see also
http://www.arts.uwaterloo.ca/~mkjackes/testing%20a%20method.pdf

CHAPTER 15

BUILDING THE BASES FOR PALEODEMOGRAPHIC ANALYSIS: ADULT AGE DETERMINATION

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INTRODUCTION

In the 1970s, most North American osteologists accepted without question that methods of adult age assessment provided reasonably accurate estimates of the ages at death of human skeletons. We not only discussed rates of age-dependent pathology and trauma believing that our conclusions had some meaning, we undertook demographic analyses in the belief that we could make realistic statements about the structure of past societies. When Bocquet-Appel and Masset published their ideas in English in 1982, questioning methods of adult age assessment, they provided a lifeline to people who were struggling with data that did not make sense (Jackes, 1988). But there was a very strong reaction that received much attention (e.g., Van Gerven and Armelagos, 1983), so that Wood and colleagues could write in 1992 that the rebuttals had lain to rest the concerns raised by Bocquet-Appel and Masset.

Since 1982, there has been a shift in approach to adult assessment for the reconstruction of archaeological populations. Many ideas rejected in the early 1980s (Jackes, n.d.), are now widely accepted and can be restated word for word (Jackes, 1992). Where researchers commonly dismissed adult age assessment as requiring little comment beyond the fact that "standard" methods were used, it is now standard to specify methods and acknowledge that there may be limitations to data (e.g., Storey, 1985; Storey and Hirth, 1997).

A general introduction to skeletal biology can now state: "At present, the lack of a wholly satisfactory technique for estimating age at death in adult skeletons from archaeological sites is one of the most thorny problems facing human osteoarchaeology" (Mays, 1998:50). Crubézy and Murail (1998:72) write: "The determination of the age at death of adults is at present the major problem within the whole field of anthropology" [*my translation*]. No longer do we hold to the simple acceptance that adult age assessment requires only an application of techniques summarized in standard laboratory books—Krogman (1962), Bass (1995), Brothwell (1981), Ubelaker (1989), Anderson (1969), the work of Acsádi and Nemeskéri (1970, and as summarized by members of the Workshop of European Anthropologists or WEA, 1980)—with choice of technique determined by mother tongue and geographical location rather than research considerations. The trend illustrated by, for example, Masset (1989) and Rose and Ungar (1998) of writing historical introductions to discussions on specific methods of age assessment, is a clear indication that adult age assessment is

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an evolving and interesting field of study, not simply the routine application of standard methods.

Maples (1989) considered adult age assessment to be more an art than a science, and skeletal biologists may well practice that art with skill. But the description of an archaeological sample of skeletons is but one step in interpretation. The next step requires comparisons with other samples from other places and other time periods, analyzed by other researchers. We need to know how data are collected and what they are based on. It is clear that: (1) similar samples analyzed using different methods provide different results; and (2) different samples analyzed using the same methods provide similar results (e.g., Jackes, 1985, 1992).

We may assume that in the past skeletal biologists relied on their experience and their intuition: they applied their "art." But comparison requires systematization and standardization, and further effort at systematization has begun to lead to deeper questioning of the likelihood that we can achieve accurate adult age estimates for large samples of archaeological skeletons.

Meindl and Russell (1998:388) consider that "unknown age distributions could be approximated quite well by . . . multifactorial methods as long as actual adult life expectancy is low, that is, e_{15} is less than about 30 years," by which they mean that a 15 year old can expect to die at 45. Although many aspects of this approach have been criticized (as summarized in their review), the work of Meindl and colleagues has been a motivating force. Their insistence on examining indepth the age assessment methods accepted at the time of the analysis of the Libben site, their detailed publications, and their questioning of age estimation by "handbook-styled . . . comparison-matching a specimen to a series of discrete archetypes . . . (illustrating) mean age stages" (Meindl et al., 1990:356), have all contributed to the change in attitudes to adult age assessment.

The low adult life expectancy specified by Meindl and Russell (1998:388) seems to imply, as did Van Gerven and Armelagos (1983), that nearly everyone died by 50 and so it does not matter that we are unable to age older adults. But were there really no "old folks" (Weiss, 1973; Jackes and Lubell, 1985). Does it matter that we cannot age them? If we cannot rely on our ability to give accurate ages to all adults in a sample, then we must employ techniques that are not standard in demographic studies in order to examine basic demographic parameters such as fertility rates (Jackes, 1994). But, and this is more significant, we cannot get a clear idea of clear idea of incidences of caries and osteoarthritis, and cannot adequately study rates of cortical thinning.

There can be little doubt that people lived into old age—even in times of conflict, disease and famine—despite the fact that standard palaeodemographic methods would give no indication of this (Jackes, in press). Figure 15.1 (data from Russell, 1948) shows that, during the worst of the medieval period when the plague struck England again and again, the average age at death of males over 15 was around 47 years. In better times, males would live to an average age of 54. For married males of the aristocracy born before 1700 (and the seventeenth century condition of life was poor as a result of conflict and epidemics in England), the average age at death was 55 years (n = 1644): 60% of these men lived beyond age 50 (Westendorp and Kirkwood, 1998). Russell (1985:60–61) shows that, with variations with time and place over the first 1500 years A.D. across Europe and North Africa, quite a number of those who reached age 20 could expect to survive beyond 60. Ten percent survival beyond age 60 would be a conservative estimate, since reliable estimates of over a quarter, even a third, exist. As long ago as 1978, Sjøvold wrote of the "remarkable number of deaths between 70 and 80 years of age" that were recorded in an Austrian village in the 250 years prior to 1852. We have long known that it was possible for people to live to a great age prior to the twentieth century.

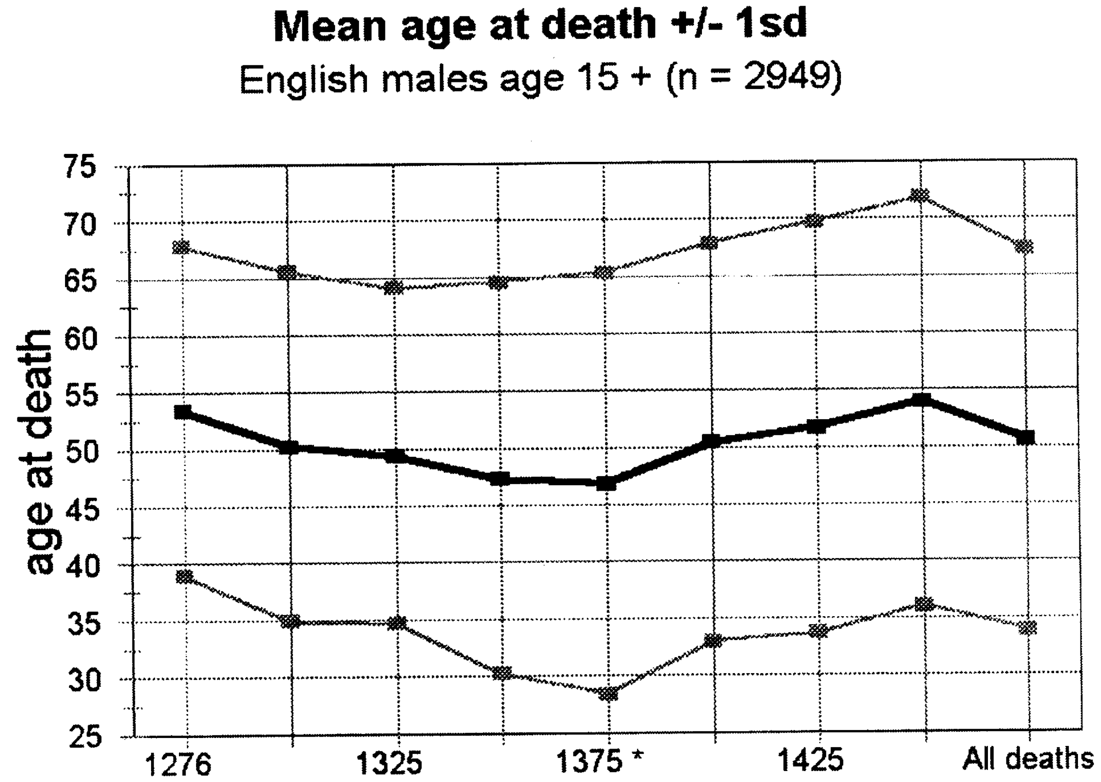

Figure 15.1 The mean age at death (± 1 SD) for English medieval males who survived to age 15. The x axis records those born before 1276, 1276 to 1300, 1301 to 1325, 1323 to 1348, 1348 to 1375* (the period of the Black Death and its aftermath), 1376 to 1400, 1401 to 1425, and 1426 to 1450, and, finally, all deaths. (Data from Russell, 1948.)

Current research emphasizes both the genetic and nongenetic aspects of longevity (Vaupel et al., 1998). There must be a selection against frailty early in life, but not against "late-acting deleterious genes" (Promislow, 1998), so we cannot assume that those who survive early adverse circumstances must necessarily live into old age. On the other hand, there is no reason to maintain that archaeological mortality is by definition different from more recent mortality. In fact, Montagu (1994) maintains that those born before 100 B.C. had life spans equal to any but those recorded in the last 50 years.

The focus of our questions about adult age is slowly changing. We are beginning to accept that adults did live longer than osteologists have previously recognized and to accept that our methods of age assessment must be flawed. Many years after Howell (1982) first pointed out the inherent improbability of the Libben village composition, Harpending (1997:92) wrote the following: "We must dismiss these [archaeological age distributions] as artifacts of the formation of the collection or of the aging procedures, else follow Lovejoy and colleagues and posit that human biology in the Precolumbian New World was different in kind from the biology of the rest of our species."

Skeletal biologists are now willing to question the accuracy of their age estimates for adult akeletons. It is not hard to understand why the trek to this point has been so drawn-out and hard-fought: questioning and drawing attention to the subjective, the intuitive basis of our age assessments seems to threaten the validity of much of our work in skeletal biology over many years.

Molleson (1995) has wondered whether those who die as young adults have "old bones," and those who die as old adults have "young bones," calling into question the uniformity of age changes even within one population. We can only hope that our skeletal samples are large enough, and the causes of mortality diverse enough, to provide us with a general picture that is acceptably close to reality in the study of paleodemography. The implications of this question for skeletal biology in general are beyond the scope of this chapter, but paleodemographers must be very wary of drawing generalizations from small, limited, possibly biased samples precisely because of possible variability

Variability within a population in the expression of age changes is a pressing concern if some methods of age assessment are more suitable for "older" individuals or for skeletal samples that are "older" (e.g. Molleson, 1995). Figure 15.2 (data from Galera et al., 1998) demonstrates that inaccuracy would be reduced if two methods of cranial suture assessment could be used, one for younger, and another for older, adults. Meindl and Russell (1998:389) proposed that young and middle-aged adults be given ages "in a general way, such as the subjective estimation of clinical age," while different methods be applied to "those skeletons determined to be older than 40 years . . . [by] dental attrition and especially from the auricular surface." Aiello and Molleson (1993) suggest that the best compromise is to use the Todd/Brooks or the McKern/Stewart/Gilbert pubic symphysis methods for those under 45 years of age, and the Acsádi/Nemeskéri technique for those over 45.

Meindl and Russell (1998) do not discuss the basic problem: while we may be able to identify someone in their early twenties, we do not know if a skeleton is from a fairly young, middle-aged or old adult. If we rely on

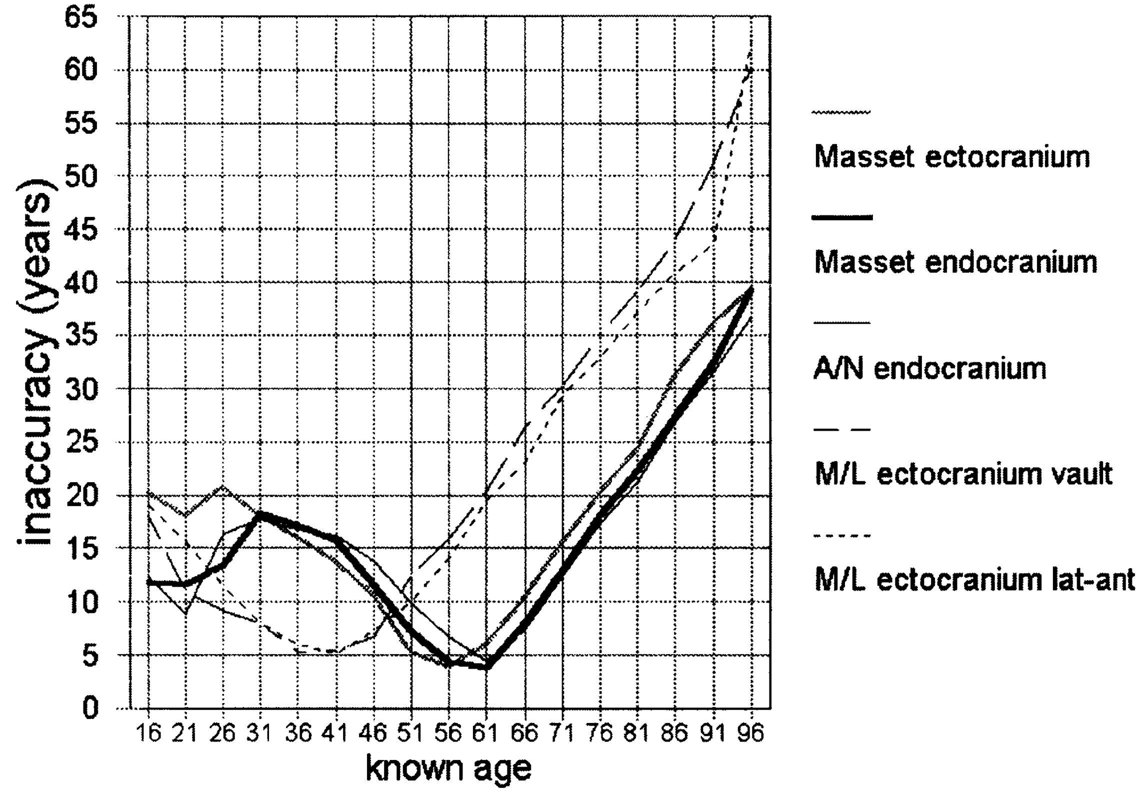

Figure 15.2 Differences among methods of analysis for cranial suture closure in individuals from the known age Terry Collection. Deviation of assessed age from real age is expressed as inaccuracy in years. The lines describe differences among the methods of three sets of researchers, based on internal or external suture closure: Masset, Acsádi and Nemeskéri (A/N), and Meindl and Lovejoy (M/L), who use both external vault closure with external closure in the lateral anterior portion of the cranium. The Masset and A/N methods give nearly identical results, the M/L results are different, but internally consistent. (Data from Galera et al., 1988.)

age-dependent skeletal changes to place people into age categories, and then analyse those skeletal changes to show the differences in the population as it aged, we are going in circles. Aiello and Molleson (1993) have suggested that initial sorting be done using bone histology, but there are acknowledged difficulties inherent in this method which will be discussed below.

Degenerative joint changes have been used as an adjunct to age assessment (e.g., by Kvaal et al., 1994), but this may well be invalid. Milner and Smith (1990) state that "The ages assigned to adult skeletons were generally consistent with subjective assessments based on the extent of dental attrition and arthritic lipping of the vertebrae, especially in the lumbar region, and of major joints." These authors are to be congratulated for stating openly that subjective assessments do enter into adult age estimation techniques. But we need to recognize that there are limitations: Molleson and Cox (1993:178) have shown that the correlation coefficient for real age and lumbar vertebral osteophytosis is .34 in females and .39 in males (see Jackes, 1977, for one explanation of this low correlation).

A skeptical attitude is now the norm, and the change in attitude has been quite revolutionary. In 1985, Buikstra and Konigsberg stated that adult age could be determined and proposed the value 30+/5+ years (used by Coale and Demeny, 1966) as a substitute for the paleodemographic estimator suggested by Bocquet-Appel and Masset (1977). Later amended by Konigsberg and colleagues (1989), the original statement of Buikstra and Konigsberg has remained in the literature as a frequently cited rebuttal of criticisms of paleodemography (e.g., Lanphear, 1989; Wood et al., 1992). It is clear that Konigsberg no longer supports his earlier ideas. Konigsberg and Frankenberg (1994:95), say that determining the sex of an adult "is not particularly problematic," but that "determination of age-at-death is an entirely different matter." In their wide-ranging summary of statistical approaches to paleodemography, these authors argue for the use of further statistical techniques to overcome the intransigent problems of paledemography

The question of adult age has relevance far beyond the problem of paleodemography. If age at death cannot be determined, then we can make no completely valid statements about any human characteristics that are subject to age-dependent changes (see, e.g., Caselitz, 1998, for a discussion of caries rates based on assumptions about archaeological life spans). That would certainly reduce the field of enquiry of skeletal biology to a very narrow focus. Nevertheless, it is legitimate to emphasize the importance of accurate adult age estimation to paleodemography. Paleodemography has three basic problems: (1) the accurate distribution of skeletons over the adult years, (2) the recognition of sample bias, and (3) the identification of population increase or decrease. Once these basics are dealt with, paleodemography can claim a place in skeletal biology. Therefore, we must enquire whether mathematical solutions will allow us to gain some reasonable approximation of the underlying adult age distribution of an archaeological sample, and to support Konigsberg and Frankenberg (1992) in saying that the time has come to stop fussing about the accuracy of age assessment techniques.

STATISTICAL APPROACHES

The idea that statistical techniques will solve a basic problem of paleodemography must be examined in some detail. Rather than discuss the techniques in a separate section, however, their value is tested here while examining methods of age assessment. Earlier concerns—mean age at death or life expectancy at birth, survivorship, prediction by linear regression analysis, probability distribution over 95% confidence limits (CL) of the mean age per age indicator stage—have been examined in Jackes (1992).

Konigsberg and co-authors (1997) discuss prediction of age by regression, but suggest that no method using regression is efficient.

Calibration of age by regression, with emphasis on multifactorial indicators, has been discussed by Lucy and colleagues (1995, 1996) and Aykroyd and colleagues (1999). These authors come to the conclusion that Bayesian approaches are worthy of more investigation. Here most emphasis will be given to Bayesian and iterative proportional fitting techniques for estimating age at death distributions (Bocquet-Appel and Masset, 1996; Konigsberg and Frankenberg, 1992), and to demonstrating how they function when applied to several methods of age assessment and known age samples.

The methods are illustrated for situations where reference population stage age data are available or can be reconstructed, so that the matrices can be used to calculate the prior probabilities. In other words, where the data used in the development of a method of age assessment have been published in detail, we can use those data to form a matrix. The matrix allows us to know how many individuals there are in each age category within the reference population who exhibit a particular stage of an age indicator. The basic idea is simple. For iterative proportional fitting, the cell frequency is divided by the total for that age category in order to give the probability that an individual with an indicator at a particular stage will fall into that age category (this probability is known as the "prior probability"). These probabilities are then used and multiplied by the stage distribution of the target sample in order to arrive at an estimate of the age distribution (the "target" always refers to the sample for which an age distribution is sought, while "reference" indicates the sample of known age individuals from which the prior probabilities are derived). Next, the operation is repeated (iterated). Experimentally, one example has been iterated 1165 times using femoral trabecular data from Bocquet-Appel and Bacro (1997) and stability is not reached. Thus, the program used here (written by N.G. Prasad), requires the setting of a tolerance level (e.g., 0.01 or 0.001) that limits the iterations at the point at which there is no change above the tolerance limit between one iteration and the next.

What is called Bayesian here could be iterated in the same way (but only the first iteration has been provided here). The prior probabilities are based on the cell frequency divided by the total for that stage (see the Appendix for an example). The probabilities provided by Masset (1989) for cranial sutures are no doubt of this type. The "proportional method" proposed by Boldsen (1988) should not be confused with the method referred to above as proportional fitting. Boldsen's method is a technique of smoothing adult age distributions: each individual is fractionally distributed across the entire assigned age range. It results in an age distribution similar to that given by the 95% confidence limits.

Another suggestion, hazard analysis (see for example Wood et al., 1992), is mentioned briefly. The hazard rate is, in fact, the *m* column (age-specific mortality) of a life table, and as such is highly correlated with the *q* column (probability of death within a certain age category). The *m,q* correlation coefficient rounds to .999 for the known age Christ Church, Spitalfields, London adults aged by three and four skeletal elements (Molleson and Cox, 1993), and for the assessed age distribution $r = .985$. Probability of death (*q*) has been used fairly consistently in paleodemography for the last decade and more (Jackes, 1992).

The hazard rate may be useful because it can be expressed plus and minus its standard error (SE, easily calculated using the Survival program in SPSS). As an example, we can use the people excavated from the church crypt in Spitalfields, London (Molleson and Cox, 1993) and reconstruct the real and assessed ages for 166 individuals who were aged by three or four skeletal elements. Figure 15.3 shows the Spitalfields known age adult distribution. The ±SE hazard rate range for the real ages, calculated under the assumption that the population is stationary, is shown by the heavy lines. This range is so broad for the last 55 years of the distribution that it encompasses the *m* rates of up to $r = \pm.15$. The *r* here refers to the rate of natural increase, and the dashed lines show the range encompassed by the calculations based on the assumption of either population increase or decrease of 1.5%. What is clear is that the assessed age-at-death distribution, shown in solid thin lines, being inaccurate, cannot be adjusted by using hazard rates, or ranges derived from estimates of rates of natural increase. With the Spitalfields sample, the method of adult age assessment determines the distribution of assessed ages at death, and adjustments do not alter the basic form of the curve, which lies within the known age error range only at age 40 and between ages 55 and 60. Adjustments derived from estimates of rates of population increase or decrease do not overcome the basic inaccuracy of the estimated age distribution.

We can test the efficacy of age indicators only through analyses of known age samples. Nevertheless, even if we were able to make a decision on the basis of work on known age samples, we still do not have an understanding of whether a method works better with one population rather than another. Bocquet-Appel (1986) and Masset (1976) have stated that a method will work best for a population with an age distribution similar to that of the original population, the "reference" sample around which the method was originally formulated. Thus, Molleson emphasizes (e.g., 1995) that the Spitalfields mean adult age at death is perhaps accurately estimated using the Acsádi and Nemeskéri complex method because the "reference" and "target" populations (the original sample used by Ascádi and Nemeskéri in developing their method and the Spitalfields sample to be given estimated ages) have the

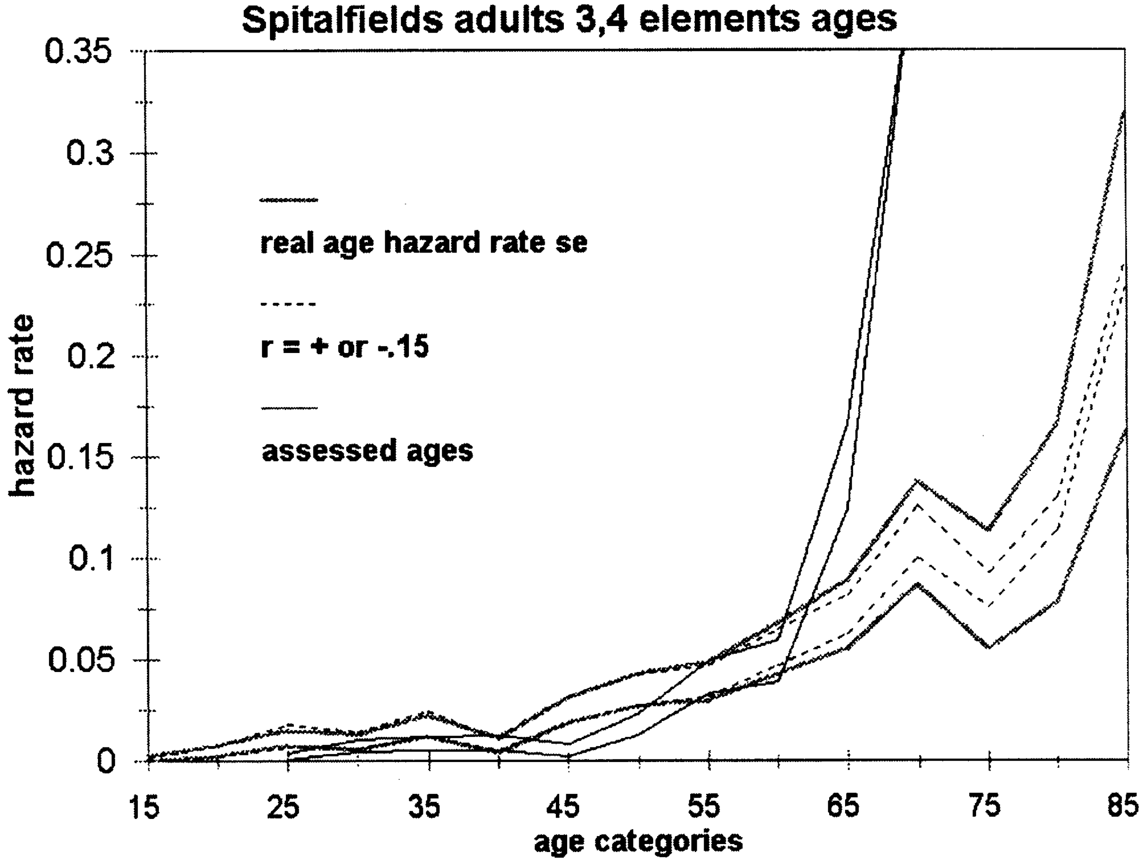

Figure 15.3 The hazard rate plus and minus its standard error for the best preserved Spitalfields known age adults. The stationary ±SE hazard rate range encompasses the hazard rates for natural increase of the population from +0.15 to -0.15. The assessed age distribution is also plotted here and is quite different from the true age distribution.

same general distribution of adult ages. The apparent accuracy of the method is not inherent in the method, but is predicated on the lucky chance of sample similarities in this case. Such a basic problem cannot be overcome by sophisticated statistical manipulation. It can only be dealt with by a better understanding of the course of human senescence over space and over time.

TAPHONOMY

Meindl and Russell (1998) argue that the taphonomic problems affecting age assessment of archaeological populations have been overstated. But it is, in fact, of paramount importance to be able to age samples for comparison in the same way, by the same methods. If preservation bias controls methods, the comparisons essential to an understanding of human population structure will not be valid.

Considerations of taphonomy and sample bias are fairly new in skeletal biology, as distinct from paleontology. Masset (1973) urged their importance many years ago; Toussaint (1991) and Tiley-Baxter (1997) have considered body part representation and Waldron (1987) and Walker and colleagues (1988) have discussed general implications of this. Detailed work on the taphonomy of Portuguese archaeological dentitions showed how age-dependent biasing of a sample gives rise to misleading information on age-dependent characteristics (Jackes and Lubell, 1996). In the past, paleodemographic comparison was based on life expectancy calculated from life tables, actually mean age at death. Mean age at death cannot be used as the basis for comparisons unless unbiased and comparable samples are analyzed by comparable techniques (Jackes, 1984, 1992). Hoppa and Saunders (1998) in testing these ideas, stress the importance of the representativeness of samples.

Taphonomy should be a major consideration for those researchers who maintain that the use of more than one age indicator leads to greater accuracy in age assessment. Meindl and Lovejoy's multifactorial method (1985; summary age computed by principal components analysis of the estimated ages), and Acsádi and Nemeskéri's complex method (1970) both require the conjoint use of several skeletal elements. Storey and Hirth (1997) use the multifactorial method for the site of El Cajón, but state that "relatively few individuals were aged by more than one indicator." Attrition and suture closure and alteration to the auricular surface of the hip bone were the osteological techniques employed, but 46% of the adults could not be assessed for age. The representativeness of this 46% is an important consideration.

Sciulli and colleagues (1996) provide details of their method of age assessment and the diversity of means they had to employ to assign an age to each of 209 individuals from the Pearson cemetery. This is an excellent example of how osteologists simply cannot provide standardized age estimates on more than a small percentage of adults. It is legitimate to enquire how the age estimates are affected by this problem that all osteologists have had to face.

There has been no exploration of how differential preservation of elements may alter age estimates. Bedford and colleagues (1993) tested the accuracy of the multifactorial method on a sample of 55 individuals from the Grant Collection. It appears that not all individuals had all four elements tested, and 13% lacked the auricular surface of the ilium. While these authors indicate that the summary age was more accurate than the individual indicators from ages 30 to 60, this cannot be fully evaluated without knowing the exact real age distribution of the indicators.

Two studies allow us to investigate the importance of evaluating the effect of taphonomy on age assessments. The data of Kemkes-Grottenthaler (1993) provide a very clear picture of the differences in representation of skeletal elements used for age assessment. Figure 15.4 demonstrates that there can be great differences even with two sites of the same general age, location, and type. Eltville, with a sample of 500 of which 317 are adult, is located in the ideal depositional environment for skeletal preservation (loess). Langenlonsheim contained 457 individuals, only 188 assessed as adult, and clearly offers a less satisfactory array of skeletal elements for adult age assessment. The information contained in Figure 15.4 would suggest that it is essential to consider cranial suture closure the major technique for adult age assessment, though it will not age more than about 70% of the sample. Such an approach would make comparison with some sites an impossibility, those with secondary or ossuary burial for example, which commonly retain no more than a small fraction of analyzable skulls.

At Christ Church, Spitalfields, only 76 of 219 (35%) individuals over age 17, of known age and sex, retained skull vaults, pubes, proximal femora, and proximal humeri (Molleson and Cox, 1993). The situation is actually worse since new analyses undertaken for this chapter have shown that very few individuals had cranial vaults sufficiently well preserved to allow a distribution among the Acsádi and Nemeskéri suture stages 1 to 5 (see Table 15.1).

There are no significant differences between the total sample known age and the age distribution for each individual skeletal element (all analyses done separately for males and females). There is, however a clear indication that the distribution by elements does not adequately represent the total known age sample.

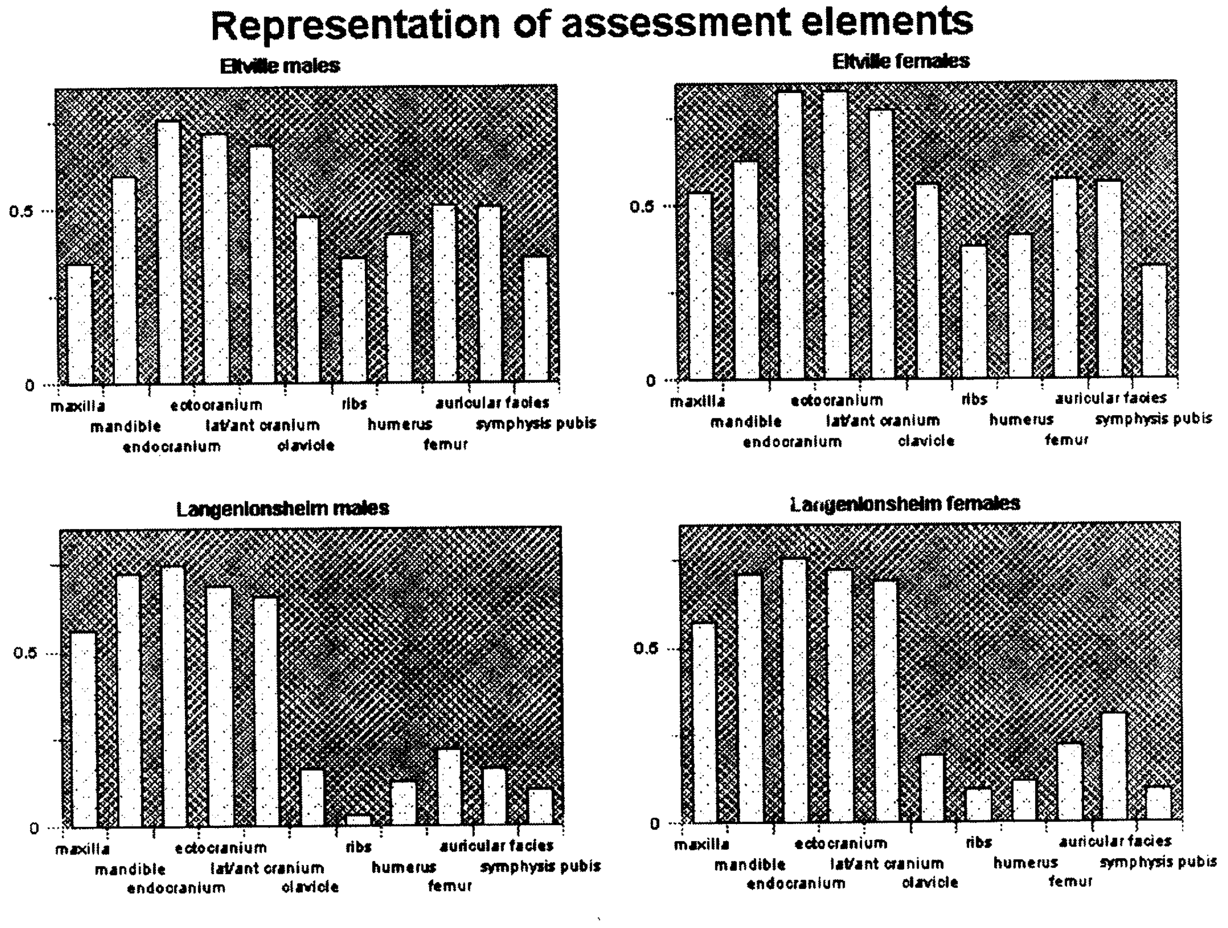

Figure 15.4 Differences in representation of skeletal elements used for age assessment between two German medieval sites. Y axes record ratio of numbers of elements present to total numbers of individuals. (Data from Kemkes-Grottenthaler, 1993.)

TABLE 15.1 Spitalfields Known Age Sample: Representation of Skeletal Elements for the Complex Method of Age Assessment

Known	Measurable Humeral Head %		Measurable Femur Head %		16 Endocranial Suture Points %		16 and Fewer than 16 Suture Points %		Pubic Symphyses %		Known Age n	Known Age n
Age	F	M	F	M	F	M	F	M	F	M	F	M
20	0.0	66.7	100.0	66.7	0.0	0.0	0.0	0.0	100.0	33.3	1	3
25	54.5	75.0	72.7	75.0	27.3	50.0	27.3	50.0	18.2	50.0	11	4
30	50.0	18.2	100.0	54.5	50.0	0.0	50.0	0.0	100.0	36.4	2	11
35	55.6	20.0	88.9	70.0	33.3	20.0	44.4	20.0	55.6	60.0	9	10
40	16.7	75.0	50.0	75.0	16.7	0.0	16.7	0.0	33.3	75.0	6	4
45	54.5	40.0	72.7	60.0	9.1	0.0	18.2	20.0	63.6	40.0	11	10
50	78.6	73.3	71.4	80.0	21.4	20.0	28.6	33.3	42.9	46.7	14	15
55	52.9	70.0	82.4	90.0	41.2	10.0	47.1	20.0	47.1	50.0	17	10
60	63.6	57.1	81.8	76.2	45.5	19.0	45.5	23.8	63.6	66.7	11	21
65	53.8	50.0	76.9	72.2	15.4	5.6	15.4	11.1	61.5	61.1	13	18
70	43.8	50.0	56.3	61.1	12.5	11.1	12.5	16.7	50.0	50.0	16	18
75	41.2	22.2	58.8	77.8	23.5	22.2	29.4	33.3	23.5	44.4	17	9
80	75.0	25.0	62.5	75.0	25.0	0.0	25.0	0.0	50.0	50.0	8	4
85	100.0	0.0	85.7	50.0	28.6	0.0	42.9	0.0	85.7	0.0	7	2
Total	55.9	48.2	72.0	71.2	25.2	12.2	29.4	18.7	49.0	51.8	143	139

The difference between the total male and female age distribution is significant.[1] But there is no difference between males and females on any specific skeletal element except, marginally, for the presence of a measurable humeral head (99% CI = 0.0455, 0.1065). In other words, there is a definite age at death difference between Spitalfields known age males and females, but this difference will not be evident from the surviving skeletal elements, perhaps caused by method of analysis, but more likely resulting from the very poor representation of crania and pubes. Of the total 836 adults excavated at Christ Church, Spitalfields, of both known and unknown age, only 70% retained at least one of the four elements used for age assessment, and only 425 (51%) could be given estimated ages based in whole or in part on pubes and/or skulls. In summary, taphonomical considerations are of great importance both in the calculation of the prevalence of any skeletal characteristic, and in paleodemography.

POPULATION DIFFERENCES

Fundamental to all comparative work in skeletal biology is the question of whether age changes are uniform across populations. Possible heterogeneity within samples has been mentioned, and there is an increasing recognition that aging differences between the sexes must be discussed. But our knowledge of population differences for skeletal age changes is still rudimentary.

While it is agreed that there are significant differences among population groups (Katz and Suchey, 1989), no analyses have been published that would allow confirmation of this. Such analyses have been urged (Jackes, 1992; Loth and İşcan, 1989), but existing reference samples are presently unavailable for this purpose. Katz and Suchey (1989) have stated that while they have been able to show aging differences among Americans of European, Mexican, and African origin, they believe that the "racial" ambiguity and mixture in their sample from southern California would frustrate efforts to reach a clear-cut result. Galera and colleagues (1998) argue for a population difference in rates of cranial suture closure, but this difference cannot be fully evaluated since they do not specify the difference between Black and White Americans. With the exception of the Black male/female age distributions, differences in age distributions among the samples are all highly significant. We would predict that Black males and White females are most different, based on the rounded value of 79, the highest in Table 15.2. This prediction is supported by the degree and direction of bias on all methods reported by Galera and co-workers.

Comparison of the work of Kemkes-Grottenthaler (1996b) and Galera and colleagues (1998) suggests that population differences in skeletal aging could be very important. The two known age samples examined by these researchers produce the same pattern of bias using the two Meindl/Lovejoy suture methods, but the deviation of assessed age from real age is greater for the Terry Collection sample than for the 109 skulls from Mainz. The specific details of the 236 crania from the Hamann-Todd Collection upon which the Meindl/Lovejoy method was originally based (Meindl and Lovejoy, 1985) have not been published, but the two American samples must be different in sex and age distribution, or in race, in order to generate differences in deviations of assessed age from real age in tests. The Hamann-Todd cranial sample probably consisted of about 54% individuals of European and about 45% individuals of African descent (see Lovejoy et al., 1985:table 1), while the Terry Collection sample used by Galera et al. (1998) comprises 42% individuals of European and 58% individuals of African descent. The two samples are thus different enough to suggest that population differences can lead to differing results in cranial suture closure.

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[1] The 99% confidence interval (CI) of the Monte Carlo estimate of P is 0.0077, 0.0443. This analysis was done using StatXact-3, which provides an estimate of the probability by testing 500 tables, thus allowing a greater confidence that there is no error when describing a difference as significant.

A test of auricular surfaces (Murray and Murray, 1991) led to the conclusion that the method "is not equally valid for black and white individuals." This is not surprising since the age distribution for black males and white males is inverted. However, Murray and Murray re-tested using only those 69 individuals with a true age of 40 to 60, and found no difference in the performance of the auricular surface method by "race" in this age group. Thus, at present we simply do not know whether this method is equally valid across these two population groups. Loth and İşcan (1989) have noted very significant differences between Americans of European descent and Americans of African descent in age-dependent changes to the ends of ribs. More recently, Hoppa (2000) has discussed the possibility that inaccuracy in adult age assessment using pubic symphyses is related to population differences between the reference sample and the target sample.

If there is difficulty in fitting a sample to the type descriptions or illustrations of stages within a particular age indicator scheme, the difficulty will be reflected by assignment of one individual to multiple stages. Does the difficulty arise because the stages are not well defined and accurate, or are the age stages, as defined, inapplicable to the particular sample under study? Is this because of basic differences in the biology of the indicator and not just because of differences in age structure? This type of question must be answered before we can begin to have any confidence in "age" indicators as age indicators, rather than as relative stages in the senescence of the adult human skeleton, controlled by several factors. Genetics is certainly not the single controlling factor (Jackes, 1992), especially since secular change within a population is a possibility that has received a minimum of attention.

Masset (1989:98–99) discerned the possibility of diachronic changes in suture closure. Boldsen and Paine (1995) do no mention this when using ectocranial medial sagittal suture closure to hypothesize an increase in the length of life in Europeans over the last 9,000 years.

This allows room for temporal change, or for any factor other than a direct relationship between age and suture closure. A test on known age individuals from Spitalfields shows the relationship of midsagittal ectocranial suture closure with known age to be quite weak ($r = .44$). While the suture closure categories used (partial closure and complete closure) cover the whole spread of adult ages from the twenties to the eighties, the mean ages given the stages for a medieval Danish sample are very much younger than those for the later Londoners (many of Huguenot origin). Either diachronic change or inaccurate age estimation of the Danish sample used by Boldsen and Paine (1995) may be at work here. We cannot evaluate the factors until there is a different approach to skeletal changes; these changes have in the past been considered only in their capacity as "age indicators" but they merit study from other perspectives.

TABLE 15.2 Terry Collection Samples Used in Analysis of Cranial Methods of Age Estimation

Rounded χ^2 values for age distribution comparisons		Blacks Males	Blacks Females	Whites Males	Whites Females
Blacks	Males	—	14	44	79
	Females		—	35	64
Whites	Males			—	34
	Females				—

Data from (Galera et al., 1998).

TESTS OF METHODS

Histology

Stout and co-workers (1996) have applied the method of predicting ages from the sum of intact and fragmentary osteons per unit area of the clavicular cortex to a sample of 83 nineteenth-century Swiss skeletons, apparently with cemetery records that report age at death. Estimated ages deviated from reported ages after age 40, so that the maximum estimated age was 54 years, while the maximum reported age was 75 years. The results indicate that the relationship of osteons per unit area with age is not linear. The authors note that there is "a loss of reliability in age prediction inherent in microscopic methods." At a certain point (which will differ for different bones and for the same bone from different individuals, depending on cross-sectional area, and factors affecting bone remodeling) the entire cortex will be remodeled, and the evidence of former remodeling will be removed by further remodeling. Thus, at some stage in the aging process, unknown for each population, indeed for each individual, histological age assessment cannot be applied (see also Robling and Stout, Chapter 7, for a discussion of these issues.

Although it was hoped that histological age assessment would provide accurate data for paleodemography (e.g. Buikstra and Konigsberg, 1985), histological aging has not lived up to its early promise. For example, Molleson and Cox (1993) report that a variety of histological techniques provided age estimates on the sample of known age individuals from eighteenth- and nineteenth-century coffin burials in the Spitalfields Christ Church crypt that were no better than macroscopic age estimates. Aiello and Molleson (1993) note that Kerley's histological techniques are no more accurate than the Acsádi/Nemeskéri pubic symphysis estimations, the latter also having the advantage of not requiring unaltered periosteal cortical bone.

Dudar and colleagues (1993) show that the regressions of morphological and histological age-at-death estimates derived from ribs of known age at death do not differ significantly and suggest that a linked morphological and histological analysis will best estimate adult age at death. Pfeiffer (1998), in an important paper focusing on basic methodology in histomorphometry, has proposed that ribs should be used in histological examination because they may be less subject to interindividual and interpopulation variation in terms of osteon size.

The requirement of microscopically intact bone is a major problem for archaeological age assessment. Plate 1 illustrates examples of microbial decomposition, showing how the microstructure of cortical bone and tooth roots comes to be disrupted by the activities of bacteria that dissolve bone, extract collagen, and then redeposit the mineral fraction in a form that is denser and in which the crystals are altered. The bone cortex may appear to be very well preserved to the naked eye, but the bone in the outer portion of the cortex (specified in histological techniques) is very likely to be unusable (Aiello and Molleson, 1993; Jackes, 1992). Sampling location has a significant effect on cortical remodeling assessments (Pfeiffer et al., 1995).

Auricular Surface

Two tests allow us to examine this technique of age assessment first proposed by Lovejoy and colleagues (1985). Murray and Murray (1991) tested the auricular surface method of adult age estimation on a sample of 189 individuals aged over 20 from the Terry Collection (St. Louis, Missouri), a large cadaver collection of indigents from the first half of the twentieth century. Their subsample of the collection included both males and females, and Americans of both European and African descent. We do not know the actual age range of the sample, but those over 60 had average ages for males of 70 (Europeans) and 77 (Africans), and for females of 73 (Europeans) and 80 (Africans). Thus, the two identified population groups were also different in age. Sixty-seven percent of the sample was actually aged over 50 years, but the method placed only 21% over age 50. By contrast, although 28% of the sample actually fell between ages 30 and 50, the method gave 75% of the sample an age of 30 to 50. The difference between the real age distribution and the estimated age distribution (as derived from their figure 1) over the eight adult age categories is significant beyond expression.

Santos (1995, 1996, per. comm.) has tested the method on a known age population of individuals born between 1824 and 1916, housed at the University of Coimbra, and has provided information that allows comparison of her results with those of Murray and Murray (1991). The sample sizes are comparable (189 for Terry and 215 for Coimbra), as is the percentage of females (52 and 51%). The major difference is that 48% of the Terry sample is not of European extraction. The two samples tested are not different in terms of actual ages

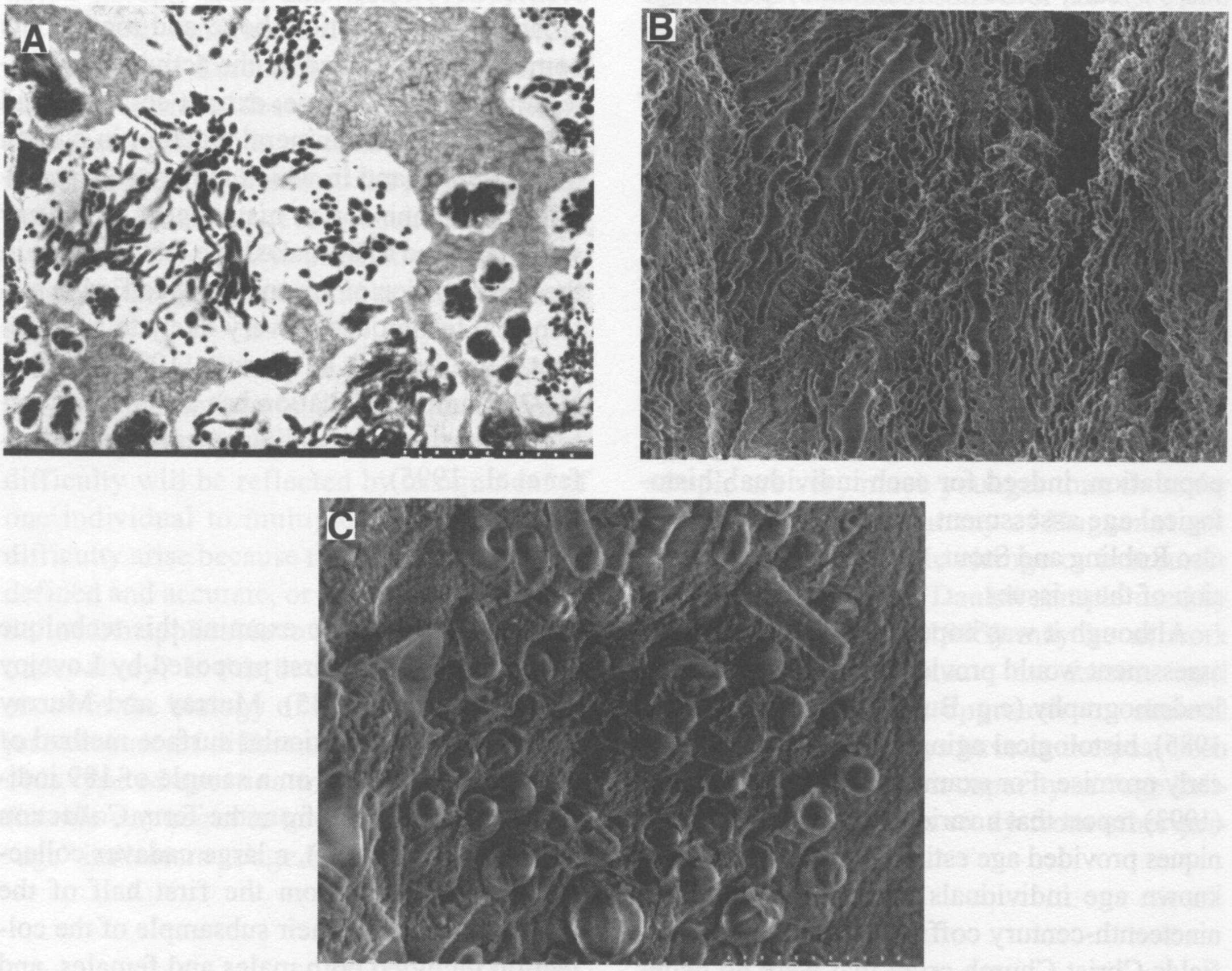


Plate 1 (A) Polished embedded thin section of left femoral mid shaft cortex (unnumbered sample given project designation 10DR). Normal bone matrix is compared with the redeposited and altered bone around the bacterial colonies from which the organic fraction has been removed. CM Barker SEM (Hitachi S-2700) 9/9/92 at 15kV, original magnification 2,000. (B) Broken surface of unpolished, unembedded section of Gruta da Caldeirão O14/34 right anterior femoral cortex, just below mid shaft. Bacterial tunnelling has been transected across and lengthways. R. Sherburne Field Emission SEM (Hitachi S-4100) 17/7/93:72 at 2.5 kV, original magnification 2,500. (C) Broken thin section of left anterior mid femoral cortex, just below the mid shaft, from Cabeço da Arruda 35. Bacteria emerging from the break just at the margin of, not within, an Haversian canal. R. Sherburne Field Emission SEM (Hitachi S-4100) 17/7/93:81 at 2.5 kV, original magnification 11,000.

TABLE 15.3 Tests Showing that When Auricular Facies Estimates Are Tested They Demonstrate Method Control of Estimates, Not Sample Control of Estimates

χ^2 (7 *df*)	Collections	χ^2 Value	99% CI, 500 Tables, Monte Carlo Estimate of *P*
Real ages vs. stage "ages"	Terry	95.90	0.0000, 0.0092
Real ages vs. real ages	Terry vs. Coimbra	11.53	0.0948, 0.1732
Real ages vs. stage "ages"	Coimbra	80.53	0.0000, 0.0092
Stage "ages" vs. stage "ages"	Terry vs. Coimbra	0.02248	0.9908, 1.0000

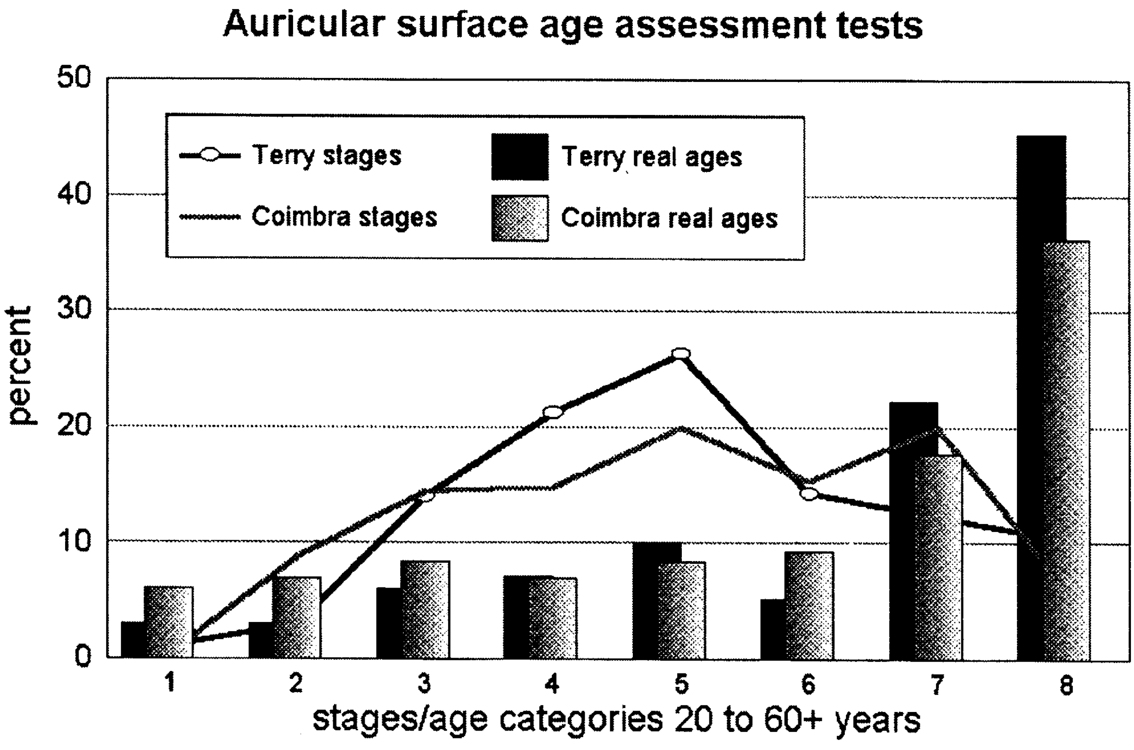
(Table 15.3). When real ages of the collections are compared, the estimate of the probability (*P*) would be around 0.1 in 99% of 500 tests. Nor are the two samples different in terms of the distribution of auricular surface stages. In fact, since the estimate of the probability that there is any difference between the two would be 1.0 in 500 tests, we can say that the samples are identical with regard to stages.

On the other hand, the stage "age" distribution and the real age distribution in each case bear no relationship to each other. In the case of each of the two samples, the difference between the real age distribution and the estimated age distribution is so large that in over 500 tests the probability of the difference occurring by chance is more or less zero. For this reason, we can say that the method governs the "age" distribution, the estimated ages. The estimated ages are not characteristic of the target sample, they are in some way reflecting the built-in biases of the method, probably determined by the characteristics of the reference population. This is illustrated in Figure 15.5a. As shown in Figure 15.5b, it is likely that the method should be evaluated with the sexes separated.

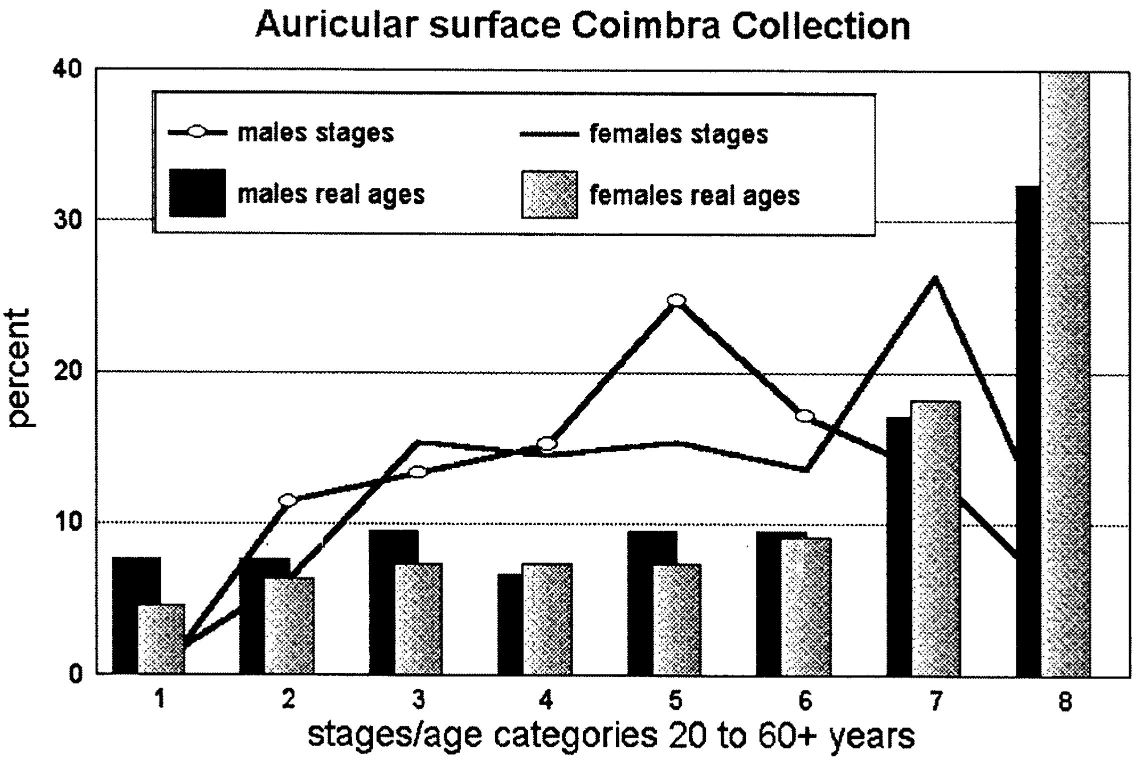
Bradford and co-workers (1993) tested the method on a sample of 54 males and one female from the Grant Collection of unclaimed dead from the Toronto area dating to the middle of the twentieth century. The results were reported in terms of 10-year age intervals, so that it is not possible to show how each of the auricular age stages performs. Males from the twenties to the fifties were over-aged by 5 to 10 years on average, while those over 60 were under-aged. An eight- to nine-year inaccuracy in age assessment of those from 30 to 60 years was demonstrated, similar to the results of Murray and Murray (1991), but the degree and direction of bias may have been different. Unfortunately, we do not know the age distribution of the sample tested. As such, this test of the method is not definitive as was found to be the case with a similar study by Saunders and colleagues (1992).

Ribs

Adult age assessment by means of the sternal ends of ribs has been proposed by İşcan (summarized in Loth and İşcan, 1989), based on the fourth rib. Molleson and Cox (1993) have noted that the second rib is the most robust and easily identified rib; even so, only 29% of the second ribs survived in the Spitalfields known age sample. The coding of the Spitalfields ribs was based on the work of İşcan and colleagues (1984), prior to the systematization proposed by Loth and İşcan in 1989, when it was recommended that males and females be scored separately. The work on the Spitalfields ribs is a clear demonstration of the value of this recommendation, since the correlation of total score with known age for males is .772, but for females is only .354. Dudar and co-workers (1993) also found a reasonably high correlation between rib end morphology and known age. Mann (1993) and Dudar et al. (1993) have



(A)



(B)

Figure 15.5 (A) Comparison of the Terry and Coimbra known age skeletal collections. (B) comparison of real age and facies auricularis stage "ages" for males and females in the Coimbra skeletal sample.

discussed the problems of identifying and using ribs in skeletal analyses.

Kemkes-Grottenthaler (1996a) has stated that ribs did not provide a good method of age assessment based on her two early medieval German samples. Analysis done for this chapter certainly showed "rib age" to be far removed from all other variables, when represented by midpoint of stage age range. A dissimilarity matrix (Euclidean distance proximity analysis) shows that rib changes, represented by the midpoint of the assessed age range, bear no relationship to other age markers and this is confirmed by hierarchical cluster analysis (average linkage between groups) of the matrix. Kemkes-Grottenthaler (1996a) suggests that preservation may be a factor here, causing difficulty in differentiating stages. Fully 43% of the 121 individuals she aged using ribs fell between two or more of the described stages, so that population differences should also be considered as one of the contributing factors.

Pubic Symphyses

The pubic symphysis, the most intensively studied of the age indicators and the one long believed to provide the most accurate age estimates, has actually received less than complete support in the literature. In 1955, Brooks noted: "regrettably [the results were] not very encouraging." Forty years later, Santos said: "the results of this study were not very encouraging" (1995).

The first systematization was that of Todd, who published his data on males (1920). Because the data were published, we are able to see that Todd's method was perhaps given too much clarity when it was published as a simple 10-point system in the first 1962 edition of Krogman's *The Human Skeleton in Forensic Medicine* (see Jackes, 1985, for a discussion). The method was re-evaluated by Brooks (1955), but it is not possible to reconstruct Brooks' data in its entirety. It would seem desirable to base tests on the Suchey/Brooks system, which has been well published (most recently in Suchey and Katz, 1997) and can be reconstructed very easily from diagrams. The published diagrams differ slightly from the diagrams sent out with the casts and used for the construction of probabilities (Jackes, 1992). The new probabilities are therefore given in the Appendix.

The method of categorizing age changes in pubic symphyses developed by Meindl and Lovejoy derives from the Todd method, and the Acsádi/Nemeskéri method is also not completely independent in its origin (Acsádi and Nemeskéri, 1970). Because of this common origin, it is surprising that in Figure 15.6 the four methods of adult age assessment provide such different results (based on the work of Kemkes-Grottenthaler [1993], specifically the midpoints of the age ranges). Since the pubic symphysis has long been regarded as the standard skeletal element in adult age assessment (although pubes over age 35 have recently been characterized as "not particularly valuable for age estimation" by Meindl and Russell, 1998), it is important to emphasize that there is no certainty of adult age based on pubes.

While the Suchey/Brooks and Todd methods do provide some similarities in the ages individuals are given, skeletons that would be broadly distributed over a wide range of ages from 35–65 when the Suchey/Brooks method is used, would be grouped by the Todd method into the 40–50 age range. The Suchey/ Brooks method is actually quite similar to the Acsádi/Nemeskéri method. Both would put Todd phase VI individuals into stage 3 and group males and females from Todd's phases VII and VIII into stage 4. Because Suchey/ Brooks has six pubic symphyseal stages, the method would put individuals from Todd phase IX into stage 5 and the males would be distributed from stages 4 to 6, perhaps with most in stage 6. Todd's phase X individuals would go into stage 6. It seems to have been difficult to sort the younger adults in Kemkes-Grottenthaler's sample into Todd phases. Many individuals were put in I–II or I–III. Acsádi/Nemeskéri and Suchey/

Brooks, however, are more or less equivalent at stages 1, 2, and 3.

Meindl/Lovejoy, on the other hand, have the following equivalencies with the Todd phases: 2 = VI; 3 = VII; 4 = VIII; 5 = IX, X. The Meindl/Lovejoy method groups all the Todd phase I–V pubes into stage 1. This leads to a high correlation between the results of the

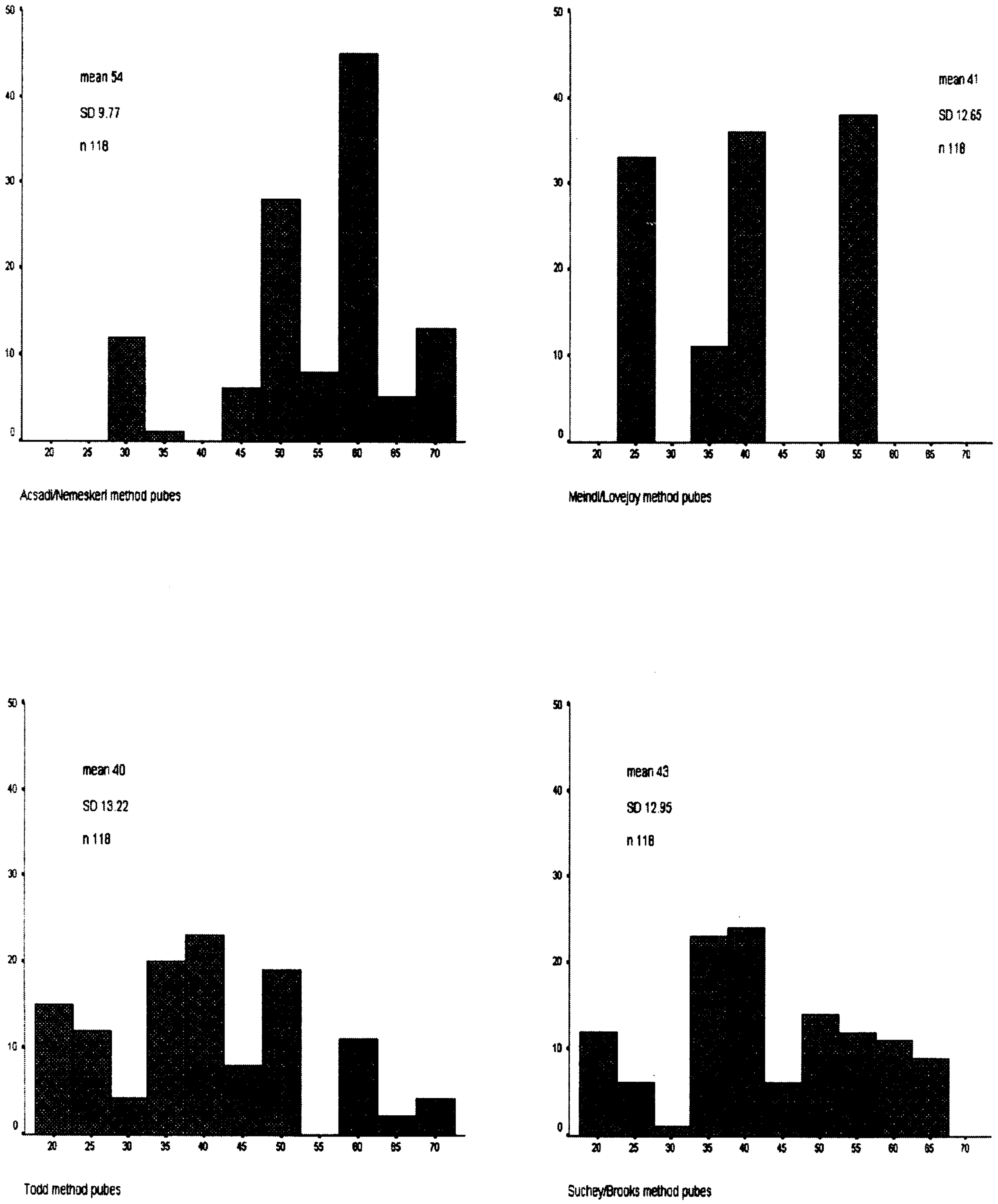


Figure 15.6 The distribution by midpoints of assessed age ranges illustrate, differences in four methods of adult age assessment based on the symphysis pubis. X axes represent assessed ages, y axes represent numbers of cases. (Data from Kemkes-Grottenthaler, 1993.)

TABLE 15.4 Distribution of Individuals over Pubic Symphysis Stages (Information Recalculated from Kemkes-Grottenthaler, 1993). The Double Ages Provided for the Suchey/Brooks Ranges Take Sex Differences into Account

Stage	Suchey/Brooks	Age	Acsádi/Nemeskéri	Age	Meindl/Lovejoy	Age
1	13	15–23/24	12.5	18–45	32.5	18–37
2	8	19–34/40	9	23–69	11	30–35
3	22	21–46/53	28.5	25–76	16.5	36–40
4	40	23/26–57/70	52.5	24–81	22	40–49
5	14	27/25–66/83	15.5	41–86	36	45–50
6	21	34/42–86/87	—	—	—	—

two methods. In Table 15.4, the frequency distributions have been simplified by assigning the individuals falling between two stages equally to the two stages, explaining why in the columns for the Acsádi/Nemeskéri and Meindl/Lovejoy methods fractional individuals are recorded. The Todd pubes frequencies were excluded since the number of individuals falling firmly within a stage was very limited (only 51/118 or 43.2% of pubes were classified as falling directly within a stage, all other pubes fell between two or more stages). Of the individuals in stage 1 in Table 15.4, 12 are placed there by both the Suchey/Brooks and Acsádi/Nemeskéri methods. These 12 individuals would be given an age of around 28 by the Acsádi/Nemeskéri method, but only about 20 by the Suchey Brooks method. Since it is generally possible to distinguish a 20 year old from a 28 year old, the problem is minor and could be resolved. However, the 14 individuals who fall into stage 4 by both methods, would certainly be given different ages based on the Suchey/Brooks (44 for males and 48 for females) and the Acsádi/ Nemeskéri (52.5 years) methods. The large number of individuals who fall into the Acsádi/Nemeskéri and Suchey/Brooks stage 4 are distributed over Meindl/Lovejoy stages 3 to 5, and would thus be given variously ages 38, 45, and 48. Since the data here are derived from Kemkes-Grottenthaler's research on early medieval populations, we have no way whatsoever of determining which age at death distribution is closest to reality. For that, we require tests on known age samples.

In Figures 15.7a and b the reconstructed Suchey/Brooks Los Angeles sample of individuals over 15 years of age (see Appendix) has been used to provide the prior probabilities. In other words, the Los Angeles sample provides the reference data from which we determine the probability that an individual with a pubic symphysis at a certain stage will be of a certain age. Figure 15.7a shows the results of different suggested methods of fitting symphysis stage to age for males, and Figure 15.7b illustrates the Suchey/Brooks method for female pubes. Distribution by iterative proportional fitting ("by iteration" in the legend), as suggested by Bocquet-Appel and Masset (1996) and Konigsberg and Frankenberg (1992), is shown to be completely ineffective in replicating the real age-at-death distribution. Proportional fitting is compared with two other methods that are also shown to be unsatisfactory as methods of deriving the real age distribution.

Figures 15.8a and b use data collected by Sheilagh Thompson Brooks on Spitalfields known age adults. Individuals with pathology or trauma and those whose pubic symphyses did not fall cleanly in a Suchey/Brooks stage have been excluded. Once again, as with the Coimbra sample pubes, we see that iterative proportional fitting does not provide reasonable age at death distributions. Comparison of Figures 15.7a and b and 15.8a and b demonstrates that programming for iteration of what are here called "Bayesian probabilities" would not provide accurate age distributions. The shapes of the curves are determined, not by the underlying real age distributions, but by the

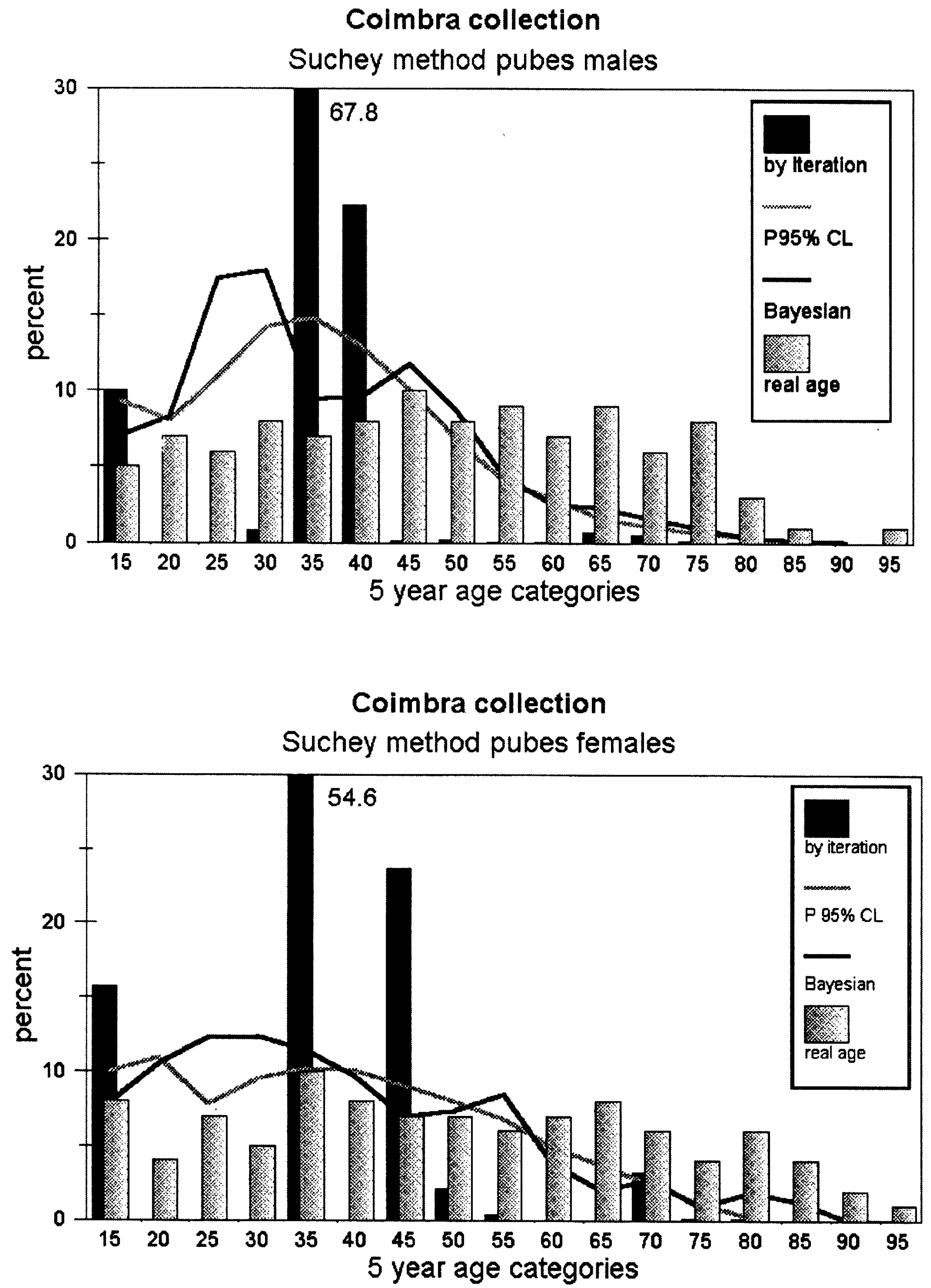


Figure 15.7 (A) Males and (B) females in Coimbra known age sample. Y axes represent numbers of cases. Real ages compared with assessed Suchey/Brooks ages distributed by probability over 95% CL of the stage mean, by Bayesian type calculation (given the reference indicator stage, this is the age class), and by proportional fitting (given the reference age class, this is the indicator stage distribution).

prior probabilities imposed by the method. Thus, while the Coimbra and Spitalfields real age distributions are quite different, the Bayesian curves are very similar, and this similarity would be intensified by iteration.

Reporting of Data

It is important that researchers publish their results in comparable forms, and in full, so that adequate evaluation by other researchers can be undertaken. In fact, there is no satisfactory method of economically summarizing a distribution. Reporting only the mean age of the distribution is inadequate. Molleson and Cox (1993) have suggested that the Spitalfields real and assessed ages are very similar because the target population (Spitalfields), and the reference population (the sample used by Acsádi and Nemeskéri as the basis for their method), are actually similar in age. Indeed, the 157 adults of known age in the Spitalfields sample who were assessed by Molleson using the symphysis pubis by the Acsádi and Nemeskéri method have a mean age of 59.12 years (15.75, standard deviation on five-year frequency data). The mean age by morphological phase for the symphysis pubis in the reference sample (Acsádi and Nemeskéri, 1970) is 57.60 years (SD = 8.88). From these figures, one would say that the pubic symphysis provides an accurate estimation of Spitalfields adult age. But Molleson's argument that this similarity is based on the similarity of the reference and target populations is justified when the Suchey/ Brooks symphysis pubis method is applied. (The Suchey/Brooks reference population has a younger mean age: males, n = 737, mean = 40.72 years, SD = 17.97; females, n = 273, mean = 37.61 years, SD = 17.25). Besides this problem, there is the added disadvantage that the mean age at death does not provide an adequate summary since mean age does not give a clear picture of differences in age distributions. It certainly gives no idea of the actual distribution of the real ages at death (compare Table 15.5 and Figures 15.7 and 15.8).

The normal type of scatter diagram does not allow a reconstruction of cell frequencies, and numerals or symbols to display cell frequencies are clumsy. Yet the next stage in our understanding of skeletal senescence involves finding ways of examining and testing the differences among matrices rather than trying to find ways of estimating distributions from prior probabilities. Thus, it is essential that we report results as fully as possible. The method established by Meindl and Lovejoy (e.g., 1989) of reporting results by inaccuracy and bias, as a replacement for a correlation coefficient expressing the relationship of real and estimated age, provides more information. But it limits methods of comparison, and renders the research data completely opaque to other methods of analysis and testing. The solution is to provide the data in matrix form.

Constandse-Westermann (1997) has provided real age (in years) by stage frequency data for her sample and it is obviously desirable to follow her example. It is then possible to use any age category necessary (5 or 10 years). Mean age by stage or mean stage by age can easily be calculated, and the information can be analyzed by parametric or nonparametric statistical tests. More, however, is needed. We need to have data by sex, and we must have data by population or subsample groupings so that the interaction of stage, age, sex, and ethnicity can be fully understood. For example, Hershkovitz and co-workers (1997a) provide interesting information on the closure of the jugular synchondrosis of the skull base, an element that has eluded the notice of osteologists in the past. But the 1869 skulls examined are not reported in such a way that we can judge the interplay of sex and ethnicity and possible biases in representation of subgroups in each age category. In fact, in view of the questions of asymmetry (Santos, 1996), laterality should also be checked by subgroup.

We also need to examine skeletal changes with regard to cause of death. Masset and de Castro e Almeida (1990) have demonstrated that, while tuberculosis does not seem to affect cranial synostosis, those who died of epidemic diseases are those whose external cranial sutures are likely to be in a more advanced state of closure. It is essential to our understanding of age changes that we know something of the life of the individuals within the reference population. Katz and Suchey (1989), for example, mentioned plans for a study relating to alcohol abuse, a very important consideration. There has been discussion that McKern and Stewart based their age estimates on a sample biased toward very young adults. But we should also recognize that in their sample 70% of the men 28 years and over had been prisoners of war before death. In fact, 60% of the men 28 to 50 years of age had been in captivity for anywhere from three months to over a year before they died (McKern and Stewart, 1957).

Cranial Sutures

Cranial suture observation for age assessment has a long history in anthropology, summarized by Masset (1989). Masset's work came at the end of a long period in which received wisdom stated that cranial sutures gave no clear idea of the ages of adults, whereas pubic symphyses gave the most reliable estimates (e.g., Brooks, 1955). Emphasis is again being placed on cranial sutures (Boldsen and Paine, 1995), but there are clear signs of a healthy scepticism, leading to the provocative conclusion that "[sagittal] suture condition appears to be an age-independent, sexually biased phenomenon" (Hershkovitz et al., 1997b).

The detailed approach to cranial sutures, as laid out in Martin (1959), involves the observation of endocranial suture changes at 16 points on the vault. The results for these 16 points are expressed as a "mean closure stage" for each skull. Using a known age sample of 68 reasonably complete adult skulls from Spitalfields, the highest correlation between known age and mean closure stage ($r = .531$) is obtained from a quadratic regression model with age as the independent variable.

The Workshop of European Anthropologists (WEA, 1980) followed Acsádi and Nemeskéri (1970) in suggesting that the mean closure stage should be collapsed into five suture closure stages. For example, Spitalfields known age adults, males and females 20 years and over, in which all 16 points on the sutures were observable, can be redistributed into the five suture closure phases as shown in Table 15.6. We can add individuals for whom missing data could be estimated based on an assumption of symmetry in suture closure: however, care must be exercised since suture closure analysis

TABLE 15.5 Mean Age for Adults in Spitalfields (Brooks' data) and Coimbra (Santos, 1995, and in litt. 11/2/99) Known Age samples, and Mean of Ages Assessed for Symphysis Pubis by the Suchey/Brooks Method. Means Based on Frequency Data Within 5-Year Age Categories.

	Spitalfields				Coimbra			
	Males (n = 62)		Females (n = 56)		Males (n = 103)		Females (n = 100)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Real age	56.61	15.93	54.11	18.37	50.20	18.81	50.98	21.08
Using mean age for phase (Suchey & Katz, 1997:211)	42.04	12.72	41.02	11.65	38.12	10.72	40.24	12.51
Proportional fitting at .001	44.48	18.30	41.29	13.10	37.23	8.26	38.34	11.73
Number of iterations	548		144		470		822	
Bayesian fitting	42.54	16.13	41.62	16.22	38.62	14.24	40.87	16.84
Probability from reference stage mean age 95% CL	42.07	15.51	39.23	14.95	38.16	13.59	40.54	16.04

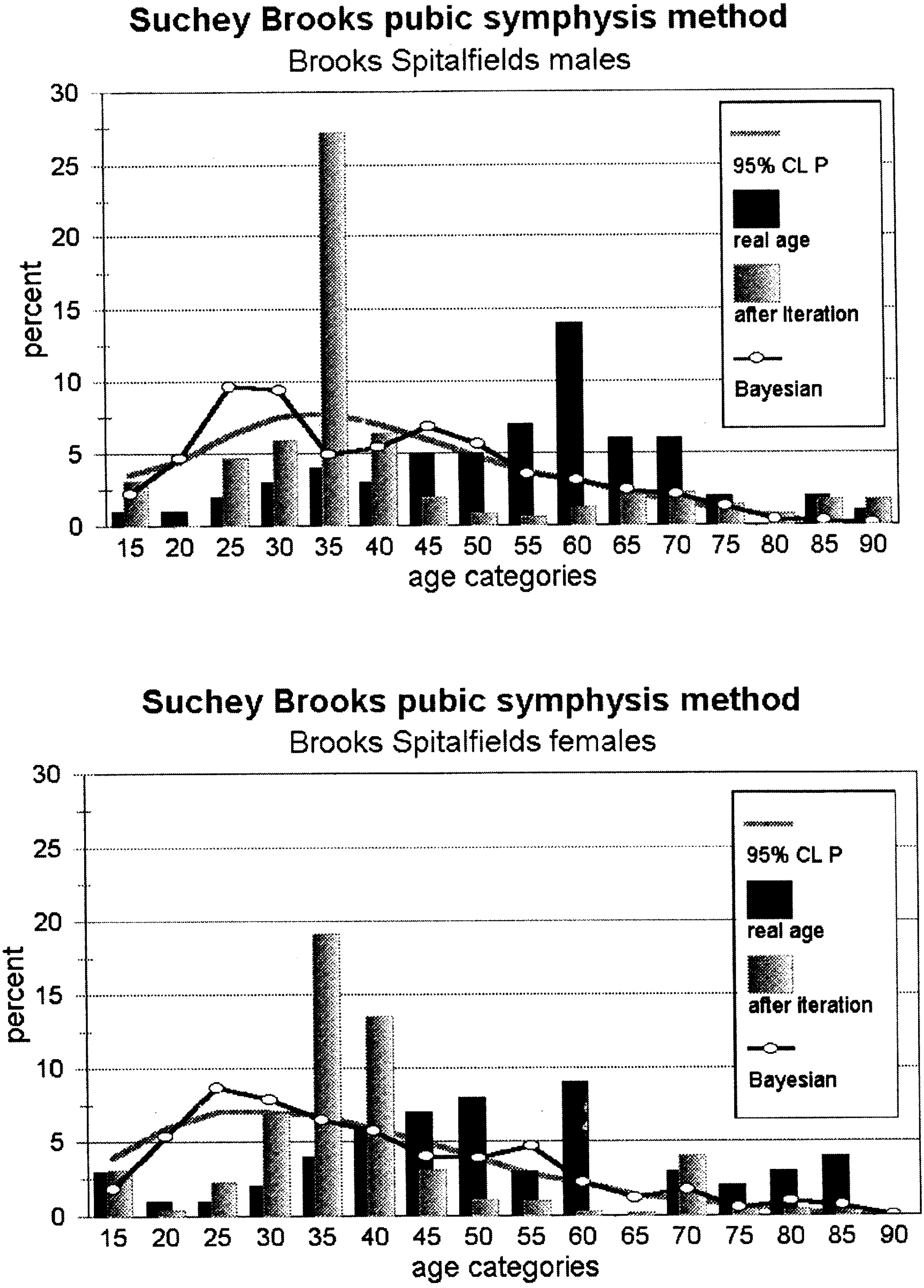


Figure 15.8 Pubic symphyses data on Spitalfields known age adults. Y axes represent numbers of individuals assessed for each five-year age category by Suchey/Brooks method redistributed by probability over 95% CL of the stage mean, by Bayesian type calculation (given the reference indicator stage, this is the age class), and by proportional fitting (given the reference age class, this is the indicator stage distribution), compared with real age distribution: (A) males, (B) females. (Data collected by Sheilagh Thompson Brooks.)

of this type "requires good preservation of the coronal, sagittal and lambdoidal sutures" (WEA, 1980). Overall, the left and right sides of the total Spitalfields adult sample seem equivalent, the mean suture closure and standard deviations being almost identical between sides, but symmetry is a concern. Acsádi and Nemeskéri (1970) actually seem to have chosen their reference sample on the basis of suture closure symmetry, 285 crania were used from a total of 402 available to them in Budapest.

Kemkes-Grottenthaler (1996b) has shown that the lateral anterior sutures (Meindl/Lovejoy system) are particularly vulnerable to asymmetry. Her sample of 109 known age skulls does not provide evidence of overall difference between left and right sides, but her data suggest that first one side of the skull and then the other passes through each of the Meindl/Lovejoy scores.

The Spitalfields known mean age is a little older for each stage (Table 15.7) than that found by Acsádi and Nemeskéri (1970), except in the case of stage 3. In stage 3 it is seven years older than the 49.1 years mean age for stage 3 in the Budapest medical school dissection specimens upon which the system was based, and the standard deviation is greater.

Acsádi and Nemeskéri (1970) gave 30-year ranges: stage 2, 30–60; stage 3, 35–65; stage 4, 45–75; stage 5, 50–80. With such broad ranges, it is hardly surprising that, in general terms, there is no contradiction between the two samples. While examination of the Spitalfields mean stage-for-age category data (given in Table 15.8) show that suture closure is an age-dependent characteristic, the original Acsádi and Nemeskéri sample (1970) provided little assurance that age could be accurately estimated from cranial suture closure, as demonstrated by the last column in Table 15.8. Because the data for the original Acsádi and Nemeskéri reference sample are easily available, we can examine other methods proposed for generating adult age distributions. Our test target sample is the Spitalfield known age adults, and the reference sample (Acsádi and Nemeskéri, 1970) is 280 adults of age 20 and over with a mean age of 58.36 years (SD = 15.98). Iterative manipulation of the Spitalfields sample, deriving estimated age from suture closure stage, generates an age distribution that has no relationship to reality (Table 15.9). On the other hand, the estimated ages for the Spitalfields sample Bayesian type probability distribution is not significantly different from the actual known age distribution (the 99% CI of the *P* value = .63, .4).[2]

Bocquet-Appel (Bocquet, 1978) long ago proposed that assessed age distributions cannot be relied upon unless there is an almost perfect linear correlation between the indicator and age. However, Masset (1989) suggested that "an image of the unknown age sample" can be obtained by distribution over probable age classes. This is a much simpler process than that suggested by Jackes (1985, 1992). While Masset appears to have little confidence in the method of distributing based on prior probabilities when the indicator is not highly correlated with age, Table 15.9 belies that lack of confidence in this case with regard to the Bayesian type probabilities. In the Spitalfields adults aged 20 and over, the linear correlation coefficient between known age and mean points over all sutures is only $r = .486$.

TABLE 15.6 Frequency Counts for Acsádi and Nemeskéri Stages of Cranial Suture Closure for Complete Spitalfields Known Age Skulls

Stages	Males	Females	Total
1	0	0	0
2	2	9	11
3	3	4	7
4	6	10	16
5	3	6	9
Total	14	29	43

---

[2] The difference between the two methods of estimation is obvious: it is hardly necessary to point out that the χ^2 value for testing the difference from the real age distribution and the probability distribution is 3.74, while that for the estimation from iteration is 97.75.

TABLE 15.7 Acsádi and Nemeskéri Stages of Cranial Suture Closure by Known Age for Complete and Almost Complete Spitalfields Known Age Skulls

	WEA stages					Total
Known ages	1	2	3	4	5	n
20	0	3	2	0	0	5
30	0	4	2	1	0	7
40	0	3	1	1	0	5
50	0	5	1	9	4	19
60	0	2	1	7	4	14
70	0	1	2	4	6	13
80	0	0	2	2	1	5
Mean age	—	46.3	56.4	61.1	67.3	57.8
SD	—	14.1	22.4	11.5	9.1	15.8
Total	0	18	11	24	15	68

Masset (1989) considers that the use of 16 cranial suture points may not deal adequately with the correlation between sides of the coronal and occipital sutures. He thus proposes using the mean of each right/left pair of points, reducing the number of suture points to 10. While the difference appears to be minimal (tested using the 53 Spitalfields adults with all 16 points available, for ranges, means, and standard deviations), the Masset 10-point system is used to determine the age category/suture closure distribution of the Spitalfields adults with complete skulls by sex. Males and females are distributed among the seven age stages by Masset's distribution of mean suture closure points (Table 15.10), which allows for sex assignment. A test of age estimation by prior probabilities as suggested by Masset for endocranial sutures (Masset, 1989), with separate probabilities provided for males and females, provides a very fair approximation of the mean age of the samples. Although the estimated age distribution is not identical with the real one, there is no statistical significance to the differences (males, $P = .590$; females, $P = .868$).

The mean age of the Spitalfields known age adults can be estimated with almost perfect accuracy by the method of Masset (1989) based on cranial sutures, using the probabilities derived from his work on two Portuguese collections of known age adults. Galera and colleagues (1988), however, provide an interesting demonstration of the fact that the error in age assessment is not controlled solely by cranial sutures and their inherent variability, but by the methods utilized when examining cranial sutures (Figure 15.2). Since they point out that the Masset endocranial stage system is most accurate for those in their early sixties, we can only assume that Table 15.10 provides good support for the contention that age assessment will be accurate only when the target and reference samples are similar in age distribution. While it is impossible to test this conclusion on the basis of the Spitalfields sample, it appears possible that Masset's attempts (Masset and de Castro e Almeida, 1990) to circumvent the problem of the age structure of the reference population have not been successful.

Key and co-workers (1994) summarized discussions on whether or not there is sexual dimorphism in suture closure. They have devised a new method for dealing with suture closure by sex, based on the Spitalfields sample and taking into account the fact that the Spitalfields sample is biased towards individuals older than 50 years. Their test of this method, using a known age sample of South

Africans in the Dart Collection in Johannesburg, has produced "quite encouraging results." Key and co-workers (1994:205) state that, "further testing on populations with widely varying geographical, temporal and ethnic associations" is required and that "research should be directed towards understanding" suture closure. This is disconcerting given the long history of interest in cranial suture closure as a basic technique of age assessment.

Multifactorial Methods

This section examines the data of Kemkes-Grottenthaler, who has undertaken an interesting study of 505 adult skeletons from two medieval cemeteries in Germany (1993, 1996a). The skeletons were given ages, as ranges associated with stages, using 16 methods, with the idea of checking the complex method emanating from the work of Acsádi and Nemeskéri, and used as the basis for recommendations on age assessment (WEA, 1980). The 16 techniques employed are listed in Table 15.11. Since Kemkes-Grottenthaler (1993) provides data for each individual as age ranges, and sex assignments, it is possible to assess her results in detail.

The first multifactorial method is the summary age that Meindl and Lovejoy developed during the 1970s analysis of Libben, a large Ohio Woodland village cemetery (Lovejoy et al., 1985). The system was tested on the Hamann-Todd Collection at the Cleveland Museum of Natural History, skeletons collected from 1912 to 1938, of autopsied individuals born throughout the United States and in a number of other countries (Meindl and Lovejoy, 1989; Meindl et al., 1990). Tests of the method have been done on two known age samples, one of 130 skeletons and one of 131 each, as the authors say, "designed to match a known ethno-historical mortality profile" (Meindl et al., 1990). They chose a survivorship curve from a population in the literature and specimens from the known age samples were selected so that the age-at-death distribution would approximate the survivorship curve: (Meindl and Lovejoy, 1989:144; see Jackes 1992;196–197 for a discussion of this test methodology).

Principal components analysis using the results of several indicators provides the basis in the Meindl and Lovejoy method for the calculation of a summary age, the age estimates being derived by weighting based on the results

TABLE 15.8 Spitalfields Known Age Individuals with Almost Complete Skulls: Mean Suture Closure Stage for Real Age Compared with the Reference Population Data

Known Age	Mean	N	SD	Acsádi/Nemeskéri
25	2.4	5	.548	2.79
30	2	1	—	2.63
35	2.67	6	.816	3.23
40	4	1	—	3.36
45	2.25	4	.500	3.12
50	3.44	9	1.130	3.32
55	3.8	10	1.135	3.47
60	3.8	10	1.033	3.69
65	4.25	4	.957	3.57
70	4.25	5	.837	3.71
75	4.12	8	1.126	3.78
80	4.5	2	.707	3.52
85	3.33	3	.577	3.87
Total	3.53	68	1.113	—

TABLE 15.9 Comparison of Age Distributions for 68 Spitalfields Known Age Adults for Acsádi and Nemeskéri Suture Closure Stages Estimated by Proportional Fitting and Bayesian Probabilities

Age Categories	Spitalfields Adults Known Age	Estimation by Iteration	Estimation by Bayesian Probability
20–29	5	0.3	6.5
30–39	7	0.3	6.8
40–49	5	60.4	11.9
50–59	19	0.001	13.5
60–69	14	0	13
70–79	13	5.8	11.8
80–89	5	1.2	4.3
Mean	57.85	48.46	55.53
SD	16.52	9.94	17.15

of the analysis. Principal components analysis provides a way to examine relationships among variables when the data comprise a set of more than two variables. Principal components are a new set of variables computed from the original set, organizing the total variability so that it can be represented with fewer variables. This method is used at several points in this chapter. It allows the researcher to pinpoint ways in which the original variables are associated with each other. A further advantage of using a principal components analysis is that it allows graphing on two axes and the investigator can specify the cumulative percentage of variation accounted for by the two most important of the component variables. If more than two axes are taken into account, the data can be rotated so that the relationship among the data points can be understood in more detail.

Table 15.12 presents the results of a principal components analysis using the midpoint of the age range given by Kemkes-Grottenthaler (1993) for her sample of early medieval German skeletons. Here 58.44% of the variance is explained by the first principal component. In the Meindl/Lovejoy method, the correlation of each variable with the unrotated first principal component (in the first column of figures) "is then taken as its weight, and the final age of any individual is the weighted average of all available age indicators for that specimen" (Lovejoy et al., 1985:4). Age assessment may be based on the assumption that there is a one-to-one relationship between an age indicator and a single age estimate, derived from the mean age per stage, but the Meindl/Lovejoy system assumes that the principal components analysis will show that some methods of assessment have a stronger relationship with real age than others. Table 15.12 shows that there are actually three sets among the age indicators used here. When the component matrix is rotated (third and fourth columns of figures), we can see more clearly that the three sets are based on (1) changes to os coxa surfaces, (2) dental attrition, and (3) cranial sutures. It appears here, especially from the rotated coefficients (in column 3, rotated first principal component), that mandibular attrition has the highest correlation with real age (0.896). It is not clear that introducing further variables such as cranial sutures actually increases the accuracy of the age assessment. However, we cannot test this because we cannot judge whether age-biased preservation differences are controlling the result of the principal components analysis.

Figure 15.4, based on the samples analyzed by Kemkes-Grottenthaler (1993), shows that no individual will be aged by all indicators, so that in using the Meindl/Lovejoy multifactorial method, we would have to weight final adult ages for these individuals when the majority could only be aged by suture closure. Age assessment would therefore be based on the indicator shown to have the weakest correlation with the first principal component (assumed to manifest age). Thus, in this example, age is controlled by taphonomic factors.

While it has long been considered that using more than one indicator in concert will give improved accuracy to age estimates (e.g., Brooks, 1955), it would seem desirable to have an improved understanding of the relationship among the indicators before multiple methods are used. This is because it is more difficult to assess the unique effects of each indicator and of taphonomic factors when elements are amalgamated. It would be cleaner in this case to use mandibular attrition as the age assessment method, and admit that a percentage of the adults must remain of indeterminate age at this stage of the analysis.

The "complex method" was first described in English by Acsádi and Nemeskéri in 1970 and then again by the Workshop of European Archeologists (WEA, 1980) with the tables for conjoint age assessment based on four or combinations of two or three age indicators calculated by Sjøvold. The basis for the method is a series of regression analyses (Acsádi and Nemeskéri, 1970) illustrating the relationship among the indicators. The complex method can be illustrated by again using the data provided by Kemkes-Grottenthaler (1993). Only 52 of 294 individuals from the medieval German cemetery at Eltville have all four age indicators, 24 males and 28 females. The situation for the Langenlonsheim site is even worse: two males and two females of a total of 181 individuals were the only individuals who retained all four indicators of the complex method.

The complex method scores derived from the Eltville sample were analyzed by principal components; only one component was extracted, explaining 54.6% of the variability. Assuming that the principal component extracted from these data actually expresses age, radiog-

TABLE 15.10 Distribution by Sex over the Masset Stages of Endocranial Suture Closure for Spitalfields Known Age Adults

Known	Masset Stage								Estimated from Prior Probabilities	
Age Category	4 Female	4 Male	5 Female	5 Male	6 Female	6 Male	7 Female	7 Male	Female	Male
20	2	—	1	1	—	1	—	—	2	1
30	1	—	3	—	—	2	—	—	4	2
40	1	—	—	—	1	—	—	—	5	3
50	2	—	1	1	4	—	3	3	6	3
60	—	—	1	—	4	—	2	5	7	3
70	1	—	—	—	1	2	4	2	7	3
80	—	—	1	—	2	—	1	—	4	1
		Females real age			Males real age					
Mean		57.83			56.26				57.65	55.83
SD		17.57			17.04				17.66	17.94

TABLE 15.11 Mean Ages Derived from Midpoints of Age Ranges for Age Indicators Applied to Two Medieval German Cemeteries. Group Statistics for Midpoint of Age Range

	Eltville Males (n = 145)			Langenlonsheim Males (n = 87)			Eltville Females (n = 149)			Langenlonsheim Females (n = 94)		
Indicator	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
Endocranial suture obliteration[a]	109	51.6	14.9	65	54.2	14.0	123	42.7	15.4	71	43.0	15.8
Femur[a]	74	50.7	5.6	19	50.1	4.2	85	48.4	6.6	22	47.3	5.0
Humerus[a]	62	55.3	4.9	11	54.8	5.6	62	56.5	4.5	11	54.3	5.3
Symphysis pubis[a]	52	54.7	8.9	9	58.3	6.0	48	53.1	10.6	9	51.8	12.6
Complex Method[a]	139	53.0	12.8	73	55.0	12.3	139	48.5	14.4	80	45.3	15.0
Maxillary attrition[b]	50	37.6	8.7	49	37.2	8.6	80	31.2	10.1	54	30.4	8.9
Mandibular attrition[b]	86	41.0	9.0	63	39.0	9.2	93	34.0	10.6	67	32.8	9.4
Ectocranial suture obliteration lateral-anterior[c]	99	38.0	5.4	57	38.4	5.6	115	35.4	5.4	65	35.3	5.4
Ectocranial suture obliteration vault[c]	104	38.3	7.0	60	38.6	7.1	123	34.9	7.2	68	33.2	6.5
Ribs[d]	52	31.3	9.5	3	36.3	2.0	57	24.4	11.7	9	20.0	4.1
Auricular surface[e]	73	40.7	10.2	14	37.9	7.8	84	37.9	11.4	29	40.0	11.5
Pubic symphysis[f]	52	40.9	12.4	9	44.4	12.6	48	40.0	13.2	9	38.3	12.5
Pubic symphysis[g]	52	40.2	11.4	9	45.9	11.8	48	44.7	14.1	9	41.7	15.1
Humerus spongiosa[h]	62	36.6	10.4	11	29.5	6.7	62	37.0	10.2	11	30.2	7.5
Femur spongiosa[h]	74	36.7	8.3	19	35.2	7.1	85	37.1	9.4	21	34.2	8.0
Pubic symphysis (Todd/Brooks)[i]	52	38.9	13.1	9	42.2	12.1	48	40.3	13.9	9	37.8	13.0

[a] WEA, 1980; [b] Lovejoy, 1985; [c] Meindl and Lovejoy, 1985; [d] İşcan and Loth, 1986a, 1986b; [e] Lovejoy et al., 1985; [f] Meindl et al., 1985; [g] Brooks and Suchey, 1990; [h] Szilvássy and Kritscher, 1990 (the overall difference between the sites is significant: $P = .000$.); [i] Krogman, 1962.

Data from Kemkes-Grottenthaler (1993).

raphy of the proximal humerus is least efficient in this sample as an age indicator. Proximal humeral trabecular stages are less correlated with this component than are the other three age indicators. Nevertheless, when all methods used by Kemkes-Grottenthaler (1993) are subject to Euclidean distance proximity analysis, a dissimilarity matrix is generated which shows that the femoral, humeral, and symphysis methods proposed by Acsádi and Nemeskéri for the complex method link closely, separated from all other techniques. This suggests that these three methods reinforce each other in giving older ages than those given by other age assessment methods. It is questionable then whether using four indicators of the complex method together will give a more accurate age; the central tendency of the indicators will simply be reinforced.

The matrix also reveals an interesting divergence between two methods of assessing radiographs of proximal femora. When examined in detail, it is clear that the Acsádi and Nemeskéri stages for femoral proximal trabecular alteration group individuals at around 35, 45, 55, and 65 years of age. On the other hand, the Szilvássy and Kritscher (1990) method, which provides a slightly different approach to femoral trabecular change produces a smoother distribution across all age groups from 20 to 70. This suggests that the reference population upon which the Acsádi and Nemeskéri complex method is based contributes to overaging in adults (as has been noted previously, e.g., Jackes, 1985).

Attrition and Other Dental Characteristics

Several age assessment methods are possible using the dentition. These are (1) for the occlusal and interproximal surfaces, observation of the removal of enamel and measurement of changes in crown dimensions; (2) radiographic examination of the height of the cemento-enamel junction above the inferior dental canal and radiographic or half tooth section examination of changes to the pulp chamber through the deposition of secondary dentin; and (3) histological studies of dentin and cementum. Rösing and Kvaal (1998) provide the most recent and comprehensive review of these methods.

Teeth are believed to be of particular value in age estimation (e.g. Hillson, 1998; Meindl and Russell, 1998). Attrition has even been used as the primary method of adult age estimation (Grauer, 1991). New methods of studying attrition using image analysis are proposed (Kambe et al., 1991; Mayhall and Kageyama, 1997) which require that dentitions be cast. Since casting before mandatory reburial is an obvious solution to the time-consuming nature of detailed dental analyses (Jackes, 1988), these suggestions are of great interest to researchers.

TABLE 15.12 Results of a Principal Components Analysis Using the Midpoint of Age Range Given by Meindl/Lovejoy Age Indicators

Component Matrix	Unrotated		Rotated (Varimax with Kaiser Normalization)	
Component	1	2	1	2
Auricular facies	0.653	–0.315	0.715	0.123
Pubic symphysis	0.731	–0.177	0.698	0.281
Maxillary attrition	0.845	–0.322	0.874	0.229
Mandibular attrition	0.875	–0.316	0.896	0.252
Lateral anterior sutures	0.733	0.609	0.242	0.922
Ectocranial vault sutures	0.726	0.602	0.241	0.912

Data from Kemkes-Grottenthaler (1993) for early medieval German skeletons.

The method proposed by Pot (Constandse-Westermann, 1997) appears to provide more detail than others similarly based only on removal of occlusal enamel. It has recently been tested by Constandse-Westermann on a known age and sex sample of middle-class Dutch from Zwolle who died between 1819 and 1828. Her study shows that, using attrition and alveolar resorption, it is possible to obtain a higher number of age estimates, and more accurate age estimates, than if the auricular surface, the pubic symphysis, or the Meindl/Lovejoy cranial suture methods are used. The average discrepancy from real age is 3.8 years for males, and 6.3 years for females. The difference between males and females in accuracy is not related to sex differences in attrition; it occurs because dental pathology is high in females in the sample.

The work on occlusal attrition in Portuguese teeth (e.g., Jackes, 1992; Lubell et al., 1994) has involved modifications of the Smith (1984) system. The modifications were introduced when the system was found to be unsatisfactory because teeth pass through wear levels at different rates, so that some wear levels must represent many years of adult life. The general applicability of the method has been tested on low attrition Chinese Neolithic teeth (Jackes and Gao, in press) and is being examined in high attrition Algerian Capsian teeth (sample discussed in Haverkort and Lubell, 1999). It would, even in its least detailed form, provide a much finer-grained picture of adult age than the Meindl/Lovejoy method. For example, in the Meindl/Lovejoy method of recording mandibular M1 attrition, their stages 2, 3, and 4 would be equivalent to the modified Smith stage 2; their 5 would be ca. 2.5; their 6 ca. 3 to 3.5; their 7 and 8 is equivalent to 4; 9 is 5; 10 is 6. There is no equivalent to the Smith stages 7 or 8. The Meindl/Lovejoy method examines cheek teeth as a unit, an approach that does not allow an understanding of differential wear between M1 and M2, and is therefore unable to compare rates of wear between samples based on coded differential wear among molars. Subtle changes in the rates of attrition occur even within samples that are separated by the minimum of dietary change (Jackes and Lubell, 1999; Lubell et al., 1994).

Jackes (1992) has proposed the use of dental changes beyond the simple removal of occlusal enamel. In fact, crown height by quadrant and details of enamel removal by quadrant are available for the Portuguese Neolithic, in association with changes in interproximal surfaces and wear plane angle. These data were gathered more than 10 years ago, but have not been analyzed in full. Others have used crown height as a variable in considering occlusion (Mayes et al., 1995; Walker et al., 1991; see Jackes, 1992, for discussion), and Molleson and Cohen (1990) experimentally studied the relationship of attrition stage to crown height reduction. Use of detailed type of information such as quadrant crown height is perhaps infrequent because of the enormous amount of time required for data collection and analysis.

Based on a very detailed method of scoring molar attrition, Dreier (1994) has shown a difference in attrition between males and females for a sample of Arikara of unknown age, with sex determined from crania and innominates. Other studies have shown a similar pattern (Larsen, 1997 provides a summary), but we cannot assume that the attrition in females was actually greater, unless the sample under study is of known age. Perhaps the females in the Arikara sample were actually older, on average, than the males (although the studies that have shown female dentitions to be more worn can generally associate female dental wear to the use of teeth as tools). In the unusual case of the Narrinyeri (84 male skulls and 72 female skulls from the nineteenth-century mass burials at the River Murray mouth in South Australia studied by Richards, 1984), some teeth do appear to wear relatively faster in females. In providing regression equations describing the relationship between tooth wear and age, based on known age individuals, Richards and Miller (1991) find no need to separate the sexes.

Bite force may be a factor in sex differences in tooth wear (Brothwell, 1989) although some evidence contradicts this idea (Hojo, 1954; Solheim, 1988). The need to consider sex in studies of the degree of cheek teeth attrition is not clearly determined, but not such study whether of occlusal or interproximal attrition, of secondary dentin deposition, or periodontal recession, should ignore the possibility of sex differences based on diet, activity, strength of jaw muscles, or jaw and tooth size.

Spitalfields individuals were coded for attrition using a simple grading system, derived from Brothwell (1981). Figure 15.9 shows the first right lower molars of males (n = 31) and females (n = 26) of known age and sex plotted against fit calculated by exact maximum likelihood. This is an estimation technique that finds those parameter estimates that are "most likely" to have produced the observed data (calculated for a sum of squares change of 0.001%, stability was reached at four iterations). Back plotting of the fit values against the actual wear codes shows clearly that predicted age from maximum likelihood would not be accurate. Categorical regression with optimal scaling of the five-year age categories and attrition scores as ordinal data provides a correlation coefficient of .578 and standard error of .11, but 66% of the sum of squares is unexplained.

It should be noted that the Lowess lines plotted on Figure 15.9 do not assume a linear or nonlinear relationship of the variables—either could be produced.[3] Figure 15.9 provides a clear indication that Spitalfields male attrition is greater than female attrition. Some of the analyses undertaken on the Spitalfields

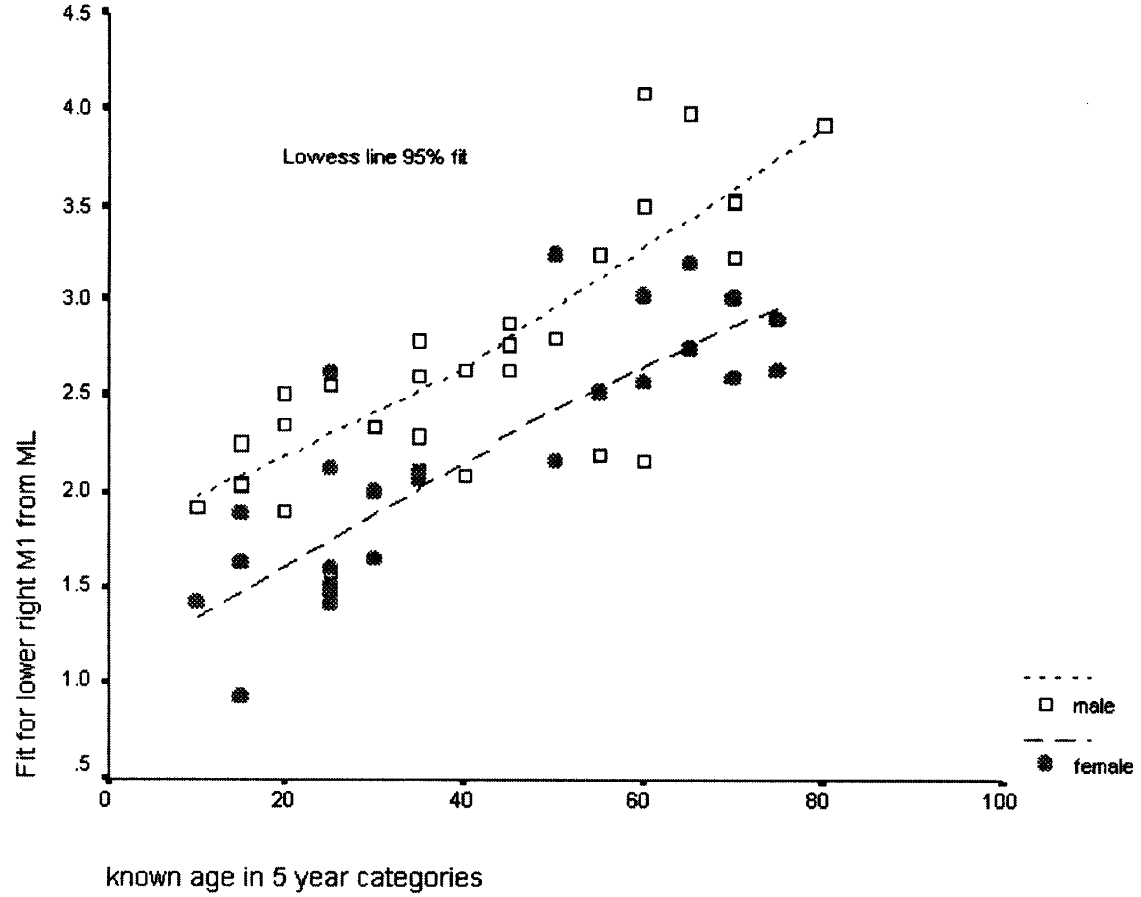


Figure 15.9 First right lower molars of males (n = 31) and females (n = 26) of known age and sex from Spitalfields plotted against fit calculated by exact maximum likelihood.

data suggest that female attrition levels off before male attrition. We can assume that the differential is not related to dietary or activity factors, but directly to the forces developed under male masticatory muscle strength. This would indicate that samples showing no sexual difference in attrition, or heavier female attrition, either have much reduced sexual dimorphism or strong differences in female diet and dental use. The standard error of the fit does not indicate that male attrition is more variable than female attrition. However, the information on the Spitalfields attrition is limited by the grading system used, which is not sensitive to subtle changes in crown wear, demonstrated by the fact that in most individuals the first molar was not recorded as more worn than second the molar. Santini and colleagues (1990) tested Brothwell's system on Chinese dentitions of known age at death and concluded that the inaccuracy of the method was too great for it to be useful. They did, however, note the differential rates of wear between first and second molars, asserting that the first molar actually wears faster than the second.

The use of maximum likelihood illustrates a growing concern that anthropologists have used regression analysis in an inappropriate way. It has been common to accept that, say, 11 attrition grades can be treated statistically as though they are continuous data. They could be more properly regarded as ordinal data. They can be used as frequency data for hazard analysis, or nonparametric analyses can be performed. In this latter case, performing a (nonlinear) regression analysis of stages used for the Spitalfields right lower first molars on five-year age categories yields an *r* of .468 (SE = 1.19).[4]

Future research on dental attrition rates should take into account that Richards and Miller (1991) have demonstrated the relationship between age and cheek tooth attrition to be nonlinear. They suggest the possibility that the first molars wear at a faster rate than the second molars. This idea deserves testing. The M1 comes into wear in association with the dm2, which may provide less of a buffering effect than is provided by the M2 when it comes into wear. The difference in the force of the bite of a child, as against that of an adolescent, may, however, offset the difference between the dm2 and the M2 as the proximate tooth. Constandse-Westermann (1997) provides fascinating data from a series of Dutch cemeteries ranging over 1600 years suggesting that, not only the difference between M1 and M2 wear, but the trajectory of that difference (the comparison between the two teeth at different states of wear), has altered over time.

Along with attrition, radiographic examination of dentitions may provide important information on age-dependent changes, but radiographic techniques of age estimation have yet to be tested in full.

Kerr and Ringrose (1998) have summarized work on the compensatory eruption of teeth, a method that could be used to check age estimates in samples with severe attrition. The method is based on the proposal that as a tooth crown wears, bone is laid down at the root tip so that the occlusal level of the tooth is maintained. This compensatory bone can be observed on radiographs by measurements from the fixed point of the inferior dental canal. Data reconstructed from the diagrams provided by Kerr and Ringrose (1998) indicate that the inferior dental canal to tooth root tip measurement (AP) seen on mandibular radiographs does correlate with the inferior dental canal to occlusal surface (OS) measurement. But attrition does not bear a close relationship to these variables. Rather, we see a bimodal distribution of the AP measurement, requiring that sex be entered into the equation, and several outlying data points require explanation. At present, the hypothesis appears unproven.

[3] Lowess lines are locally weighted regression lines produced by smoothing collections of values along the X scale; the curve is produced by connecting successive smoothed values from left to right by line segments.

[4] Giles and Klepinger, 1988, and Rösing and Kvaal, 1998, urge that the SE of the regression estimate, also called *m*, be reported in age estimation by regression analysis.

Examination of dental radiographs for Portuguese Mesolithic and Neolithic material suggests that specialized radiography may be required, especially when root tip and the margin of the inferior dental canal must be identified with great precision. Perhaps because of heavy redeposition of minerals, or because of the radiographic techniques available under some study conditions, the Portuguese material is not easily amenable to this type of analysis.

Drusini and colleagues (1997) have proposed the use of panoramic radiography, and this was also used in my studies of Mesolithic Portuguese dentitions, with rather poor results. Enhanced radiographic techniques may have to be employed before accurate measurements can be made. Image enhancement techniques have not proved very useful thus far. It is probable that the measurements required by this method, which uses a ratio of crown height to the height of the coronal pulp cavity (Drusini et al., 1997) can be made with more accuracy using some form of image analyzer, than can the method of Kvaal and colleagues (1995), which requires that the root tip be clearly visualized. The tooth coronal index of Drusini appears to have a high correlation with real age, higher than the pulp height and width indices of Kvaal and co-workers.

There is a great deal more information on sectioned tooth root analysis than radiography. The examination of microscopic changes in conjunction with macroscopic features has a long history in forensic dentistry and anthropology since Gustafson (1950) first published his system based on six age-related characteristics. More recently, Solheim (1993) has proposed a new series of multiple regressions for dental age estimation. In each one, root translucency is an essential variable and color is a frequent variable. We need to enquire how important translucency is to age estimation. Lucy and colleagues (1995) have noted that it is impossible to use color and translucency when assessing archaeological teeth, and have suggested modifying dental estimation techniques to take this into account. Kvaal and coworkers (1994) suggest that the length of the apical translucent zone of the root be ignored in archaeological contexts.

It seems likely that cemental annulation will be of greatest value in the analysis of sectioned tooth roots from archaeological contexts (and Grosskopf, 1990, determined that this may even include cremations). Cipriano-Bechtle and colleagues (1996), using early medieval skeletons from a Bavarian cemetery, compared the results of age assessment derived from the complex method with those from microscopic examinations of the cementum of premolar tooth roots. Figure 15.10 demonstrates that the two distributions of adult ages, one derived from cemental annulations and the other from macroscopic methods of adult age estimation, are discrepant. The cemental annulation technique provides a distribution that has apparent biological validity, in contrast with standard macroscopic methods of adult age assessment, and gives a smoother distribution extending well beyond 60 years of age.

The counting of cemental annulations is not simple, however, and we cannot take it for granted (Jackes, 1992; Rösing and Kvaal, 1998). The most ambitious test of cemental annulation counting is that by Geusa and colleagues (1999). The roots of 150 canines and premolars (from 129 individuals) were sectioned and separately examined by phase contrast microscopy and digital enhancement of images of thin sections. Consequently, there are two separate cemental annulation age estimates to compare with age assessed by standard macroscopic methods. The degree of diagenesis is also recorded. Differences between teeth of the same individual, between estimates from the two separate laboratories (ranging from 0 to 29 years), and between estimates based on macroscopic age (which can be regarded as reasonably accurate up to age 25 or so) and those derived from cemental annulation, all raise questions as to the accuracy of cemental annulation age estimates. Testing indicates that there is no obvious effect of jaw, tooth, or sex on preservation, or interaction among these factors, nor indeed is there an in-

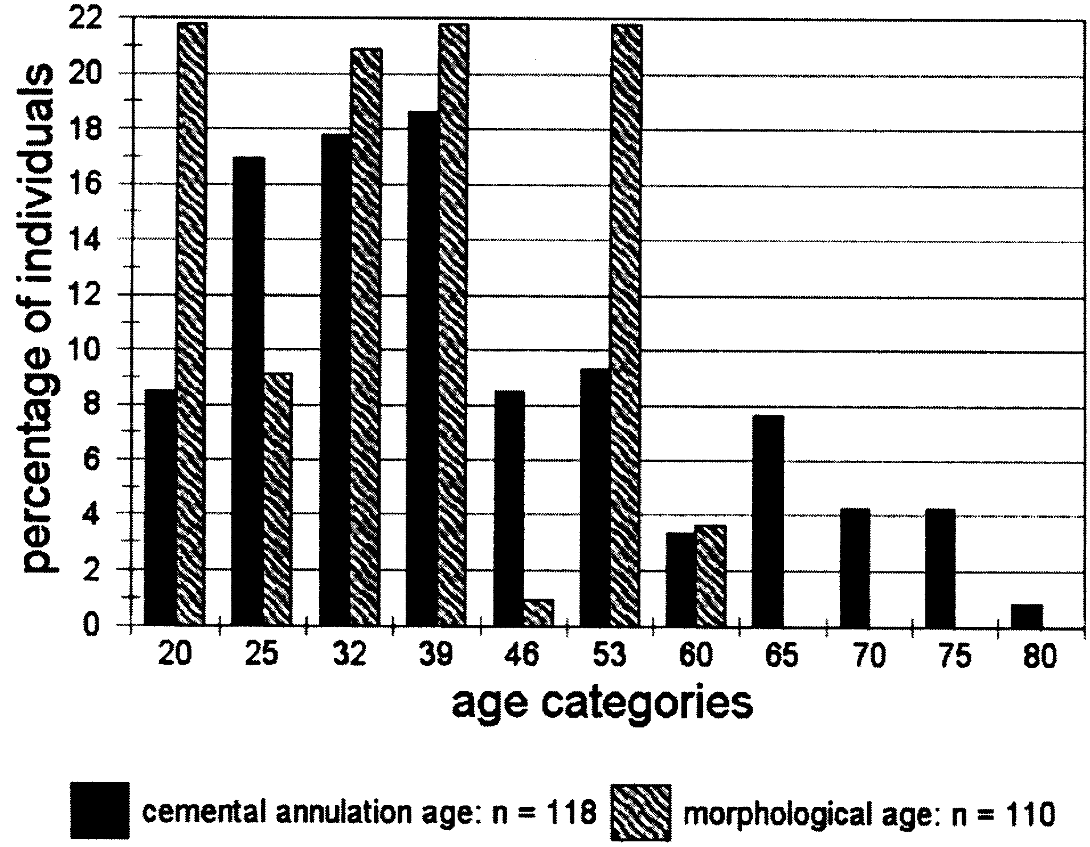


Figure 15.10 Comparison of distribution of adult ages derived from morphological indicators and from cemental annulation. (Data from Cipriano-Bechtle et al., 1996).

teraction between preservation differences and the discrepancy in the results from the two laboratories. Problems of preservation do not, therefore, explain the discrepancies.

DISCUSSION OF POSSIBLE SOLUTIONS

As yet we have no firm solutions to the problem of adult age assessment. We have seen that proposed statistical techniques do not provide the magic answer, and we could hardly expect that this would be so. If the "age indicators" do not directly manifest age, then redistributing frequencies of age indicators by a variety of statistical approaches will not lead to true ages. It would be beneficial to reexamine the reference data where possible, for example all the data of Acsádi and Nemeskéri, in such a way as to confirm the relationships of indicators with age. The data on cranial suture closure given in Acsádi and Nemeskéri (1970) may well be best analyzed by categorical regression with optimal scaling. When the suture closure points are treated as ordinal data, age categories as numerical, the correlation coefficient is .571 with a standard error of .049. It should be noted that the residual sum of squares in this analysis, the unexplained error around the regression line, constitutes a full 67% of the total.

I believe that we must use indicator stages as they are—simply stages of skeletal change, which, like degrees of degenerative change in joints, have some relationship with age, but a relationship that is governed by many and complex factors. Age may contribute no more than 30% of the variability to these changes. I suggest that we observe and record age-dependent changes fully and in detail, seeking to compare them in systematic ways (as Kemkes-Grottenthaler, 1993, 1996a, has done). This will provide a foundation for analysis of these data across time and space. They will *not* be recorded and analyzed as age indicators, but rather as further data in our attempt to understand human populations in the past. In studying how the "erstwhile age-indicators"correlate with each other and with other skeletal characteristics, and gender, diet, activity, trauma, pathology, etc., we may begin to approach the "great unknown"(Jackes, 1992) of skeletal biology, the absolute age at death of adults in past populations.

What type of approach should be taken? As a first step and an example, Figure 15.11 shows the result of analyses of data from Kemkes-Grottenthaler (1993), but not in terms of age range or mean age or probability. These data were reworked into the original stage assignments. The Todd pubic age was excluded since the number of individuals falling firmly within a stage was very limited (only 51/118 or 43.2% of pubes were classified as falling directly within a stage, all other pubes fell between two or more stages). Acsádi/Nemeskéri complex age (which is derived from regression formulae) and clavicle age were also excluded. All other variables were analyzed as ordinal variables based on stage coding.

The data, as converted back into the defined stages, can be treated as multivariate ordinal data (in this analysis integer data only are used, so that all cases where the individual fell between predefined stages have been excluded). Optimal Scaling by Alternating Least Squares procedures using Nonlinear Principal Components Analysis (PRINCALS) in SPSS provides an easy method of analyzing such ordinal data.

It is obviously essential that such data be analyzed separately for males and females. Here I have simplified, not analyzing by site and choosing only one set of data for each indicator, attempting to use definitions provided and indicators proposed by a variety of researchers, in order to minimize the intercorrelations. The following will be used: Suchey/Brooks pubic symphyses; Meindl/Lovejoy auricular facies and dental attrition; Acsádi/Nemeskéri suture obliteration; humeral and femoral spongiosa (Szilvássy and Kritscher, 1990); and rib stages (Loth and İşcan, 1989).

Figure 15.11a and b suggests that some "former age indicators" may function very differently from others. Several analyses have confirmed the grouping of suture, by whichever method, and dental stages. An obvious explanation for Figure 15.11 might be that individuals lacking skulls and teeth are different in "age" from those with skulls and teeth. This has been checked by comparing Suchey/Brooks pubes data for individuals with and without "dental age" (i.e., mandibular and maxillary ages combined): there is no significant difference (Monte Carlo estimate of $P = .42$).

The distribution of suture closure stages in skulls with and without "dental age" is significantly different ($P = .000$), however, but when the suture closure stage frequencies are translated into distributions over 10-year age categories by probability, there is no statistical significance to the difference: $P = .53$ (Monte Carlo estimate).

A more likely explanation for the grouping of attrition and suture closure is that both suture obliteration and the Meindl/Lovejoy attrition method have a very specific cutoff point. Once sutures are closed, no further changes can be recorded. Closure may well occur long before death. Thus, in the known age individuals at Spitalfields with complete suture closure, four died in their fifties, four in their sixties, six in their seventies, and one in the eighties. Similarly, the Meindl/Lovejoy attrition method has the characteristic of reaching its maximum level at a relatively early stage of dental wear, when the first molars still have some crown height and occlusal enamel remaining. The maximum stage would be reached well before death in most long-lived individuals.

Further analyses have indicated that the sternal ends of ribs, and humeral or femoral proximal spongiosa may provide results dif-

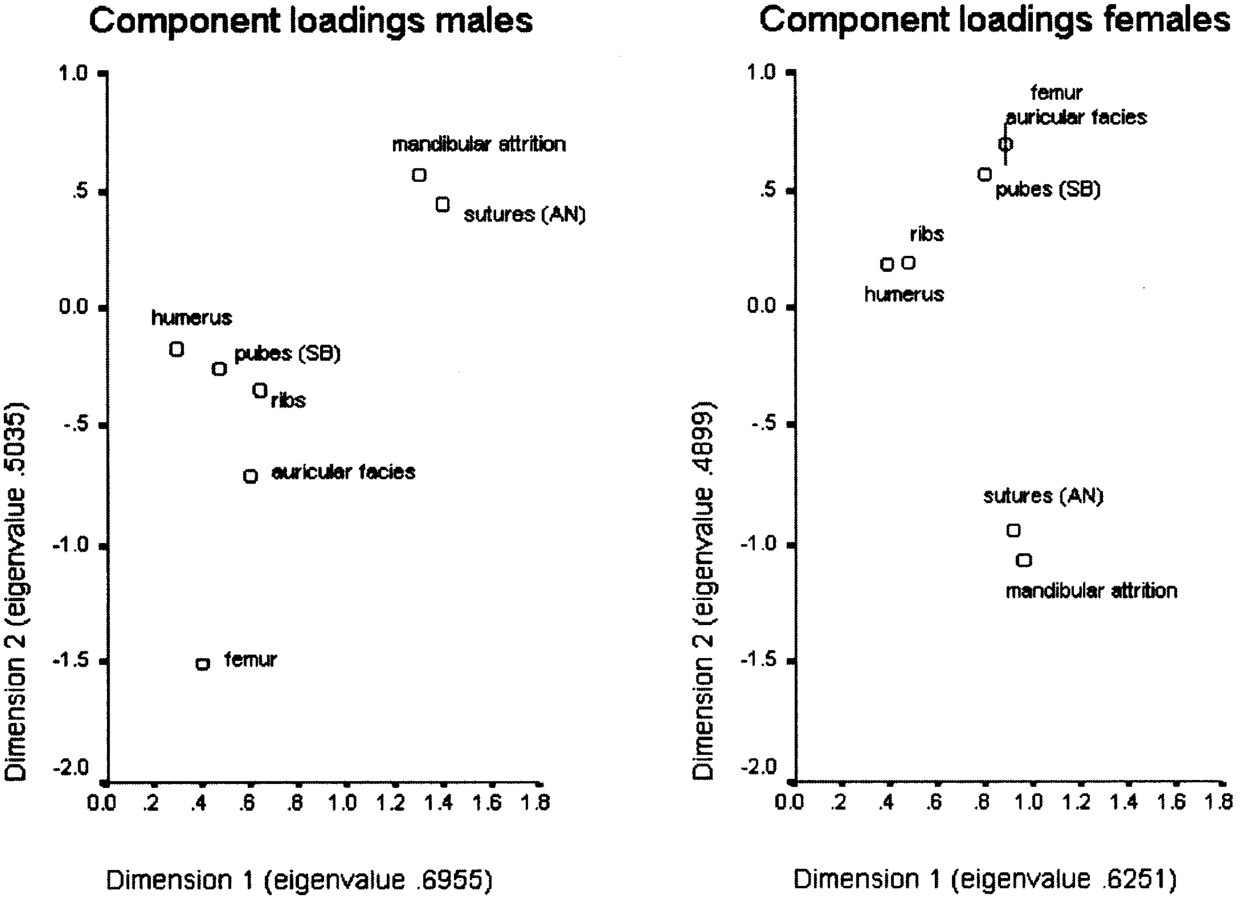


Figure 15.11 Nonlinear principal components analysis of ordinal data derived from Kemkes-Grottenthaler (1993): (A) males, (B) females. Component loadings show the relative contribution of the variables to the two dimensions.

ferent from those of other "age indicators." Pasquier and colleagues (1999) have proposed a new method of examining Suchey/Brooks male pubic symphysis stages, adding variables and recording both the right and left pubes, thereby increasing the linear correlation between pubic symphysis and true age to .86. While this computed tomography radiograph technique is hardly available to those working on archaeological samples, the idea that variables can be added to our present series will provide motivation for further research, perhaps using radiography.

Although not discussed in detail in this chapter, research into changes in spongiosa with age is of importance to the question of age-dependent changes in the human skeleton. Recent work is summarized by Brickley and Howell (1999). But what methods can be used to get a true picture of age changes in cortical thickness and trabecular structure? Brickley and Howell (1999) show changes across their morphologically determined age categories, as is to be expected. But it is very unlikely that they have demonstrated the true pattern of change across older age categories, since females of age 36 and above show no significant differences across age categories.

Seriation of adults by many different "stage" methods, in a consistent manner and without preconceptions as to a necessary linkage of "stage" and "age," may free skeletal biology from something of a quagmire. The major focus will be to understand skeletal changes during the course of adult life, with emphasis on sex differences (evident from

Figure 15.11), on how to cope with sampling bias, and on sample differences. Thus we may begin to understand more clearly the impact of adult lives on skeletons. It would, of course, be desirable to have some age control for the particular sample being analyzed. In the recent past, it has been assumed that bone histomorphometry will supply all that is needed by way of age assessment, but this can no longer be accepted (e.g., Pfeiffer, 1998). There can be little doubt that, for the type of large archaeological samples under consideration, detailed analysis of dental attrition, including not simply loss of occlusal enamel but loss of crown height and other considerations (Jackes, 1992), will be a first step. Dental radiographs should be included in the analyses, especially if there is to be reburial.

While we cannot yet be certain that the methods used by Drusini and colleagues (1997), Kerr and Ringrose (1998), or Kvaal and colleagues (1995) will always provide useful information, such nondestructive methods must be explored for their potential. Selection of individual teeth, male and female, representative of stages of change identified by the seriation, can be made to allow the identification of the age of adults, and especially of those who appear oldest in a sample, as proposed by Jackes (1992) using cemental annulations. Rösing and Kvaal (1998) identify cemental annulations as the best choice for age estimation after amino acid racemization, which cannot be used on archaeological samples. Advances in the accuracy of cemental annulation counting (±2 years) are being reported (Wittwer-Bachofen, per. comm). Direct microscopy of various types, rather than image enhancement, contributes to the accuracy (also found to be true for our Portuguese thin section analysis). An important factor is likely to be the method of preparation of the unpolished thin sections.

We cannot doubt the necessity of using cemental annulations as a control when we read that "By the age of 40 years, occlusal wear (in almost all individuals prior to the seventeenth century [in a Scottish sample]) had reached the amelocemental junction with very few individuals retaining fully functional dentitions beyond the age of 40 years" (Kerr and Ringrose, 1998:245). These individuals had no evidence of hypercementosis, suggesting little heavy mastication. We can compare this with the situation reported by Richards and Miller (1991) of central Australian desert-living Aborigines who still, when studied in the 1950s and 1960s, maintained "food preparation, dietary preferences, and use of teeth for non-masticatory purposes" little removed from that of hunter-gatherers. The level of attrition reported for medieval Scots at age 40 (complete removal of occlusal enamel) would be highly unusual for desert Aborigines at age 70: most individuals from 60 to 80 years still maintained 20% of their occlusal enamel on the first molars. At age 40 in desert Aboriginal teeth, 60% of the occlusal enamel remained.

When tooth root microbial destruction is not too great, examination of tooth roots must be undertaken, and if facilities are not available, then it would seem essential that representative samples of roots be retained in event of reburial. Permission to take samples for cemental annulation counting should always be sought when arranging for samples for DNA amplification (whether for biological distance studies, or for confirming the sex of individuals for whom sex ascription is uncertain), for dating and for stable isotope analysis. Casts and radiographs of the dentition and the use of technology that will allow direct input of detailed dental measurements should be the very first steps in the recording of any skeletons that may be subject to reburial. A major consideration is the standization of radiographs when measurements are to be taken, unless all variables are expressed as ratios. The Portuguese femoral radiographs (Jackes, 1992) were taken in several facilities, but standardization is possible because all proximal femora were photographed in standardized ways that allow the checking of measurements made in the field with absolute accuracy using electronic scaling techniques. Radiographs can be laid over standardized photographic images and the scale adjusted electronically.

CONCLUSIONS

The effort here has been to try to establish viable methods for researchers working with samples large enough to allow reconstruction of population prevalences of age-dependent characters and of paleodemographic parameters. Our concern is to enquire into what is feasible under the conditions prevailing now, and considerations required by comparison of material being studied now with that studied in the past. Because large and representative samples are absolutely necessary in order to make valid statements about the adult age-at-death distribution of past populations, the question of feasibility is basic. One cannot, and should not, section all teeth within a large sample, saw through all long bone proximal ends (Molleson and Cox, 1993; WEA, 1980), or obtain readable thin sections from all femoral cortices, fourth ribs, or clavicles. A consideration here is what can most profitably be done to collect information quickly, accurately, and economically, especially when reburial is a possibility.

There must be detailed examination of dentitions, with careful consideration of which teeth might be sacrificed for root sectioning. Standardized photography and radiography of jaws and long bones must be undertaken, and casting of teeth should be undertaken where reburial is likely. No great advances have been published in recent years on the question of adult age assessment, and cemental annulation remains the method most likely to restore paleodemography to importance within skeletal biology. Work on known age samples has brought light to some dark corners, as has the vast amount of work undertaken by Kemkes-Grottenthaler. The increased interest of skeletal biologists in the use of categorical analyses will provide a new approach, freeing us from feeling coerced into estimating "ages" from stages. We will use indicator stages, not as age estimators, but as categories of change during adult life, which will provide us with ways to understand how the human skeleton responds to the exigencies of adult life under many circumstances. The lack of age control will be an acknowledged limitation. Where possible, the limitation will be partially alleviated by the provision of a scale through cemental annulations. This scale will be a control for seriation based on detailed analyses of dentitions.

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APPENDIX: SUCHEY BROOKS PUBIC SYMPHYSEAL DISTRIBUTION REFERENCE DATA

TABLE A1 Midpoint of Age Categories: Male Sample Distribution by Age and Stage

Stage	17.5	22.5	27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	Total
1	73	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	103
2	6	52	12	4	1	0	0	0	0	0	0	0	0	0	0	0	75
3	0	11	24	7	4	2	3	0	0	0	0	0	0	0	0	0	51
4	0	12	41	47	23	18	14	11	2	0	2	1	0	0	0	0	171
5	0	1	9	15	11	19	35	23	13	4	2	0	1	1	0	0	134
6	0	0	0	6	2	11	15	25	27	37	27	27	16	4	4	2	203
Total	79	106	86	79	41	50	67	59	42	41	31	28	17	5	4	2	737

TABLE A2 Mid point of Age Categories: Female Sample Distribution by Age and Stage

Stage	17.5	22.5	27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	Total
1	25	22	1	0	0	0	0	0	0	0	0	0	0	0	0	0	48
2	3	23	16	2	1	2	0	0	0	0	0	0	0	0	0	0	47
3	0	10	11	15	4	1	1	1	0	1	0	0	0	0	0	0	44
4	0	0	10	7	7	7	3	1	2	0	0	2	0	0	0	0	39
5	0	0	2	5	8	5	4	7	6	2	1	0	1	2	1	0	44
6	0	0	0	0	0	4	7	6	11	8	5	5	1	2	2	0	51
Total	28	55	40	29	20	19	15	15	19	11	6	7	2	4	3	0	273

TABLE A3 Males Bayesian Probabilities Cell/Stage Total

Midpoint of Age Category	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Total
17.5	0.709	0.080	0.000	0.000	0.000	0.000	0.789
22.5	0.291	0.693	0.216	0.070	0.007	0.000	1.278
27.5	0.000	0.160	0.471	0.240	0.067	0.000	0.938
32.5	0.000	0.053	0.137	0.275	0.112	0.030	0.607
37.5	0.000	0.013	0.078	0.135	0.082	0.010	0.318
42.5	0.000	0.000	0.039	0.105	0.142	0.054	0.340
47.5	0.000	0.000	0.059	0.082	0.261	0.074	0.476
52.5	0.000	0.000	0.000	0.064	0.172	0.123	0.359
57.5	0.000	0.000	0.000	0.012	0.097	0.133	0.242
62.5	0.000	0.000	0.000	0.000	0.030	0.182	0.212
67.5	0.000	0.000	0.000	0.012	0.015	0.133	0.160
72.5	0.000	0.000	0.000	0.006	0.000	0.133	0.139
77.5	0.000	0.000	0.000	0.000	0.007	0.079	0.086
82.5	0.000	0.000	0.000	0.000	0.007	0.020	0.027
87.5	0.000	0.000	0.000	0.000	0.000	0.020	0.020
92.5	0.000	0.000	0.000	0.000	0.000	0.010	0.010
	1	1	1	1	1	1	6

TABLE A4 Females Bayesian Probabilities Cell/Stage Total

Midpoint of Age Category	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Total
17.5	0.521	0.064	0.000	0.000	0.000	0.000	0.58
22.5	0.458	0.489	0.227	0.000	0.000	0.000	1.17
27.5	0.021	0.340	0.250	0.256	0.045	0.000	0.91
32.5	0.000	0.043	0.341	0.179	0.114	0.000	0.68
37.5	0.000	0.021	0.091	0.179	0.182	0.000	0.47
42.5	0.000	0.043	0.023	0.179	0.114	0.078	0.44
47.5	0.000	0.000	0.023	0.077	0.091	0.137	0.33
52.5	0.000	0.000	0.023	0.026	0.159	0.118	0.33
57.5	0.000	0.000	0.000	0.051	0.136	0.216	0.40
62.5	0.000	0.000	0.023	0.000	0.045	0.157	0.23
67.5	0.000	0.000	0.000	0.000	0.023	0.098	0.12
72.5	0.000	0.000	0.000	0.051	0.000	0.098	0.15
77.5	0.000	0.000	0.000	0.000	0.023	0.020	0.04
82.5	0.000	0.000	0.000	0.000	0.045	0.039	0.08
87.5	0.000	0.000	0.000	0.000	0.023	0.039	0.06
92.5	0.000	0.000	0.000	0.000	0.000	0.000	0.00
	1	1	1	1	1	1	6

TABLE A5 Revised Probabilities over 95% CL for Suchey/Brooks Pubic Symphysis Method, Males

5-Year Age Categories	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
15	0.7226	0.1490	0.0691	0.0311		
20	0.2172	0.4975	0.1923	0.0866	0.0011	
25		0.2966	0.2905	0.1513	0.0430	
30		0.0114	0.2535	0.2010	0.0872	
35			0.1278	0.2029	0.1411	0.0186
40			0.0213	0.1556	0.1819	0.0510
45				0.0907	0.1869	0.0871
50				0.0352	0.1531	0.1262
55					0.1000	0.1549
60					0.0520	0.1612
65					0.0083	0.1423
70						0.1064
75						0.0675
80						0.0363
85						0.0030

TABLE A6 Revised Probabilities over 95% CL for Suchey/Brooks Pubic Symphysis Method, Females

5-Year Age Categories	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
15	0.5521	0.1276	0.0670	0.0251	0.0007	
20	0.3947	0.3464	0.1476	0.0657	0.0265	
25		0.3491	0.2248	0.1132	0.0462	
30		0.1315	0.2367	0.1586	0.0719	
35			0.1723	0.1809	0.0995	0.0222
40			0.0867	0.1678	0.1228	0.0581
45			0.0160	0.1266	0.1349	0.0994
50				0.0777	0.1320	0.1416
55				0.0388	0.1151	0.1679
60					0.0894	0.1658
65					0.0618	0.1363
70					0.0381	0.0932
75					0.0154	0.0531
80						0.0168

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