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# Upgrading calculation methods for age estimation from cranial sutures in 594 crania from the Poschiavo ossuary

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**Summary**

The paper presents a different approach for the calculation of age estimation based on observation of the cranial suture closure. Instead of a linear regression, multivariate statistics and specifically detrended correspondence analysis (dCA) is applied to the data. Two series of known sex and age were used, whereas the new approach was also applied to a large series of cranial material originating from an ossuary in Poschiavo, Switzerland. The aim of the study is to acquire more refined results for age estimation from cranial sutures, especially useful with poorly preserved or incomplete skeletal material. Taking the single observations as an assignment of multivariate statistics proved to be useful, and dCA has been demonstrated as a suitable method. Estimation of biological age based on skulls was possible with a precision of ±10 years. The accuracy of age estimations was improved when taking both surfaces of the skulls into account. Significant differences between the sex groups were recorded, therefore sex specific formula should be developed.

*Keywords: correspondence analysis; regression; ossuary; Graubünden; Switzerland*

## Introduction

The sutures of the skull are open at birth and close with ongoing age. The founding papers of the modern scientific discussion of this phenomenon are the theses of Ribbe (1885) and Frédéric (1906, adopting Broca 1861, 1875), followed by four papers of Todd and Lyon (1924, 1925a–c), which in sum established the standard way of observation by defining stages of closure at specific parts of the ectocranial and endocranial sutures. These and following studies tried to clarify the correlation of the closure with calendaric age, and explored probable influences of sex and ancestry. While differences in ancestry could not be verified (Frédéric 1906, p 444–445; Todd and Lyon 1924, 1925a–c, in particular 1925b, p 65 f.; Meindl and Lovejoy 1985, p 65 f.), differences in sex are still under discussion (no differences between sex groups: Acsádi and Nemeskéri 1970, p 115 f.; Schmitt and Tamaska 1970; Meindl and Lovejoy 1985; differences between sex groups: Frédéric 1906, p 437–444; Hajniš and Novák 1976; Perizonius 1984, p 204 f., tab. 2–3; Hershkovitz *et al.* 1997; Sahni *et al.* 2005).

In 1970 Acsádi and Nemeskéri developed a general scheme for age estimations on skeletal material and used the closure of the three main endocranial sutures – coronal, sagittal and lambdoid sutures – as one of their criteria for the "complex method". Following their handbook, most European anthropologists use the observation of the endocranial sutures as one part of the age estimation for adult individuals (Ferembach *et al.* 1979, 1980). This method transfers the single observations on the endocranial parts of the sutures to the overall mean stage of closure, and relates the classified means to a scheme of age spans, each measuring 30 years. When shorter age spans of 20 years are needed, as e.g for the standard life tables, the resulting numbers of individuals have to be split schematically (Appendix, Tab. 1). One could object to this traditional way, in that it is combined with an unnecessary loss of information. A more suitable way could be based on applying estimations by regression, starting with the observed mean stage of sutures closure. This concept was already embedded in the research of Acsádi and Nemeskéri (1970, p 120 Fig. 19), where they published a regression formula on the basis of their reference population. The use of such regressions will result in estimations along a continuous scale, which could be more suitable for further analysis from a statistical point of view.

On the other hand, the multivariate nature of the variables and the question of unimodal versus linear distribution indicate that perhaps another statistical approach would be more appropriate for the calculation of such data. Many phenomena in anthropology follow a linear model, e.g. stature has a mainly linear relation to long bone measurements. Alternatively in a unimodal model observations are rare at first, becoming more frequent then, but are diminishing after a maximum again. Concerning age estimation, the general relation between age and sutures closure is thought to be more linear than unimodal, the mean stage of closure gets higher with growing age. But the special way of coding the observed informations causes a unimodal behaviour. Closure stage 2 for example is most likely related to a certain age, while it is less frequently observed for instance at ages 10 years higher than 10 years lower. Potentially, a statistical method for unimodal data is more suitable to the problem.

The aim of the present paper is to test a new calculation method of age estimation parameters by using correspondence analysis (CA) and to compare its results with the standard calculation method of Acsádi and Nemeskéri, using cranial series (Shetty 2009; Frédéric 1906) with known age and sex. This refined analysis is especially important when applied to poorly preserved skeletons with limited availability of cranial and post-cranial age-indicators. In such cases maximum use of the available data is necessary in order to get optimal accuracy. We applied this new calculation method to a large sample of cranial material from a late medieval ossuary in order to optimise the available age estimation data, since in this case the sutures of the skull were the only traits available.

## Material and Methods

The cranial material originates from the ossuary of Poschiavo, situated in Graubünden, Switzerland. The ossuary includes 637 well preserved crania mostly lacking their teeth and mandibles. The ossuary dates to the beginning of the 20th century, but the cranial material was brought there from the church and the cemetery of Saint Vittore. It is estimated that the skulls date to the 16th–19th century AD (Papageorgopoulou *et al.,* in press). Information on the individuals like names, age, sex or kinship is not available. According to the morphognostic sex determination (Ferembach *et al.* 1979; 1980) there were 303 males (54%: 221 certain, 82 probably) and 261 females (46%: 187 certain, 74 probably). Sex determination was not possible for 30 crania (Tab. 1). Suture recording was done after Ferembach *et al.* 1979 at the ecto- and endocranial surface by four experienced anthropologists. To evaluate the observer error, after the first observation of the total series 96 crania were selected at random and recorded a second time. The observer error was calculated following the procedure described by Gapert *et al.* (2009).

As reference series with known sex and age the data from Shetty (2009) were used, who examined the endocranial and ectocranial closure on 100 forensic cases from India and published the original data of his observations, and the data of Frédéric 1906, who examined 291 individuals of known age, sex and ancestry (Anatomical Collection in Strasbourg; 89% of these skulls are from western and central Europe, 11% from Asia, America and Africa; Tab. 1). Frédéric observed all ectocranial sutures. His observation of the endocranial sutures was restricted to 109 skulls which he dissected, whereas the observations on the not dissected skulls were of poorer quality. Therefore his collection was divided into two series: one in which the skulls had been opened (n=109), and one in which the skulls were kept intact (n=182) and only the sutura sagittalis was observed at the inner surface of the crania.

The table of Acsádi and Nemeskéri (1970, p 119, tab. 29) was used to calculate a regression formula. Following Acsádi and Nemeskéri, the quadratic regression formula [1] was chosen. This will result into estimations along a continuous scale, which could be more suitable for further analysis from a statistical point of view. Calculations were done with SPSS vers. 17.

For the application of a multivariate method each skull was taken as one case, and the stage of closure of each part of its sutures as variables. The statistical method of choice is Correspondence Analysis (CA), which is frequently used in archaeology (e.g. Siegmund 1998, 2000; Müller and Zimmermann 1997), ecology (e.g. ter Braak 1987) or sociology (e.g. Bourdieu 1979) as a multivariate technique suitable for categorical data (for statistical theory see: Benzécri 1973; Greenacre 1983, 2007). In contrast to many other multivariate methods missing values are not a problem for CA, all cases can be considered without leaving out cases or filling up the missing values. As a result the CA should show the relative sequence of the crania and of the stages of the sutures. The calculations of the CA were done by PAST (version 1.97 from Jan. 2010; Hammer *et al.* 2001; see: http:// folk.uio.no/ ohammer/ past/ [visited Febr. 1st 2010]).

To apply a CA to the crania, some initial preparation of the raw data is necessary. The two observations of a single part of the sutura coronalis and the lambdoidea from the right and from the left side of the skull were taken together to avoid an overemphasising compared to the sutura sagittalis, while ecto- and endocranial observations were kept strictly separate. To calculate

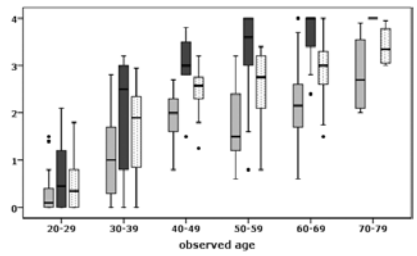


**Fig. 1:** Boxplot with median and interquartile range of mean stages of closure related to age for the series Shetty (2009). Boxes in darkgrey: mean stage from endocranial sutures; box in light grey: mean stage of ectocranial sutures; white and dotted boxes: mean of ecto- and endocranial sutures; black dots: outliers.

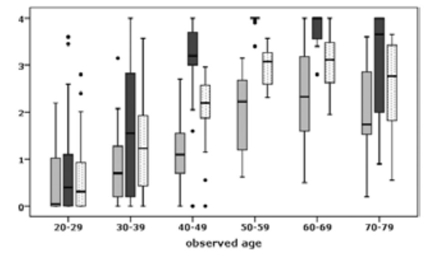


**Fig. 2:** Boxplot with median and interquartile range of mean stages of closure related to age for the series Frédéric (1906, opened). Boxes in dark grey: mean stage from endocranial sutures; box in light grey: mean stage of ectocranial sutures; white and dotted boxes: mean of ecto- and endocranial sutures; black dots: outliers.

a correspondence analysis, the observations were transferred into the typical notation of presence and absence: a suture originally noted as “ecS1 observed stage 3” becomes “ecS1–3 present” (i.e. “1”), while ecS1–1, ecS1–2 and ecS1–4 are set to zero. When a broken value for a sutura was noted or derived by the middling between the right and left side, both neighbouring numbers were set to “1”.

Similar to a principal component analysis, CA results in several “factors” with the single variables and cases ordered along them. A plot of the first two axes (Fig. 5) shows the typical distribution of the single cases and variables like a “horseshoe” or parabola. This indicates that the resulting order is good and the data follow the unimodal model against the underlying axes well. A closer look at the crania shows that they are ordered well along the first axis according to their age, and that the following axes seem to have no further valuable meaning, like sex for example. As usual in cases like that, a detrending is computed to eliminate the quadratic relationship between axis 1 and 2, which results in a better scaling for the first axis.

Typically the axis of a CA (as of PCA) gives a good relative order with interpretable distances between the cases, but these axes are not scaled in the sense of the original data. To get an estimation of biological age the relative scale has to be calibrated to age. To avoid errors from possible singularities with the oldest individuals the 90%-span of our cases was taken to get the necessary data for rescaling, which then gives the estimation of the biological age.

To compare the results mean life expectancy for the series is calculated using the standard abridged life tables with age-spans of 20 resp. 10 years (Acsádi and Nemeskéri 1970, p 29-45). Further life expectancy at the age of 20 years ($e_{20}$) is noticed because the topic and the series do not incorporate subadults. To follow a clear methodology when developing this new approach one of the four series was taken as reference series (Shetty 2009), and the other two (Frédéric 1906, opened and unopened) for validation. This choice of the series will be reasoned by their characteristics which become visible from the first results.

## Results

For the series recorded in the present study, Poschiavo, calculation of observer error based on 96 crania showed a technical error of measurements (TEM) of 0.293, a relative technical error of measurement (rTEM) of 0.296 and a coefficient of reliability (R) of 0.834 for the mean of the ectocranial sutures, and a TEM of 0.346, a rTEM of 0.152 and a R of 0.949 for the mean of endocranial sutures.

The overall frequency of the different stages of endocranial closure differed significantly between the three series (Tab. 2). The mean of the ectocranial sutures as the mean of the endocranial sutures show a high correlation, which is always statistically significant, with observed age in all of the three series with known calendaric age (Tab. 3). Comparing ectocranial stages with endocranial stages of closure showed that the correlation between ectocranial closure and calendaric age is only slightly poorer than with endocranial sutures.

The least squares regression on the basis of Acsádi and Nemeskéri (1970, p 119, tab. 29) gave the following formula, with $r^2 = 0.297$:

[1] $\text{estimated age} = 16.079 + (15.407 \times \text{mean stage}) - (0.852 \times \text{mean stage}^2)$

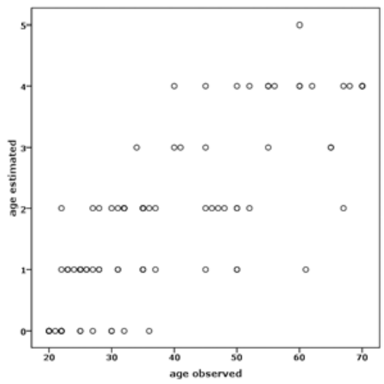


**Fig. 3:** Comparison between observed ages and age estimations with the classification approach by Acsádi and Nemeskéri (1970, tab. 32) for the series Shetty (2009). Age class 0: up to 25, 1: 15–40, 2: 30–60, 3: 35–65, 4: 45–75, 5: 50–80 years.

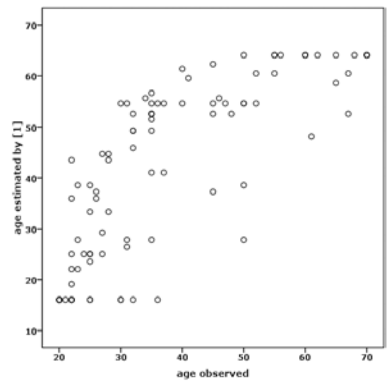


**Fig. 4:** Comparison between observed ages and age estimation by regression [1] for the series Shetty (2009).

The comparison between the observed and estimated ages by the standard classification approach and by the regression [1] shows similar results (Figs 3–4).

The correspondence analysis (CA) for the series Shetty (2009) showed the expected "horseshoe" at the plot of the first two axes (Fig. 5) which indicates that the resulting order is good in a statistical sense and that the data follow the unimodal model against the underlying factors well. The crania are ordered along the first axis according to their known calendaric age, and the following axes seem to have no further valuable meaning. As usual in cases like that, a detrending is computed to eliminate the quadratic relationship between axis 1 and 2, which results in a better scaling of the first axis. After detrending, the eigenvalues for the first three axes are 0.779, 0.254 and 0.161, with eigenvalue 1 explaining 20.2% of the total inertia (variance). Appendix gives the resulting formula which enables to calculate the position of a new skull after the stages of his sutures along the axis 1 ("supplementary points" after Greenacre 2007, p 89–96). The rescaling to age based on the 90%-span of values showed eigenvalues from 0.00 to 4.72 and calendaric ages from 20 to 65 years there. Therefore calibration can be done by multiplying the first eigenvalue with 9.54 (i.e. 45/4.72) and adding 20 years, which gives the estimation of the biological age according to the series Shetty (2009). The correlation of the age estimated by dCA and observed age is high for the series with observation of ecto- and endocranial sutures, and lower, but still significant for the series with unopened crania (Tab. 4, to compare with Tab. 3).

To sum up the results of CA and of the regression [1] for the three series with known ages, we transfer them to the 20-years-classes often used for demography (Tab. 5). As $\chi 2$-statistics shows, the deviations between observed and estimated frequencies are similar and remain tolerable for the two series with good observations. When applied to the series Frédéric (1906, unopened), all methods give poor results. For all the series the number of adult individuals is estimated very similarly by all methods, while dCA overestimates the amount of mature individuals and regression [1] overestimates the amount of senile individuals.

To have a closer look at the results and to make use of the advantage of a continuous scale with the estimations by regression [1], we classify them into shorter spans of 10 years (Tab. 6). Again, estimations are similar for adult individuals, while dCA overestimates the amount of elder mature (50–60 years) and regression [1] overestimates the amount of seniles. For the difficult series Frédéric (1906, unopened) the estimations based on dCA are closer to the observed values and result in a good estimation of $e_{20}$.

Table 7 shows the mean difference between observed and estimated ages, specific for males and females; the upper rows take the whole populations into account, the two lower rows are restricted to individuals of observed age between 20 and 65 to exclude outliers caused by very old age. The mean difference indicates the accuracy of the estimations of which the deviation now can be recognized as very systematical: with estimations after Acsádi and Nemeskéri (1970) males get about 5–6 years too old and females about 2–4 years too old, with

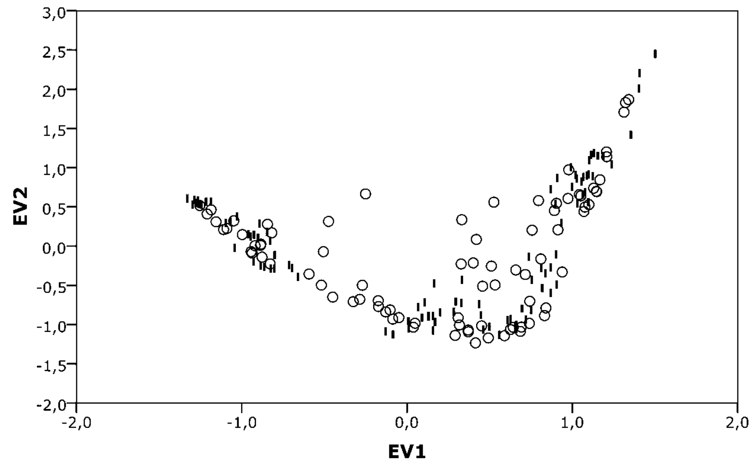


**Fig. 5:** Scatterplot of the first two axes of CA for the series Shetty (2009). Circles indicate crania, upright dashes indicate sutures.

estimations by dCA males get 4–6 years too old and females 2–3 years too old. The standard deviation shows the precision of the estimations which is slightly better with dCA than with regression [1], and better for males than for females. Table 8 shows the application of the estimation methods to the crania from the ossuary of Poschiavo.

## Discussion

Compared to other studies (e.g. Gapert *et al.* 2009; Veroni *et al.* 2010), the series from Poschiavo showed low values of TEM and rTEM, and a reliability (R) of about 0.83–0.94, which is close to the ideal of 1.0. It should be noted, that similar values for ecto- as endocranial sutures were achieved, although the crania from Poschiavo had not been dissected. Applying the observed TEM to regressions [1] after Acsádi and Nemeskéri (1970) would cause differences of about ±4 years at estimations based on endocranial sutures. Although neither Shetty nor Frédéric made calculations of observer error, we presume their recordings are of similar accuracy.

In the two good observed series the mean stage of closure for endo- and ectocranial sutures is well correlated with calendaric age, the correlation coefficient is about 0.7 (Tab. 3) and always highly significant. These correlations (Figs 1–2) do not support other theses which take ectocranial sutures as improper or significantly less suitable for age estimations (Todd and Lyon 1924, 1925; Schmitt and Tamaska 1970; Perizonius 1984; Hershkovitz *et al.* 1997). At a first look, Figs 1–2 could be taken as a verification of the thesis from Hershkovitz *et al.* (1997), that after the age of 35 ectocranial sutures remain more or less stable and are not age-specific. But Figs 1–2 also show that after a time of stability or degression from the fifth to seventh decade of life the ectocranial sutures are more closed in really high ages. Significant negative correlations of suture closure with age within an older age group as shown by Perizonius (1984) could not be verified here (Appendix, Tabs 2–3). In general the relation of the mean stage of closure to advancing age is not linear, and it is different at ecto- and endocranial sutures. Therefore the combination of both sides should give optimal results, while actually many European anthropologists prefer endocranial sutures only (Ferembach *et al.* 1979) and many American anthropologists prefer ectocranial sutures only (Meindl and Lovejoy 1985).

The detrended Correspondence Analysis (dCA) based on ecto- and endocranial sutures brought results similar to the standard method with slightly better accuracy and precision. Taking the problem as a topic of multivariate statistics and the choice of dCA as a suitable multivariate method is therefore justified. Application of dCA to the series with unopened skulls produced much better results, so dCA is more robust against poor observation conditions. Although the comparison between standard approach (regression 1) and dCA shows differences, in a certain sense they are remarkably low, because the reference series used by Acsádi and Nemeskéri (1970) had a much higher mean life expectancy ($e_{20}$ ca. 38.5 years after ibid., p 119, tab. 29) than the series of Frédéric (2009; $e_{20}$ 19.6 years). This could indicate that the influence of the different age structure of the reference series is lower than often presumed.

No differences in the development of sutures along age between people of different ancestry have been reported (Frédéric 1906, p 444–445; Todd and Lyon 1924, 1925a–c, in particular 1925b, p 65 f.; Meindl and Lovejoy 1985 p 65f.). This is underlined by the present study where the dCA based on a reference series from India gave good and comparable results when applied to the two series (Frédéric 1906) mainly from eastern France and southern Germany.

Some publications could not detect a difference between males and females in the relation between age and suture closure (Acsádi and Nemeskéri 1970, p 115 f.; Schmitt and Tamaska 1970; Meindl and Lovejoy 1985). Therefore larger series were published without observing this topic (Dérobert and Fully 1960; Voigt *et al.* 2006). Although other publications noted differences between males and females (e.g. Frédéric 1906, p 437–444; Hajniš and Novák 1976; Perizonius 1984, p 204 f., tables 2–3; Kemkes-Grottenthaler 1993; Hershkovitz *et al.* 1997; Sahni *et al.* 2005). In this study two different estimation methods were applied to three series with known age-at-death, and for all of them and with both methods a significant difference in accuracy and precision between males and females was observed. Further refining of age estimations by closure of the sutures should try to develop sex-specific estimations.

Application of standard regression [1] and dCA to the ossuary of Poschiavo shows similar results for both methods (Tab. 8). The mean life expectancy of males is calculated as 8–10 years higher than for females. Such a difference is too high to be plausible which indicates that some selection must have taken place when the crania were transferred from the original cemetery to the ossuary at the beginning of the 20th century. Taking the results of table 6 as background when reading table 8, the real amount of older matures in Poschiavo is expected to be closer to 111 than 143 and the amount of seniles closer to 63 than 141.

## Conclusions

The correlation of the closure of ecto- and endocranial sutures with calendaric age is high which makes age estimations possible when appropriate schemes and methods are used. The accuracy of age estimations from closure of sutures can be improved by taking both surfaces of the crania into account. Taking the single observations as a mission of multivariate statistics seems to be useful, and correspondence analysis has been demonstrated as a good choice. Applying estimations by dCA as proposed here (Appendix) to the sutures, estimation of biological age based on skulls only is possible with a precision of ±10 years. There are clear differences between the sex groups, wherefore sex specific formula should be developed.

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| Series | n adults | n males | n females | n indet. | $e_{20}$ |
|---|---|---|---|---|---|
| Poschiavo | 594 | 303 | 261 | 30 | ? |
| Shetty 2009 | 100 | 72 | 28 | - | 19.6 |
| Frédéric 1906 (total) | 291 | 208 | 83 | - | 37.4 |
| - opened | 109 | 81 | 28 | - | 33.7 |
| - unopened | 182 | 127 | 55 | - | 39.4 |

**Tab. 1:** Overview over the series used in this study.

| ectocranial: | Frédéric 1906 | Shetty 2009 | Poschiavo |
|---|---|---|---|
| 0 | 1833 | 400 | 2633 |
| 1 | 117 | 270 | 1835 |
| 2 | 178 | 165 | 778 |
| 3 | 193 | 102 | 487 |
| 4 | 578 | 73 | 217 |
| **endocranial:** | | | |
| 0 | 659 | 250 | 2468 |
| 1 | 19 | 123 | 695 |
| 2 | 41 | 155 | 335 |
| 3 | 75 | 21 | 634 |
| 4 | 1024 | 271 | 1847 |

**Tab. 2:** Frequency of observed stages of endocranial and ectocranial sutures.

| | Shetty 2009 | | Frédéric – opened | | Frédéric – unopened | |
|---|---|---|---|---|---|---|
| | ecto- | endo- | ecto- | endo- | ecto- | endo- |
| **all** | 0.753 | 0.797 | 0.609 | 0.684 | 0.479 | 0.572 |
| | *0.000* | *0.000* | *0.000* | *0.000* | *0.000* | *0.000* |
| **male** | 0.805 | 0.829 | 0.586 | 0.725 | 0.606 | 0.661 |
| | *0.000* | *0.000* | *0.000* | *0.000* | *0.000* | *0.000* |
| **female** | 0.643 | 0.744 | 0.699 | 0.610 | 0.330 | 0.483 |
| | *0.000* | *0.000* | *0.000* | *0.001* | *0.014* | *0.000* |

**Tab. 3:** Correlation coefficient (Pearson, above) and its two-sided significance (below, in italics) between the mean stage of suture closure and observed age for the three series in total and for males and females separately.

| | Shetty 2009 | Frédéric opened | Frédéric unopened |
|---|---|---|---|
| **all** | 0.797 | 0.704 | 0.559 |
| | *0.000* | *0.000* | *0.000* |
| **male** | 0.703 | 0.720 | 0.670 |
| | *0.000* | *0.000* | *0.000* |
| **female** | 0.842 | 0.693 | 0.446 |
| | *0.000* | *0.000* | *0.001* |

**Tab. 4:** Correlation coefficient (Pearson, above) and its two-sided significance (below, in italics) between the age estimated by dCA and observed age for the three series in total and for males and females separately.

| | Shetty 2009 | | | | Frédéric – opened | | | | Frédéric – unopened | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | obs. | A-N c | A-N r | dCA | obs. | A-N c | A-N r | dCA | obs. | A-N c | A-N r | dCA |
| **adult** | 63 | 45.7 | 44 | 45 | 51 | 45.0 | 46 | 46 | 87 | 58.3 | 56 | 71 |
| **mature** | 21 | 33.1 | 35 | 38 | 31 | 30.8 | 20 | 40 | 54 | 52.9 | 28 | 87 |
| **senile** | 16 | 21.2 | 21 | 17 | 27 | 33.2 | 43 | 23 | 41 | 68.8 | 96 | 24 |
| **Σ** | 100 | | | | 109 | | | | 182 | | | |
| **$\chi^2$** | | 6.2 | 7.6 | 7.9 | | 1.1 | 6.4 | 1.7 | | 12.7 | 37.0 | 13.8 |
| **sign.** | | 0.045 | 0.023 | 0.019 | | 0.566 | 0.041 | 0.423 | | 0.002 | 0.000 | 0.001 |

**Tab. 5:** Comparison of the results of age estimation into 20-years-classes for the three series. obs.: observed frequency after known age; A–N c: standard age estimations after Acsádi and Nemeskéri (1970), 121 tab. 32, with application of the rules in table 1; A–N r: age estimations with regression [1] after Acsádi and Nemeskéri (1970); dCA: estimations by detrended Correspondence Analysis. The $\chi 2$ gives the distance and its significance between the observed and estimated frequencies.

| | Shetty 2009 | | | Frédéric – opened | | | Frédéric – unopened | | |
|---|---|---|---|---|---|---|---|---|---|
| | obs. | A-N r | dCA | obs. | A-N r | dCA | obs. | A-N r | dCA |
| **<30** | 38 | 35 | 31 | 31 | 35 | 32 | 44 | 46 | 47 |
| **30–40** | 25 | 9 | 14 | 20 | 11 | 14 | 43 | 10 | 24 |
| **40–50** | 10 | 11 | 17 | 17 | 5 | 12 | 28 | 8 | 46 |
| **50–60** | 11 | 24 | 21 | 14 | 15 | 28 | 26 | 21 | 41 |
| **>60** | 16 | 21 | 17 | 27 | 43 | 23 | 41 | 97 | 24 |
| **Σ** | 100 | | | 109 | | | 182 | | |
| **corr.** | | 0.775 | 0.797 | | 0.677 | 0.704 | | 0.566 | 0.559 |
| ***sign.*** | | *0.000* | *0.000* | | *0.000* | *0.000* | | *0.000* | *0.000* |
| **δ ± σ** | | +3.3 | +3.7 | | +0.4 | –0.7 | | +4.0 | –0.8 |
| | | ±11.7 | ±10.7 | | ±15.7 | ±14.0 | | ±17.8 | ±15.3 |
| **$\chi^2$** | | 13.2 | 8.8 | | 13.1 | 6.9 | | 55.0 | 17.7 |
| ***sign.*** | | *0.010* | *0.067* | | *0.011* | *0.140* | | *0.000* | *0.001* |
| **$e_{20}$** | 19.6 | 24.2 | 23.3 | 24.3 | 27.8 | 25.2 | 24.3 | 32.5 | 23.7 |

**Tab. 6:** Relation between the observed calendaric age and estimated age by detrended CA. obs.: observed frequencies in the reference series; A–N r: estimations after regression [1] following Acsádi and Nemeskéri (1970); dCA: estimations by detrended Correspondence Analysis; corr.: correlation coefficient after Pearson and its significance (in italics) between observed and estimated ages; δ shows the mean difference between estimated and observed ages, and its standard deviation; $\chi 2$ gives the distance and its significance (in italics) between the observed and estimated frequencies in the 10-years-spans; $e_{20}$ = further life expectancy at age of 20, calculated from a life table, where ">60" is taken as lasting 15 years.

| | Shetty 2009 | | | Frédéric – opened | | | Frédéric – unopened | | |
|---|---|---|---|---|---|---|---|---|---|
| | n | A-N r | dCA | n | A-N r | dCA | n | A-N r | dCA |
| **males** | 72 | +4.6 | +4.9 | 81 | +2.0 | +1.0 | 127 | +7.1 | +2.0 |
| | | ±11.0 | ±9.5 | | ±14.4 | ±12.9 | | ±15.2 | ±12.6 |
| **females** | 28 | +0.1 | +0.7 | 28 | -4.2 | -5.8 | 55 | -2.8 | -7.5 |
| | | ±12.9 | ±13.0 | | ±18.3 | ±15.9 | | ±21.2 | ±18.7 |
| **males 20–65** | 66 | +5.8 | +5.9 | 65 | +5.2 | +4.1 | 107 | +9.5 | +4.1 |
| | | ±10.4 | ±9.0 | | ±12.1 | ±9.8 | | ±15.3 | ±11.5 |
| **females 20–65** | 25 | +2.0 | +3.0 | 18 | +3.6 | +1.6 | 41 | +4.5 | +0.6 |
| | | ±12.0 | ±11.6 | | ±16.3 | ±11.7 | | ±17.4 | ±12.6 |

**Tab. 7:** Comparison of the results of age estimations for males and females separately, both by regression [1] after Acsádi and Nemeskéri (1970) as by dCA. The cells show mean and standard deviation of individually estimated ages *minus* observed calendaric age. The three rows at the bottom show the series restricted to individuals of observed age of 20 to 65 years.

| | Poschiavo all | | males | | females | |
|---|---|---|---|---|---|---|
| | A–N r | dCA | A–N r | dCA | A–N r | dCA |
| <30 | 243 | 226 | 94 | 85 | 139 | 131 |
| 30–40 | 59 | 78 | 24 | 32 | 32 | 43 |
| 40–50 | 40 | 84 | 20 | 48 | 20 | 30 |
| 50–60 | 111 | 143 | 68 | 92 | 35 | 42 |
| >60 | 141 | 63 | 97 | 46 | 35 | 15 |
| Σ | 594 | 594 | 303 | 303 | 261 | 261 |
| $e_{20}$ | | | 27.5 | 24.8 | 17.5 | 16.2 |

**Tab. 8:** Age estimations for the ossuary of Poschiavo. A–N r: estimations after regression [1] following Acsádi and Nemeskéri (1970), tab. 29; dCA: estimations by detrended Correspondence Analysis.

# APPENDIX

**Formula to calculate age from the stage of closure of the sutures after results of dCA.**

[1]
Eigenvalue 1 = [ sum (ecS10 × 1.1891, ecS11 × 3.011, ecS12 × 3.6109, ecS13 × 6.5384, ecS14 × 4.765, ecS20 × 0.94013, ecS21 × 2.68, ecS22 × 3.6568, ecS23 × 5.9885, ecS24 × 5.4831, ecS30 × 0.23289, ecS31 × 2.0635, ecS32 × 3.999, ecS33 × 5.1378, ecS34 × 4.5376, ecS40 × 0.6346, ecS41 × 2.3008, ecS42 × 3.812, ecS43 × 5.2837, ecS44 × 5.6016, ecC10 × 1.1536, ecC11 × 2.7057, ecC12 × 4.1047, ecC13 × 4.7967, ecC14 × 7.224, ecC20 × 0.99078, ecC21 × 2.7864, ecC22 × 4.0002, ecC23 × 4.0924, ecC24 × 7.224, ecC30 × 1.0647, ecC31 × 2.3844, ecC32 × 3.6449, ecC33 × 5.0441, ecC34 × 7.224, ecL10 × 1.0452, ecL11 × 2.9873, ecL12 × 3.8944, ecL13 × 5.7591, ecL14 × 6.7809, ecL20 × 0.89978, ecL21 × 2.7766, ecL22 × 4.1181, ecL23 × 5.4385, ecL24 × 6.7809, ecL30 × 0.41129, ecL31 × 2.2471, ecL32 × 3.8302, ecL33 × 4.2405, ecL34 × 6.7618, enS10 × -0.35956, enS11 × 1.4062, enS12 × 2.0687, enS13 × 3.5665, enS14 × 4.9882, enS20 × -0.54732, enS21 × 1.3462, enS22 × 2.3667, enS23 × 3.5117, enS24 × 5.2933, enS30 × -1.2836, enS31 × 1.1197, enS32 × 1.9356, enS33 × 3.3551, enS34 × 3.9959, enS40 × -0.82743, enS41 × 0.98682, enS42 × 1.8828, enS43 × 3.3202, enS44 × 4.5731, enC10 × -0.7322, enC11 × 1.3649, enC12 × 2.2995, enC13 × 3.4352, enC14 × 4.7098, enC20 × -1.0744, enC21 × 1.2274, enC22 × 2.3958, enC23 × 3.1072, enC24 × 4.1311, enC30 × -0.87163, enC31 × 1.2292, enC32 × 2.1692, enC33 × 3.0389, enC34 × 5.2192, enL10 × -0.93218, enL11 × 1.1944, enL12 × 2.4746, enL13 × 3.4205, enL14 × 5.3142, enL20 × -0.93218, enL21 × 1.0778, enL22 × 2.3622, enL23 × 3.4297, enL24 × 5.389, enL30 × -1.0016, enL31 × 0.55697, enL32 × 2.2161, enL33 × 3.2162, enL34 × 5.0743 ) ] / number of non-zero-observations.

[2]
estimated age by dCA = (eigenvalue 1 × 9.540) + 20

| from mean stages | to span Acsádi & Nemeskéri | to 20-years-span |
|---|---|---|
| 0.0 - 0.4 | < 25: juvenile - young adult | 1:1 to adult |
| 0.4 - 1.6 | 14-40: juvenile - young adult | 1:1 to adult |
| 1.6 - 2.6 | 30-60: young - middle adult | 1/3 to adult, 2/3 to mature |
| 2.6 - 3.0 | 35-65: young - middle adult | 1:1 to mature |
| 3.0 - 4.0 | 45-75: middle - old adult | 1 /2 to mature, 1 /2 to senile |
| 4.0 | 50-80: middle - old adult | 1/3 to mature, 2/3 to senile |

**Table 1:** Schedule for the system of transferring the observed mean of endocranial stages to the spans as proposed by Acsádi & Nemeskéri 1970, and rules for transferring the resulting frequencies for a population to the standard age-classes.

| right | ectocranial closure (age ≤49) | left |
|---|---|---|
| L3: 0,597** | | L3: 0.600** |
| L2: 0.596** | | L2: 0.589** |
| L1: 0.602** | | L1: 0.602** |
| | S4: 0.667** | |
| | S3: 0.656** | |
| | S2: 0.624** | |
| | S1: 0.615** | |
| C1: 0.582* | | C1: 0.598** |
| C2: 0.603** | | C2: 0.607** |
| C3: 0.584** | | C3: 0.638** |

| right | endocranial closure (age ≤49) | left |
|---|---|---|
| L3: 0.737** | | L3: 0.737** |
| L2: 0.751** | | L2: 0.749** |
| L1: 0.736** | | L1: 0.718** |
| | S4: 0.676** | |
| | S3: 0.683** | |
| | S2: 0.632** | |
| | S1: 0.643** | |
| C1: 0.720** | | C1: 0.688** |
| C2: 0.729** | | C2: 0.722** |
| C3: 0.713** | | C3: 0.685** |

**Table 2:** Series Shetty 2009, subsample individuals up to 50 years (n=73): Spearman's rank correlation between stage of closure and observed age. Significant correlations are marked after the scheme: * sign. < 0.05; ** sign. < 0.01. To be compared with Perizonius 1984.

| right | ectocranial closure (age ≥50) | left |
|---|---|---|
| L3: 0.425* | | L3: 0.425* |
| L2: 0.547** | | L2: 0.547** |
| L1: 0.478* | | L1: 0.451* |
| | S4: 0.261 | |
| | S3: 0.490* | |
| | S2: 0.475* | |
| | S1: 0.381* | |
| C1: 0.179 | | C1: 0.244 |
| C2: 0.182 | | C2: 0.139 |
| C3: 0.037 | | C3: 0.079 |

| right | endocranial closure (age ≥50) | left |
|---|---|---|
| L3: 0634** | | L3:0.634** |
| L2: 0.634** | | L2: 0.634** |
| L1: 0.634** | | L1: 0.634** |
| | S4: 0.434* | |
| | S3: 0.588** | |
| | S2: 0.500** | |
| | S1: 0.562** | |
| C1: 0.465* | | C1: 0.555** |
| C2: 0.546** | | C2: 0.635** |
| C3: 0.555** | | C3: 0.555** |

**Table 3:** Series Shetty 2009, subsample individuals 50 years and older (n=27): Spearman's rank correlation between stage of closure and observed age. Significant correlations are marked after the scheme: * sign. < 0.05; ** sign. < 0.01. To be compared with Perizonius 1984.