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# New data on the biological age estimation of children using bone measurements based on historical populations from the Carpathian Basin

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**Abstract** – Measurements from long bones and from clavicles (the maximum length and two diameters) were taken from 535 children (0–14 year-old) from 17 Carpathian Basin series. Regression equations calculated from these data can be helpful in the biological age estimation of children of historical populations from the Carpathian Basin, as knowing the diameter or the maximum length of a single bone allows the calculation of the maximum length of other longbones. The equations can also be useful for separating children in ossuaries. With 6 tables.

**Key words** – Physical anthropology, human skeletal remains, age estimation.

## INTRODUCTION

Biological age estimation and morphological sexing are both essential parts in the classical anthropological examination of human skeletal remains. This paper provides new data for the biological age estimation of the skeletal remains of children. Age at the time of death in the case of children is usually estimated using the longitudinal measurements of different longbones and by examining the sequence of formation and eruption of teeth. After using the "longbone longitudinal measurements" method in several series we made the following observations:

(1) the applied methods estimate the biological age based on the maximum length of longbones, therefore they can only be used on intact bones (the most commonly used methods are summarized in the book of Scheuer & Black (2000));

(2) tendentious differences were observed in the biological age by almost any given individual in relation to which of his or her bone was used for gaining

the biological age. That means it would be worthy of examination that how reliable are the methods worked out on foreign samples for the series from the Carpathian Basin. These observations motivated us to begin our investigations.

## MATERIAL AND METHOD

The data used for the method were taken from the following Carpathian Basin series:

Bátè, village cemetery (Middle Ages);
Edelény–Borsod ($10^{th}$–$12^{th}$ centuries);
Fonyód-Bézsenypuszta ($16^{th}$–$17^{th}$ centuries);
Jánoshida-Berek (Bronz Age); Kaposvár Road 61, Site 1 (Middle Ages);
Kaposvár Road 61, Site 26 ($7^{th}$–$9^{th}$ centuries);
Keszthely-Dobogó ($4^{th}$ century); Kéthely-Melegoldal ($8^{th}$ century);
Rákóczifalva-Bivalytó, Rokkant Föld Site I.3 (Sarmatian, Gepids);
Rákóczifalva-Kastélydomb (Bronz Age); Somogyszil ($4^{th}$ century);
Vál-Plébániakert (Middle Ages);
Vörs-Majori dűlő ($10^{th}$ century);
Vörs-Papkert „B" ($8^{th}$–$10^{th}$ centuries);
Zalavár-Récéskút ($9^{th}$–$12^{th}$ centuries);
Zalavár-Rezes (Karoling age); Zsámbék-Premontrei Templom (Middle Ages).

Altogether 535 children (0–14 year-old) from 17 series were examined. Measurements were taken from seven bones on complete skeletons (clavicle, humerus, radius, ulna, femur, tibia and fibula), but incomplete skeletons with lesser measurable bones were also involved into the investigations. Besides, the data from several series, where only four bones were measured (humerus, radius, femur and tibia) were also used. The clavicle was used because there is a strong correlation between child growth and biacromial diameter (EIBEN *et. al.* 1991), and thus, the length of the clavicle. Three measurements were taken on each bone: the maximum length (according to MARTIN & SALLER (1957), but without their unfused epiphyses), the antero-posterior diameter /A-P/ at the middle part of the midshaft and the transversal (or cranio-caudal in the case of clavicle) diameter /T – perpendicular to A-P/ at the same point. The fibula was an exception, because here instead of the A-P and T diameters, the maximum and minimum diameter were measured at the middle part of the midshaft. When both bones were measurable from a given type, the longer one was always used. Measurements were taken using a sliding caliper and osteometric board.

## RESULTS

The different bones varied in their preservation. Table 1 shows the percentage of the cases where a bone were examinable and measurable. Data for this table was taken only from those cemeteries where all the seven bones were used for taking measurements.

**Table 1.** Percentages of measurable bones

| Bone | Clavicle | Humerus | Ulna | Radius | Femur | Tibia | Fibula |
|---|---|---|---|---|---|---|---|
| Measured (%) | 52.4 | 64.7 | 41.9 | 47.1 | 72.8 | 58.9 | 24.9 |

Most bones (with the exception of the fibula, which was measurable only in approximately the quarter of the cases) were examinable in many of the cases. Femora were measurable with the biggest frequency (in 388 cases from the 535 children). Based on the maximum length of femur, individuals were grouped into nine classes (with 35 mm femur length intervals for scaling). Table 2 shows the average maximum length and sample numbers of those non-femur bones that belong to a given femur length group.

**Table 2.** Distribution of the average lengths and sample sizes of measurable non-femur bones

| Max. length of femur | Clavicle | Humerus | Ulna | Radius | Femur | Tibia | Fibula |
|---|---|---|---|---|---|---|---|
| | | | Average maximum lenght | | | | |
| 55–89 | 46.1 | 65.1 | 60.9 | 53.2 | 77.2 | 68.3 | 64.5 |
| 90–124 | 59.4 | 90.5 | 78.7 | 70.8 | 110.3 | 90.5 | 85.0 |
| 125–159 | 64.6 | 113.2 | 94.4 | 86.1 | 142.6 | 116.7 | 113.8 |
| 160–194 | 73.0 | 134.3 | 112.7 | 107.9 | 174.2 | 142.4 | 141.9 |
| 195–229 | 77.9 | 156.7 | 130.2 | 119.9 | 211.5 | 172.3 | 167.7 |
| 230–264 | 91.8 | 181.7 | 148.4 | 135.9 | 248.3 | 200.8 | 195.9 |
| 265–299 | 96.3 | 201.6 | 170.8 | 149.1 | 282.3 | 230.3 | 218.3 |
| 300–334 | 105.6 | 226.8 | 186.4 | 168.8 | 316.2 | 255.1 | 252.0 |
| 335–369 | 112.7 | 247.1 | 203.7 | 183.2 | 347.1 | 282.7 | 260.3 |
| | | | Sample size | | | | |
| 55–89 | 8.0 | 17.0 | 14.0 | 16.0 | 24..0 | 16.0 | 6.0 |
| 90–124 | 10.0 | 17.0 | 7.0 | 11.0 | 28.0 | 13.0 | 4.0 |
| 125–159 | 22.0 | 35.0 | 21.0 | 29.0 | 62..0 | 34.0 | 13.0 |
| 160–194 | 29.0 | 47.0 | 27.0 | 32.0 | 71.0 | 44.0 | 17.0 |
| 195–229 | 17.0 | 29.0 | 13.0 | 21.0 | 53.0 | 37.0 | 13.0 |
| 230–264 | 23.0 | 33.0 | 16.0 | 21.0 | 47.0 | 35.0 | 15.0 |
| 265–299 | 21.0 | 25.0 | 16.0 | 19.0 | 33.0 | 28.0 | 15.0 |
| 300–334 | 20.0 | 33.0 | 14.0 | 27.0 | 47.0 | 39.0 | 15.0 |
| 335–369 | 11.0 | 18.0 | 7.0 | 11.0 | 23.0 | 20.0 | 4.0 |
| Σ | 161.0 | 254.0 | 135.0 | 187.0 | 388.0 | 266.0 | 102.0 |

With the data from Table 2 linear regression equations were made to describe the relation between the maximum length of femur and non-femur bones.

$$M1_{clavicle} = 0.238 \times M1_{femur} + 30.445$$
$$M1_{humerus} = 0.663 \times M1_{femur} + 16.669$$
$$M1_{ulna} = 0.528 \times M1_{femur} + 19.755$$
$$M1_{radius} = 0.471 \times M1_{femur} + 19.376$$
$$M1_{tibia} = 0.798 \times M1_{femur} + 3.810$$
$$M1_{fibula} = 0.755 \times M1_{femur} + 6.505$$

With the help of these equations it is possible to calculate the maximum length of a non-femur bone from the maximum length of femur or to calculate the maximum length of each bone from a bone with known maximum length. This can be useful for separating children in ossuaries. However, it is essential to know what biological age belongs to a given bone length. For the Carpathian Basin series, the most accurate "longbone longitudinal measurement" age estimation method is the work of STLOUKAL & HANÁKOVÁ (1978) (worked out on Moravian series). Therefore we created a table (Table 3), where one can see the average maximum femur lengths and the corresponding biological ages given by STLOUKAL & HANÁKOVÁ (S-H in the table), and the maximum lengths of non-femur bones calculated from the average maximum lengths of femurs with our equations.

**Table 3.** Calculated average maximum lengths of non-femur bones

| Age (S-H) | Clavicle | Humerus | Ulna | Radius | Femur (S-H) | Tibia | Fibula |
|---|---|---|---|---|---|---|---|
| 0.0 | 50.7 | 73.2 | 64.8 | 59.5 | 85.3 | 71.9 | 70.9 |
| 0.5 | 56.1 | 88.4 | 76.8 | 70.3 | 108.1 | 90.1 | 88.1 |
| 1.0 | 59.4 | 97.6 | 84.2 | 76.9 | 122.0 | 101.2 | 98.6 |
| 1.5 | 63.1 | 107.9 | 92.4 | 84.2 | 137.5 | 113.6 | 110.2 |
| 2.0 | 66.0 | 115.9 | 98.8 | 89.9 | 149.6 | 123.2 | 119.4 |
| 2.5 | 68.7 | 123.4 | 104.7 | 95.2 | 160.9 | 132.3 | 127.9 |
| 3.0 | 71.8 | 132.2 | 111.7 | 101.5 | 174.1 | 142.8 | 137.9 |
| 4.0 | 75.2 | 141.6 | 119.2 | 108.2 | 188.3 | 154.1 | 148.6 |
| 5.0 | 78.7 | 151.5 | 127.1 | 115.2 | 203.2 | 166.0 | 159.8 |
| 6.0 | 83.0 | 163.3 | 136.5 | 123.6 | 221.1 | 180.3 | 173.3 |
| 7.0 | 87.0 | 174.6 | 145.5 | 131.6 | 238.1 | 193.9 | 186.2 |
| 8.0 | 90.5 | 184.5 | 153.4 | 138.7 | 253.0 | 205.8 | 197.4 |
| 9.0 | 93.7 | 193.5 | 160.5 | 145.0 | 266.5 | 216.6 | 207.6 |
| 10.0 | 97.2 | 203.2 | 168.2 | 152.0 | 281.2 | 228.3 | 218.7 |
| 11.0 | 99.9 | 210.7 | 174.2 | 157.3 | 292.5 | 237.3 | 227.2 |
| 12.0 | 102.4 | 217.6 | 179.7 | 162.2 | 302.9 | 245.6 | 235.0 |
| 13.0 | 106.2 | 228.3 | 188.2 | 169.8 | 319.0 | 258.5 | 247.2 |
| 14.0 | 109.6 | 237.8 | 195.8 | 176.5 | 333.3 | 269.9 | 258.0 |

Using paired t-test we compared the original average maximum lengths of non-femur bones given by STLOUKAL & HANÁKOVÁ and the average maximum lengths of non-femur bones calculated from femurs with our equations. Data were standardized for the test. The presumed normal distribution of the differences between the standardized data pairs was tested with Kolmogorov-Smirnov test for goodness of fit.

No significant differences were found between the original average values given by STLOUKAL & HANÁKOVÁ and our calculated ones. Table 4 shows the results of the paired t-tests. The small differences suggest that there is a great similarity in the growth rate between the Carpathian Basin series and the Moravian series of STLOUKAL & HANÁKOVÁ. One of our earlier observations that the radius usually gives a lower biological age as compared to the humerus, femur or tibia was not shown by the statistical analysis. That is an important confirmation and suggests that this method is correct in estimating the biological age for Carpathian Basin series.

**Table 4.** Results of the statistical tests

| | |
|---|---|
| Humerus | 0.384 |
| Radius | 0.264 |
| Ulna | 0.382 |
| Tibia | 0.460 |
| Fibula | 0.367 |

Correlations between the length and diameter data for each bone were also examined. For the calculation of regression equations only those data were used, where an average maximum length of a bone belonging to a given diameter value was gained from at least ten individuals. With these regression equations it became possible to calculate the maximum length of an incomplete bone knowing its A-P or T value.

$$M1_{clavicle} = 9.516 \times AP_{clavicle} + 14.883$$
$$M1_{clavicle} = 11.652 \times T_{clavicle} + 21.828$$
$$M1_{humerus} = 15.303 \times AP_{humerus} - 20.908$$
$$M1_{humerus} = 18.656 \times T_{humerus} - 54.327$$
$$M1_{ulna} = 22.069 \times AP_{ulna} - 24.510$$
$$M1_{ulna} = 19.021 \times T_{ulna} - 25.221$$
$$M1_{radius} = 19.272 \times AP_{radius} - 9.022$$
$$M1_{radius} = 14.319 \times T_{radius} - 4.740$$
$$M1_{femur} = 17.946 \times AP_{femur} - 40.521$$
$$M1_{femur} = 19.799 \times T_{femur} - 73.406$$
$$M1_{tibia} = 11.901 \times AP_{tibia} - 5.156$$
$$M1_{tibia} = 16.838 \times T_{tibia} - 37.988$$
$$M1_{fibula} = 22.026 \times Dmax_{fibula} - 1.688$$
$$M1_{fibula} = 30.619 \times Dmin_{fibula} - 18.057$$

**Table 5.** Average bone lengths belonging to a given antero-posterior (A-P) diameter* = maximum diameter at the middle part of the midshaft of fibula

| AP | Clavicle | Humerus | Ulna | Radius | Femur | Tibia | Fibula* |
|---|---|---|---|---|---|---|---|
| 3.5 | 48.20 | – | 52.70 | – | – | – | 75.40 |
| 4.0 | 52.90 | – | 63.80 | 68.10 | – | – | 86.40 |
| 4.5 | 57.70 | – | 74.80 | 77.70 | – | – | 97.40 |
| 5.0 | 62.50 | 55.60 | 85.80 | 87.30 | – | – | 108.40 |
| 5.5 | 67.20 | 63.30 | 96.90 | 97.00 | – | – | 119.50 |
| 6.0 | 72.00 | 70.90 | 107.90 | 106.60 | – | 66.20 | 130.50 |
| 6.5 | 76.70 | 78.60 | 118.90 | 116.20 | – | 72.20 | 141.50 |
| 7.0 | 81.50 | 86.20 | 130.00 | 125.90 | 85.10 | 78.20 | 152.50 |
| 7.5 | 86.30 | 93.90 | 141.00 | 135.50 | 94.10 | 84.10 | 163.50 |
| 8.0 | 91.00 | 101.50 | 152.00 | 145.20 | 103.00 | 90.10 | 174.50 |
| 8.5 | 95.80 | 109.20 | 163.10 | 154.80 | 112.00 | 96.00 | 185.50 |
| 9.0 | 100.50 | 116.80 | 174.10 | 164.40 | 121.00 | 102.00 | 196.50 |
| 9.5 | 105.30 | 124.50 | 185.10 | 174.10 | 130.00 | 107.90 | 207.60 |
| 10.0 | 110.00 | 132.10 | 196.20 | 183.70 | 138.90 | 113.90 | 218.60 |
| 10.5 | 114.80 | 139.80 | 207.20 | – | 147.90 | 119.80 | 229.60 |
| 11.0 | – | 147.40 | 218.20 | – | 156.90 | 125.80 | 240.60 |
| 11.5 | – | 155.10 | – | – | 165.90 | 131.70 | 251.60 |
| 12.0 | – | 162.70 | – | – | 174.80 | 137.70 | 262.60 |
| 12.5 | – | 170.40 | – | – | 183.80 | 143.60 | – |
| 13.0 | – | 178.00 | – | – | 192.80 | 149.60 | – |
| 13.5 | – | 185.70 | – | – | 201.80 | 155.50 | – |
| 14.0 | – | 193.30 | – | – | 210.70 | 161.50 | – |
| 14.5 | – | 201.00 | – | – | 219.70 | 167.40 | – |
| 15.0 | – | 208.60 | – | – | 228.70 | 173.40 | – |
| 15.5 | – | 216.30 | – | – | 237.60 | 179.30 | – |
| 16.0 | – | 223.90 | – | – | 246.60 | 185.30 | – |
| 16.5 | – | 231.60 | – | – | 255.60 | 191.20 | – |
| 17.0 | – | 239.20 | – | – | 264.60 | 197.20 | – |
| 17.5 | – | 246.90 | – | – | 273.50 | 203.10 | – |
| 18.0 | – | 254.60 | – | – | 282.50 | 209.10 | – |
| 18.5 | – | – | – | – | 291.50 | 215.00 | – |
| 19.0 | – | – | – | – | 300.50 | 221.00 | – |
| 19.5 | – | – | – | – | 309.40 | 226.90 | – |
| 20.0 | – | – | – | – | 318.40 | 232.90 | – |
| 20.5 | – | – | – | – | 327.40 | 238.80 | – |
| 21.0 | – | – | – | – | 336.30 | 244.80 | – |
| 21.5 | – | – | – | – | 345.30 | 250.70 | – |
| 22.0 | – | – | – | – | – | 256.70 | – |
| 22.5 | – | – | – | – | – | 262.60 | – |
| 23.0 | – | – | – | – | – | 268.60 | – |
| 23.5 | – | – | – | – | – | 274.50 | – |
| SD/mm | 1.76 | 1.66 | 2.66 | 2.20 | 1.83 | 0.96 | 2.93 |

**Table. 6.** Average bone lengths belonging to a given transversal (T) diameter. * = minimum diameter at the middle part of the midshaft of fibula

| T | Clavicle | Humerus | Ulna | Radius | Femur | Tibia | Fibula* |
|---|---|---|---|---|---|---|---|
| 2.5 | 51.00 | – | – | – | – | – | – |
| 3.0 | 56.80 | – | – | – | – | – | 73.80 |
| 3.5 | 62.60 | – | – | – | – | – | 89.10 |
| 4.0 | 68.40 | – | – | – | – | – | 104.40 |
| 4.5 | 74.30 | – | 60.40 | – | – | – | 119.70 |
| 5.0 | 80.10 | – | 69.90 | 66.90 | – | – | 135.00 |
| 5.5 | 85.90 | – | 79.40 | 74.00 | – | – | 150.30 |
| 6.0 | 91.70 | 57.60 | 88.90 | 81.20 | – | 63.00 | 165.70 |
| 6.5 | 97.60 | 66.90 | 98.40 | 88.30 | – | 71.50 | 181.00 |
| 7.0 | 103.40 | 76.30 | 107.90 | 95.50 | – | 79.90 | 196.30 |
| 7.5 | 109.20 | 85.60 | 117.40 | 102.70 | – | 88.30 | 211.60 |
| 8.0 | 115.00 | 94.90 | 126.90 | 109.80 | – | 96.70 | 226.90 |
| 8.5 | – | 104.20 | 136.50 | 117.00 | 94.90 | 105.10 | 242.20 |
| 9.0 | – | 113.60 | 146.00 | 124.10 | 104.80 | 113.60 | 257.50 |
| 9.5 | – | 122.90 | 155.50 | 131.30 | 114.70 | 122.00 | 272.80 |
| 10.0 | – | 132.20 | 165.00 | 138.50 | 124.60 | 130.40 | – |
| 10.5 | – | 141.60 | 174.50 | 145.60 | 134.50 | 138.80 | – |
| 11.0 | – | 150.90 | 184.00 | 152.80 | 144.40 | 147.20 | – |
| 11.5 | – | 160.20 | 193.50 | 159.90 | 154.30 | 155.60 | – |
| 12.0 | – | 169.50 | 203.00 | 167.10 | 164.20 | 164.10 | – |
| 12.5 | – | 178.90 | 212.50 | 174.20 | 174.10 | 172.50 | – |
| 13.0 | – | 188.20 | – | 181.40 | 184.00 | 180.90 | – |
| 13.5 | – | 197.50 | – | – | 193.90 | 189.30 | – |
| 14.0 | – | 206.90 | – | – | 203.80 | 197.70 | – |
| 14.5 | – | 216.20 | – | – | 213.70 | 206.20 | – |
| 15.0 | – | 225.50 | – | – | 223.60 | 214.60 | – |
| 15.5 | – | 234.80 | – | – | 233.50 | 223.00 | – |
| 16.0 | – | 244.20 | – | – | 243.40 | 231.40 | – |
| 16.5 | – | 253.50 | – | – | 253.30 | 239.80 | – |
| 17.0 | – | – | – | – | 263.20 | 248.30 | – |
| 17.5 | – | – | – | – | 273.10 | 256.70 | – |
| 18.0 | – | – | – | – | 283.00 | 265.10 | – |
| 18.5 | – | – | – | – | 292.90 | 273.50 | – |
| 19.0 | – | – | – | – | 302.80 | 281.90 | – |
| 19.5 | – | – | – | – | 312.70 | – | – |
| 20.0 | – | – | – | – | 322.60 | – | – |
| 20.5 | – | – | – | – | 332.50 | – | – |
| 21.0 | – | – | – | – | 342.40 | – | – |
| SD/mm | 1.78 | 1.80 | 2.64 | 1.89 | 1.68 | 1.58 | 4.54 |

In order to simplify, the average maximum length of bones belonging to an A-P or T diameter are given in Tables 5 and 6. Diameter data has a large standard deviation, and this should be taken into consideration when using the diameters for estimating biological age. This can be due to several factors and one of these reasons is sexual dimorphism.

The sex of the examined individuals (children) were unknown, therefore we were not able to examine wether the length/diameter proportions of children's longbones are suitable for the determination of sex of a child. For a better arrangement, we did not give the S.D. values for all the data, instead we gave the average S.D. values belonging to one mm of diameter for every bone in the lowest row of the table.

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