bones and measures of their fragments, we believe that these relations are more stable, when we compare different populations.

Akman, Karakap and Bozkir (2006) found similarities between mean values of measurements of five segments of the humerus and its maximum length, comparing Turkish population and other different European population. The authors, however, did not analyzed possible differences

among populations related to relationship between humeral length and measures of their segments.

Bioanthropologists have getting the attention that one of the largest difficulties in developing a stature estimation formula is the unavailability of skeletal series with information about body height data, making possible to test the accuracy of the estimates of the living stature from the fragments of the bones (BOLDSEN, 1984; FORMICOLA, 1993; ISCAN, 2005).

Because unavailability of information about individuals in the present study, it was not possible to establish correlations between measurements of fragments of the humerus and height of each person. In general, there are no register about height in anatomical collections in Brazil, considering skeletal material. However, Salles et al. (personal communication) found significant simple correlation ($r = 0.82$; $p < 0.05$) between height of thirty handball players from Rio de Janeiro League and humeral length. These data were obtained by means computed-tomography image.

Derivation and eventual use of generalized equations is a task accomplished by Steele (1970) and Steele and Bramblett (1988). The Hamann-Todd, Terry and the Raymond Dart Pretoria skeletal collections are some of the few samples that assist those demands (TAL and TAU, 1983; SIMMONS, JANTZ and BASS, 1990, 1990; ISCAN, 1990; CUENCA, 1994; ISCAN, 2005).

In the present study we cannot obtain any information about sex of individuals, considering origin of the skeletal material from anatomical collection. Thus, in our investigations data were sex-aggregated, despite Scheuer (2002) and Iscan (2005) have admitted that greatest accuracy in estimating living stature from long bones length will be obtained when sex and ethnic identity are available. Bidmos (2007) found significant related-sex differences in measurements of fragments of the femur in indigenous South Africans. However, analyzing 431 skeletons from Danish mediaeval cemetery, Petersen (2005) assumed that the differences of femur length were independent of sex and, thus, his analysis was taken considering both sexes combined.

Despite upper limbs bones do not contribute to body height, Pearson (2000) found a relationship between humerus and radius and living stature, examining skeletal remains of ancient populations. Petrovecki, Mayer, Slaus et al. (2007) observed a significant correlation between stature and humerus in females individuals (modern groups), in Croatia. Examining skeletal material of Spanish actual population, Muñoz, Iglesias and Penaranda (2001) show correlation between living stature and length of humerus, radius and ulna. A correlation between humerus, radius and ulna and living stature was observed by Mall, Hubig, Buttner et al. (2001) from Anatomical Institutes in Munich and Cologne collections. Nath and Badkur (2002) analyzed skeletal remains from modern population in India, and found a correlation between humeral length and stature. Kate and Majumdar (1976) successfully estimated stature from lengths of femur and humerus by regression method in an Indian sample.

To estimate maximum length of long bones from fragmentary remains, it is important that accurately recognizable landmarks be used. As a result, the measures used to developed regressions formulae for estimates long bones length are restricted. In general, measures of transversal

dimensions along the diaphyses are not appropriate because difficulties on define precise landmarks. Therefore, the only remaining locations suitable for measurements on fragmentary remains are the proximal or distal epiphyses. For this reason, in our investigation proximal and distal segments of humeri were selected.

Analysis involving estimate stature from fragments of long bones is developed because long bones are sometimes presented to investigators in different states of fragmentation (STEELE and McKERN, 1969; BIDMOS, 2007). Several researchers have used linear regressions to estimate maximum length of the long bones, and stature, from measurements of their fragments. Analyzing Terry Collection skeletal remains, Simmons, Jantz and Bass (1990) have a revision of the maximum length of femur from its fragments. Similar studies have also been conducted from fragments of the upper end of the radius and the lower end of the femur (MYSOREKAR, VERRMA and NANDEDKAR, 1980), ulna and tibia (MYSOREKAR, NANDEDKAR and SARMA, 1984) and tibia (HOLLAND, 1992; CHIBBA and BIDMOS, 2007).

Analyzing skeletal remains from forensic exhumations in Guatemala, Wright and Vásquez (2003) found significant correlations between fragments and maximum length of humerus, considering sexes separately and combined. However, these authors employed only longitudinal measurements and associating proximal and distal segments of the humerus. In our study, proximal and distal segments were analyzed separately, because we considered the hypothesis that just one of the humeral epiphyses was available for analysis.

In our investigation we could observe that humerus length can be estimated from measures of several proximal and distal segments. Results obtained on the right side were different from those observed on the left side, despite specimens were unmatched, that is, they did not belong to the same individuals. For this reason, direct comparisons between mean values of right and left sides were not accomplished. Right side segments showed better results in estimates of the humeral length, considering proximal distal ends. Differences between sides were greater, however, in proximal humeral epiphyses.

Considering proximal measures, maximum horizontal and vertical diameters of humeral head showed better results in estimating of the humeral length in right side. However, in left side, only maximum vertical diameter exhibited a significant correlation. Thus, only in the P1 and P6 segments, a significant correlation could be found, in right and left sides.

Excepting segment D4 (horizontal distance from medial epicondyle to capitulum), in the left side, all the other lateromedial segments of the distal end of the humerus, showed a significant correlation with humeral length, in both sides. Anteroposterior diameter of the trochlea (D5) did not show a significant correlation to this respect, in both sides.

Using measures of maximum length of humerus and epicondylar width from 143 individuals came from the Anatomical Institutes in Munich, Mall, Hubig, Buttner et al. (2001) did not find a significant correlation with stature, in both sexes. Akman, Karakap and Bozkir (2006) analyzed lengths of humeral segments in the Turkish population and compare these data with other population for use in forensic and archeological cases. Only longitudinal segments were

selected in this study. However, estimates of total length of the humerus from these fragments were not performed.

Our results lead us to conclude that is possible estimate maximum length of the humerus from measures of its proximal and distal fragments with relative accuracy. This study creates perspectives not only to forensic investigations, because the estimate could be extended to living height of individuals, but also in archaeological material, considering similarities of the proportions about fragments of long bones.

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