TECHNICAL NOTE

Denis R. Barrès,[1] *M.D., Ph.D.; Michel Durigon,*[1] *M.D.; and François Paraire,*[1] *M.D.*

Age Estimation from Quantitation of Features of "Chest Plate" X-Rays

REFERENCE: Barrès, D. R., Durigon, M., and Paraire, F., **"Age Estimation from Quantitation of Features of 'Chest Plate' X-Rays,"** *Journal of Forensic Sciences,* JFSCA, Vol. 34, No. 1, Jan. 1989, pp. 228-233.

ABSTRACT: This study presents a method for estimating the age at death from the quantitation of roetgenologic features of X-ray films of chest plates obtained during routine autopsies. Multiple linear regression analysis allows estimation of coefficients of regression of features on known age-at-death individuals. The regression equation can be used in turn for age estimation of an unknown age-at-death individual. The accuracy of age estimation is about ±8.4 years (standard error) which is in the range of previously published macroscopic methods, though the present method is much faster and simpler.

KEYWORDS: pathology and biology, physical anthropology, human identification, X-ray analysis, age determination, chest plate

A number of methods for the determination of the age at death have been investigated. Some of them, like the pattern of tooth eruption, the closure of epiphyseal plates, or the appearance of centers of ossification, though very precise, are only useful for infants or children [*1*]. Gross morphology of cranial suture closure, pubic symphysis, and other periarticular changes have proven to be of low sensitivity for age estimation of adult cadavers [*1,2*].

Of the past methods, one of the most accurate and still up to date is the assessment of dental age according to Gustavson's criteria [*3,4*]. More recently, quantitative bone microscopy demonstrated better accuracy over classical macroscopic examination [*5-9*]. The ratio of amino acids racemization determination in bone or teeth seems to have good potential [*10*]. Unfortunately, these last three techniques require laboratory facilities and technical processing.

Thus, recent investigations tend to turn up easy-to-work methods for age determination of bone, İşcan et al. [*11,12*] used a macroscopic evaluation of the sternal extremity of the rib. McCormick [*13*] studied the mineralization of the costal cartilages on an X-ray of a "chest plate" (that is, consisting of the sternum, costal cartilages, rib ends, and attached soft tis-

Received for publication 19 Jan. 1988; revised manuscript received 7 March 1988; accepted for publication 1 April 1988.

[1]Associate professor, professor and head of department, and, assistant, respectively, Department of Pathology and Forensic Pathology, Hospital R. Poincaré, Garches, France. (All authors are also forensic pathologists.)

sue) available during routine autopsy. Both authors demonstrated a quite good relationship between morphological changes and the age at death.

The aim of this study was to evaluate the later two features along with some others on a sample of chest plate X-ray films of cadavers of known age.

Material and Methods

The chest plates from 55 subjects were removed during either forensic or scientific autopsies performed in the Department of Pathology and Forensic Pathology. Each chest plate was X-rayed in postero-anterior orientation at 50 kV and 200 mA for 1 s with Kodak X-Omat MA film.

Three observers independently scored the X-ray films without knowledge of the age or sex. The following features were evaluated from 1 (very light) to 5 (heavy):

- bone demineralization (BD),
- fusion of the pieces of the manubrium (FM),
- rib-to-cartilage attachment changes (RC),
- cartilage mineralization (CM), and
- cartilage-to-sternum attachment changes (CS).

Each observer achieved two successive assessments at two different periods three months apart. The first evaluation was made without any experience. The second evaluation was achieved with the help of a photographic template (Fig. 1) reproducing the grading of typical features on which the three observers agreed. The three-month time lapses prevented recognition of most of the individual chest plates and memory of the first evaluation.

Results

The sample consisted of 51 subjects of known age (4 unidentified corpses) ranging from 18 to 74 years. Of these, 41 were white males aged 18 to 74 years and 10 were white females aged 31 to 74 years.

Predicting Value of Features for Age Estimation

Two-Dimensional Analysis—For males, the coefficients of correlation between the age at death and a given feature vary from judge to judge, but are consistently ranked in the same order for the three stronger coefficients, namely: cartilage-to-sternum attachment, rib-to-cartilage attachment, and sternal fusion (see Table 1). The correlations between the age and bone demineralization and cartilage mineralization are the weakest whoever the judge. As it was expected, the order of ranking is quite different for females and a little confusing because of the between-judges discrepancies. However, unlike for the males, bone demineralization and cartilage mineralization seem to be the two best predictors. Also, note that the sample of females is 14 years older (45 versus 31) than the sample of males and much smaller (10 versus 41).

Multivariate Analysis—For multidimensional analysis, stepwise multiple regression (SML) was used both stepdown and stepup. SML was tested on each judge's results as well as on the mean set consisting in the score of each feature averaged over the three judges.

Apart from differences between the values of coefficients and deviations, the four analyses yielded to comparable ranking of features within sexes. The accuracy of the regression computed on the mean set is almost as good as that obtained on the results of the best judge. The stepup and the stepdown procedures yielded to the same ranking of features, namely: CS which accounted for 58% of total variance; FM, RC, and CM each accounting for 2% of total variance; and BD accounting for 1% of total variance.

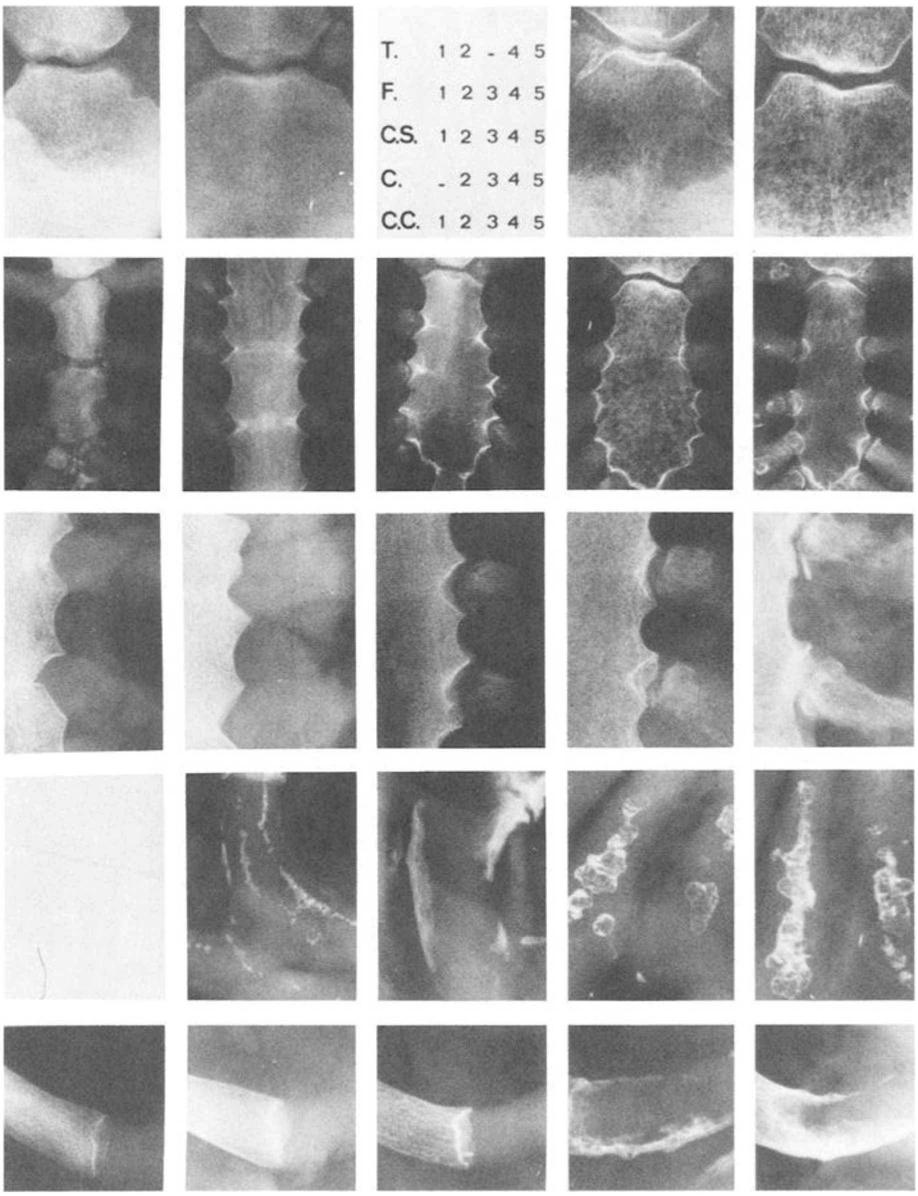

FIG. 1—*Photographic template used for feature assessment of chest plate X-ray films. First stage of cartilage mineralization is not shown for it corresponds to the absence of mineralization. Stage 3 of bone demineralization lies inbetween bone density of Stage 2 and Stage 4.* T: *bone demineralization,* F: *sternal fusion,* C.S.: *cartilage-to-sternum attachment,* C: *cartilage mineralization, and* C.C.: *cartilage-to-rib attachment.*

TABLE 1—*Correlation between age at death and features as evaluated by each judge on chest plates of known age.*

Features	BD	FM	RC	CM	CS
		JUDGE 1			
Age of males	0.40	0.45	0.58	0.34	0.55
Age of females	0.94	0.13	0.37	0.57	−0.27
		JUDGE 2			
Age of males	0.45	0.62	0.76	0.61	0.71
Age of females	0.83	0.23	−0.04	0.32	0.02
		JUDGE 3			
Age of males	0.27	0.54	0.67	0.41	0.64
Age of females	0.46	0.04	0.59	0.60	0.58

The correlation between the estimated age at death of males computed from the regression equation on the three best variables and the actual age is shown in Fig. 2. The scattering of points around the first bissectrix gives an idea of the regression accuracy.

Reproducibility of Feature Scoring and Efficacy of Use of Photographic Template

The between-judges agreement is assessed by the linear correlation coefficient computed for each feature and for each possible couple of judges on the whole set of observations (Table 2). The strongest correlation is found for cartilage mineralization followed, in descending order, by cartilage-to-sternum attachment, sternal fusion, rib-to-cartilage attachment, and bone demineralization. The efficacy of the use of photographic template is demonstrated by the increase of the values of correlation when using the template. The increase is almost constant except for bone demineralization and rib-to-cartilage attachment between Judge 1 and Judge 3.

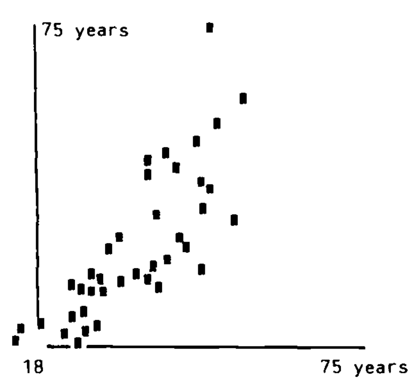

FIG. 2—*Scatterplot of computed age from the equation of multiple regression analysis at third step (ordinate) against actual age at death (abcissa).*

TABLE 2—*Between-judges coefficients of correlation of evaluated features on the 55 chest plates, without photographic template (italic numbers).*

Couple of Judges	BD	FM	RC	CM	CS
J1, J2	0.49	0.73	0.69	0.82	0.82
	0.61	*0.69*	*0.67*	*0.80*	*0.75*
J1, J3	0.57	0.73	0.59	0.94	0.84
	0.63	*0.64*	*0.66*	*0.90*	*0.67*
J2, J3	0.46	0.76	0.73	0.86	0.83
	0.68	*0.68*	*0.67*	*0.83*	*0.78*

Discussion

Roentgenologists and rhumatologists are well aware of morphologic changes of the anterior chest wall during the life span. Fully and Dehouve [*14*] first reported these changes as a qualitative forensic science tool. McCormick [*13*] quantified the mineralization of costal cartilage of 210 corpses on chest plate X-rays and found a significant positive correlation between cartilage mineralization and age at death. As one could see on the graph he published, estimation of the age from mineralization scoring could not be very accurate. For example, a score of 1.5 belonged to males aged from about 25 to 85 years and to females aged from about 30 to 85 years. Scoring the sternal extremity of the rib, İşcan et al. [*11*] found a good correlation between the score and the age at death of male subjects allowing a 95% confidence interval of about ±15 years as extrapolated from their results. In females [*12*], they found a different evolution of the rib-to-cartilage attachment. However, their method was time-consuming, necessitating soft tissue dissection, soaking in water for several weeks, and boiling of specimens for 10 to 15 min.

Our study showed a positive correlation between cartilage mineralization and age both for males and females which is in agreement with McCormick's findings [*13*]. We also found good correlations between all the features we scored and the age of males, especially between the scoring of rib-to-cartilage attachment and the age, which, in turn, is in agreement with İşcan et al. [*11*]. For females, most of the features were also positively correlated with the age at death. Moreover, all the scored features showed a good between-judges reproducibility as demonstrated by the between-judges coefficients of correlation which are all strongly positive. The use of a photographic template made the scoring easier and lead to a small increase in reproducibility.

The multiple linear regression showed quite surprising results for cartilage mineralization and bone demineralization, both features exhibiting a negative coefficient of regression after other variables were taken into account. This means that for an unchanged value of the first three features (namely cartilage-to-sternum attachment, sternal fusion, and rib-to-cartilage attachment), the expected change in age is negative when cartilage mineralization or when bone demineralization increase. As our sample is not large, this could well be due to a particular behavior of this very sample.

Finally, using the coefficients of the three best variables of the multiple linear regression, the predictive value of the model could be estimated from the square root of mean square deviation at Step 3 as ±8.43 years, thus giving a 95% confidence interval of ±17 years. This interval is of the same order of magnitude than that of İşcan et al. [*11*], though our method is much simpler and faster and does not requisite special processing of the specimens. From the results of multiple linear regression, the following method of age computation of an unknown individual could be proposed: multiply each scored feature by 15 so as to get 5 different estimations of the age, then weigh each feature and add them as shown thus:

$$CS \times 0.89 + FM \times 0.03 + RC \times 0.03 + CM \times 0.03 + BD \times 0.02$$

for example, for BD = 2, FM = 3, CS = 2, CM = 4, and RC = 2, it is:

$$30 \times 0.89 + 45 \times 0.03 + 30 \times 0.03 + 60 \times 0.03 + 30 \times 0.02 = 31.35 \text{ years.}$$

References

[1] Stewart, T. D., "Estimation of Age," in *Essentials of Forensic Anthropology*, Charles C Thomas, Springfield, IL, 1979.

[2] Barrès, D. R., Paraire, F., Guillon, F., and Durigon, M., "Détermination de l'âge par l'examen des sutures crâniennes. Approche Bayesienne et Euclidienne," *Journal de Médecine Légale Droit Médical*, Vol. 30, 1987, pp. 327-331.

[3] Gustafson, G., "Age Determination on Teeth," *Journal of American Dentist Association*," Vol. 41, 1950, pp. 45-54.

[4] Solheim, T. and Sundnes, P. K., "Dental Age Estimation of Norwegian Adults—A Comparison of Different Methods," *Forensic Science International*, Vol. 16, 1980, pp. 7-17.

[5] Durigon, M., "Identification à partir des os. Bilan des méthodes actuelles," *Bulletin et Mémoire de la Société d'Anthropologie de Paris*, Vol. 10, 1983, pp. 385-392.

[6] Thompson, D. D., "The Core Technique in the Determination of Age at Death in Skeletons," *Journal of Forensic Sciences*, Vol. 24, No. 4, Oct. 1979, pp. 902-915.

[7] Thompson, D. D. and Galvin, C. A., "Estimation of Age at Death by Tibial Osteon Remodeling in an Autopsy Series," *Forensic Science International*, Vol. 22, 1983, pp. 203-211.

[8] Stout, S. D., "The Use of Bone Histomorphometry in Skeletal Identification: the Case of Francisco Pizarro," *Journal of Forensic Sciences*, Vol. 31, No. 1, Jan. 1986, pp. 296-300.

[9] Hauser, R., Barrès, D., Durigon, M., and Dérobert, L., "Identification par l'histomorphométrie du fémur et du tibia," in *Catastrophe et mort collective*, Collection de Médecine Légale No. 117, Masson, Lyon, 1980.

[10] Helferman, P. M. and Bada, J. L., "Aspartic Acid Racemization in Tooth Enamel from Living Humans," *Proceedings of the National Academy of Sciences USA*," Vol. 72, 1975, pp. 2891-2894.

[11] İşcan, Y. M., Loth, S. R., and Wright, R. K., "Age Estimation from the Rib by Phase Analysis: White Males," *Journal of Forensic Sciences*, Vol. 29, No. 4, Oct. 1984, pp. 1094-1104.

[12] İşcan, Y. M., Loth, S. R., and Wright, R. K., "Age Estimation from the Rib by Phase Analysis: White Females," *Journal of Forensic Sciences*, Vol. 30, No. 3, July 1985, pp. 853-863.

[13] McCormick, W. F., "Mineralization of the Costal Cartilages as an Indicator of Age: Preliminary Observations," *Journal of Forensic Sciences*, Vol. 25, No. 4, Oct. 1980, pp. 736-741.

[14] Fully, G. and Dehouve, A., "Renseignements apportés dans la détermination de l'âge par l'étude anatomique et radiologique du sternum et des côtes," *Annales de Médecine Légale*, Vol. 45, 1965, pp. 469-474.

Address requests for reprints or additional information to
D. R. Barrès, M.D.
Department of Pathology and Forensic Pathology
Hospital R. Poincaré
92380 Garches, France