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Chapter 7

RADIOGRAPHIC AGING OF THE ADULT

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INTRODUCTION

Radiography can be a useful method for the estimation of age in the adult in skeletonized and non-skeletonized forensic cases (Murphy et al., '80; Murphy and Gantner, '82; Schmidt, '82; Krogman and İşcan, '86; McCormick and Stewart, '88; İşcan, '88; İşcan and Loth, '89), as well as archaeological investigations (Walker and Lovejoy, '85). Although x-rays are routinely used at autopsy to evaluate disease and trauma, detect the presence of foreign material, establish individual identity, or estimate age in a child, they are much less frequently used to estimate age in the adult. This procedure is occasionally used to assess pathological conditions in archaeological skeletons but, again, infrequently to estimate age. Nevertheless, radiographic techniques can be helpful in evaluating adult skeletal age as it is reflected in (1) late epiphyseal union, (2) demineralization, (3) some age-specific disorders, and (4) selected soft tissue changes.

Radiology was first developed nearly a century ago and has since been used widely in clinical medicine to visualize internal structures **in vivo** (Morse, '78). Faced with a scarcity of human skeletal populations of known age, sex, and race, physical anthropologists and physicians were quickly attracted to radiographic technology as a means of documenting human osteological variation within and between populations of all ages. Particularly useful in evaluating skeletal versus chronological age in children, x-rays were used to screen large populations of living subjects in order to develop standards of child growth and development (e.g., Greulich and Pyle, '59; Pyle and Hoerr, '69).

With the creation of the Hamann-Todd, Terry, and other human skeletal collections, as well as the opportunity for osteological research on Korean War dead, American standards based on macroscopic examination were developed and are now routinely used to estimate adult skeletal age (İşcan and Loth, '89). Currently, both macroscopically and radiographically based standards are used in anthropology and medicine to estimate skeletal age. Yet, there has been no systematic assessment of the comparability of results from these two techniques.

In this chapter, we review the radiographic standards that have been, or can be applied to, the estimation of age in the adult skeleton. We also assess the advantages and disadvantages of this method (especially as compared with macroscopy) in interpreting skeletal changes and present current research on the epiphyseal union of the medial clavicle in females, and on the evaluation of the normal chest x-ray.

RADIOGRAPHY VERSUS MACROSCOPY: ADVANTAGES AND DISADVANTAGES

Evaluation of Epiphyseal Union

Because of the scarcity of (especially subadult) skeletal study populations of known age, researchers have utilized radiographs of living subjects to establish standards for epiphyseal union (e.g., Flecker, '32/'33, '42; Greulich and Pyle, '59). Macroscopic standards have been developed using war dead or other limited populations; these standards are frequently biased toward young adult males (e.g., McKern and Stewart, '57). For younger age/sex groups, x-ray studies generally provide the most comprehensive standards for comparison, while for the late teens and early twenties both anatomical and radiographic standards are available.

Several investigators have commented on the variance between radiography and macroscopy in the evaluation of the progress of epiphyseal union; some disagreement persists. Krogman and İşcan ('86) show an example of a proximal humerus which, macroscopically, appears partially fused; radiographically, it appears completely fused, because, they explain, the process of fusion begins in the center and can progress quite far before the external epiphyseal margin is fused. Thus, in this instance, the x-ray would indicate a more advanced state of union than would the naked eye. Drennen and Keen ('53) suggest the radiograph might show union as much as three years earlier than is anatomically apparent; Krogman and İşcan ('86) argue the difference is no more than plus or minus six months.

On the other hand, during the process of fusion there is a buildup of compact bone at the epiphyseal plate. This can appear on x-ray as a line of radiodensity, sometimes referred to as a "persistent line of fusion," which remains visible up to several years after the epiphyseal line appears macroscopically to be completely obliterated (Krogman and İşcan, '86). In this second instance, if this radiodense line is interpreted as evidence of recent fusion, the x-ray might indicate a less advanced state of union than would the naked eye.

One problem in understanding how radiographic and macroscopic observations of epiphyseal union might vary is that not many longitudinal studies have been done; hence, there is some difficulty in knowing how to interpret the later stages of union as seen radiographically. Secondly, there are no systematic studies comparing the two methods. We would agree with Krogman and İşcan ('86) that the macroscopic method is apt to be more accurate, all other factors being equal.

Evaluation of Demineralization

Radiographs are clearly superior to external macroscopic observation when evaluating the level of demineralization or osteoporosity. Although not necessarily superior to an actual cross section of the bone, an x-ray is usually more feasible. This is particularly true, since demineralization occurs in different bones at different rates and it may be advisable therefore to examine several bones.

Evaluation of Age-Specific Pathologies and Soft Tissue Changes

Pathological conditions such as Paget's disease and spondylytic or arthritic changes can be satisfactorily demonstrated either radiographically or macroscopically. Occasionally, however, special views may be needed to observe spondylosis (Eisenberg et al., '80a,b).

Soft tissue changes such as calcification of the aorta can be seen on x-ray but are probably best evaluated anatomically. The extent of changes in the costal cartilages, on the other hand, may be more completely evaluated using an x-ray of the anterior rib cage than macroscopically according to Semine and Damon ('75) and, later, McCormick and Stewart ('88).

When Maceration is Difficult or Contraindicated

Assuming equipment is available, radiography is usually easier and faster than maceration of the remains in forensic cases. It may be preferable to maceration if soft tissue preservation is necessary, such as in the early states of a forensic investigation. When speed is of the essence, such as in a mass disaster, radiography can be used as a primary sorting tool to narrow age/sex possibilities. In some burn cases, radiographs may provide sufficient information to make an age estimate without further potential destruction of either soft or bony tissue. In some forensic cases the medical examiner may not have appropriate experts available to evaluate gross skeletal morphology and may wish to use an x-ray for this reason (McCormick and Stewart, '83).

Parenthetically, taking standard radiographs can prove extremely useful in cases where unidentified remains are to be buried or cremated and the opportunity to make an x-ray identification may occur subsequently. (Unfortunately, Murphy's law dictates that the x-ray taken will either be of the wrong bone or with the wrong view to make the identification.)

Thus, the use of radiographs may be indicated in cases where: (1) the best standards available to evaluate epiphyseal union are radiographic; (2) it is necessary to evaluate demineralization without doing a cross section of several bones; (3) maceration is difficult or contraindicated; and/or (4) expertise in human osteology is unavailable. Radiography should generally not be used unless the observer is trained in this area.

RADIOGRAPHIC METHODS

General Comments

Radiographic methods chosen by the investigator must depend on the type of remains to be examined, on the equipment available, and in some cases the radiographic standard to be used in the study. In general, fewer kilovolts of current are needed for macerated bone relative to fleshed bone, but the exact level is often determined by trial and error.

The density of the bone being examined as well as its archaeological context and resultant mineral uptake/loss will also affect the current and exposure time needed. The best approach is for the investigator to keep a record of techniques and results using their specific equipment (Morse, '78).

Ortner and Putschar ('81) list the following factors to be considered in producing a good radiograph:

1. electric current flow (mA, or milliamperes)
2. energy of current (kV, or kilovolts)
3. time of exposure (usually measured in seconds)
4. distance between x-ray source and film
5. speed of film emulsion
6. density of specimen

Whether one is examining macerated or fleshed bones, the best approach is to use standard views; these are more easily interpreted. Some creative approaches may be required in order to make the bone "assume the correct position," but the result is worth the effort. A reminder is in order here to be sure the film is correctly and completely labeled, including the side and case number; it may prove helpful to insert a scale as well.

A concomitant problem in the application of radiographic standards for epiphyseal union is the lack of uniformity in evaluating stages of union. Some investigators construct the age range for a given stage of union around the entire age distribution of that stage in their sample population; others simply note a median point or use some other percentile, usually the 80th. It is therefore important to know which approach was used in the standard to be applied in any particular case.

Thus, it is clear that the investigator should avoid using standards developed radiographically to interpret macroscopic observations, or vice versa. Furthermore, care should be taken in applying standards to a specific case. For example, if the standard being used gives the age of fusion based on the age by which 50% of a sample population appears fused, the age estimate made by the investigator may need to be broader to allow for ample variation around that median point.

Evaluation of Epiphyseal Union

Although most epiphyses close during the teens and early twenties, a few sites may persist in the open or partly fused state up through the early thirties. Patterns of variation for age and sex have been reported for many of these sites and will be reviewed below. Identification of such unfused or partially fused sites may provide important information about the age of an unknown individual, using appropriate caution regarding the range of human variation, the discrepancies between skeletal and chronological age, the intervention of pathological conditions, and the appropriate application of standards reported in the literature. We focus our attention below on radiographic standards of epiphyseal closure; hence, we include both late teen and adult age groups.

Todd ('30:193) outlined nine stages of epiphyseal union as seen radiographically:

> The first extends to the period when diaphyseal and epiphyseal bone approximate each other but as yet show no intimate relation, the adjacent surfaces being ill-defined and composed of cancellous tissue.
>
> The second is the stage of obscuration of the adjacent bony surface by their transformation into thick hazy zones.
>
> The third stage shows clearing of the haze with appearance of a fine delimiting surface of more condensed tissue shown on the roentgenogram as a fine white line.
>
> The fourth stage exhibits billowing of adjacent surfaces.
>
> In the fifth the adjacent surfaces show reciprocal outlines which are parallel to each other.
>
> In the sixth the gap between adjacent surfaces is narrowed.
>
> The seventh is the stage of commencing union when the fine white billowing outlines break up.
>
> In the eighth stage union is complete, though recent, and appears on the naked bone as a fine red line.
>
> The ninth stage is that of perfected union with continuity of trabeculae from shaft to epiphysis.

It might be possible to observe all of these stages in a longitudinal series, but it is not practical or feasible to discriminate all of them when estimating age in an unknown individual. Most standards reported in the literature use only four stages: (1) epiphysis not present; (2) epiphysis present and unfused; (3) epiphysis partly fused; and (4) epiphysis completely fused. In fact, stage one cannot be discriminated from stage four reliably in a radiograph. Flecker ('42) mentions that in some individuals the "linear shadow" which may persist for several years after actual fusion has taken place, but he nevertheless scores these cases simply as "fusion."

Although published over forty years ago, Flecker ('32/'33, '42) conducted one of the most comprehensive radiographic investigations of epiphyseal union. Done in Australia on a large sample of hospital patients (mostly of European descent), the sample population ranged in age from fetuses of 8.5 weeks to adults 29 years of age. Unlike many other studies, Flecker describes the range of variation he found. For example, he reports the latest age in which he observes unfused or partially fused epiphyses in his samples; he also reports the earliest age in which he observes fused epiphyses, as well as the age at which the majority (50% or more) is fused. Table 7.1, adapted from Flecker ('42), summarizes his results for partially fused epiphyses in males and females. Included in Table 7.1 are results from Galstaun ('30), Jit ('76), and Prasad et al. ('79) on Hindus, Sidhom and Derry ('31) on Egyptians, and Sorg et al. ('85) on Americans.

The clavicle is one of the earliest bones to ossify in humans and one of the last to fuse. Because of its late epiphyseal union at the sternal end, the clavicle can sometimes offer valuable information for estimating age of individuals in their late twenties and early thirties, particularly in combination with other indicators. Although Jit ('76) includes some data from skiagrams, the only two major radiographic studies of the clavicle are by Flecker ('42) on Australian males and females and Sorg et al. ('85) on American females.

The study by Sorg and associates ('85) included 432 normal chest x-rays on 301 female hospital patients aged 14–35. Only clavicles which were 100% visible were accepted. Each clavicle was scored for stage of union:

Stage 1. epiphysis not yet present
Stage 2. epiphysis present and unfused
Stage 3. epiphysis partially fused
Stage 4. epiphysis completely fused

Table 7.2 presents the data on 405 right and 377 left clavicles. Clavicles with formed but unfused epiphyses (stage 2) are seen as early as age 14 and as late as 34. Clavicles with partially united epiphyses (stage 3) are seen virtually throughout ages 15–35. Since one cannot reliably discriminate a fused epiphyseal end (stage 4) from a diaphysis which has not yet formed its epiphysis (stage 1), it is difficult to assign the age of earliest fusion.

These data compare with those reported in Flecker ('42) for males and females. His sample of 321 clavicles from females and 280 clavicles from

TABLE 7.1
REPORTED AGE RANGES FOR STAGES OF EPIPHYSEAL UNION IN MALES AND FEMALES

Epiphysis	Older Age of Partial Fusion		Earliest Age of Fusion		Earliest Age That Majority Are Fused	
	F	M	F	M	F	M
Medial Clavicle	26	25	-	-	18	-
American (Sorg et al., '86)*	35	-	15	-	-	-
Hindus (Jit, '76)*	23	23	22	23	-	-
~~Corked~~ Coracoid	16	19	-	-	13	-
Acromion	16	19	-	-	17	17
Proximal Humerus	20	19	15	16	17	18
Distal Humerus	16	16	13	14	13	16
Egyptian (Sidhom and Derry,'31)	-	-	-	-	-	15
Medial Epicondyle	16	17	10	12	14	16
Egyptian (Sidhom and Derry,'31)	-	19	-	-	-	16
Olecranon Tip	16	17	13	-	14	16
Hindu (Galstaun, '30)	18	-	-	-	-	-
Distal Ulna	22	23	15	17	17	19
Egyptian (Sidhom and Derry,'31)	-	-	-	15	-	18
Hindu (Galstaun, '30)	-	-	14	-	-	-
Hindu (Prasad, '79)*	-	-	16	-	-	-
Proximal Radius	19	20	13	14	14	16
Distal Radius	20	23	15	17	18	19
Egyptian (Sidhom and Derry,'31)	-	-	-	16	-	19
Hindu (Galstaun, '30)	-	-	14	19	-	-
Hindu (Prasad, '79)*	>18	-	16	-	>18	-
First Metacarpal	15	17	13	14	15	18
Egyptian (Sidhom and Derry,'31)	-	-	-	-	-	16
Hindu (Galstaun, '30)	-	-	14	-	15	-
Distal Metacarpals 2-5	18	20	14	16	16	18
Hindu (Galstaun, '30)	18	-	-	-	14	-
Hindu (Prasad, '79)*	16	-	-	-	16	-
Proximal 1st Carpal Phalanx	15	19	14	15	15	17
Proximal Carpal Phalanges 2-5	16	19	13	14	14/15	18
Distal 1st Carpal Phalanx	15	19	13	14	13	17
Distal Carpal Phalanges 2-5	15/16	17	14/15	14	14/15	16/17
Union: Ilium, Ischium, Pubis	16	17	10	13	13	15
Iliac Crest	22	22	17	-	21	21
Ischium	24	21	-	-	21	20
Femoral Head	18	20	13	14	14	17
Greater Trochanter	16	17	14	15	14	16
Middle 2nd Tarsal Phalanx	18	16	12	15	15	17
Distal 1st Tarsal Phalanx	18	16	13	15	15	17
Distal Tarsal Phalanges 2-4	18	16	12	15	13	15

Unless indicated by *, results are those reported in Flecker ('42), Table LXI. Unless otherwise referenced, results are those of Flecker ('42).

TABLE 7.2
AGE DISTRIBUTION OF THE STAGES* OF UNION OF THE MEDIAL CLAVICLE IN FEMALES

		Right (%) Stage of Union					Left (%) Stage of Union		
Age	**N**	**2**	**3**	**1/4**	**Age**	**N**	**2**	**3**	**1/4**
14	2	50	-	50	14	3	-	-	100
15	11	9	27	64	15	9	11	33	56
16	14	50	14	36	16	12	33	42	25
17	12	50	17	33	17	13	31	15	54
18	12	25	50	25	18	11	55	18	27
19	18	28	17	56	19	15	40	13	47
20	16	13	19	69	20	15	7	20	73
21	18	6	6	89	21	18	-	22	78
22	25	8	8	84	22	24	8	13	79
23	21	10	10	81	23	22	5	5	91
24	21	5	14	81	24	20	5	15	80
25	21	-	5	95	25	18	-	-	100
26	22	-	18	82	26	19	-	5	95
27	20	-	-	100	27	18	-	6	94
28	22	-	18	82	28	25	-	12	88
29	32	3	16	81	29	29	-	21	79
30	25	4	16	80	30	21	5	14	81
31	25	8	12	80	31	24	4	8	87
32	20	-	5	95	32	19	5	-	95
33	15	-	13	98	33	13	-	15	85
34	17	-	-	100	34	14	7	-	93
35	16	-	6	94	35	15	-	13	87
N	405					377			

*Stages of union: 1, nonunion without epiphysis; 2, nonunion with separate epiphysis; 3, partial union; 4, complete union.

males shows stage 2 as early as age 11 in both sexes; not yet fused epiphyses are found as late as 25 in males and 26 in females.

The medial end of the clavicle is extremely variable in morphology and, apparently, in the timing of fusion. McKern and Stewart ('57), commenting on their macroscopic study of males, say that the epiphysis may never form in some individuals, but that there is only a "glazing over" of the diaphyseal end. They further comment that in some individuals the epiphysis forms but may never fuse. Finding individuals 35 years old with stage 3 epiphyses in the study by Sorg et al. ('85) tends to corroborate this suggestion. Thus, in using an x-ray to evaluate clavicular fusion, it is possible to find stage 3 epiphyses as late as age 35 (at least in females) and possibly later. Furthermore, clavicles that appear radiographically to be stage 4 may actually be stage 1 and can be found all through the teens and twenties.

The medial clavicle is not the only epiphysis which persists in some individuals. Flecker ('42) comments that persistent epiphyses may occasionally be found at the tips of some vertebral processes and rarely at the base of the fifth metatarsal and the posterior tubercle of the calcaneus.

Fusion of a number of other epiphyses is frequently delayed into the mid and late twenties, as seen radiographically. Girdany and Golden ('52) comment that the secondary centers in the vertebrae (i.e., spinous processes, transverse processes, and lumbar mammillary processes) may not fuse until age 25; likewise the heads and tubercles of ribs. They also state that the fusion of the sacral bodies may be delayed until age 30.

Evaluation of Demineralization

The process of demineralization and trabecular involution of bone during adulthood is known to occur throughout the human species and in prehistoric as well as contemporary populations (Exton-Smith, '70; Perzigian, '73; Pawson, '74; Dequeker, '75; Rundle and Dollimore, '76; Riggs et al., '80). Acceleration of research on osteoporosis in the past decade has resulted in a refinement of knowledge about age- and sex-specific patterns of bone tissue loss (Riggs and Melton, '86). In general, bone mass increases in the skeleton until age 30 when it becomes stable for several years. Eventually, women lose about 35% of their cortical and 50% of their trabecular bone mass; men eventually lose about 23% of their cortical and 33% of their trabecular bone mass. In men the process is rather even across years, while in women it is accelerated after menopause. Although there are some population patterns (e.g., blacks tend to have greater initial bone density and Eskimos tend to have accelerated loss), the age and sex patterns for the species generally supersede any population tendencies.

Information about age and sex patterns of bone mass loss must be applied with caution when estimating skeletal age. Most research on demineralization has focused on evaluating its extent in living individuals and comparing that to a reference population base of "normals," controlling for age and sex. The fact is that, although osteoporosis occurs in most humans as a consequence of the aging process, it may occur in middle age or be delayed until very old age. Thus, the range of variation in demineralization for any specific age is very great. The focus in medicine has been on diagnosing osteoporosis when age and sex are known, rather than estimating age when bone density (and perhaps sex) are known.

In using radiographs to assess osteoporosis, both observer variation and variation in radiographic technique (such as rotation of the bone or angulation of the tube) can hamper the results (Cockshott and Park, '83; Ott et al., '83). A number of methods are currently used to observe relative bone density, including the assessment of trabecular trajectories, measurement of cortical bone thickness, calculation of cortical to medullary thickness ratios, and photodensitometric evaluation.

Now-classic descriptions by Schranz ('59) and Acsádi and Nemeskéri ('70) trace the age-related changes in the architecture of the proximal humerus and femur. Illustrating these changes with radiographed thin-section views (Figures 7.1 and 7.2), Acsádi and Nemeskéri propose six phases for each, which are presented below. Changes occur in the height of the apex of the medullary cavity, the structure of trabecular bone, cavity formation, and the thinning of the cortex. These changes for the humerus are as follows (Figure 7.1):

Phase I: The apex of the medullary cavity well below surgical neck; trabeculae exhibit radial systems (ogival arrangement appears in smaller portions) (mean age 41.1, s.d. 6.60, actual range 18–68, calculated range at 3 s.d. 21.3–60.9).

Phase II: Medullary cavity extending proximally, apex at height of surgical neck or above, to one-quarter of the distance to the epiphyseal line. Trabecular system more fragile and in part exhibits ogival structure (mean age 52.3, s.d. 2.51, actual range 24–68, calculated range at 3 s.d. 44.8–59.8).

Phase III: Apex of the medullary cavity may reach the epiphyseal line; trabecular system is ogival. Columnar structure appearing along the cortex at the border of diaphysis and epiphysis while individual trabeculae become thicker (mean age 59.8, s.d. 3.59, actual range 37–86, calculated range at 3 s.d. 49.0–70.5).

Phase IV: Apex of medullary cavity reaches the epiphyseal line or higher; trabecular system shows gaps in the major tubercle, and the columnar structure along both sides of the medullary cavity is occasionally breached (mean age 56.0, s.d. 1.84, actual range 19–79, calculated range at 3 s.d. 50.5–61.6).

Phase V: 2 mm–5 mm lacunae develop in the major tubercle. Apex of the medullary cavity ranges above the epiphyseal line. Only discon-

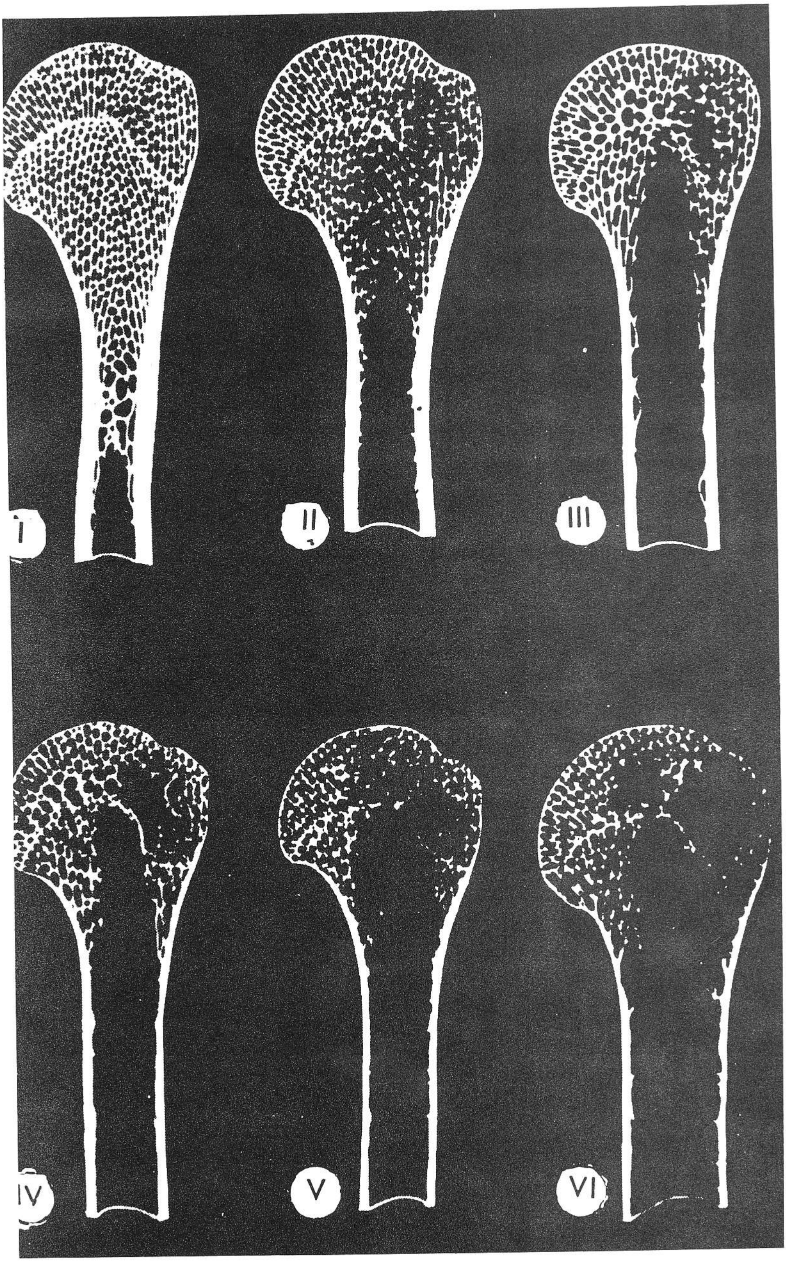

Figure 7.1. Phases of structural changes in the spongy substance of the proximal epiphysis of the humerus (Acsádi and Nemeskéri, '70, Figure 20).

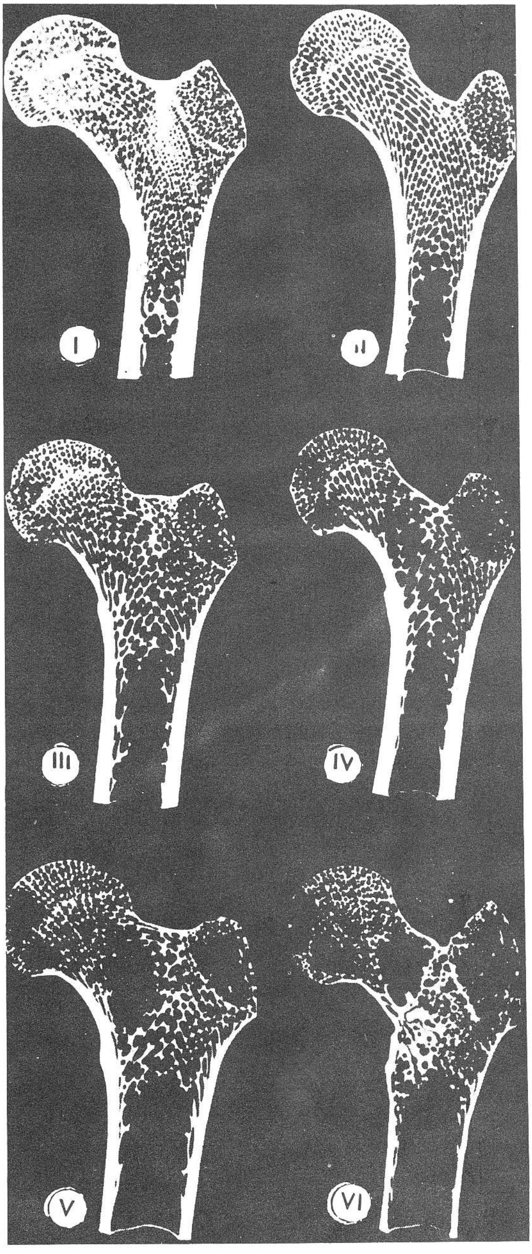

Figure 7.2. Phases of structural changes in the spongy substance of the proximal epiphysis of the femur (Acsádi and Nemeskéri, '70, Figure 22).

tinuous remains of the columnar structure appear on both sides of the medullary cavity (mean age 61.0, s.d. 2.05, actual range 40–84, calculated range at 3 s.d. 54.9–67.2).

Phase VI: Diameter of the cavity formed in the major tubercle exceeds 5 mm and may reach the cortex. Trabecular system in the head is intensely rarefied; the trabeculae become cobweb-like and torn. Apex of the medullary cavity extends upward and merges with the cavity formed in the major tubercle; there are only remains of the spongiosa. The cortex becomes thin and transparent. The anatomical features on the face of the proximal epiphysis are atrophied and the cortical substance becomes fragile (mean age 61.1, s.d. 3.39, actual range 38–84, calculated range at 3 s.d. 50.9–71.2).

There are six similar phases described by Acsádi and Nemeskéri ('70) for the proximal femur (Figure 7.2):

Phase I: Apex of the medullary cavity well below the lesser trochanter; truss texture of trabeculae is thick; individual features hardly distinguishable (mean age 31.4, actual range 18–52, no s.d. given).

Phase II: Apex of the medullary cavity reaches or surpasses the lower limit of the lesser trochanter; at the border of diaphysis and epiphysis and in the neck, trabecular pattern of fasciculus trochantericus and fasciculus arciformis begins to rarefy. Incipient rarefaction is most marked in the medial part of the neck (mean age 44.0, s.d. 2.60, actual range 19–61, calculated range at 3 s.d. 36.2–51.8).

Phase III: Apex of the medullary cavity reaches the upper limit of the lesser trochanter. Rarefaction of the trabecular pattern in the medial part of the neck is marked, individual trabeculae become thinner and are breaking down. The bony structure becomes loose also in the greater trochanter (mean age 52.6, s.d. 1.86, actual range 23–72, calculated range at 3 s.d. 47.0–58.2).

Phase IV: Apex of the cavity extends over the upper limit of the lesser trochanter. A delimited cavity of 5–10 mm diameter appears in the medial part of the neck. Distinct rarefaction at the border diaphysis and epiphysis, in the greater trochanter and in the head below fovea capitis (mean age 56.0, s.d. 2.32, actual range 32–86, calculated range at 3 s.d. 49.0–63.0).

Phase V: Only cellular remnants of the original trabecular system appear in the neck. A delimited cavity of about 3 mm diameter is formed in the greater trochanter. Formation of cavities in the head beneath fovea capitis and at the medial and lateral borders. Apex of the medullary cavity extends beyond the upper limit of the lesser trochanter (mean age 63.3, s.d. 2.17, actual range 38–84, calculated range at 3 s.d. 56.8–69.9).

Phase VI: Cavities formed in the neck and greater trochanter have enlarged (more than 10 mm and 5 mm diameter, respectively). Cavities in the medial part of the neck merge with the medullary cavity as a result of a further loosening of the bony structure, and only fractions of the original trabecular structure remain along the cortex. Cortex becomes thin and transparent, relief of outer surface of bone atrophies (mean age 67.8, s.d. 3.64, actual range 25–85, calculated range at 3 s.d. 56.9–78.7).

These stages developed by Acsádi and Nemeskéri ('70) are based on a sample size of 105. The number of males and females is not mentioned and there is no attempt to describe sexual dimorphism. This phase approach is meant to be used with other macroscopic age indicators in order to estimate age. The reader should note the wide range of age variation within each of the phases.

More recently, Lovejoy et al. ('85), and Walker and Lovejoy ('85), have used radiography in order to estimate age in skeletal populations. Radiographs of the proximal femur, proximal humerus, clavicle, and calcaneus of 130 individuals from the Hamann-Todd Collection were visually seriated on the basis of trabecular involution to estimate age (Walker and Lovejoy, '85). The clavicle series provided the most consistent relationship to age in both sexes. Figure 7.3 presents the radiographs of the clavicle series corresponding to the following eight phases:

Phase 1 (18–24): Posterior cortex is prominent and thick. Entire medullary canal is filled with dense trabeculae, which are fine-grained and densely packed and tend to align in parallel plate-like layers. Posterior cortex is fine grained but not necessarily dense. Both sternal and lateral metaphyses are filled with fine-grained trabeculae (Figure 7.3A).

Phase 2 (25–29): Phase 2 is similar to phase 1 but with slight evacuation of metaphyses. Posterior cortex shows little change. There is slight coarsening of medullary trabeculae. Anterior cortex shows slightly increased trabecularization. No increase in translucency is seen (Figure 7.3B).

Phase 3 (30–34): Here there is further evacuation of metaphyses, which contain more moderately grained and fewer trabeculae. There is slight thinning of posterior cortex but not scalloping. Medullary canal is

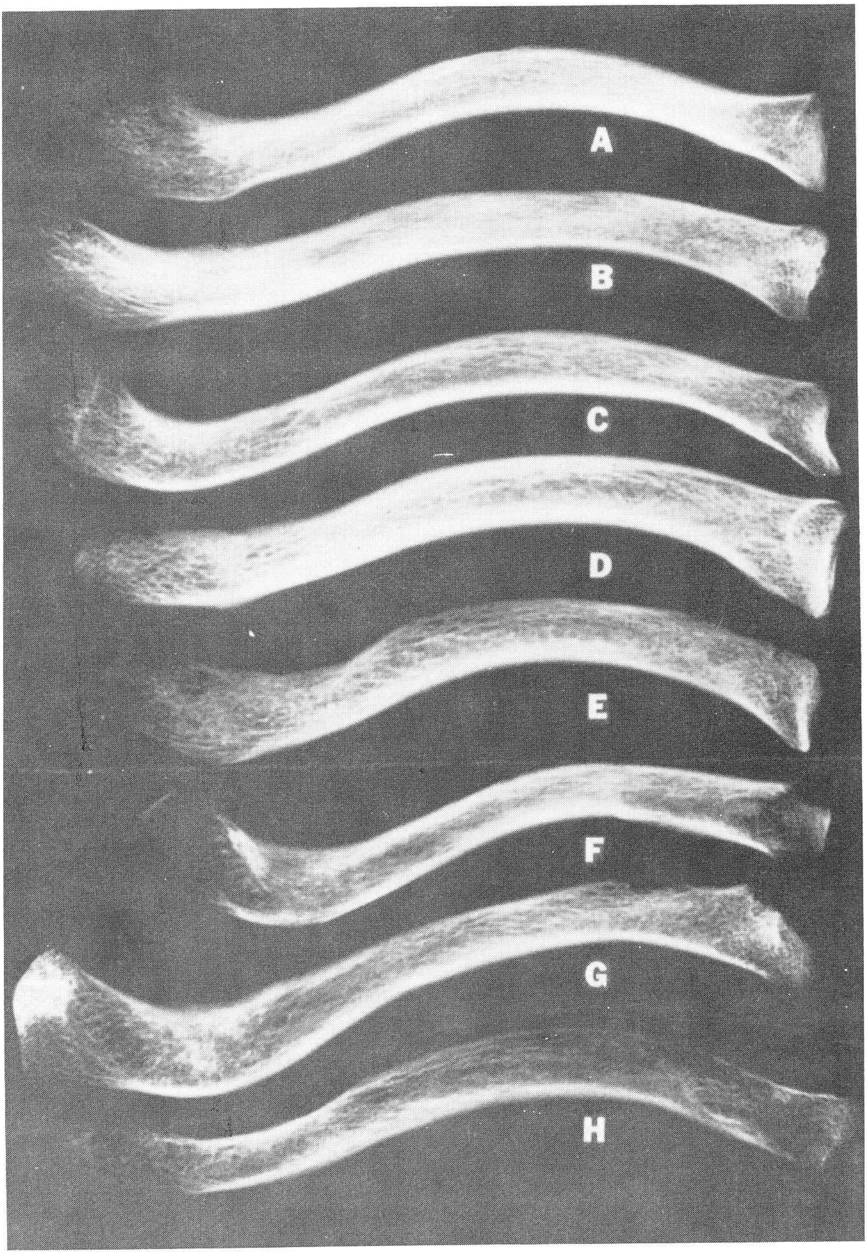

Figure 7.3. Radiographic standards for seriation of the clavicle. (A) Phase 1, 18–24 years, (B) Phase 1, 25–29 years, (C) Phase 1, 30–34 years, (D) Phase 1, 35–39 years, (E) Phase 1, 40–44 years, (F) Phase 1, 45–49 years, (G) Phase 1, 50–54 years, (H) Phase 1, 55+ years (Walker and Lovejoy, '85).

still filled, but dense, parallel, plate-like pattern is significantly less evident (see phase 1) (Figure 7.3C).

Phase 4 (35–39): Significant reduction of posterior cortex is evident, especially at sternal and lateral extremities. Continued evacuation of metaphyses and coarsening of trabeculae are seen. Little or no plate-like pattern of trabeculae is found anywhere in bone. There is distinct increase in translucency (Figure 7.3D).

Phase 5 (40–44): Sternal and lateral metaphyses may contain only coarse trabeculae. There is definite coarseness to those in medullary canal. Demonstrable thinning of posterior cortex at sternal and lateral ends and significant thinning of anterior cortex, with trabecularization in evidence, are seen, as is general enlargement of medullary lumen (Figure 7.3E).

Phase 6 (45–49): Phase 6 is a continuation of phase [illegible] trends but slightly accelerated. Overaging is possible. General increase in translucency indicates systemic bone loss (Figure 7.3F).

Phase 7 (50–54): Very coarse trabeculae are the key feature. There is significant bone loss but without evacuation of central medullary lumen. Cortex is reduced at all points (Figure 7.3G).

Phase 8 (55+): It is difficult to discern phase 8 from the previous phase because of biological variation in individual rate of bone loss. Seriation is on same criteria as phase 7, with older ages assigned to greatest trabecularization and translucency. Generally, there is great reduction in both cortex and trabeculae, which are very coarse or absent. Older members present extreme reduction of cortex approaching cortical shell condition. It is very translucent. Sternal and lateral metaphyses may lack any significant trabeculae. Cortical trabecularization of anterior cortex may be extreme. There is marked cortical scalloping along medullary lumen (Figure 7.3H).

Fujita ('68) measured midshaft cortical thickness in the clavicle on chest x-rays of 197 males and 168 females aged 10–80. Femoral and metacarpal cortical thickness were also measured, but the clavicle showed the most dramatic relationship to age. Fujita suggests using this to estimate age with chest x-rays. Unfortunately, the published graph is unusable. The results of this study indicate, however, that this avenue of research might be of use in estimating age.

Age-Specific Pathological Conditions and Soft Tissue Changes

Most standards of skeletal change are based on the "normal" population. However, in rare cases, the presence of age-specific pathologies may provide additional clues to the age of an individual. For example, Paget's disease and vertebral osteoarthritis generally indicate an age of 50 or more (Price, '75).

McCormick and Stewart ('88) have recently continued their investigation of age changes as reflected in the ossification of costal cartilages. They suggest that, in general, by the age of 25 virtually all individuals will show a trace of costal cartilage ossification; by the age of 50, ossification frequently becomes marked. Based on a sample size of 1965 individuals over the age of 14, McCormick and Stewart ('88) describe the progressive age and sex-related changes they observe with a radiograph of the plastron. The plastron, removed at autopsy for x-ray, consists of the (still articulated) terminal 2–6 cm of the sternal rib ends, the costal cartilages, the sternum, and the medial clavicles. The authors conclude that "specific age ranges are not easy to arrive at for an individual case" (McCormick and Stewart, '88:117). They outline an 8-level scoring system and additional qualitative observations for estimating male and female ages. Tests of this method suggest it allows age determination within 5 years of real age in only 55% of cases; age estimates for 95% of cases are within 25% of real age. The reader is referred to their publication for the details of this scoring system.

Although the focus of radiographic age estimation is on the skeleton, some soft tissue changes seen in x-rays may suggest an unknown individual's age range. For example, calcification of the aorta generally does not begin until after the age of 40 or 50 and is progressive after that.

Evaluation of Chest X-Rays

In fleshed remains, when other age indicators are unavailable, a regular chest film may be used to obtain a rough age estimate. This x-ray provides data on many organ systems at once; a single P–A view, for example, exposes 99% of pathologies that affect the chest (Eisenberg et al., '80b). They caution, however, that radiologists frequently disagree when asked to discriminate normal from degenerative dorsal vertebrae.

Gross et al. ('85), noting that some radiologists informally assert their ability to estimate age from chest x-rays, tested the ability of four radiologist observers to determine age for 171 x-rays. They were asked to estimate the correct decade (i.e., 20–29, 30–39, etc.). As a group they came within 10 years of the real age a minimum of 57% of the time; the more experienced observers, surprisingly, did not produce the higher scores. They further note that in order to estimate age, an observer must assume the subject is "normal" with respect to the various age-related changes. Gross and associates do not offer any specific guidelines for the estimating procedure but state that "the actual method for estimating age is not easily explained (Gross et al., '85:145). While many factors are probably taken into account (e.g., arthritis, bone mineralization, heart size, lung inflation, etc.), the process seems largely subconscious, and 'gestalt' likely plays an important role."

In general, based on the literature reviewed for this chapter, age estimation by x-ray of individuals above the pediatric range has not been particularly successful in objective terms, producing rather wide age-range estimates of a decade or more, and being correct only slightly over the majority of the time. Major problems of interobserver variation and variability in methods consistently hamper results (Cockshott and Park, '83; Gross et al., '85). Even when more objective and complex approaches are taken (e.g., McCormick and Stewart, '88), the results are not greatly improved.

It is in this light that we present the following survey of age-related changes in the normal chest x-ray, supporting the use, when necessary, of subjective age determination into broad generational categories. Assuming application to individuals in whom epiphyseal union has occurred, the following other criteria are available for use: general bone density, degenerative changes in the spine, aortic calcification and tortuosity, and overpenetration (seen in the living person as hyperaeration).

Given that the deceased is normal for their age group, and that sex is known, it is possible for the radiologist or other trained observer to subjectively estimate age within 10–20 years of real age using a male and female series of "normal" films for reference. The goal is to then place the individual x-rayed broadly within the following ranges: 20–39, 40–59, and 60+.

Bone density decreases with age more rapidly in postmenopausal women than in men (Riggs et al., '81). Bone-density reduction does not generally become noticeable on x-ray, however, until after the age of 40 in both sexes. Although cortical thickness indicates bone density (e.g., Murphy and Gantner, '82; Notman et al., '87), it is more difficult to apply as a criterion than general bone density. Scoring an x-ray subjectively as having no significant loss in density, some loss, and significant loss allows one to place the x-ray into one of the three broader age categories, 20–39, 40–59, and 60+, respectively. Figure 7.4 illustrates representative chest films of normal individuals of both sexes.

Degenerative changes in the spine also occur with increased frequency during aging. An x-ray can be graded as to the degree of involvement of vertebrae: none or mild (20–39), moderate (40–59), and severe (60+).

The aorta uncoils and calcifies with advancing age. After the age of 60 (in the non-diabetic individual), aortic dilatation is often present along with variably extensive calcification and uncoiling. In the middle years, 40–59, there is an intermediate phase with uncoiling and some calcification. Below the age of 40 the aorta tends not to be calcified or particularly prominent.

Hyperaeration, seen in a deceased subject as apparent overpenetration, generally occurs with age. It is more common when there is a history of smoking and may be more likely when there is decreased bone density, increased kyphosis, and loss of chest flexibility and pliability—all occurring with aging. Although not as definitive as the other criteria discussed above, the appearance of overpenetration suggests an age of 60+.

The representative radiographs of the normal male and female population are presented here and the criteria discussed. We feel that the use of the above criteria by an experienced radiologist will permit estimation of age into broad categories. Although this approach should not be taken in the presence of more reliable data (e.g., macroscopic inspection of the sternal end of the rib [Loth and İşcan, '89] or histological osteon counting [Stout, '89]) and should not be attempted by an inexperienced observer, it may be appropriately applied in some cases.

A recent preliminary study took the approach of evaluating several aspects visible in a small sample of chest x-rays and comparing them to each other and to chronological age (Barrès et al., 1989). Using a scale of 1 to 5, this group scored changes in bone demineralization (BD), manubrium-corpus fusion (FM), the sternal end of the rib (RC), cartilage mineralization (CM), and the costal notches of the sternum (CS). They calculated a regression formula as follows:

$$\text{Age (yrs)} = 2(0.89\text{CS} \times 0.03\text{FM} \times 0.03\text{RC} \times 0.03\text{CM} \times 0.02\text{BD})$$

They found that their results were considerably better than those of McCormick ('80). Although this method did not approach the accuracy obtained by direct morphological assessment of the sternal end of the rib

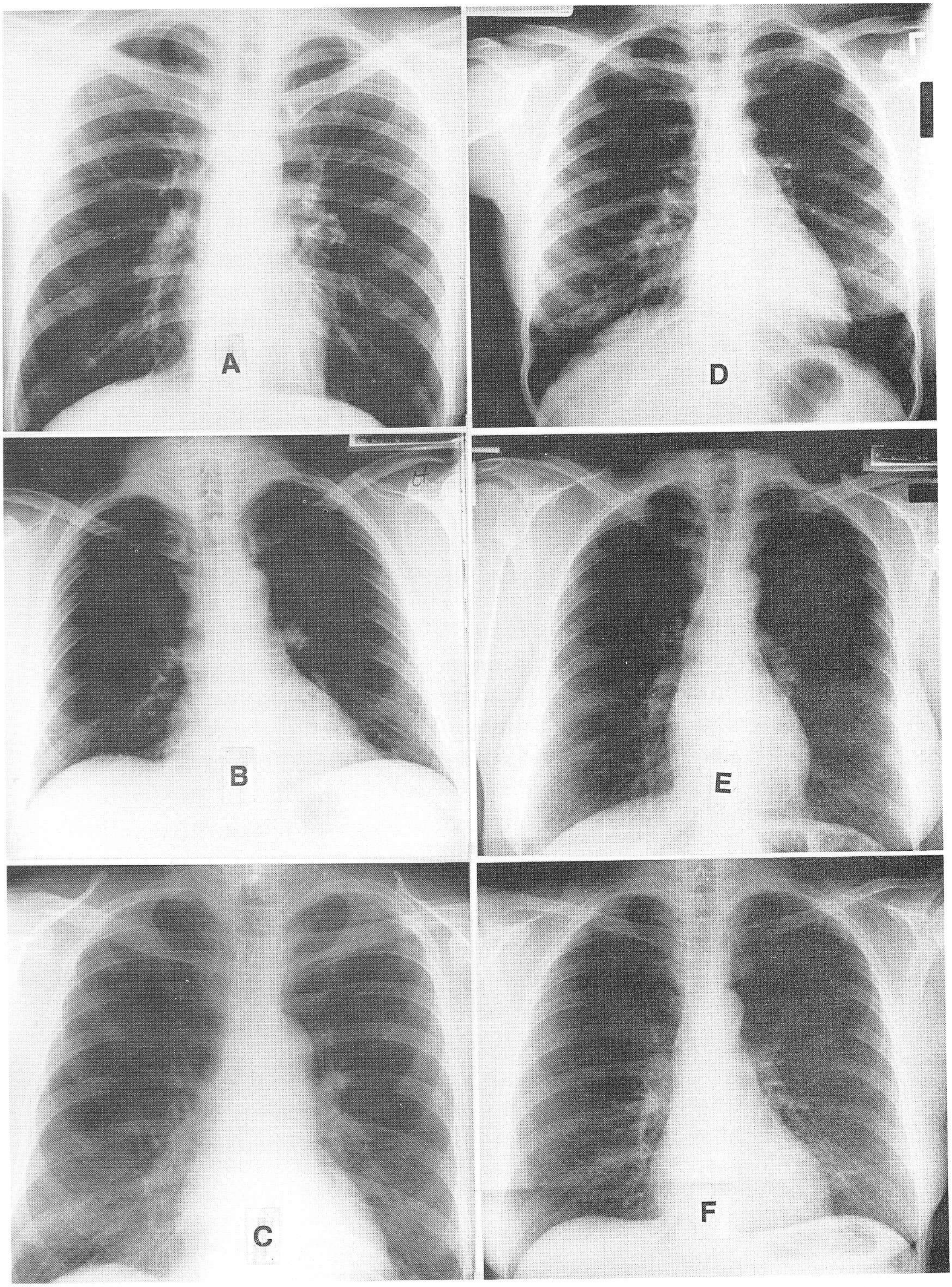

Figure 7.4. Representative chest films of normal individuals: (A) male—age 20; (B) male—age 40; (C) male—age 60; (D) female—age 20; (E) female—age 40; (F) female—age 60.

alone using the phase method of İşcan et al. ('84, '85), they state that radiography has the advantage of being applicable when skeletonization of remains is not possible.

This multifactorial analysis appears to be a promising radiological method of aging. However, there are some problems that must be addressed. First, it must be kept in mind that it is a preliminary attempt using only 41 males and 10 females. The standards of assessment are not adequately described. For example, they do not indicate which rib end is depicted. This can be a source of error since there is a certain amount of intercostal variation. Furthermore, despite the fact that there are definite sex differences in the aging process in the rib and costal cartilage, they present only one set of standards. Addressing these issues and testing them on a much larger sample may lead to the development of an excellent radiographic technique.

CONCLUSIONS

A number of factors can operate to confound the estimation of age using radiographs. First, the discrepancy between biological and chronological age can be remarkable in some individuals resulting in over- or underaging remains. Second, the application of standards reported in the literature frequently depends on the replication of particular techniques, on a minimum of interobserver error, and on experienced interpretation. Third, each case presents its own idiosyncrasies calling for the use of one technique over another, or a certain combination of approaches. Thus, one must approach each case with caution and a certain amount of humility.

We conclude with a quote from Meindl and Lovejoy ('85): "No single skeletal indicator of age at death is ever likely to accurately reflect the many factors which accumulate with chronological age, each of which can contribute valuable information to the age estimate." Radiographic methods can often be of assistance in the estimation of age in specific instances calling for the evaluation of epiphyseal union, bone density, and certain other age-related changes in those cases where macroscopy is contraindicated.

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