William F. McCormick,[1] *M.S., M.D. and*
John H. Stewart,[2] *M.A., M.D.*

Age Related Changes in the Human Plastron: A Roentgenographic and Morphologic Study

REFERENCE: McCormick, W. F. and Stewart, J. H., **"Age Related Changes in the Human Plastron: A Roentgenographic and Morphologic Study,"** *Journal of Forensic Sciences,* JFSCA, Vol. 33, No. 1, Jan. 1988, pp. 100-120.

ABSTRACT: Characteristic changes that can be demonstrated on roentgenograms occur with increasing age in the plastron (chest plate) of humans. These alterations include progressive ossification in the costal cartilages (located characteristically in the sternal rib end, centrichondrally, and peristernally—often with sex and age distinctive patterns), maturation of the newly formed bone with trabeculation formation, loss of the smooth contour of the costo-manubrial junction, cupping of rib ends, osteoporotic changes, and arthritic changes in the sternal head of the clavicles. The sequence of development of these alterations has been examined by X-ray of 1965 cadavers of 15 years of age or over and correlated with the gross bone and cartilage morphology changes in many cases. This technique allows for age determination within 5 years of real age in 55% of cadavers and within 25% of real age in 95% of all cadavers. The greatest departures from real age are in the over-60-year groups. The same roentgenograms can allow for correct sex prediction in 99% of the population.

KEYWORDS: chest plate, costal cartilages, sternum, clavicle, aging, sex, plastron

In our continuing work on age, race, sex, and disease related changes in the human chest plate area (plastron), we have come to recognize a number of morphologic features that are related to age and can be easily seen on the plastron X-ray and on the gross bone and cartilage specimens [*1-6*]. Detailed evaluation of a large number of high-quality roentgenograms of the plastron and, in many cadavers, visual examination and comparison of the defleshed bones and cartilages with the roentgenograms have allowed us to develop a number of criteria for age estimation that have proven to be reliable. The techniques employed are easy to accomplish and to teach, are relatively inexpensive, and give a permanent, easily stored record.

Materials and Methods

The plastron, or chest plate, consisting of the terminal 2 to 6 cm of the sternal rib ends, the costal cartilages, the sternum and sternal head of the clavicles with their associated soft

Presented in part at the 38th Annual Meeting of the American Academy of Forensic Sciences, New Orleans, LA, 10-15 Feb. 1986. Received for publication 17 April 1987; accepted for publication 20 May 1987.

[1]Professor of pathology and chief, Division of Forensic Pathology, East Tennessee State University College of Medicine, Johnson City, TN, and clinical professor, University of Texas Medical Branch, Galveston, TX.

[2]Staff pathologist, St. Mary Hospital, Port Arthur, TX, and clinical assistant professor of pathology, University of Texas Medical Branch, Galveston, TX.

tissues, was removed at the time of autopsy from 1965 cadavers of known age, race, and sex (Table 1) and X-rayed in a closed cabinet unit (Faxitron 43805: Hewlett-Packard) at 25 to 30 kV for 1.8 to 2.2 min with Kodak X-Omat TL film "Ready Pack" according to the material previously reported [*1–6*]. Two hundred and thirty-six of these chest plates were then processed to remove soft tissues and the bones and intact costal cartilages examined and compared with their corresponding roentgenograms (Fig. 1). Portions of 49 other plastrons were removed, fixed in 10% neutral buffered formalin, decalcified in 5% formic acid, processed for paraffin embedding, cut, and stained for light microscopy. A final group of 162 cadavers had their clavicles removed, defleshed, and examined by both X-ray and visual inspection for degenerative changes of their sternal ends.

The roentgenograms and, when available, the osseous specimens were examined for location, pattern, density, and extent of costal cartilage ossification, the amount of osteoarthritic (degenerative) changes in the sternal head of the clavicles, the contour of the costo-manubrial junction, and flaring ("cupping") of the sternal rib ends. In addition, nonmetrical traits—individual traits such as sternal foramina, epi- (supra-)sternal bones, duplication of ribs or costal cartilages were recorded. These data, together with data from the clinical and complete autopsy examinations, were entered into a microcomputer (Macintosh Plus) database (OverVUE from ProVUE Development Corporation) and used to generate the tables and to document the conclusions set forth in this paper. Values for each parameter studied were recorded for a subseries of 863 cases (most recently collected) and criteria for aging from chest plate roentgenograms were generated from this subseries. A rapid age screening was subsequently performed on 929 cases, none of which were included in the above 863 case analysis.

Results

Costal Cartilage Ossification

Microscopic examination of multiple specimens confirmed the bony nature of the changes seen on X-ray and by gross examination. This new bone developed both peripherally (subperichondrially, see Fig. 2) and centrally, deep within the costal cartilage. Marrow development was common (Fig. 3).

First Costal Cartilage

The first costal cartilage ossifies at a rate and in a pattern distinctively different from the lower costal cartilages. Far more often it becomes completely enveloped in a bony "case" that appears solid on X-rays (Fig. 4), although a core of cartilage actually persists (Fig. 1). Typically, ossification first begins in the mid or late twenties as small globular ossifications along the inferior (caudal) border of the cartilage of the rib end (Fig. 5). With increasing age, the ossifications enlarge and coalesce, proceeding from rib end to sternal end, until a solid, trabeculated appearance with loss of fusion lines results, usually in the fifties. Heavy ossification occurs somewhat more rapidly in men than in women, particularly in the so-called "type F" males [*6*]. Table 2 gives the amount of ossification from 0 (none) to 4+ (complete) by age and sex in our study population, and Fig. 6 illustrates this sequence.

Second Through Seventh Costal Cartilages

Ossification occurs in peristernal, rib end, and central locations, with each location having a somewhat different relationship to age and sex; the least sex-predictive ossifications occur in the peristernal location (Fig. 7). Peristernal ossification can be first seen in a few cadavers in the mid-teens and increases in prevalence, density, and extent with increasing

TABLE 1—*Study population by age, race, and sex.*

	White		Black		Hispanic		Oriental		Indian		Amerind		All		
Age	M	F	M	F	M	F	M	F	M	F	M	F	M	F	All
15-19	22	1	9	5	6	6	2	0	0	0	0	0	39	12	51
20-24	51	21	18	8	10	3	0	1	0	0	0	0	79	33	112
25-29	56	26	12	11	5	5	2	0	1	1	0	0	76	43	119
30-34	50	21	31	14	24	5	0	0	0	0	0	0	105	40	145
35-39	45	24	24	12	17	6	0	0	0	0	0	0	86	42	128
40-44	53	18	19	6	9	2	0	0	0	0	0	0	81	26	107
45-49	63	31	22	15	8	11	0	1	0	0	1	0	94	58	152
50-54	74	45	36	17	18	8	0	0	0	0	0	0	128	70	198
55-59	106	51	35	23	12	8	0	0	0	0	0	0	153	82	235
60-64	87	69	34	30	6	7	0	0	0	0	0	0	127	106	233
65-69	94	49	22	17	6	3	0	0	0	0	0	0	122	69	191
70-74	64	19	27	14	8	3	0	0	0	0	0	0	99	36	135
75-79	44	17	11	7	8	2	0	0	0	0	0	0	63	26	89
80-84	24	12	12	6	2	5	0	0	0	0	0	0	38	23	61
85-89	11	2	6	0	1	1	0	0	0	0	0	0	18	3	21
90-94	6	1	2	0	0	0	0	0	0	0	0	0	8	1	9
95-99	1	1	1	0	0	0	0	0	0	0	0	0	2	1	3
All	851	408	321	185	140	75	4	2	1	1	1	0	1318	671	1989

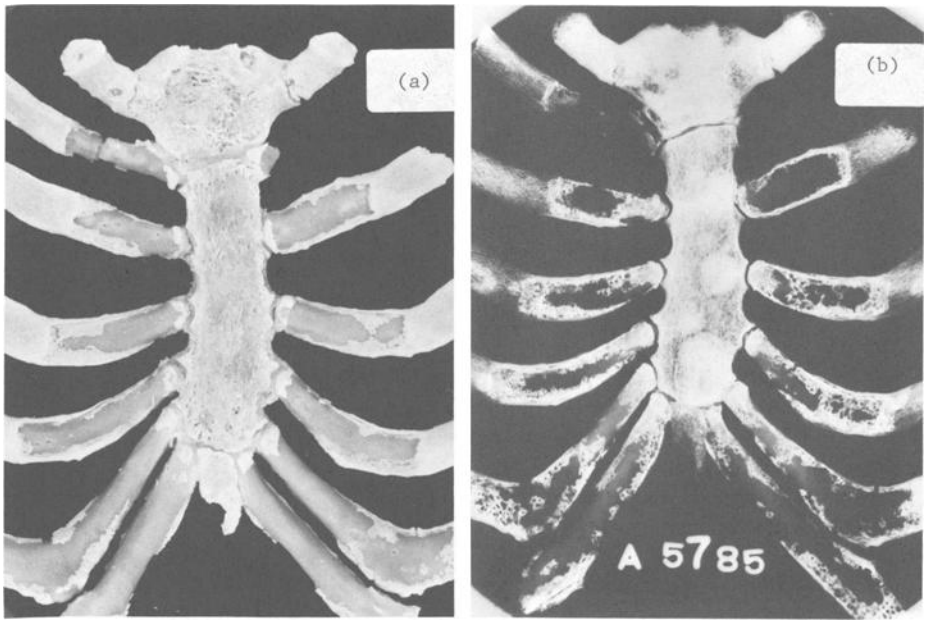

FIG. 1—(a) *Defleshed specimen of the plastron of a 47-year-old man.* (b) *X-ray of chest plate of the man illustrated in Fig. 1a. Note the close correlation between the X-ray pattern and the surface of the gross specimen. The X-ray demonstrates a number of additional features not evident on the gross specimen, including a number of osteoblastic metastases.*

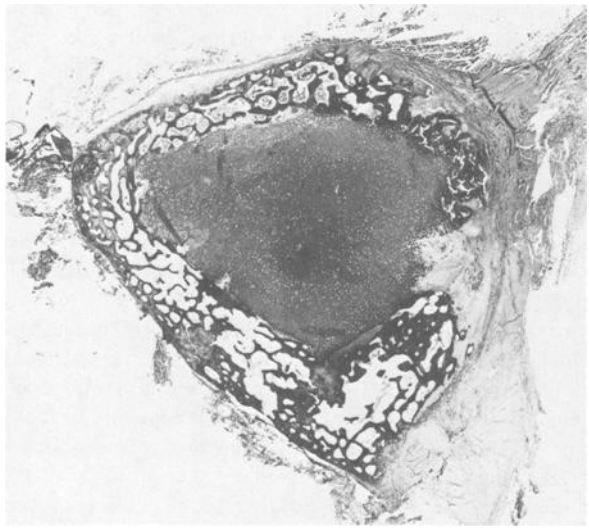

FIG. 2—*Histologic preparation of a first costal cartilage showing peripheral (subperichondrial) new bone formation with a central cartilagenous core (hematoxylin and eosin [H&E]; ×6).*

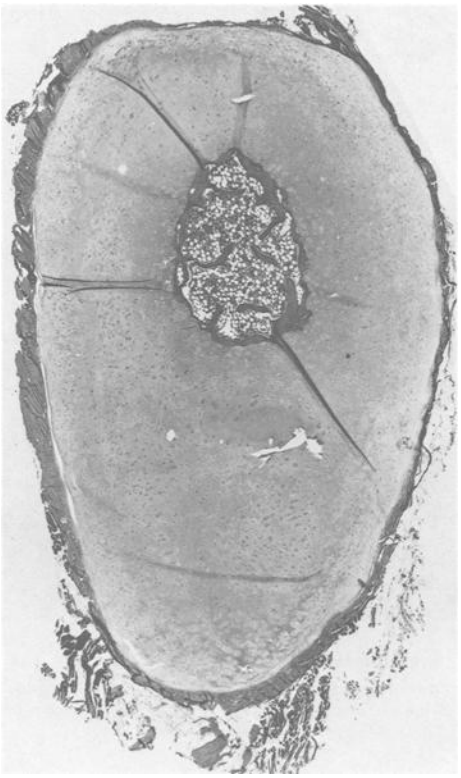

FIG. 3—*Histologic preparation of a fifth costal cartilage demonstrating a deep (central) focus of bone formation with bone marrow present (H&E; ×8).*

age. It is rare, especially in males, to have no peristernal ossification by age 35 (Table 3) (4 of 69 males and 8 of 35 females having no ossification in all of ribs 2 to 5 are beyond age 35). This peristernal ossification assumes a "mature" trabeculated pattern with moderate frequency in the 30's (early to mid-30's for males and late thirties to early forties for females) and is predominant in frequency in the over-40-year-old groups (Fig. 7), and may become massive in amounts by age 60, especially in costal cartilages 5 and 6. Rib end ossification assumes several distinct patterns and is quite highly sex predictive. Subperichondrial "spurs" projecting along the upper and lower rib margins are characteristic of males, first appearing as relatively faint or discontinuous ossifications along the inferior border in the late 20s or early 30s and are generally well-developed in men over the age of 50 (Fig. 8). This pattern has been referred to as type "E" in a previous publication [*6*]. A characteristic female rib end pattern of ossification (called type "B" in previous publications) [*5,6*] consists of cone shaped central new bone formation arising with its base parallel to the fossa costae and its apex toward the sternum (Fig. 9). This early form of ossification may become obscured with advancing age (and ossification) to produce a configuration we have termed "crab claw" (Fig. 10). Tables 4 and 5 summarize the ages at which these male (Type "E") and female (Type "B") type ossifications are seen.

Peristernal and second through seventh costal cartilage ossification can be easily evaluated in a semiquantitative manner. In this work, we have used a scale from 0+ to 4+ with half-step increments. Peristernal changes that are small, "button shaped," and occupying most of the width of the chondral-mesosternal insertion are assigned a 1+ value; large areas extending completely across the width of the insertion are assigned a 2+ value; changes that

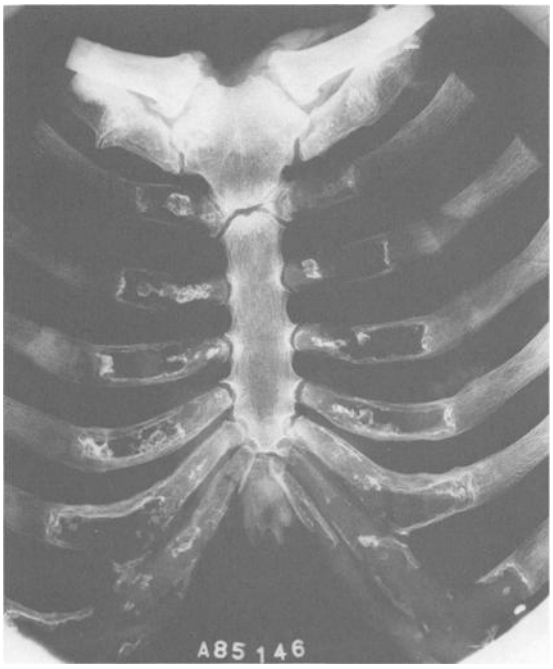

FIG. 4—*Chest plate X-ray showing virtually complete subperichondrial ossification of the first costal cartilage in an 80-year-old man. Conspicuous osteoarthritic changes are evident in the sternal head of the clavicles. The histologic section in Fig. 2 was taken from the midportion of the first costal cartilage in this case.*

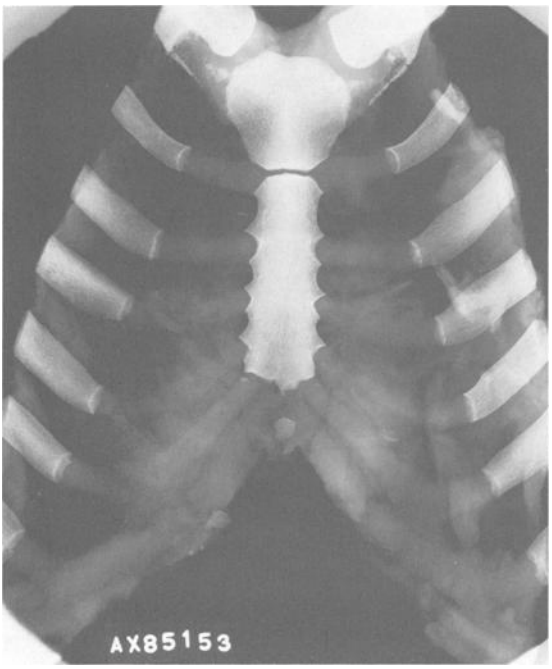

FIG. 5—*Early ossification of the first costal cartilage in a 24-year-old male.*

TABLE 2—*Rib ossification—age hemidecile versus amount.*

Age	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	All
					MALES					
15-19	9	2	1	0	0	0	0	0	0	12
20-24	28	1	3	0	1	0	1	0	0	34
25-29	12	4	7	2	1	2	1	0	0	29
30-34	13	13	9	6	1	2	2	0	0	46
35-39	6	8	11	3	3	0	1	2	0	34
40-44	3	3	7	6	7	3	3	0	0	32
45-49	5	8	10	4	6	3	2	0	1	39
50-54	1	9	9	14	7	1	3	0	2	46
55-59	1	11	20	11	14	5	8	2	2	74
60-64	2	9	16	12	10	6	11	5	4	75
65-69	0	2	11	13	18	5	7	0	1	57
70-74	0	2	14	8	11	3	3	1	1	43
75-79	0	4	3	6	6	4	8	0	2	33
80-84	0	0	2	0	2	2	4	1	0	11
85-89	0	0	1	0	5	0	0	3	0	9
90-94	0	0	1	1	2	1	1	0	0	6
95-99	0	0	0	0	1	0	0	0	0	1
All	80	76	125	86	95	37	55	14	13	581
					FEMALES					
15-19	2	1	2	0	1	0	0	0	0	6
20-24	5	0	3	0	0	0	0	0	0	8
25-29	13	2	2	0	3	1	1	0	0	22
30-34	7	5	5	2	2	0	0	0	0	21
35-39	3	5	9	2	1	0	1	0	0	21
40-44	0	2	5	1	1	1	0	1	0	11
45-49	1	1	5	1	3	0	0	0	0	11
50-54	3	7	13	2	1	0	1	0	0	27
55-59	1	6	12	3	7	1	1	0	0	31
60-64	3	11	10	2	4	1	3	1	0	35
65-69	0	0	6	9	3	2	3	1	0	24
70-74	1	0	5	3	3	2	2	0	0	16
75-79	0	2	3	1	2	0	2	0	0	10
80-84	0	0	1	2	3	1	1	0	0	8
85-89	0	0	1	0	0	0	0	0	0	1
90-94	0	0	0	0	0	0	0	0	0	0
95-99	0	0	0	1	0	0	0	0	0	1
All	39	42	82	29	34	9	15	3	0	253

are elongated laterally from a broadly ossified insertion are assigned a 2.5+ or more value. The various types (A to H) of chondral ossifications are assigned values somewhat similarly. Scattered small foci are given a 1+ value; larger areas with coalescence are given a 2+ value; changes covering a major portion of the area of the cartilage are given a 3+ or more value.

Internal reorganization and maturational changes occur in the rib end areas of ossification with advancing age, with a trabeculated appearance usually first appearing in the early 40s as discontinuous areas of maturation, often as discrete variably trabeculated foci along inferior or superior chondral margins or both. This appearance of distinct trabeculations is also generally seen in the peristernal ossifications in the over-40 ages, where it appears more advanced. Continuation of the trabecular pattern along the length of the subperichondrial (marginal) rib end ossifications is seen by the 50's (Fig. 7). At this time, fusion of subperichondrial ossifications occurs, accompanied by obliteration of fusion areas by trabeculation.

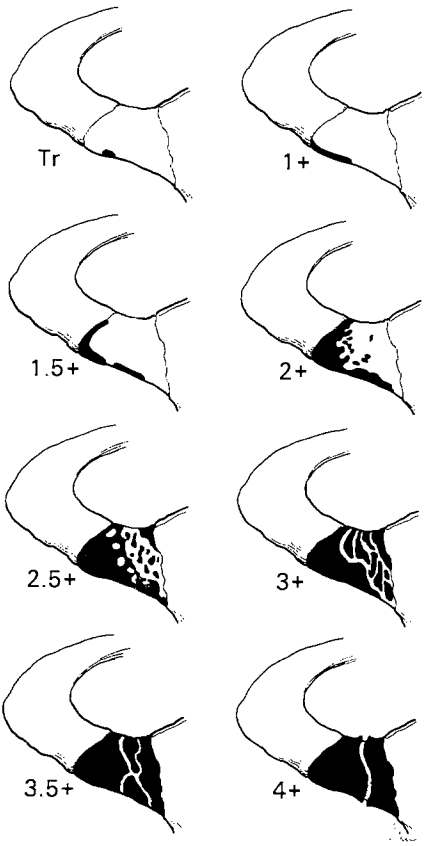

FIG. 6—*Artist's drawing of the increasing amounts of first costal cartilage ossification from trace to 4+ seen with advancing age as used in our age estimations.*

Ossifications occurring in the mid ("centrichondral") portions of the costal cartilages (that is, "central") also have typical gender predictive qualities. A very highly specific female-type pattern found only in women over 50 years of age, called type "A" in previous work [*5,6*] consists of smooth globular or spherical areas of ossification within the interior of the costal cartilages (Fig. 11). These areas are typically radiodense, sharply contrasting with surrounding cartilage, and may be less radiodense in their interiors. A large quantity of these spherical foci with considerable coalescence (Fig. 12) indicates an age of over 60 and usually 65 or greater (Table 6). Trabeculation changes in centrichondral areas typically occur with increasing age, occasionally in the 30s or very rarely in the 20s with severely pathological conditions (for example, leukemias, hemoglobinopathies), though more typically in the early 40s in males and in the mid to late 40s in females. Typically, mature trabeculated areas, particularly in older males, are relatively radiolucent and have a very irregular contour. Prominent central trabeculation (that is, 2+ or more) is a marker for ages 60 or more, particularly in males.

Conversely, plate-like areas of ossification of the mid portion of the costal cartilages, often continuous with the rib ends (fossae cootarum), having a porous or "Swiss cheese" appearance (Fig. 13), is seen in younger men and called type "F" [*6*]. This distinctive ossification pattern can be found in men as young as 30 and can become so truly massive as to largely

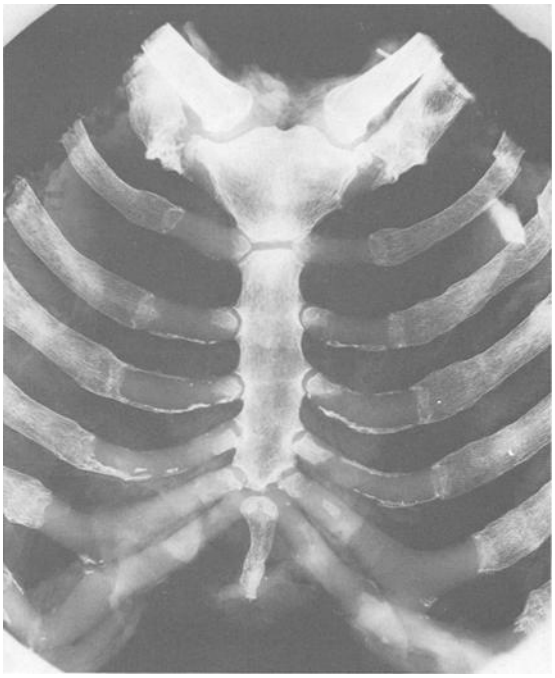

FIG. 7—*Chest plate X-ray from a 50-year-old man showing relatively heavy peristernal ossification.*

obscure the porous, Swiss-cheese appearance in the very elderly (Fig. 14). Such "solid" appearing costal cartilages, limited to men over 70, have been called type "G" [6] and probably represent only the end stage of type "F" ("Swiss cheese") in the very elderly (Table 7). Such "solid" costal cartilages have never been observed in women. Trabeculation of marginal rib spurs nonetheless can often be appreciated in type "F" cases, allowing a contribution to age estimation.

Costal Manubrial Border

The costal border of the manubrium has a smooth, slightly concave border in the teens and early 20s (Fig. 15) and thereafter becomes progressively more irregular, so that they become distinctively irregular by age 30 (Fig. 16). A smooth border indicates a probable age of less than 25, slightly irregular border at age of 25 to 35, and distinctively irregular, over 35.

Sternal Head of Clavicles

Degenerative, osteoarthritic changes occur in the sternal (medial) head of the clavicle with advancing age. Uncommonly seen on X-ray before age 50, osteophytic lipping is often conspicuous by age 65 to 70 (Fig. 16). Inspection of the defleshed clavicle head often reveals more degenerative changes than observable on the X-rays, with obvious gross changes a full decade earlier. Osteophytic lipping, subchondrial cortical cysts, and areas of eburnation all may be evident in men by the age of 60 (Fig. 17).

TABLE 3—*Peristernal ossification—age hemidecile versus amount.*

Age	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	All
					MALES					
15-19	11	1	0	0	0	0	0	0	0	12
20-24	27	3	3	1	0	0	0	0	0	34
25-29	8	4	16	1	0	0	0	0	0	29
30-34	4	12	18	6	5	1	0	0	0	46
35-39	3	4	12	10	6	0	0	0	0	35
40-44	1	4	5	8	11	2	1	0	0	32
45-49	0	2	11	9	11	3	2	0	1	39
50-54	0	2	10	16	11	3	4	0	0	46
55-59	2	1	12	25	12	11	7	3	1	74
60-64	0	2	14	20	17	7	10	5	0	75
65-69	0	1	9	13	15	7	11	1	0	57
70-74	0	1	8	12	11	3	8	0	0	43
75-79	0	0	4	6	7	2	13	1	0	33
80-84	0	0	0	2	0	4	4	1	0	11
85-89	0	0	1	1	1	0	5	1	0	9
90-94	0	0	0	0	3	1	2	0	0	6
95-99	0	0	0	0	0	0	0	1	0	1
All	56	37	123	130	110	44	67	13	2	582
					FEMALES					
15-19	4	1	0	1	0	0	0	0	0	6
20-24	5	3	0	0	0	0	0	0	0	8
25-29	12	6	4	0	0	0	0	0	0	22
30-34	1	7	10	3	0	0	0	0	0	21
35-39	1	3	13	4	0	0	0	0	0	21
40-44	1	2	7	0	1	0	0	0	0	11
45-49	1	3	6	1	0	0	0	0	0	11
50-54	0	4	14	5	4	0	0	0	0	27
55-59	1	3	20	4	2	1	0	0	0	31
60-64	1	8	17	6	3	1	0	0	0	36
65-69	0	1	13	8	0	1	1	0	0	24
70-74	0	0	9	3	1	2	1	0	0	16
75-79	0	0	4	5	0	1	0	0	0	10
80-84	0	0	2	2	3	1	0	0	0	8
85-89	0	0	0	0	0	1	0	0	0	1
90-94	0	0	0	0	0	0	0	0	0	0
95-99	0	0	1	0	0	0	0	0	0	1
All	27	41	120	42	14	8	2	0	0	254

Ossification of the Xyphoid Process

The ensiform cartilage is not ossified in the young. The first X-ray evidence of ossification is seen in occasional males in the mid-teens but is not regularly observable until the late teens. Complete or largely complete ossification is uncommon before the late 20s, and fusion with the body of the sternum is sometimes absent even in the post-60 year group.

Rib End Changes

The sternal ends of the ribs become "flared," prominently so beginning in the 40s with increase in the depth of the depression ("cup") and irregularity of its edges with increasing age (Fig. 18). This phenomenon is more striking in males than females, and is accentuated by type "E" changes.

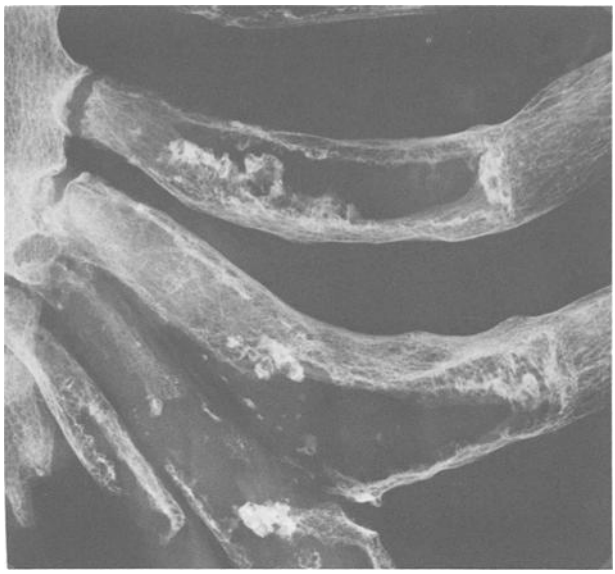

FIG. 8—*Mature trabeculated costal cartilage ossification in the lower ribs in a 72-year-old man. Prominent subperichondrial rib end "spurs" are evident.*

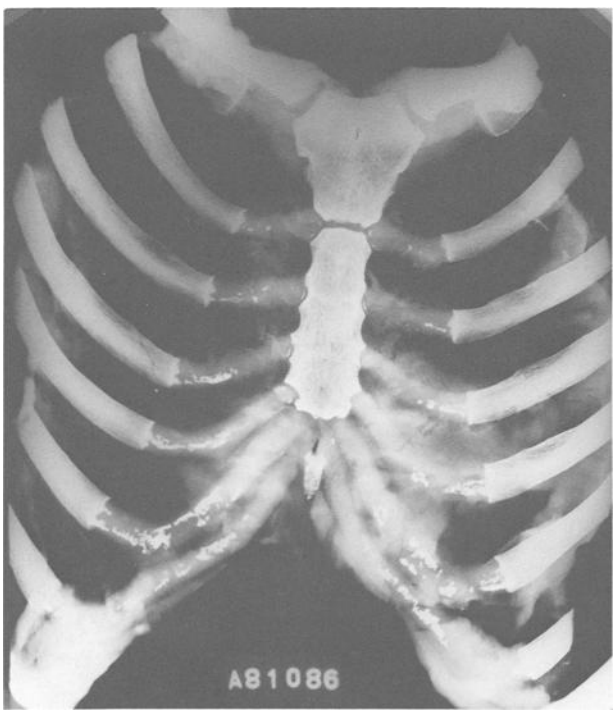

FIG. 9—*Female-type ("B") ossification in a 32-year-old woman. Such ossification begins as cones of centrally placed rib end costal cartilage ossification. With increasing age, this type of mineralization typically assumes the pattern seen in Fig. 10.*

FIG. 10—*Typical female pattern "B" ossification in another 32-year-old woman. This ossification within the costal cartilages tends to assume a "crab-claw" configuration. The degree of ossification seen in this woman is considerably more than is usual for this age.*

TABLE 4—*Type "E" ossification by age, race, sex.*

	Males					Females		
Age	White	Black	Hispanic	Oriental	Indian	White	Black	Hispanic
20–24	0	0	2	0	0	0	0	0
25–29	10	2	1	1	0	0	0	0
30–34	14	5	5	0	0	1	2	1
35–39	15	6	3	0	0	2	3	0
40–44	18	6	5	0	0	1	2	1
45–49	20	7	2	0	1	0	0	0
50–54	28	8	7	0	0	2	3	1
55–59	41	9	4	0	0	4	5	2
60–64	41	15	3	0	0	7	1	0
65–69	40	7	3	0	0	0	0	0
70–74	22	6	1	0	0	1	4	0
75–79	14	4	2	0	0	0	0	0
80–84	4	5	0	0	0	0	0	0
85–89	4	1	0	0	0	0	2	1
90–94	5	1	0	0	0	0	0	0
95–99	1	0	0	0	0	0	0	0
All	277	82	38	1	1	18	24	6

TABLE 5—*Type "B" ossification by age, race, sex.*

	Males			Females			
Age	White	Black	Hispanic	White	Black	Hispanic	Indian
15–19	1	0	0	0	2	1	0
20–24	0	0	0	2	1	1	1
25–29	1	0	0	3	1	1	0
30–34	2	1	1	5	3	1	0
35–39	0	0	0	4	1	1	0
40–44	1	0	0	2	3	1	0
45–49	0	0	0	5	1	2	0
50–54	1	0	0	2	1	1	0
55–59	0	0	0	8	1	0	0
60–64	0	0	0	8	0	0	0
65–69	1	0	0	4	1	1	0
70–74	1	0	0	0	0	0	0
75–79	0	0	0	1	0	0	0
All	8	1	1	44	15	10	1

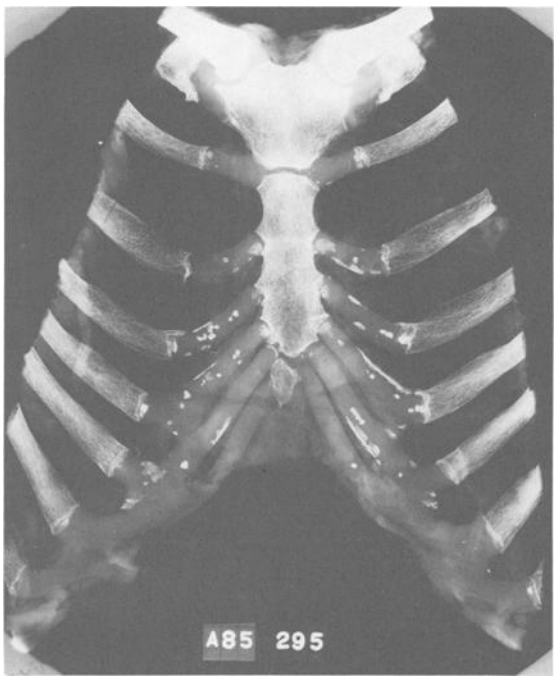

FIG. 11—*Female pattern "A" ossification in a 68-year-old woman. Such ossification tends to occur in the midportions of the costal cartilages and assumes a smooth, rounded contour. This pattern is highly sex and age predictive.*

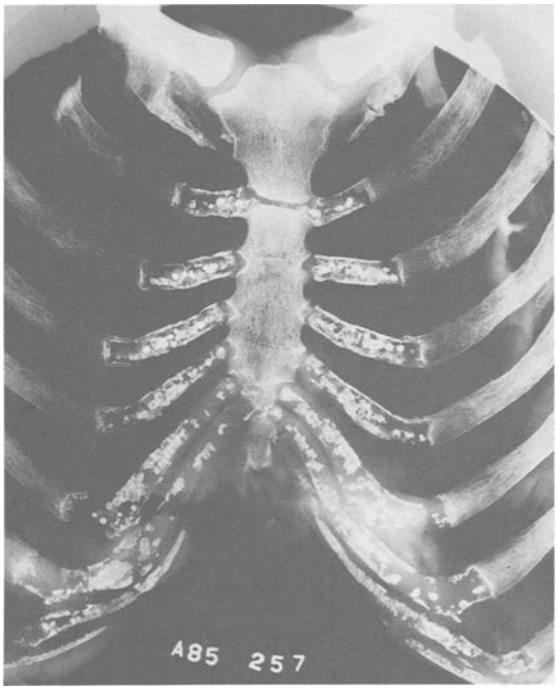

FIG. 12—*This elderly woman has more advanced type "A" ossification.*

TABLE 6—*Type "A" ossification by age, race, sex (all female).*

Age	White	Black	Hispanic
50–54	1	1	1
55–59	1	1	1
60–64	6	0	0
65–69	10	4	1
70–74	2	2	1
75–79	4	1	1
80–84	5	2	0
All	29	11	5

Osteoporotic Changes

Rather densely packed trabeculation in the sternum and rib ends is typical in younger age groups (often persisting to later ages in blacks). Significant changes may occur frequently in rib ends in the late 30s in females and early 40s in males and frequently in the sternum in the 40s in females and in the 50s in males. A subpopulation with dense packing of trabeculation relative to age exists and is composed predominantly of black individuals, despite the nearly 2:1 predominance of whites in our study population. This marker is relatively specific, though not sensitive. It is tempting to speculate a correlation with the well-known reduced risk for clinical osteoporosis in blacks compared with whites.

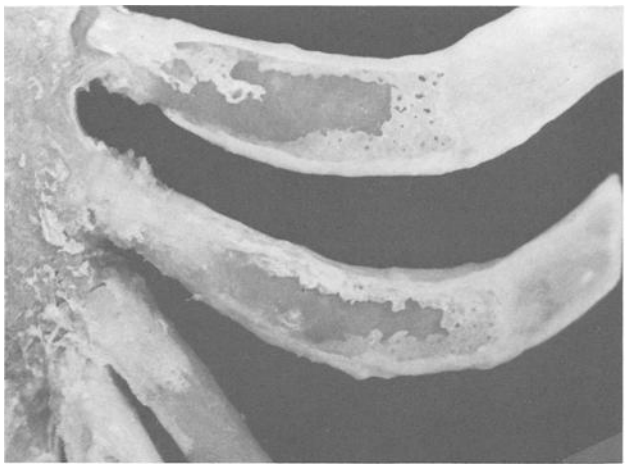

FIG. 13—*Gross specimen showing distinctive type "F" or "Swiss cheese" pattern in males. Onset of this pattern is typically at a relatively early age and may become massive (36-year-old man).*

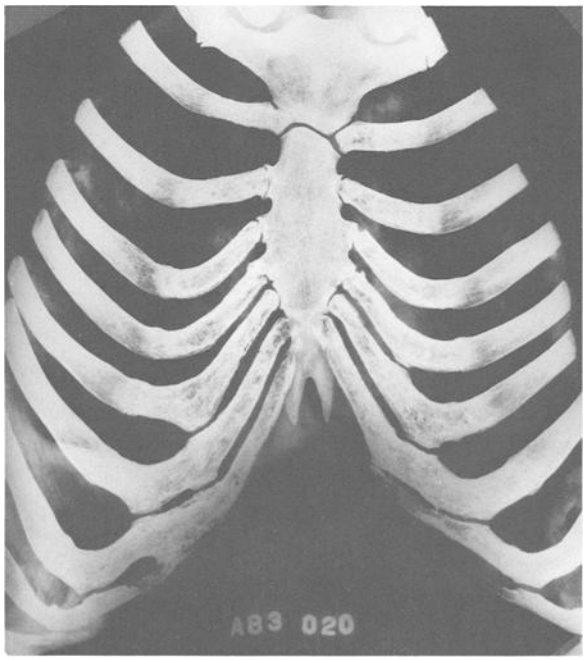

FIG. 14—*Massive ossification of the costal cartilages as seen most typically in elderly men. This has been designated type "G," but probably represents only the very advanced stage of the type "F" ossification. It can rarely be seen as early as the forties.*

TABLE 7—*Type "F" and Type "G" ossification by age and race (all males).*

Age	Type "F"			Type "G"	
	White	Black	Hispanic	White	Black
20–24	0	0	1	0	0
25–29	2	1	0	0	0
30–34	3	1	2	0	0
35–39	5	0	0	0	0
40–44	3	0	0	0	0
45–49	3	0	0	0	0
50–54	4	0	0	0	0
55–59	7	0	0	2	0
60–64	6	1	1	3	1
65–69	4	0	0	1	0
70–74	0	0	0	0	0
75–79	0	1	0	0	0
80–84	0	0	0	0	0
85–89	1	0	0	0	0
All	38	4	4	6	1

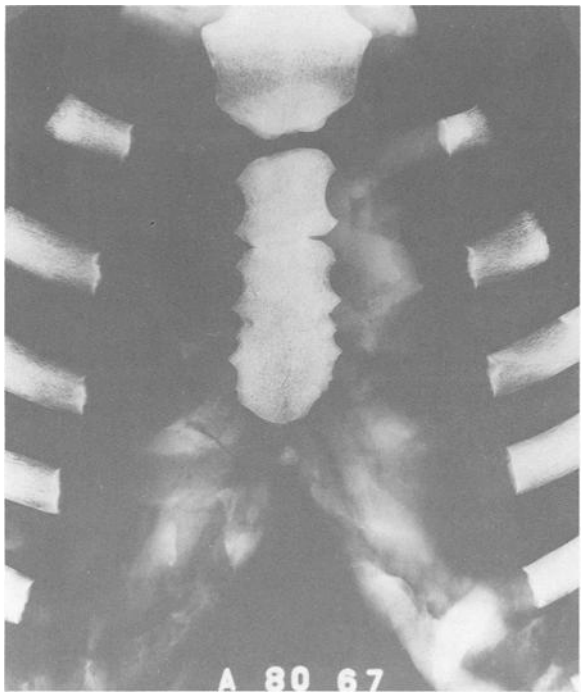

FIG. 15—*Young (19-year) male's chest plate X-ray illustrating smooth contour to the manubrium at the costomanubrial junction.*

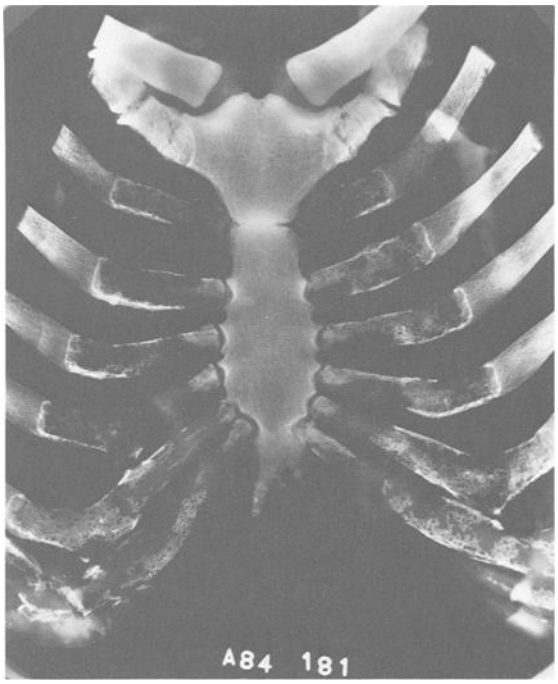

FIG. 16—*An adult male with type "F" ossification of the costal cartilages, prominent subperichondrial rib end spurs and heavy first costal cartilage ossification illustrating a smooth costomanubrial border on the left and an irregular border on the right (32-year-old Latin American male).*

Discussion

Human variability is obvious in plastron maturational changes, as should be expected with maturational changes for nearly any human anatomic characteristic. In this discussion, an attempt to elucidate some of the changes that typically occur in aging in the human chest plate, along with the range of variation found, has been undertaken, with consideration given to establishing age cutoff points for various parameter values. These are typically minimum practical age estimations for multiple different parameter values that when taken in toto may allow frequent accurate age estimations for individuals.

As a test of the utility of chest plate roentgenographs in quickly estimating ages, one of the authors (JHS) performed a rapid screen, reviewing 929 cases (579 males, 350 females; 548 White, 273 Black, 105 Hispanic, 2 Oriental, 1 Indian) in a blind fashion over a portion of approximately 5 days, making age estimates for each case. Criteria used in these estimations were based on the analysis of parameters on 863 cases in our series that were recently obtained (circa 1984 to 1986). None of the 929 cases upon which the age estimates were made were included in the 863-case study. Since consistent specific criteria for age estimations over 65 have not been developed, individuals over 65 were not evaluated for estimation of standard deviations, leaving 705 cases. An average underestimation of 1.5 years occurred, with a standard deviation of 8.2 years. For the entire subseries of 929 cases, a linear regression line was calculated to be

$$\text{"Age"} = 1.01 * \text{"Age estimate"} + 3.5$$

$$\text{Correlation coefficient} = 0.82$$

$$Sy \cdot x = 9.7.$$

Age estimates on an additional 439 cases were made in a blind fashion but in a studied manner while each case was acquired and placed into the study population. In this subseries, 5.0% (22) of estimates were overestimated by more than 10 years, and 8.4% (37) either were underestimated by more than 10 years or were estimated as less than 55, and were in fact over 65 (that is, elderly individuals greater than 65 were considered as 65 as a result of poor resolution of our method for many individuals beyond 65 years). Five of those overestimated were type "F," as might be expected by this type's exuberant mineralization effect. Fourteen of the underestimated cases had a significant disparity between very limited "peripheral" (centrichondral ossification and marginal spurring) changes and prominent "axial" (first rib and peristernal) ossification.

Specific age ranges are not always easy to arrive at for an individual case. A minimum age can be obtained by examination of the X-ray, though this estimate sometimes may be a

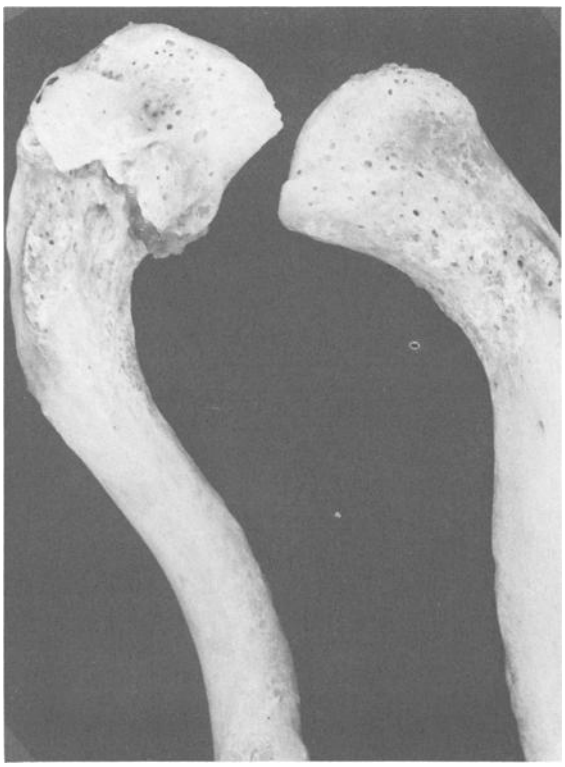

FIG. 17—*Manubrial end of the clavicle illustrating prominent osteoarthritic/degenerative changes with subchondral cysts and areas of eburnation in a 78-year-old man. These alterations are observable on the chest plate X-rays.*

FIG. 18—*Deep "cupping" of the rib ends is seen in this 65-year-old man. Such cupping tends to be markedly accentuated by male pattern rib end spurs.*

significant underestimate. The magnitude of the underestimates may be lessened, though at the expense of increasing overestimates. A working summation of our observations follows.

Males

Less than 20 Years Old—Minimum (trace or less) changes are present, though occasionally modest central mineralization (type H) may be present (2 of 12 cases for ribs 4 and 5). Often, the mesosternum is incompletely fused. The costal manubrial border is smooth. The medial clavicular epiphysis is not completely fused.

Early to Mid-20s—Usually, 0 to 1+ first rib changes (4 of 34 with 1.5 or more); usually little rib (marginal or central) changes (2 of 34 with 2+ or more). Peristernal changes are minimal (1 of 34 with 1.5+ fifth peristernal changes, none for second or fourth). The costal manubrial border has onset of modest irregularity.

Late 20s—Mostly (19 of 29) 0 to 1.5+ first rib changes (though 9 cases are concentrated at 2.5 and 3+); lower rib changes are usually 1.5 or less (4 of 29 with 2+ or more); peristernal changes typically are beginning to form, but are modest (trace to 1; 1 of 29 are 1.5). Trabeculation changes are not found in any locations. The costal manubrial border is distinctly irregular.

Early 30s—First rib changes are variable, though usually greater than trace and less than 3.5; lower rib changes are modest (0 to 1.5 in 41 of 46 cases); peristernal changes are moderate (at least 1+ in 42 of 46 and less than 2.5 in 45 of 46), but usually (37 of 45) without trabeculation. Other trabeculation changes are not seen (present in 1 of 46).

Late 30s—First rib changes run the gamut from trace to 3.5, and no changes are reliable in type F "Swiss cheese" individuals (some have 4+ first rib ossification); moderate peristernal changes are often present, with frequent peristernal trabeculation. Occasionally,

minimal trabeculation in central ossification occurs (3 of 35 cases with 1+ changes). Minimal maturational changes may occur with marginal ossification (that is, coalescence of marginal mineralization centers occurs, but elongated, continuous spurring is unusual—2 of 34 cases have 2+ maturational changes).

40s—First rib changes are mostly greater than 2.5 (20 of 72 are less than 2.5, 9 of 72 less than 1.5); lower ribs can have any values, as can peristernal changes (6 of 71 are more than 2+). Peristernal trabeculation is the rule (50 of 68), particularly in the late 40s. Marginal maturational changes are usually (57 of 68) not advanced (no continuously trabeculated spurring). Central trabeculations are often present, but are minimal (5 of 72 with 1+, none with more than 1+). Some rib osteoporotic changes are emerging in some individuals (19 of 68; 4 of 68 have some sternal osteoporotic changes). Clavicular arthritic changes are occasionally seen (10 to 15%).

50s—Prominent first rib changes are the rule (greater than 2.5); significant lower rib mineralization with significant maturational changes is seen. Central trabeculations often become increasingly prominent in the late 50s. Rib and sternal osteoporotic changes occur with significant frequency. Clavicular osteoarthritic changes begin to be seen, particularly in the late 50s (occurring in 26 of 58 in the 55 to 59 hemidecile).

60s—Prominent first rib changes are present. Lower rib maturation may be prominent. 2.5 to 3.5 peristernal changes may be seen. Central trabeculation may be prominent. Clavicular osteoarthritis is increasingly frequent (58 of 95).

70s and Older—May be little different from 60s, although very prominent marginal maturational changes are often seen. Often the edges of trabeculated bone (including marginal spurs) may have a rounded, "undulating" profile. Frequently, clavicular osteoarthritic changes are prominent (17 of 67 with 2+ changes).

Females

Less than 20 Years Old—Minimum changes are present, though moderate central mineralization may be present (3 of 6 with 1 to 1.5). Often, the mesosternum is incompletely fused. The xyphoid sometimes is not ossified. The costal manubrial border is smooth.

Early 20s—Zero to trace first rib changes (7 of 8) are the rule; usually minimal rib (central) changes (3 of 8 are 1+, none more). Peristernal changes are minimal (trace in 3 of 8), usually nonexistent (5 of 8). The costal manubrial border is smooth to somewhat irregular.

Late 20s—Zero to 1.5 first rib changes (2 of 22 more than 1.5+); lower rib changes are usually less than 1.5 (17 of 22 less than 1.5, 5 of 22 are 2 to 3+); peristernal changes typically are beginning to form, but are minimal (0 to trace in 18 of 22, 1+ in 4 cases). Trabeculation changes are not found in any locations. The costal manubrial border is becoming distinctly irregular.

Early 30s—First rib changes are variable, though usually more than trace and less than 3 (0+ in 2 of 21; 1 outlier with 4+); lower rib changes are modest (0 to 1.5 in 19 of 21; 2+ in 2 of 21); peristernal changes are moderate (trace to 1.5+; that is, none greater than 1.5, 1 of 21 with 0+ changes), but without trabeculation. Other trabeculation changes are usually not seen (3 of 21 with 1+).

Late 30s—First rib changes vary from 0 to 2.5+ (3+ in 2 of 21); modest peristernal changes (20 of 21 are greater than 0, all less than 2), with frequent (9 of 21) peristernal trabeculation. Rarely (1+ in 1 of 21), minimal trabeculation in central ossification occurs.

40s—First rib changes are variable, ranging from 0 to 3.5+ (1 of 22 is 4+); lower ribs vary from trace to 2.5+ (0+ in 1 of 22; 3.5+ in 1 of 22). Peristernal changes are essentially less than 2+ (less than 2+ in 21 of 22; 2+ in 1 of 22). Modest central trabeculation may be seen (1+ in 7 of 21). Most parameters are not too specific to the 5th decade, though rib osteoporotic changes do begin to be seen in significant percentages at this time (12 of 22 cases).

50s—Any value may be obtained for first rib changes, as may lower rib values. Trace to

2+ peristernal values are typical. Significant central trabeculation is often seen (1+ or more in 25 of 58). Maturational (type A) changes are beginning to be seen, particularly in the second half of the decade (22 of 58), as are clavicular osteoarthritic changes (16 of 54). Sternal osteoporotic changes occur in significant numbers (10 of 58), with rib osteoporosis becoming the rule (38 of 58).

60s—First rib changes are predominantly at least 1+ (2 of 60 with 0.5+), while lower ribs can have essentially any value. Peristernal changes can take on any value greater than 0 (1 of 60 have no peristernal changes). Significant central trabeculation tends to be the rule, particularly in ribs 6+ (41 of 60). Type A changes are present in more than one half of cases (32 of 60), as are clavicular osteoarthritic changes (33 of 59).

70s and Older—Changes are similar to those of the 60s, only more extensive, particularly type A changes.

Conclusion

As Meindl and Lovejoy [7] have so aptly stated "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. Any indication which both significantly reflects biological age and whose informational content is independent of other indicators will be useful to a final age estimate, whether under forensic or archaeological conditions." We think the data that can be obtained from the plastron roentgenogram are valuable and practical indicators of skeletal age as well as a very sensitive indicator of sex.

Acknowledgments

This work was supported in part by a grant (4554) from the Wenner-Gren Foundation for Anthropological Research, Inc., of New York, and from departmental funds of the Department of Pathology, University of Texas Medical Branch (UTMB), Galveston. Our appreciation is extended to Dr. P. R. Gilmer, Jr., acting chairman, and to members of the autopsy service at UTMB, especially its former director, Dr. Jerome H. Smith.

References

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

[2] McCormick, W. F., "Sternal Foramina in Man," *American Journal of Forensic Medicine and Pathology*, Vol. 2, No. 3, Sept. 1981, pp. 249–252.

[3] McCormick, W. F. and Stewart, J. H., "Ossification Patterns of Costal Cartilages as an Indicator of Sex," *Archives of Pathology and Laboratory Medicine*, Vol. 107, No. 4, April 1983, pp. 206–210.

[4] Stewart, J. H. and McCormick, W. F., "The Gender Predictive Value of Sternal Length," *American Journal of Forensic Medicine and Pathology*, Vol. 4, No. 3, Sept. 1983, pp. 217–220.

[5] Stewart, J. H. and McCormick, W. F., "A Sex- and Age-Limited Ossification Pattern in Human Costal Cartilages," *American Journal of Clinical Pathology*, Vol. 81, No. 6, June 1984, pp. 765–769.

[6] McCormick, W. F., Stewart, J. H., and Langford, L. A., "Sex Determination from Chest Plate Roentgenograms," *American Journal of Physical Anthropology*, Vol. 68, No. 2, Oct. 1985, pp. 173–195.

[7] Meindl, R. S. and Lovejoy, C. O., "Ectocranial Suture Closure: A Revised Method for the Determination of Skeletal Age at Death Based on the Lateral-Anterior Sutures," *American Journal of Physical Anthropology*, Vol. 68, No. 1, Sept. 1985, pp. 57–66.

Address requests for reprints or additional information to
William F. McCormick, M.D.
Box 19540A
East Tennessee State University
College of Medicine
Johnson City, TN 37614-0002