A Replicability Study of Radiographic Techniques for Aging and Sexing the Adult Human Thoracic Area

By Carla R. M. M. Torwalt

A Thesis

Submitted to the Faculty of Graduate Studies

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF ARTS in ANTHROPOLOGY

Faculty of Arts

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THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

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ABSTRACT

The purpose of this research is to evaluate current methods in adult human thoracic (chest plate) aging and sexing techniques as done through radiographic analysis. Sex differences as well as age related changes in the skeleton can be found within the human thoracic area. These may include morphological changes in the costal cartilage of the 1^{st} through 7^{th} ribs, sternal end of the clavicle, costo-manubrial border, as well as sternal length, and fusion rates. The thoracic region is extremely important in biological and forensic anthropological studies as it is active between the adolescent growth and adult maturation and degenerative periods, allowing age estimates to be generated with relevance to both immature and adult skeletal remains. It also presents an opportunity to obtain greater degrees of accuracy in the often difficult and subjective task of adult age estimation and sex determination, especially when dealing with partial remains. This research focuses on whether or not previous radiographic techniques for determinations of age and sex are useful in contemporary forensic situations in so much that these methods are replicable and accurate.

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Last, but definitely not least, a very special thank you to Princess, my cat.

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CHAPTER ONE

INTRODUCTION

> "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."
>
> Meindl and Lovejoy (1985: p.65).

When a biological anthropologist is asked to evaluate human skeletal remains, of primary importance are the questions of sex, age at death, and ethnic affiliation of the individual. This is basic and crucial information, whether in an archaeological or forensic context. Archaeologically these questions may help in reconstructing demographic profiles, migratory patterns, as well as health, environmental and dietary status, of past populations. In a forensic context age, sex, and population affinity are the first step in obtaining a positive identity of an unknown or tentatively identified individual.

If an individual's identity is unknown or not positively confirmed at the time of death it is usual to seek out a relative or spouse for confirmation. Identity may also be obtained through police agency files, such as fingerprints or mug shots. If the individual is in a more advanced stage of decomposition where these techniques have been rendered unusable it is usually the responsibility of the medical examiner, coroner, or forensic pathologist to confirm identity as well as cause and manner of death. As is usually the case these individuals are trained primarily in the examination of soft, or fleshy parts of the body. It is when these remains are badly decomposed, burnt, or partially or completely skeletonized, that a forensic anthropologist may be a better resource, partially because of their more extensive training in human skeletal biology, as well as experience in the recognition of normal, if sometimes extreme, variations between individuals and populations. Relatively speaking, forensic pathologists do not examine as many skeletonized remains, and hence are not as experienced in their analysis. Occasionally, other more subtle clues may be lost or misinterpreted by a less experienced individual. Thus, this type of analysis is crucial not only for the obvious ethical issues, but also in matters of law, be they of a monetary or criminal nature. Forensic anthropologists may help in determining the time frame of death, the manner of death, as well as the cause of death and as such play a vital role in the medico-legal context. As well, through this type of analysis and research, knowledge pertaining to other issues such as human aging and disease processes may become available.

The primary goal of this study is the estimation of age and determination of sex from roentgenologic features of the thorax obtained during medico-legal postmortem examination. McCormick and Stewart (1988) have found that radiographic analysis is a technique which is inexpensive and relatively easy to use, which also enables the creation of an easily stored, permanent record. As well, any methodology that may reduce the need for laborious and time consuming defleshing of decomposed or partial remains is worth pursuing. For those remains that are historic or not available to intrusive processes these techniques may also be beneficial.

Radiography has long been used in studies of growth and developmental processes (Greulich and Pyle, 1959; Pyle and Hoerr, 1969), allowing researchers to create standards for age estimation using the relationship between skeletal growth and chronological age. With adults however, age estimation becomes much more difficult as most epiphyseal areas have been fully fused by the age of 20, this requiring reliance on more variable and subjective degenerative changes.

This research utilizes techniques and criteria defined by previous investigators, most notably Barres et al. (1989), McCormick (1980), McCormick and Stewart (1983, 1988), McCormick et al. (1985), and Stewart and McCormick (1983, 1984) to assess the accuracy of age estimation and sex determination techniques using features visible radiographically within the thoracic area. In general this consists of the examination of degenerative changes within the costo-manubrial border, fusion of the sternum, sternal dimensions, changes in the sternal rib ends, osteoporotic changes, and ossification patterns of the costal cartilage, all from radiographs. Using radiographs of individuals of known sex, age, and population affinity these methods are tested and results are compared for accuracy and extent of replicability. Age and sex related changes are scored on degrees of expression and patterning within specific age ranges and groups using templates, schematic diagrams, and written criteria.

Chapter two begins with a brief review of the developmental biology of the thoracic area. A short history of radiographic analysis as related to growth and development follows with a summation of said radiographic techniques as they pertain to the identification of trauma, pathology, and the recognition of features of individuality. Besides their initial and primary objective these techniques have also contributed to the knowledge and creation of the methods used in this research and as such are also briefly examined.

The use of radiography in techniques for determination of sex is reviewed followed by an examination of the degenerative processes of the skeletal thoracic area as applicable to age, sex, and ethnicity of the individual. This section begins with a brief introduction as to the biology of cartilage and costal cartilage ossification as initially related to pathological conditions. Ossification was next studied most frequently with respect to normal aging processes and specific degeneration of the adult cartilage. Ossification patterns and frequencies were found to be related to certain areas of the thorax and appeared to be age and sex specific. The methodology of these studies with respect to age and sex are examined as they were proposed historically. Pathology has also been noted by some to play a part in some of these processes and patterns. The chapter concludes with an examination of the few studies that have dealt with this phenomenon.

Chapter three begins with a description of how data sources were selected and cases reviewed. The research design is outlined as well as the methodology with respect to reliability and replicability as it is affected by inter-observer and intra-observer error. Accuracy rates of previous studies are presented and the sample is tested statistically for any effects that population affinity may have on results. The presence or absences of such effects are noted. Finally, the actual process of the analysis of the sample is presented and any pathological influences upon the sample are discussed.

Results of the analysis are presented in Chapter four. All results are presented in similar fashion, beginning with an examination of Barres et al.'s five thoracic features, ossification pattern and score assessment, and followed by ossification feature assessment. These include the first costal cartilage, second to seventh costal cartilage, costo-manubrial border, rib-end changes, osteoporotic change, and xyphoid ossification. The section begins with results generated through statistical examination of the sample with respect to inter-observer error, intra-observer error, and ends with replicability and accuracy rates of the tests. As well as the previous categories this final section includes sternal metrical assessment and sex predictive values, ossification patterns coupled with metrical assessment, age estimation, and multiple variable results.

Chapter five discusses results of statistical observations with respect to inter-observer and intra-observer error in relation to the aforementioned techniques as well as accuracy rates of sex determination and age estimation using these techniques specifically compared to the original researcher's results. Sternal metric assessment and sex predictive value as well as the collective use and utility of multiple feature variables are noted.

The final chapter concludes with a summary and synthesis of results as well as possible future uses for these techniques and directions of further study.

CHAPTER TWO

DEVELOPMENTAL BIOLOGY OF THE HUMAN THORACIC AREA

Sternum

The sternum consists of 3 parts: the manubrium or handle; the corpus sterni, or body or blade; and the xyphoid process, or tip. It functions to connect the clavicle and scapula to the thorax as well as anchoring the anterior ends of paired ribs 1 to 7 through cartilage (White, 1991). It is initially composed of 6 segments. The first remains separate and forms the manubrium, the 2nd through 5th fuse to form the body, and the 6th remains separate to form the xyphoid process (Bass, 1987).

The process of ossification of the sternum takes place on a cartilaginous base (Kozielec, 1973). It is ossified from 6 centers: one for the manubrium beginning between the 3rd and 6th intrauterine months; 4 for the body of the sternum; and 1 for the xyphoid process (Steele and Bramblett, 1988). The first 3 body centers and manubrium appear during fetal life and the last ossification center for the body appears shortly before or after birth (Fazekas and Kosa, 1978). Xyphoid process ossification is much more variable. If it occurs it may happen between the ages of 14 and 18 years. The centers of ossification of the body usually fuse between the ages of 14 and 18 years. The manubrium and the xyphoid process do not always fuse to the body of the sternum but if they do the timing is variable (Steele and Bramblett, 1988).

Ribs

Around the 8th week of intrauterine life ribs one through ten begin to ossify from a center near the angle of the shaft which begins to develop towards the end of the second intrauterine month (Fazekas and Kosa, 1978). This progresses rapidly and by the end of the 4th month reaches as far as the costal cartilages. Secondary and tertiary centers for the head and the articular part of the tubercle appear around the age of puberty and generally fuse between the ages of 18 and 24 years. Ossification begins in the upper and lower ribs and slowly progresses towards the center (Bass, 1987), with the epiphyses of ribs one to two and ten to 12 fusing earlier than ribs three to nine, or the central ribs (Krogman, 1962).

There are 12 ribs on each side of the body (however this number may be variable). They form a paired series of narrow, flattened bones that articulate posteriorly with the vertebral column. The upper seven articulate directly with the sides of the sternum through cartilage and are called true ribs or vertebrosternal ribs. The remaining five are false ribs. Eight, nine, and ten have cartilage that ventrally connects with the cartilage of the ribs above. These are termed vertebrochondral. The 11th and 12th ribs have ventral ends that are free and tipped with cartilage and are termed floating or vertebral. The ribs increase in length from one to seven and decrease from eight to 12. The seventh is regarded as the most typical specimen with a vertebral extremity that includes a head, a neck, a tubercle, a shaft, or body, and a sternal extremity.

ESTABLISHED ANTHROPOLOGICAL TECHNIQUES FOR AGING AND SEXING THE ADULT SKELETON

Age Estimation

In a normally functioning adult skeleton there are few areas which may be examined for changes associated with growth and fusion of centers of ossification. Processes of maintenance and atrophy of the bone must be examined in their place.

In 1954 Stewart tested what he believed to be atrophic changes of the adult sternum on a group of Native North American skeletons despite the views of Dwight (1890) who believed it to be worthless as an age indicator. Stewart was unable to assign definite ages to developmental events of the sternal area with any great precision in these skeletons or to assess accurately the variability between individuals. However, when using data from a representative study population the first problem was diminished to some extent. As well, variability within the skeleton was reduced when age-related changes were correlated with more accurate and reliable morphological age-changes in other elements. This is of course assuming that these other elements are available and representative. However, after the age of 18 years, Stewart believed that unless associated with other more consistent and predictable age changes, thoracic age changes such as degenerative processes of the ribs and joint surfaces were too variable to be of much use.

In 1957 Stewart with McKern analyzed 450 skeletonized and identified war dead from North Korea for age related changes. They found the sternum to be the most morphologically variable element in the human body with the greatest divergence involving the corpus sterni and the xyphoid process. They found the manubrium sterni to be the most reliable in form.

Their findings are similar to those of Stewart's (1954) for fusion rates and processes of the sternum between the ages of 17 to 18, 19 to 20, and 22 to 23 years. However, unlike Stewart's 1954 study they noted some individuals up to age 27 had still separate sternal segments as well as evidence of recent fusion in the 3rd and 4th costal notches in some individuals in their 30's. Both studies found hypertrophic bone spur appearance around the first rib facet margins commencing at about age 30 to 35, although slight lipping was sometimes seen between the ages of 21 to 50. Large spurs were rarely found before the age of 30. The other rib facets developed spurs more slowly.

Stewart and McKern (1957) give data on the rib heads only. Earliest union appeared at age 17 with complete fusion by the age of 25. Ribs one to three and ten to 12 united soonest with ribs four to nine fusing last, similar to Krogman's 1962 findings. In the same study they have also noted that individual maturational events or features are so highly chronologically variable that previous tendencies to categorically state epiphyseal closure between certain time periods could prove to be very misleading. To improve the human identification process, they stress documentation of the full variability of epiphyseal closure as an essential requirement. However, because total skeletal variation is usually less in the chronological sense they, like many others (e.g. Krogman, 1962; Iscan and Loth, 1989), state that it is best to use as many points of reference as possible when estimating age. As for individual variation, they note that their study population was probably not truly representative of the actual American population, being that their entire data sample came from males of military age who were probably in better condition than the general populace at the time. They note that a tendency to disregard large variations from the norm in earlier and contemporary studies may have led to a misrepresentation of the actual extent of variation in some skeletal samples.

Sex Determination

Unlike the level of accuracy in age estimation, the probability of correct sex determination increases with age (except with very aged specimens wherein female crania tend to take on a male appearance). Before puberty sexual characteristics are slight or absent in the human skeleton. Often the only way to estimate sex in a sub-adult is by using population specific growth rates differentiated with respect to sex. As we age, we acquire secondary sexual characteristics reflected in our skeletal anatomy. The majority of this dimorphism involves the skull and pelvis. The bones of the pelvic area reflect the fundamental differences in functions between the sexes as associated with reproduction in the female (Ortner and Putschar, 1985) and as such are the best bones to use for sexual determination. The sex differences that occur in the rest of the skeleton are more reflective of the fact that females are generally more gracile, less muscular, and retain more adolescent features than their male counterparts. However, there is a great deal of variation in this regard, both within and between populations.

Sexual changes may be assessed metrically or non-metrically. Non-metric assessment generally involves examination of the skull and pelvis. A great deal of work has also been done on morphological assessment of the ribs (Iscan and Loth, 1985) and long bones (Iscan and Miller-Shaivits, 1984; Purkait, 2001). This does not infer that these techniques are adequate for sex determination by themselves. In most cases they have been created as an adjunct assessment after sex has already been determined in order to more accurately delineate the age range. However, if used together with other sex determination techniques, some may allow sex to be assessed with a greater degree of certainty, such as the dimensions of the long bones, (Iscan and Miller-Shaivits, 1984; Purkait, 2001) or sex and population specific pathologies, (Jaffe, 1958; Aegerter and Kirkpatrick, 1975; Ortner and Putschar, 1985; Reichs, 1986b). Even features such as sternal foramina may be useful on occasion as indicators of sex and age. McCormick (1980) in a study of 324 individuals found that 7.7% of them had sternal foramina. These were never present among individuals under the age of 20 years and were found twice as often in males.

Metric analysis of sexual dimorphism is comprised of measurements of size or robusticity, ratios or indices indicating shape, and discriminant function analysis (Reichs, 1986a). These include such methods as ischio-pubic index, long bone length, and certain skull measurements. One of the first metric methods for sex estimation, Hyrtl's Law, has been in use for over 170 years as an estimator of sex using sternal size. According to his research the manubrium of the female sternum exceeds half the length of the body. The body of the male sternum is at least twice as long as the manubrium. In 1890 Thomas Dwight published mean lengths for the body and manubrium for male and female individuals. Applying Hrytl's Law he found that two out of five cases did not meet the requirements and thus concluded that this methodology could not be relied upon in individual cases. Jit et al. (1980) in a study of 400 adult North Indian sterna (312 males and 88 females) obtained from medicolegal postmortems differentiated male and female sternum. They found that if the combined length of the manubrium and mesosternum was more than 140 mm the sternum was from a male, and if less than 131 mm it was from a female individual.

RADIOGRAPHY IN ANTHROPOLOGICAL ANALYSIS

Various anthropological studies have benefited from radiographic analysis. These include positive identifications obtained through unique skeletal formations and features to dental relationships and facial reconstruction to studies of growth and disease (Harris, 1933, Morgan and Harris, 1953; Sassouni, 1955; Lanzkowsky, 1968; Barres et al., 1989). Often radiography is used before a forensic examination is even attempted in order to differentiate between human and animal remains (Owsley and Mann, 1990; Chilvarquer et al., 1991) with one of it's chief advantages being it's relatively noninvasive and nondestructive nature. When dealing with decomposed remains it is also sometimes preferable to first attempt a radiographic analysis before a traditional anthropological postmortem examination, due in part to the time, cost, and effort involved in defleshing.

With respect to trauma, radiography is routinely used in the location of metal or other opaque intrusive fragments (Knight, 1980), and in the diagnosis of pathology (Maples, 1984; Caffey, 1950). Radiography's first documented forensic use was in 1896 in Lancashire, England where it was used to locate metal objects within a human body

(Evans and Knight, 1981). It has also been indispensable in the documentation of specific pathologies such as fractures or osteoporosis, surgical intervention, or abnormal skeletal morphologies due to trauma. Using ante- and postmortem radiographs for comparison positive identifications are often possible. Radiography has been and still is a very powerful tool in the study of growth and the aging processes (Todd, 1930; Flecker, 1932; Hill, 1939; Greulich, 1959; Kozielec, 1973; Chilvarquer et al., 1991; Kreitner et al., 1998).

AGE RELATED CHANGES OF THE THORACIC AREA

Human cartilage can be histologically classified as fibrous, elastic and hyaline. Hyaline cartilage is found especially in the joints, in the framework of the bronchi and larynx, and in the cartilage of the ribs. Historically rib calcification was commonly thought of as an ordinary occurrence of old age while bronchial asthma and pulmonary tuberculosis were perceived more to be a factor in tracheal and bronchial calcification as well as rib cartilage calcification (Falconer, 1938). As well, there was often a clear correlation between calcium deficiency (osteomalacia) and calcification. Other anomalies of calcium metabolism observed in connection with calcification of cartilage include the formation of gallstones, calcification of the mitral valves, and infarctions of the kidneys. King (1939) was the first investigator to note the unique pattern of ossification of the costal cartilage of the first rib among individuals. In (1965) Epker et al. studied the magnitude and location of cortical bone loss in human ribs and concluded that there is a physiological osteoporosis in this area among normal individuals that begins to develop after the third decade of life. Its chief effect is a progressive enlargement of the marrow cavity with periosteal bone apposition continuing throughout the lifetime of the individual. Sedlin et al. (1953) in a similar study on cross-section variations of the rib cortex with age determined that bone density as determined by the roentgenogram is a function of cortical and trabecular thickness, the degree of mineralization, and the sizes of the vascular channel in the cortex. Urist et al (1962) state that a 30% decline in bone density must occur before the decrease is apparent radiographically. From their results they suggest that a balance between bone resorption and formation in the rib area are in a positive mode from infancy until the late teens, at which time it stabilizes for a few years. It then assumes a negative balance that is greatest in the third and fourth decades of life. Similar changes in bone remodeling of the mid-20's suggests some sort of fundamental change in the physiology of skeletal remodeling.

In 1980, McCormick first described a technique for aging adult skeletal remains that he promoted as an easy, replicable, and accurate alternative method for evaluating the age of adult skeletal remains. The chest plate consisting of the sternum, the costal cartilages, and the terminal 2 to 5 cm. of rib were removed at autopsy from 210 individuals of known age, ethnic affinity, and sex. These were then x-rayed. They consisted of individuals between the ages of three months and 86 years. The degree of mineralization was arbitrarily graded from 0 (absent) to 4 + (very severe) from which a 9-point template system was developed (Figure 1). A graph reflective of the relationship between age and degree of cartilage mineralization was created from tabulated results. Resistance levels of costal cartilage to decay and degeneration were tested by placing 20 chest plates in an outdoor environment for up to four months and the cartilage was found to be quite stable.

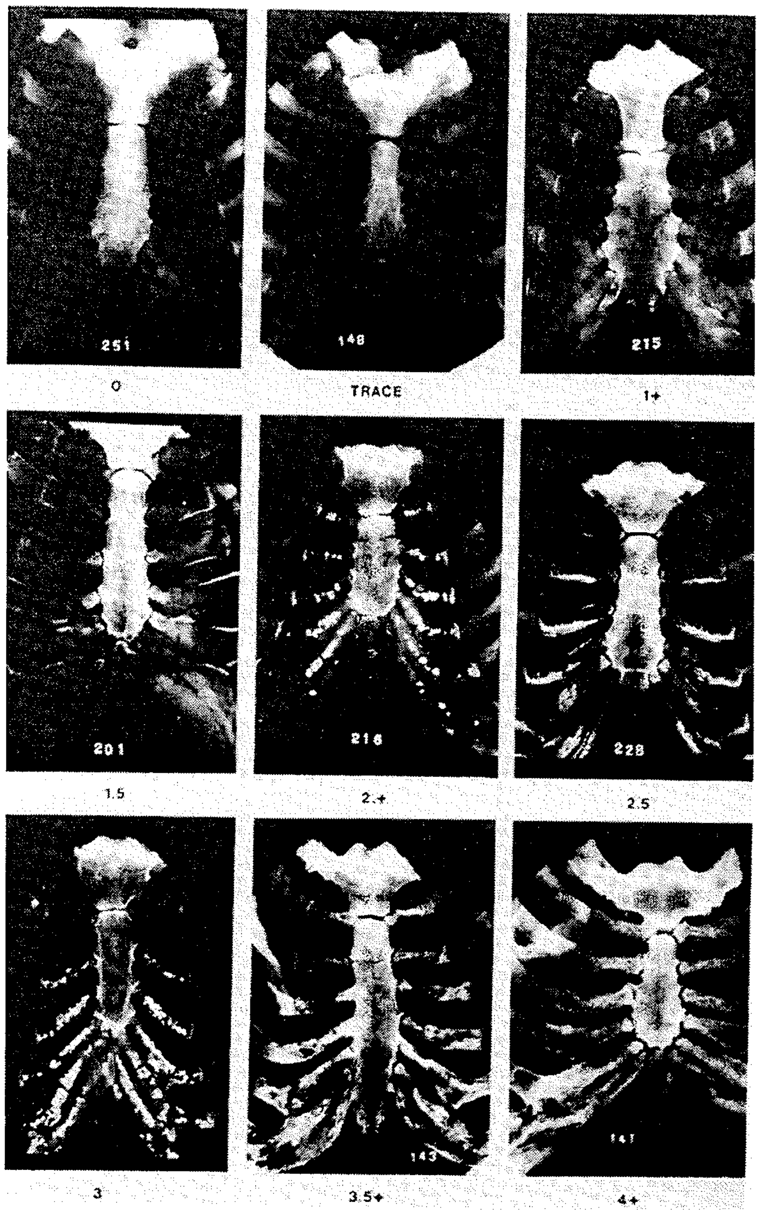

Figure 1: Grading of Calcification of Costal Cartilages. 0 to 4+

Reproduced from McCormick, 1980, Figure 1, page 738.

Calcification of the costal cartilage was first noted in a 15-year-old male but was generally uncommon before the age of 20 years. Among females calcification was first seen at the age of 21 years. It usually occurred first in the sternal rib borders of the sixth, seventh, and eighth ribs. All samples exhibited at least a trace of mineralization if over 25 years of age. Moderate mineralization of 2+ and 3+ within their grading system was rare before 40 years and usual after the age of 60. Dense mineralization of 3 to 4+ was only seen in two people over 55 years but the mild to moderate level, 1 to 2 1/2+ was common in those over 50 up to the age of 80 years.

McCormick's (1980) findings support previous results in that calcification of the costal cartilage appears to be common among individuals over the age of 25 years and that it increases with age. Dense calcification is unlikely before the age of 50 years and rare before the age of 60. However, relatively small amounts of mineral can be found even in the elderly, making age estimation based only on relatively light mineralization (1.5 to 2+) suspect.

The effects that population affinity had on the degree of mineralization was not clear in this initial study. Preliminary data did suggest that Mexican-Americans had denser and earlier mineralization than did Whites, and African-Americans. As well, males exhibited denser and earlier mineralization than did females.

While this method does not allow for the degree of precision experts in skeletal anatomy may render McCormick believed it would be useful in situations where there is a decaying adult body of indeterminate age and some reasonable estimation of age was urgent. As well, the stability of the costal cartilage in an outdoor environment boded well for future analysis.

Barres et al. (1989) estimate age at death from quantitation of roentgenologic features of chest plate radiographs obtained during routine autopsies. Multiple linear regression analysis is used to estimate coefficients for features of individuals whose age at death is known. These features include bone demineralization (BD), manubrial fusion (FM), rib-to-cartilage (RC) and cartilage-to-sternum (CS) attachment changes, and cartilage mineralization (CM). The features are initially assessed from 1 (very light) to 5 (heavy) independent of a photographic guide. After consensus of agreement of certain features they were assessed using a generated template. A regression equation was then calculated to estimate the age at death of the unknown individual. Results of their analysis showed that the best male predictors included CS, RC and FM changes while best female predictors included BD and CM. However, their female sample was significantly smaller and older than the male sample examined. Using multivariate analysis both sexes showed comparable results. Ranking of features showed a 58% total variance for CS changes. A 2% variance was found in FM, RC, and CM changes, and BD showed a 1% total variance. Correlation between judges was best for cartilage mineralization followed by cartilage-to-sternum attachment, sternal fusion, rib-to-cartilage attachment, and bone demineralization. The use of a template increased the values of all of the correlations with an almost constant increase except for bone demineralization and rib-to-cartilage attachment changes (Figure 2).

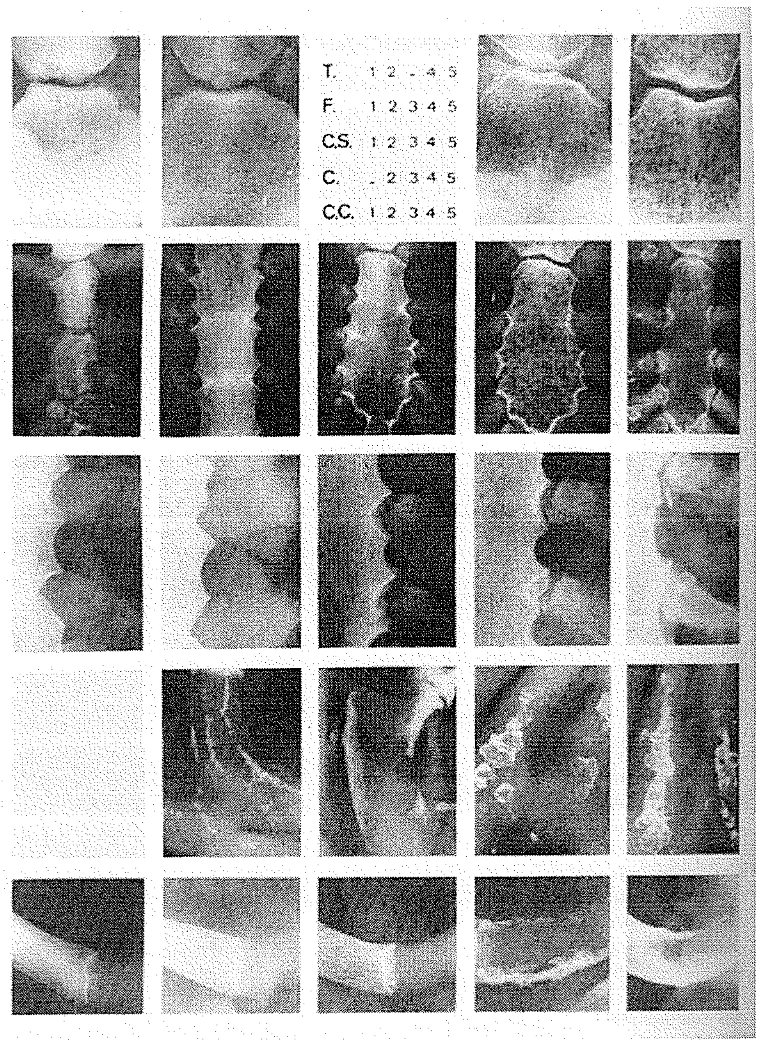

Figure 2: Photographic Template for Feature Assessment of Chest Plate X-Rays

Reproduced from Barres et al., 1989, Figure 1, page 230.

With this technique they were able to estimate age at +/-17 years with a confidence interval of 95%. This is within the range of other previously published macroscopic methods (Iscan et al., 1984), although they believed their method to be much faster and simpler.

Using McCormick's (1980) preliminary results McCormick and Stewart teamed up in 1988 to once again study age related changes of the human plastron. The thoracic area from 1,965 cadavers of known age, ethnic affiliation, and sex was removed at autopsy and examined radiographically. Some were also examined microscopically as well as macroscopically. The radiographs and whenever possible the skeletal remains themselves were examined for location, pattern, density, and extent of costal cartilage ossification. The amount of osteoarthritic changes in the sternal head of the clavicle, the contour of the costo-manubrial junction, and cupping of the sternal rib ends was also noted. Non-metric traits such as sternal foramina, epi- (supra-) sternal bones, duplication of ribs or costal cartilage were also recorded.

McCormick and Stewart (1988) found that the ossification of the first costal cartilage progressed quite differently from other costal cartilage (Figure 3), appearing as a "solid bony case" on radiographic examination. Ossification was usual first seen in the early 20's with an obliterated fusion line by the fifth decade. As well, heavy ossification appeared more rapidly in males.

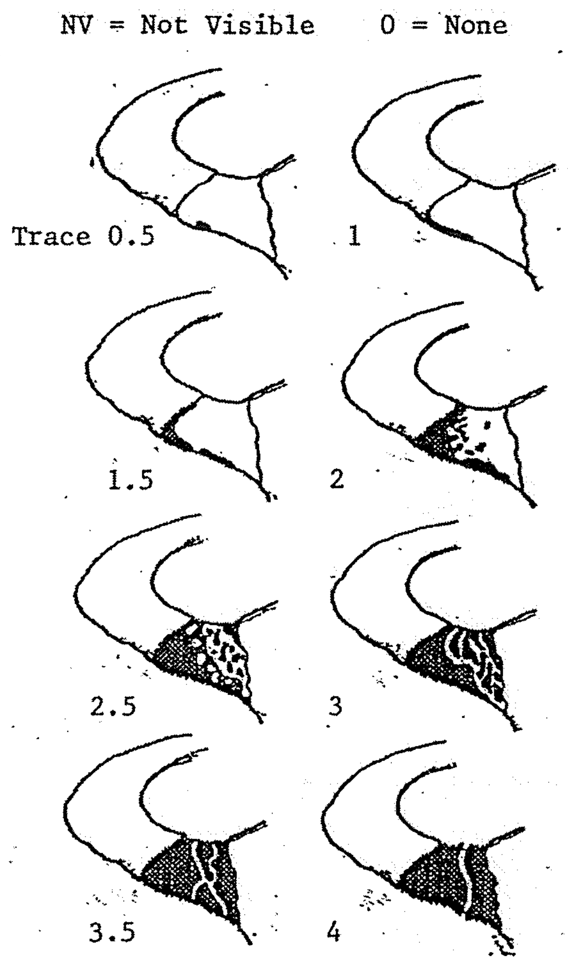

Figure 3: Schematic Diagram of First Rib Ossification Process.

Reproduced from McCormick and Stewart, 1988, Figure 6, page 107.

Second through seventh costal cartilage ossification was most frequent in peristernal, rib-end, and central locations (Figure 4) with the least sex-predictive ossification occurring peristernally. It appeared as early as mid-teens only to increase with age, in some cases becoming massive by age 60 in both sexes. Peristernal and second through seventh costal cartilage ossification was evaluated using a scale from 0+ to 4+ with half step increments. A 1+ value signifies minimal changes; represented by small button-shaped scattered foci occupying most of the width of the chondro-mesosternal insertion. A 2+ value signifies recognizable, characteristic patterning; represented by larger areas with coalescence, these extend completely across the width of the insertion. A 3+ value signifies heavy to massive patterning; represented by changes covering a major portion of the cartilage area, these are elongated laterally from a broadly ossified insertion.

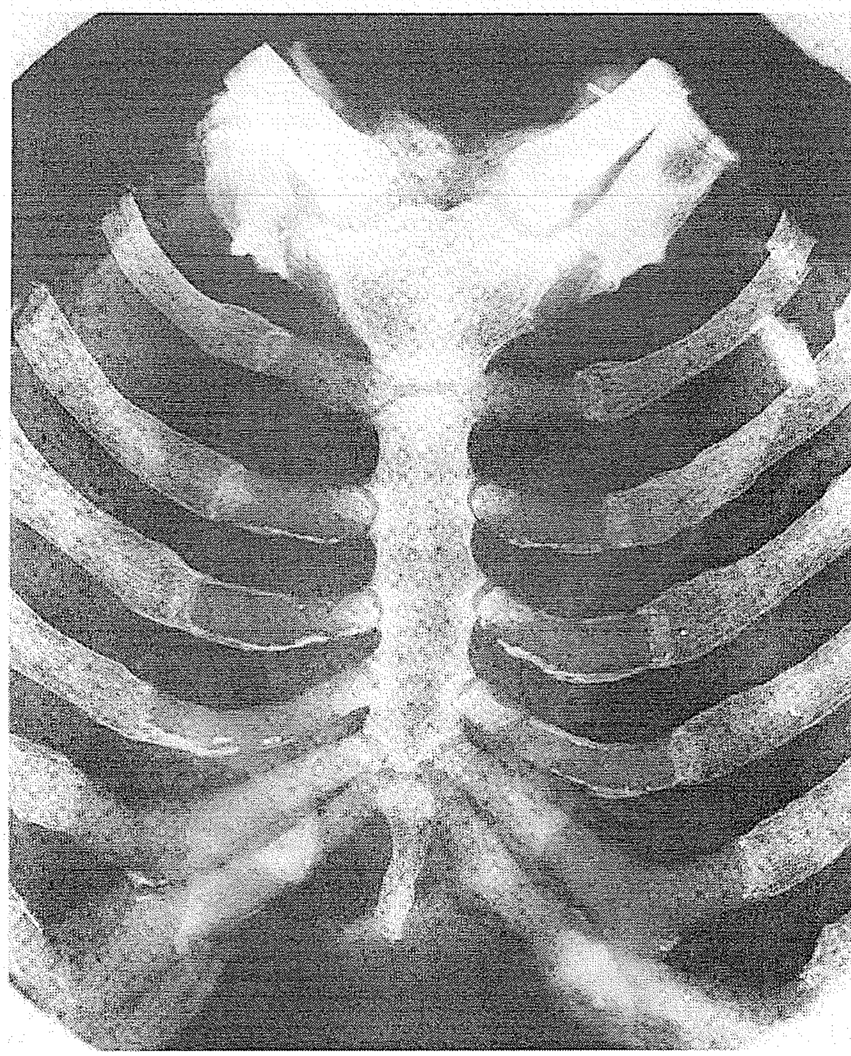

Figure 4: Peristernal Ossification of the Thoracic Area

Reproduced from McCormick and Stewart, 1988, Figure 7, page 108.

Rib end ossification was found to be very sex-predictive assuming several distinct patterns. (Figure 5). In the fourth decade of life the sternal rib ends tend to become flared with an increase in the depth of the depression and irregularity of the edges. Subperichondral spurs projecting along the upper and lower rib margins were characteristic of males. Female-type patterns consisted of cone shaped central new bone formation arising with the base parallel to the fossae costa and with the apex towards the sternum. With increased age these may begin to take on a "crab claw" pattern. In the fourth decade of life the rib end and peristernal areas take on a trabeculated appearance. Continuation and fusion along the subperichondral area occurs in the fifth decade accompanied with an obliteration of fusion areas by trabeculation.

Figure 5: Deep-cupping of Rib Ends.

Reproduced form McCormick and Stewart, 1988, Figure 18, page 118.

The costal-manubrial border was evaluated by assessing the smoothness or irregularity of its edge (Figure 6). A smooth border indicated a probable age of less than 25 years, slightly irregular an age of 25 to 35 years, and distinctly irregular an age over 35 years. Ossification of the xyphoid was assessed as none visible, partial or complete. Partial ossification was rarely seen before the late 20's (Figure 7). Osteoporotic changes were evaluated using amount of trabeculation. It was noted that dense trabeculation in the sternum and rib ends is typical in younger age groups. Dense trabeculation in the rib ends occurred in the late 30's for females and early 40's for males. Dense trabeculation in the sternum occurred in the 40's for females and 50's for males.

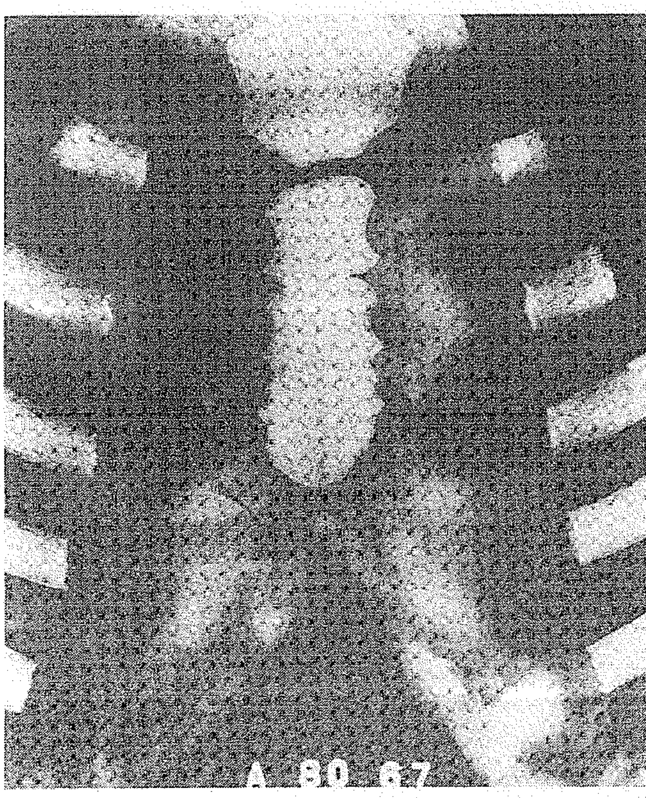

Figure 6: Costal-Manubrial Border Changes

Reproduced from McCormick and Stewart, 1988, Figure 15, page 115.

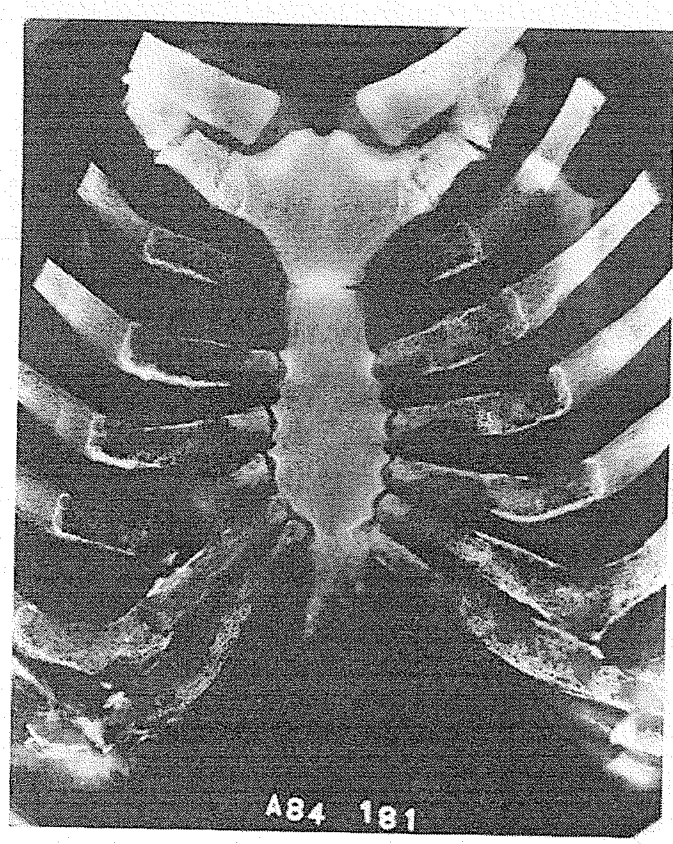

Figure 7: Ossification of the Xyphoid. (Partial Ossification)

Reproduced from McCormick and Stewart, 1988, Figure 16, page 116.

Characteristic ossification patterns were also noted (Figures 8 to 11), which were reflective of age and in some cases sex.

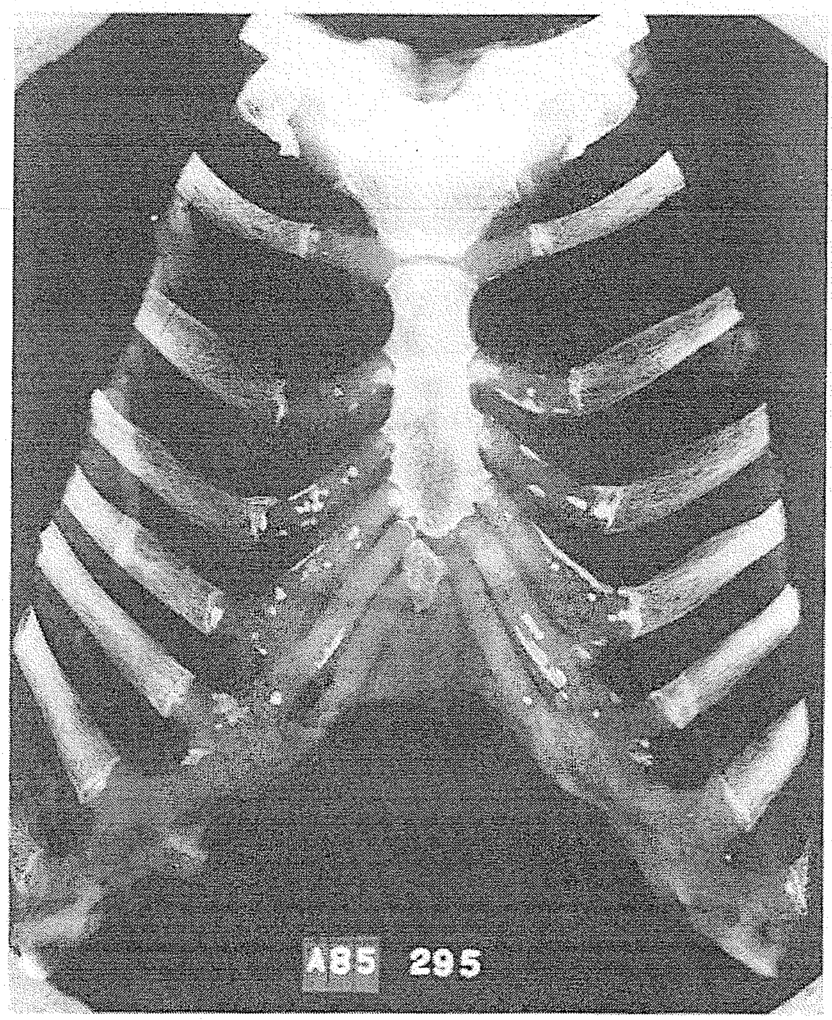

Figure 8: Ossification Pattern Type A

Reproduced from McCormick and Stewart, 1988, Figure 11, page 112.

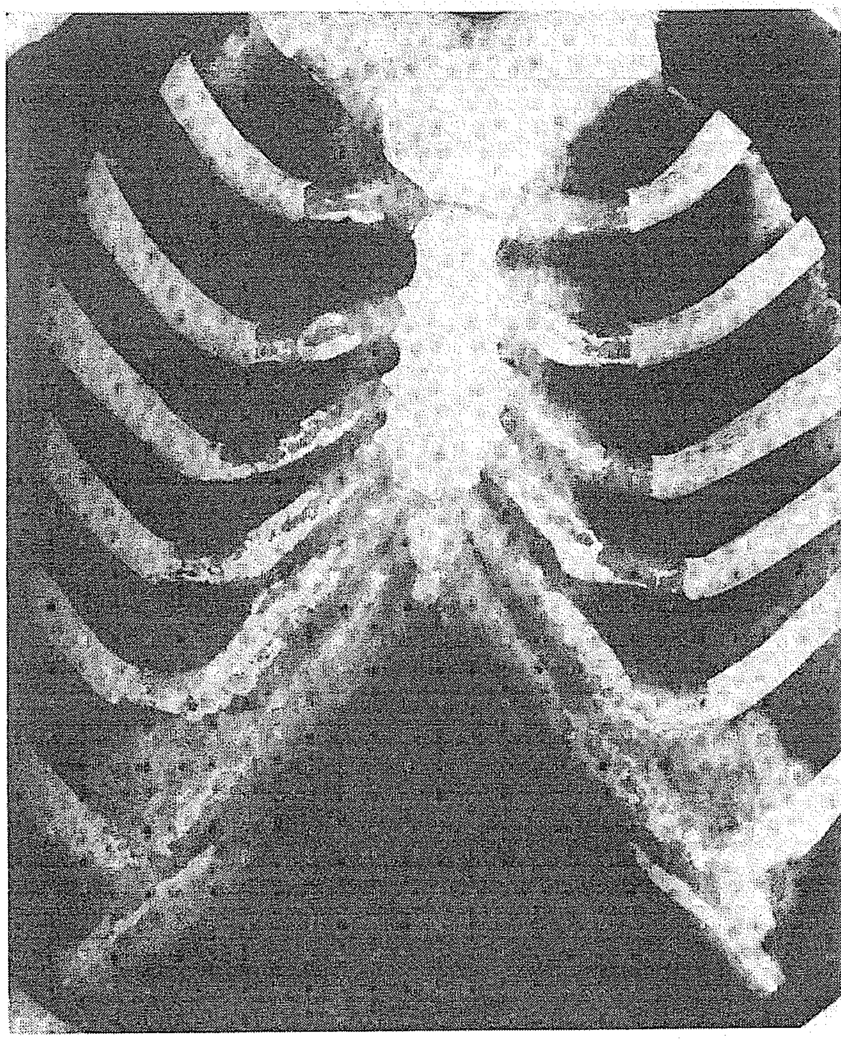

Figure 9: Ossification Pattern Type B

Reproduced from McCormick and Stewart, 1988, Figure 10, page 111.

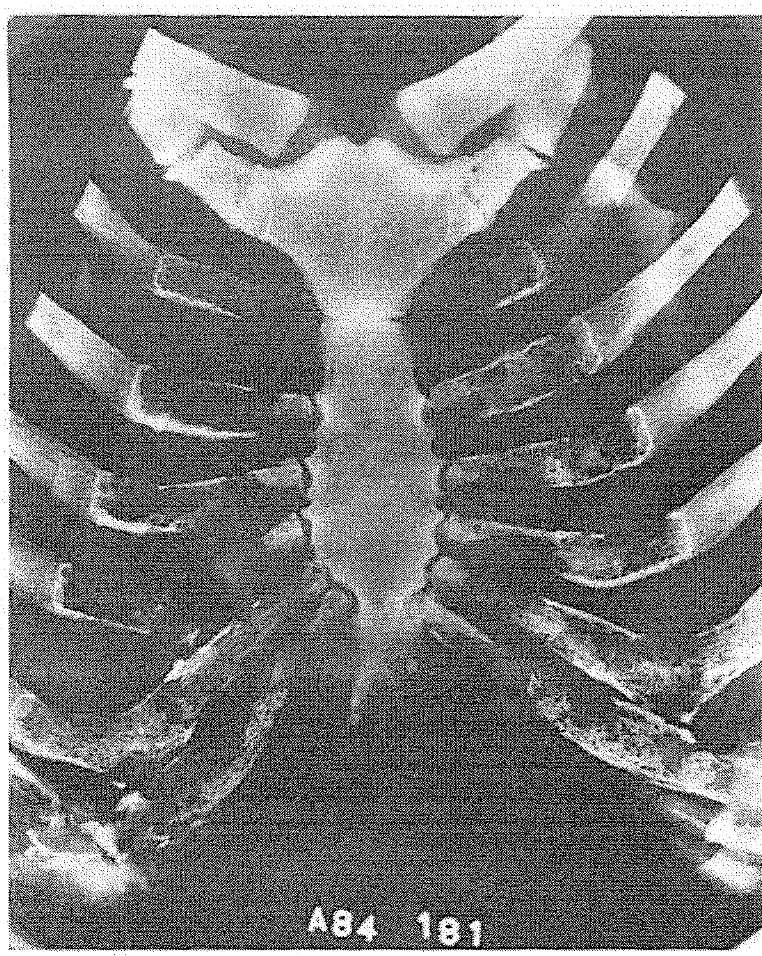

Figure 10: Ossification Pattern Type F

Reproduced from McCormick and Stewart, 1988, Figure 16, page 116.

An ossification pattern in the central portion termed Type A was only found in females over 50 years of age. It consists of smooth globular areas of ossification within the interior of the costal cartilage. A large amount indicates an age over 60 years. If seen in younger individuals it was found to be a sign of a pathological condition, such as leukemia. An ossification pattern in the central area often continuous with the rib ends is seen in males only. This has been termed Type F or Type G. These plate like areas of ossification have a Swiss cheese like appearance to the central area, often continuous with the rib ends which is visible among males in the third decade of life. Solid appearing costal cartilage, probably the end of this stage, are limited to men in their 70's.

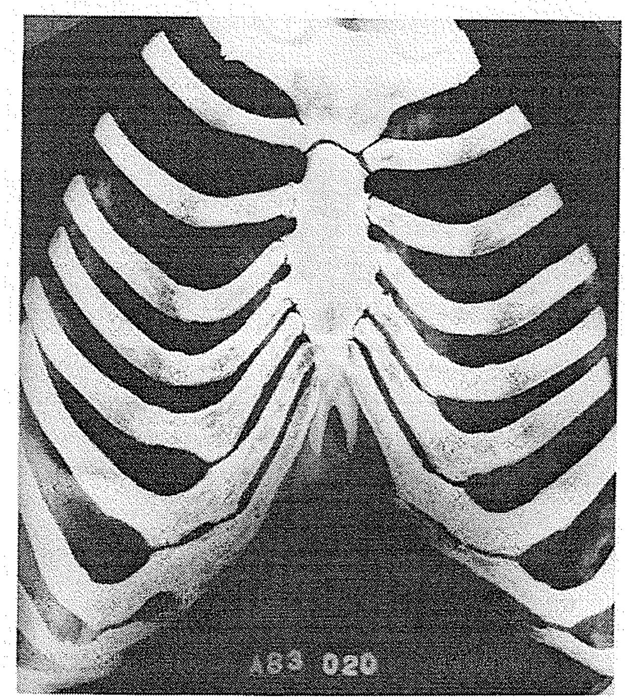

Figure 11: Ossification Pattern Type G

Reproduced from McCormick and Stewart, 1988, Figure 14, page 114.

Results of McCormick and Stewart's (1988) observations as related to their age and sex groups are summarized in Tables 1 and 2:

Table 1: Age-Related Ossification Changes in Males.

Age	Male
<20	• 0, trace, or moderate mineralization present • occasional Type H (modest central mineralization present) • smooth costal manubrial border
21-25	• 0 to 1+ first rib changes • little marginal or central rib changes as well as peristernal changes • slightly irregular costal manubrial border
26-30	• 0 to 1.5+ first rib changes • minimal lower rib changes • peristernal changes beginning • no change in trabeculation • distinctly irregular costal manubrial border
31-34	• first rib changes range between trace and 3.5 • modest lower rib changes • moderate peristernal changes • no other trabeculation changes
35-40	• first rib changes from trace to 3.5 • moderate peristernal changes with frequent peristernal trabeculation • occasional minimal central trabeculation • coalescence of marginal mineralization centers
40's	• first rib changes usually greater than 2.5 • lower rib and peristernal areas of any value • minimal central trabeculations • peristernal trabeculation common • common minimal central trabeculations • some rib osteoporosis
50's	• prominent first rib changes • significant lower rib mineralization • prominent central trabeculations • osteoporotic changes of rib and sterna prominent
60's	• prominent first rib changes • prominent lower rib changes
> 70	• prominent marginal maturational changes • edges of trabeculated bone may have a rounded profile

Table 2: Age-Related Ossification Changes in Females

Age	Female
<20	• moderate central mineralization may be present • xyphoid often unossified • smooth costal manubrial border
21-25	• 0 to trace first rib changes • minimal central rib changes • zero or minimal peristernal changes • smooth to somewhat irregular costal manubrial border
26-30	• 0 to 1.5 first rib changes • minimal lower rib and peristernal changes • no trabeculation changes • costal manubrial border becoming distinctly irregular
31-35	• 0 to 2.5 first rib changes • modest peristernal changes with no trabeculation
36-40	• 0 to 2.5+ first rib changes • moderate peristernal changes with trabeculation • rare and minimal central trabeculation
40's	• 0 to 2.5+ first rib changes • lower ribs and peristernal minimal to moderate changes • modest central trabeculation • some significant osteoporotic rib changes
50's	• any amount of first and lower rib changes • peristernal changes moderate to excessive • significant central trabeculations • Type A pattern begins to appear • Significant sternal and frequent rib osteoporotic changes
60's	• First rib changes always over 1+ • Lower ribs may be of any value • Always some peristernal change • Common central trabeculation • Type A changes present in more than half of the cases
> 70	• Similar to 60's except more extensive, and in particular, Type A changes

As can be seen from Tables 1 and 2 and Figures 1 to 11 there is a significant amount of variability present as well as a large overlap in age when you are dealing with such factors as ossification of the xyphoid, peristernal, central, and rib end changes. What appears evident is that these criteria may only be indicative of fairly broad age ranges with a high probability of accurate age determination within only the very high or low age groups. McCormick and Stewart (1988) do not evaluate individuals over the age of 65 years (due to the poor resolution of their method at the time) for standard deviations but did find an average underestimation of 1.5 years with a standard deviation of 8.2 years for the remaining cases. They found that specific age ranges were not always easy to obtain but minimum ages could be proposed, (though often this estimate was significantly too low). What may be helpful is the evaluation of all the features as a whole in order to delineate an age group. However the chance that an individual exhibits all such changes may prove to be quite infrequent. What may be of more use is the appearance of specific patterns that are absolutely indicative of sex and may suggest an age range. These would be Type A and Types F and G. These types manifest themselves among the more aged individuals, namely Type A within the over 50 year age group in females and Type G in the over 55 year age group in males. Type F spans a much larger age range but it also has only been noted among male individuals. Type B is not as frequently found within this reference population but does appear within both sexes and spans almost their entire age sample.

SEX DETERMINATION USING THE THORACIC AREA

In one of the first studies on hyaline cartilage calcification Falconer (1938) attempted to clarify the way in which calcification of the cartilage of the trachea and bronchi took place among the sexes. With samples taken at autopsy 97 men and 102 women with an average age of 62 years were studied. The first increase in calcium deposits of the respiratory tract occurred in both sexes between the ages of 45 and 55 years followed by a rise in both calcium quantity and number of areas involved. Falconer found that calcification of the trachea and the bronchi displayed a marked difference in pattern between the sexes. Calcification of the tracheal and bronchial cartilage was much more common among elderly females with the bronchial area most often affected. Males experienced deposits that extended from the bronchi up to the cricoid cartilage. As well, males experienced earlier and more marked calcification of the rib cartilage, especially to ribs six and nine.

Fischer (1955) noted that there was a difference in ossification patterning in the costal cartilages of male and female individuals using clinical chest roentgenograms. Eleven years later Sanders (1966) also published what he believed to be a typical male pattern of ossification (similar to Stewart and McCormick's male pattern of peripheral subperichondral linear ossification). Sanders found that 60% of his cases over the age of 60 years displayed these typical ossification patterns allowing all of them to be predicted accurately with respect to sex. This is similar to McCormick and Stewart results of 1988. While they were not concerned with sex determination at this time their results demonstrated the tendency for aged individuals to clearly exhibit diagnostic patterns which could be used to absolutely infer sex, (namely, Types A, F, and G). Of Sander's indeterminate or minimally ossified cases 80% were predicted correctly, and 31% of the completely indeterminate cases were predicted correctly.

In general terms, men seem to have denser ossification of their costal cartilage than women (Rist et al., 1928; Michelson, 1934; King, 1939; Fischer, 1955; Fully and Dehouve, 1965; McCormick 1980). However, Elkeles (1966) has reported finding the opposite. Through examination of the radiographs from 1,329 male and 1,277 female individuals between the ages of 30 and 80+ years he has observed calcium deposits of the aorta and found evidence to suggest that there is sex specific calcification of the ventral costal cartilage. His observations were categorized as follows:

- +, representing short linear ring-like, thin calcifications or small specks of calcium at the distal ends of the lower ribs;
- ++ if displaying granular calcifications of the cartilage with or without additional bizarre-shaped calcifications at the distal ends of the ribs; and
- +++, if calcifications of the costal cartilage were in the shape of densely calcified, curved bands in continuation with the ribs.

Elkeles (1966) noted a sex difference in the pattern, onset, and amount of calcium deposits in the costal cartilage with respect to sex and age. In males calcification was mainly confined to the perichondrium and was seen as linear densities encasing the coastal cartilage. Less frequently was a hazy type of granular calcification of the entire costal cartilage. In females, marked calcification was usually shown by curved bands of dense granular calcification in continuation with the lower ribs.

Elkeles stated it was evident that he had found a distinct difference between the pattern, onset and buildup in the costal cartilage and atrial wall between males and females. He noted that it began roughly at the age of 20 years in the costal cartilages and arterial walls of both men and women. However, its prevalence was 5 times higher in females than males between the ages of 30 and 50 years. Ossification amounts remained steady in both groups until the 7th decade, only to jump again sharply within the female study population. Male ossification amounts remained low between the 30 to 50 year age groups and only increased slowly after that age. This appears to agree with McCormick and Stewart's 1988 study on aging differences as well as sex specific ossification patterns. Both studies have noted the tendency for males to experience linear ossification peripherally while females experienced more globular, centrally located ossification within the entire costal cartilage as well as individual ribs. However, while McCormick and Stewart (1988) have found similar sex-specific patterns, they have also noted more constancy between the two sexes in age of onset and amount of ossification, albeit specific areas and types of ossification have more definite and differing ages of onset and development. This may be reflective of a difference in sample size, age, and/or population affinity of the study population.

Hately et al. (1965) and Elkeles (1966) have shown through radiographic analysis that women display a higher degree of calcification in the cartilage of the trachea and bronchi, which would suggest a greater affinity for calcification of female hyaline cartilage than male hyaline cartilage. Onset of ossification has also been reported by Rist et al. (1928), Elkeles (1966), and Fischer et al., (1975) to occur earlier in women than in men. All of these researchers have found that ossification does not usually begin until about the age of 25 years, and if it is present at a younger age it is of the indeterminate type occurring around the age of puberty. Not until the middle of the third decade of life are the typical male and female ossification patterns encountered with ossification amounts increasing with increasing age. They have found it to be only rarely evident on clinical roentgenograms before the age of 25 years. These findings are similar to Stewart and McCormick (1984), McCormick et al. (1985) and McCormick and Stewart's (1988), except that the former have noted more similarity in age of onset of calcification between the sexes, but differing areas, types, and tendencies in development.

Sanders (1966) suggests there is a close correlation between calcium deficiency and cartilage calcification and examines 1,000 patients of both sexes with costal calcification of the lower ribs. The average age of the study sample is 54 years with the youngest male and female individuals in their early 30's. From the first 60 male and 40 female individuals examined they have found that males exhibit a pattern that is quite constant and distinctive. The upper and lower borders of the cartilage tend to become calcified first, extending directly from the ends of the ribs. Calcification of the central area then follows. The more common type of female calcification is manifested as a solid tongue of calcification extending from the rib into the adjacent cartilage. This is usually triangular or tongue shaped and may reach the sternum. A less common female pattern consists of two parallel lines of calcification extending from the center of the rib into the adjacent cartilage. They found it interesting to note that of the five females that had patterning typically characteristic of the males, three had had pelvic operation. This suggested to Sanders that it was likely the difference in cartilage calcification patterning was directly influenced by hormonal activity.

Later Navani et al. (1970) also evaluated the prevalence of costal cartilage calcification in order to identify age and sex influenced patterns and distributions. Two independent observers examined frontal chest roentgenograms of 1,000 patients of unknown sex ranging in age from ten to 95 years. An evaluation of the first rib was not done as, unlike others, (King, 1939; McCormick and Stewart, 1988), they were of the belief that it lacked sex and age specific calcification patterns. Pathological influences were also not examined as citing Vastine (1948) and Horner (1949) they were not convinced that this would have any clinical significance on age and sex influenced patterns of calcification.

Rib calcification patterns were put into one of four groups:

- Type I or marginal;
- Type II or central;
- Type III which is a combination of I and II but consists of parallel linear shadows situated centrally; and lastly,
- A mixed type which consisted of a combination of I, II, and III on different ribs of the same individual. (Some other rare patterns were also included in this last category).

Using a formula to estimate the predictive value of each pattern type they found that a Type I calcification pattern in males will have a 95% accuracy rate of determining sex. It's prevalence among males alone, or in combination with other types was high at almost 70% and rose in frequency from 3.3% in the under 20 year age group to 89.3% in those over 60. However, it was also found within 11.3% of females reaching a frequency rate of 15.5% in those females over 60.

When found in females Type II calcification will give a predictive value of 93% accuracy in determination of sex. It was found in 76.2% of females increasing from 45.2% in those under the age of 20 years to 88.4% in those individuals over 60 years of age. It was present in 12.0% of the male individuals examined showing little variation with increasing age.

Type III was found fairly infrequently occurring in 0.2% of males and 1.3% of females. Mixed calcification type had a prevalence of approximately 7% in both sexes. Navani et al (1970) also noted that patterns other than the pure Type I and II occurred more frequently within their female sample than it did the male at a value of 57%. Little calcification was found in those under the age of 20 years.

While Navani et al's (1970) categories of ossification patterns are less specific in their criteria than McCormick and Stewart's 1988 criteria they do contain two of the most commonly found elements with respect to the configuration of the calcification. This would be the highly sex-specific tendency of central calcification occurrence among females and marginal calcification among male individuals. As well, the typical findings of greatly increased calcification amounts among individuals over the age of 60 and little before the age of 20 is also present in Navani et al.'s sample.

In 1983 Stewart and McCormick using a similar methodology to their later 1988 study on age related ossification patterns, examined the sex predictive value of ossification patterning coupled with sternal length. The chest plate consisting of the complete and intact sternum, costal cartilages, and terminal rib ends with the associated soft cartilage was removed at autopsy from 617 cadavers of known age and sex. The 361 men and 256 women were all over 20 years of age. Manubrial and mesosternal lengths were measured to the nearest mm individually and together. Significant xyphoid-mesosternal fusion cases were considered alone and with cases lacking significant fusion.

Stewart and McCormick (1983) found it difficult to accurately document manubrio-mesosternal lengths if there was significant xyphoid fusion. However, assuming a normal distribution they found that manubrio-mesosternal length in men and women differed significantly. They found that female sterna were at least 22 mm less than males in all age categories. All lengths less than 121 mm excluded males while all lengths greater than 173 mm excluded females. However, of the substantial number of sterna within the gray area of 143 to 157 mm accurate sex determination was less than 80%.

Stewart and McCormick (1983) then examined 64 radiographs in order to determine if there was a relationship between sternal length and pattern of costal cartilage mineralization. They found when using sex-specific mineralization patterns alone such as Type A and F they could accurately predict sex in 38 out of 41 cases. Manubrio-mesosternal length alone predicted sex correctly in 40 of 42 cases. Using both methods 31 cases were assessed accurately with three discordant results. These included one wherein a very long sternal length was taken as a more persuasive indicator of maleness than the slight, female-type ossification pattern. The second individual was correctly assessed as male using a more reliable but marginal male ossification pattern over the small female-like sternal length. The third case could not be confirmed with the available methods. Two cases, one using mineralization patterns only and the other sternal length only were both predicted incorrectly. Seven cases were indeterminable. In all 54 cases of 64 were predicted accurately. When both techniques could be used together, (which was in 87.5% of the cases), an accuracy rate of 96.4% was obtained.

Their results have shown that sternal length measurable from chest plate x-rays is predictive for sex in about 25% of adult cases, with a substantial amount lying within the gray indeterminable area. This is less than what would probably be assessed correctly using chance alone. When sternal length was combined with the pattern of ossification of the costal cartilage a correct estimation of sex was obtained in 85% of adults. Combined manubrium-mesosternal lengths over 162 mm and less than 138 mm were strongly suggestive of men and women respectively with a predictive value of >90%. These results correspond favorable with Krogman's (1986) results using only the adult skull and are better than results obtained using only the long bones.

A study by Jit et al. (1980) of Indian sternum found determination of sex could be done with 100% accuracy if the measurements were between 174 mm or greater for men and 120 mm or less for women. No sex could be assigned if the length was between 131 and 140 mm. These higher accuracy rates are probably a reflection of the more homogenous study population as well as the less discriminating sectioning points. The gray area in this study is almost 4 times as great as that used in Stewart and McCormick's (1983).

In another study published in 1983 on the relationship between sex and costal ossification patterns McCormick and Stewart analyzed the chest plates of 407 males and 244 females of known age (all were over 20 years of age) and ethnic affinity. The radiographs were examined for pattern and amount of costal cartilage ossification and changes of the chondrosternal junctions. This examination was done as detailed in McCormick's 1980 study on age related changes of the thorax.

Both "typical" female and male type ossification patterns were noted (Figures 12 and 13) as well as an indeterminate pattern (Figure 14). It was found that males tended to experience more marginal subperichondral ossification and females more central ossification patterning (Table 3) with a sex predictive ability of 80 to 90%. Indeterminate patterns were also prevalent within their sample.

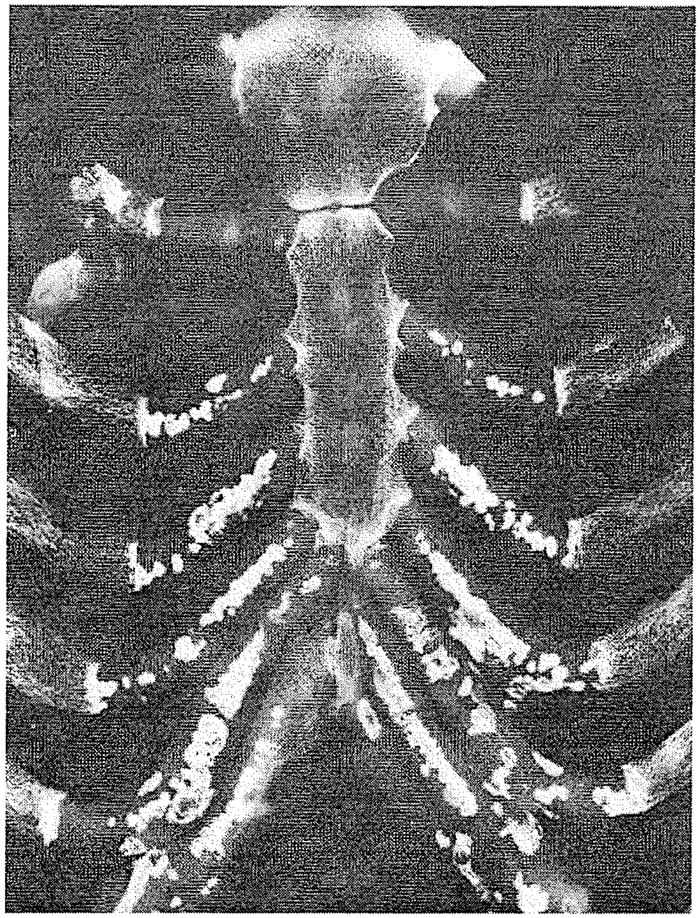

Figure 12: “Typical Female” Pattern Ossification.

Reproduced from McCormick and Stewart, 1983, Figure 3, page 208.

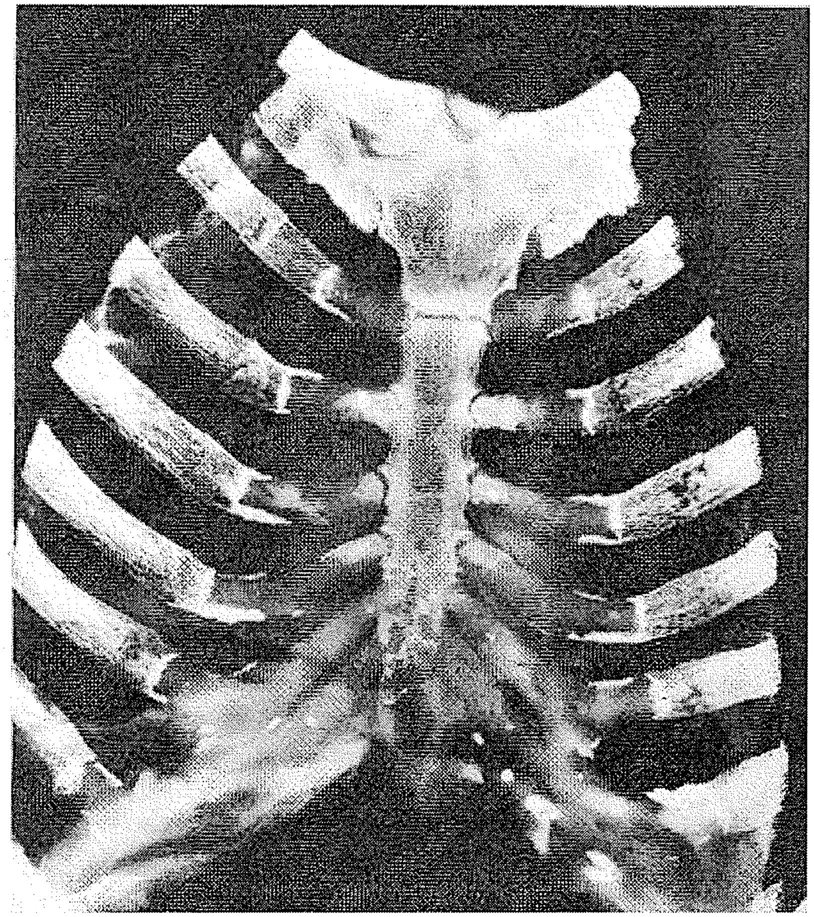

Figure 13: "Typical Male" Pattern Ossification.

Reproduced from McCormick and Stewart, 1983, Figure 1, page 207.

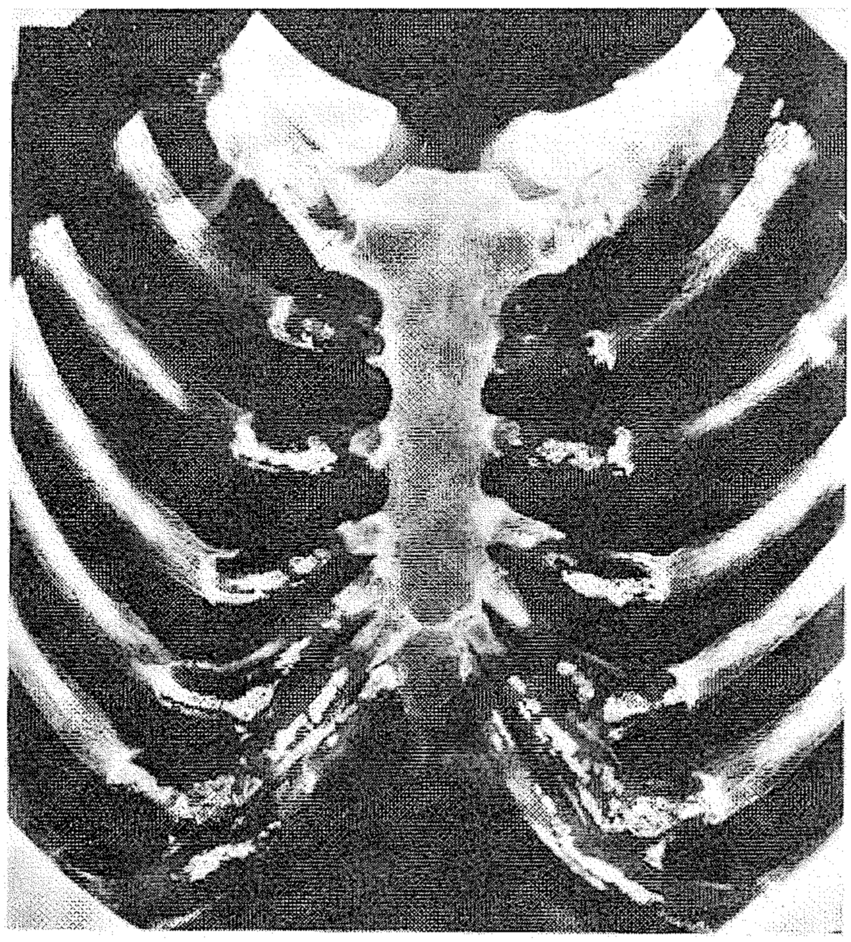

Figure 14: Indeterminate Sex Ossification Pattern. (In a 54-year-old White female).

Reproduced from McCormick and Stewart, 1983, Figure 6, page 208.

Table 3: Male and Female Ossification Patterns

	Patterns of Ossification			
Sex	Marginal Subperichondral	Central	Indeterminate	Total
Male	181	10	216	407
Female	30	81	133	244
Totals by Pattern	211	91	349	651

A typical male pattern found in 181 male individuals, consisted of peripheral linear subperichondral ossification extending from the rib ends towards the sternum (Figure 13). Slight variations of the typical female pattern were found in ten of the male costal cartilages that were examined. The typical female pattern consisted of subperichondral ossified plaques which were central in location (Figure 12). These were made of large, often associated, ossification nodules or fine, irregularly patterned ossification which arose sub-marginally as ossific tongues from the costochondral junctions. This pattern was present in 81 women. Variations of the typical male pattern of peripheral subperichondral linear ossification, most minimal, were found in 30 females.

An indeterminate pattern was also noted (Figure 14). This included ossification patterns that were too minimal for determination, too extensive for delineation of any type or a combination of marginal and central type but too mixed for specific determination. The indeterminate pattern was found in 216 men and 133 women, much more common than either of the male- or female-type patterns alone or combined. However, it was noted to be more prevalent among younger individuals than the typical male or female type.

With respect to population affinity the results were analyzed within White and Black subgroups. They found no statistically significant ethnic difference within their material. Acknowledging Michelson's 1934 study that had noted higher ossification amounts within Black individuals when compared to Whites, McCormick and Stewart believe if semi-quantitative techniques are used, as was by Michelson (1934), there may appear to be significant population affinity and age related differences.

In 1984 Stewart and McCormick evaluated sex and age-limited ossification patterns in human costal cartilage once again and for the first time specifically noted an ossification pattern they had only referred to before as typically female (McCormick, 1980; McCormick and Stewart, 1983; Stewart and McCormick, 1984) but now define as peculiar to elderly females. This is the "Type A" pattern (Figure 8). They also define and label for the first time a "Type B" pattern also common to females, but found as well, albeit rarely, in males (Figure 9).

The radiographs of 567 male and 337 female individuals over the age of 20 years were examined. Age, sex, population affinity, and disease data were available to the examiners. The radiographs were examined for both pattern and amount of ossification at the condro-sternal junctions, the central portions of the costal cartilage and the costochondral junctions, according to methods described previously by McCormick (1980) and McCormick and Stewart (1983). Some non-metric traits were also recorded.

Two particular patterns of costal cartilage ossification become relatively well developed and dense only after the age of 65 years. According to Stewart and McCormick (1984) this pattern allows for an absolutely positive determination of sex as well as an indication of advanced post-menopausal age. They state that at the time this technique enjoyed a high degree of precision and outperformed other methods with regard to this type of analysis but do not elaborate further on this aspect.

The "Type A" pattern is limited to post-menopausal females and was never seen within the male study group. It is described as consisting of spherical or globular foci of ossification which are manifest in the subperichondral region of the central portion of the costal cartilages. Typically these globular foci have smooth rounded contours which contrast sharply with the surrounding cartilage and are centrally relatively radioluescent. Type A changes do not involve the sterno-chondral junctions or immediately subperichondral cartilage (although marginal or "male" ossification may co-exist). They noted of specific interest with this type of pattern was that it occurred at a time when the body was no longer under female hormonal influences.

The "Type B" pattern, first described by Navani et al. in 1970 and called "central" or Type II is described as solid, tongue-like protrusions of calcification, of irregular sheets of ossification, which begin in the subperichondral location, often marked at the costochondral junction. This ossification pattern is mainly restricted to women and is often seen at an earlier age, sometimes as early as the mid-30's.

In 1985 McCormick, Stewart and Langford researched differences in chest plate radiographs of the sexes once again. As before they were concerned primarily with providing an accurate methodology that facilitated timely, simple, and inexpensive sex determination results from partially or completely skeletonized human remains. Besides these foremost concerns they note a need to create a technique that is amenable to analysis by relatively inexperienced, non-professional personnel who want to create a permanent, easily storable record. Other methods of sex determination such as pubic symphysis analysis, skull, and long bone morphology (Gilbert, 1973; Gilbert and McKern, 1973; Kelley, 1978; Stewart and McKern, 1957; Stewart, 1979; Black, 1978; Iscan and Miller-Shaivitz, 1984) require the availability of certain bones as well as a significant degree of expertise. This technique requires bones of the chest plate, an area most often removed during autopsy and almost always available in a decomposing or completely skeletonized individual. Sex determination is made directly from high-resolution chest plate roentgenograms, thus eliminating the need to de-flesh the individual.

McCormick et al. (1985) removed the chest plates of 698 males and 435 females over the age of 20 years at autopsy and x-rayed them according to the method previously described by McCormick and Stewart (1983). With these roentgenograms less than 1% magnification occurs because the chest plate is placed directly on the film. Although the chest plate is not flat the areas measured for sex determination are those closest to the film. All line measurements were taken directly from the roentgenogram and measured in millimeters. Five criteria were used to metrically evaluate the chest plate roentgenograms and are summarized from McCormick et al. (1985) in Table 4 and Figure 15.

Table 4: Measurements of the Sternum and 4th Rib

I. Manubrium-corpus (manubrium-body of the sternum) length Line 1: Manubrium length Line 2: Corpus length	
II..	Line 3: Fourth rib width
III.	Line 4: Corpus sterni (body of the sternum)width midway between costal notches two and three
IV. Manubrium-corpus (sternal) area: Line 6: Manubrium width at first costal notch midpoint Line 4: Corpus width midway between second and third costal notches Line 5: Corpus width midway between fourth and fifth costal notches	

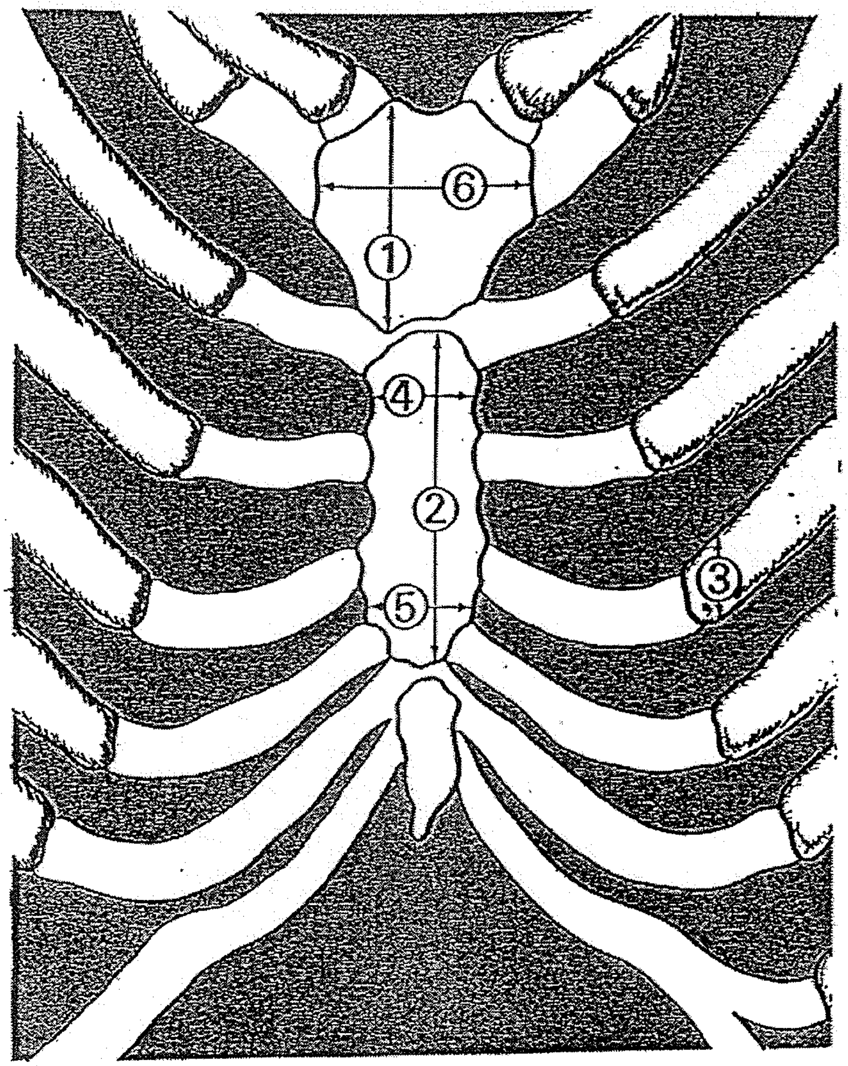

Figure 15: Measurements of the Sternum and 4th Rib

Reproduced from McCormick et al., 1985, page 174, figure 1.

As well as metrically analyzing bones of the thoracic area McCormick et al (1985) examine costal cartilage ossification patterns. The costal cartilages usually exhibit distinctive ossification patterns that can be classified as masculine and feminine types. They have noted one exclusively female pattern and two exclusively male patterns (Figures 8, 10, and 11). As well, five highly suggestive, but less sex predictive patterns are described for females and males (Figures 9, 16, 17, 18, 19). Non-distinctive configurations are either without ossification or have no predominant sex specific patterning (Figures 20 to 22). It should be noted here that McCormick et al.'s (1985) Type X and Type Y patterns were mistakenly transposed (Figures 14 and 15 in the original publication) and are shown here with corrected labeling. Results of their analysis are summarized in Table 5 and 6 as follows:

Table 5: Male Ossification Patterns

Type E	• Ossification of inferior and superior margins • Frequent sternal-costal articulations ossification • Most typical male pattern
Type F	• Sheet-like, central "Swiss-cheese" ossifications
Type G	• Massive ossification • May be end-stage F • Seen in elderly males
Type H	• Fine granular "Salt and Pepper" type ossification

Table 6: Female Ossification Patterns

Type A	• Centrally placed globular ossification • Never found in women under age 50 • Never found in males
Type B	• Central pyramidal ossification • Usually in females under age 50 • Can be found in males
Type C	• Central fragmented ossification • Not common
Type D	• Ossification at the costal fossa and sternal-costal articulations • Not common

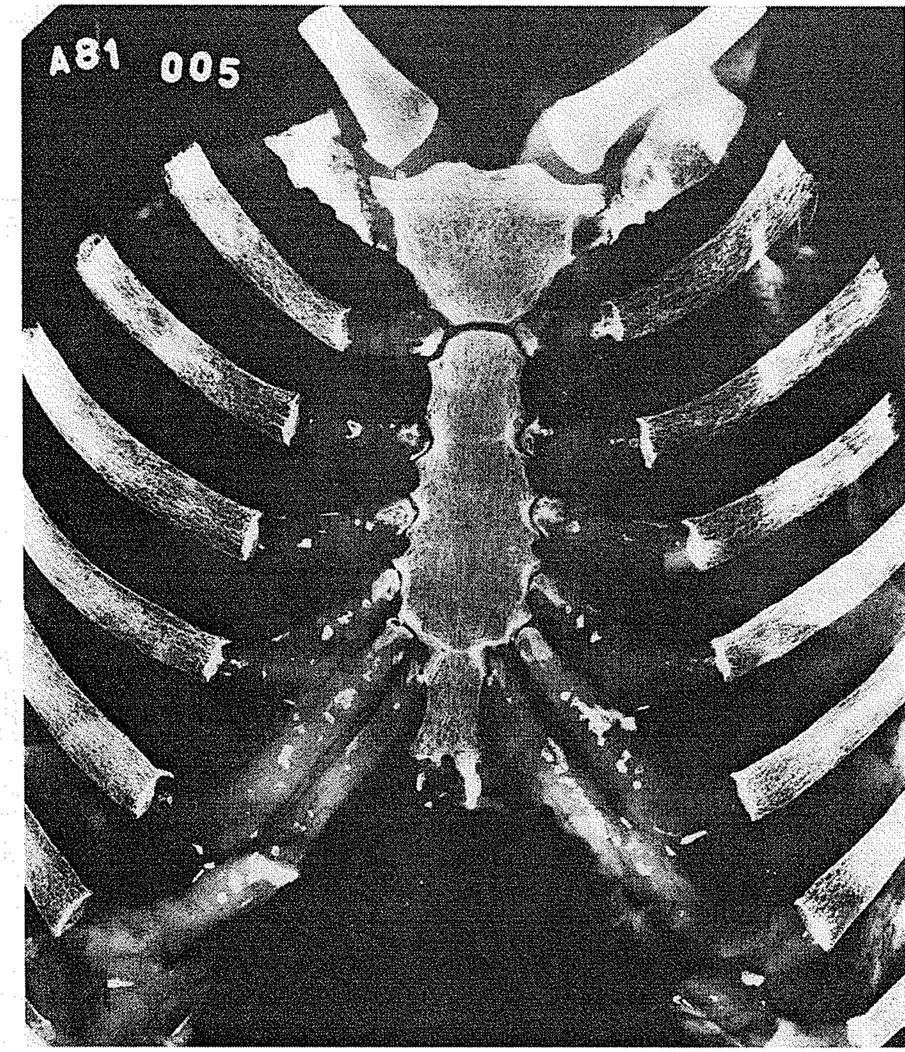

Figure 16: Ossification Pattern Type C

Reproduced from McCormick et al., 1985, page 180, Figure 6.

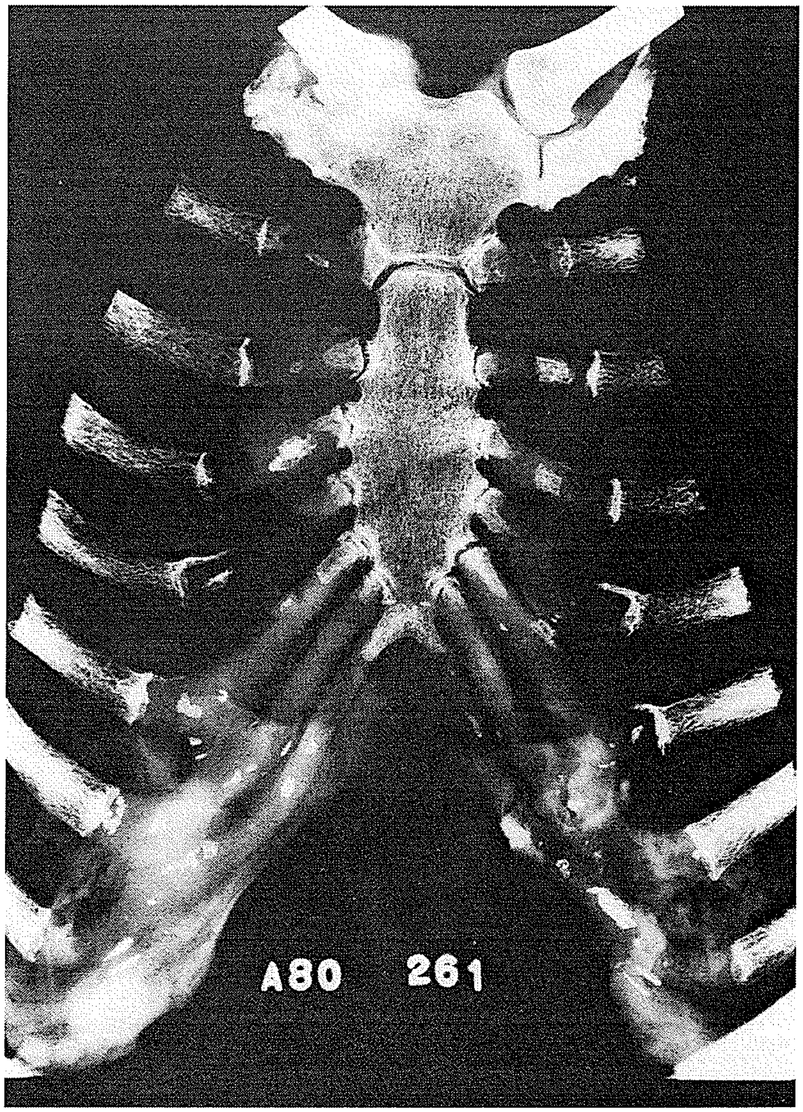

Figure 17: Ossification Pattern Type D

Reproduced from McCormick et al., 1985, page 181, Figure 7.

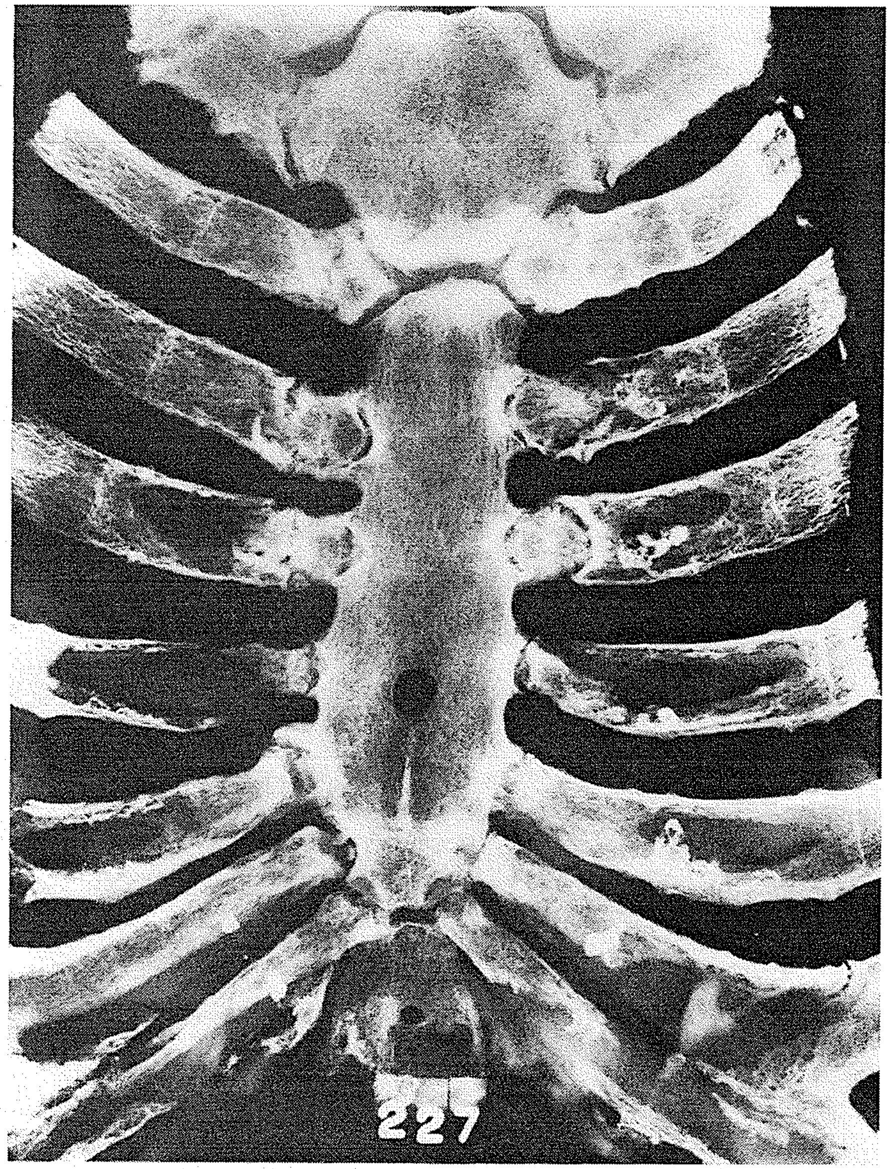

Figure 18: Ossification Pattern Type E

Reproduced from McCormick et al., 1985, page 182, Figure 8.

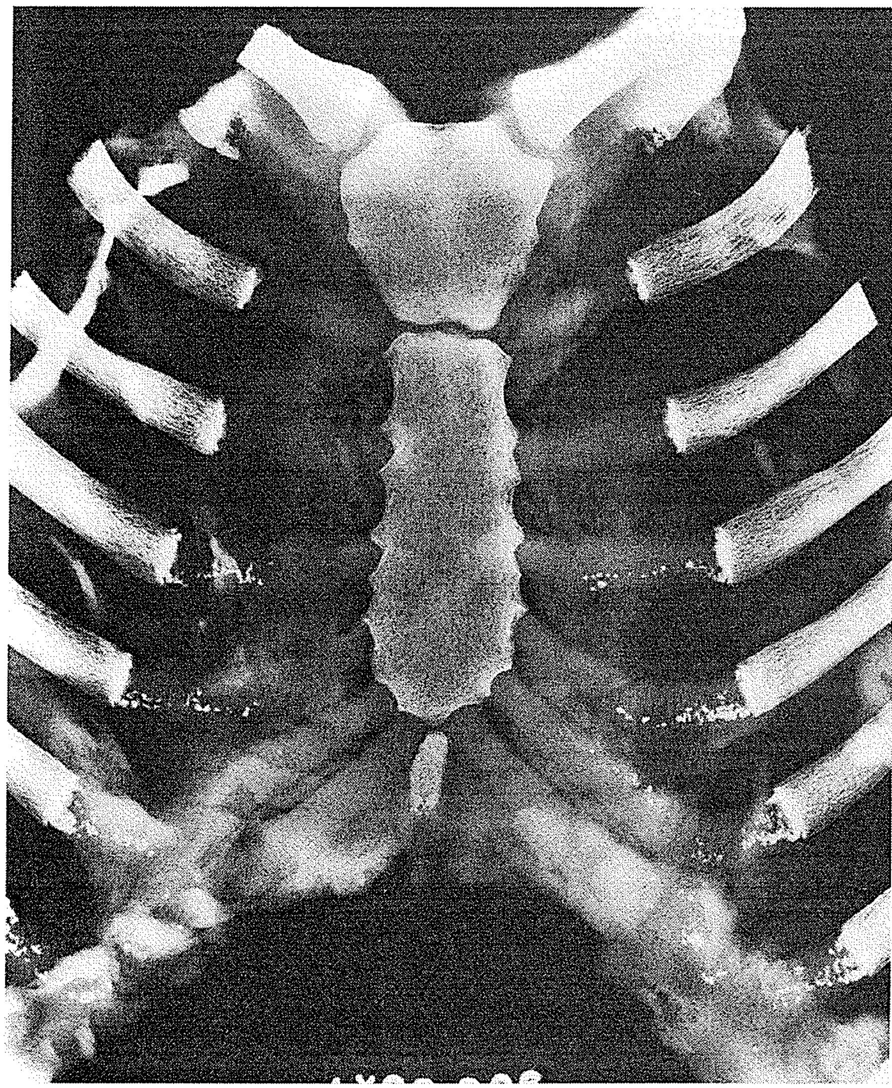

Figure 19: Ossification Pattern Type H

Reproduced from McCormick et al., 1985, page 187, Figure 12.

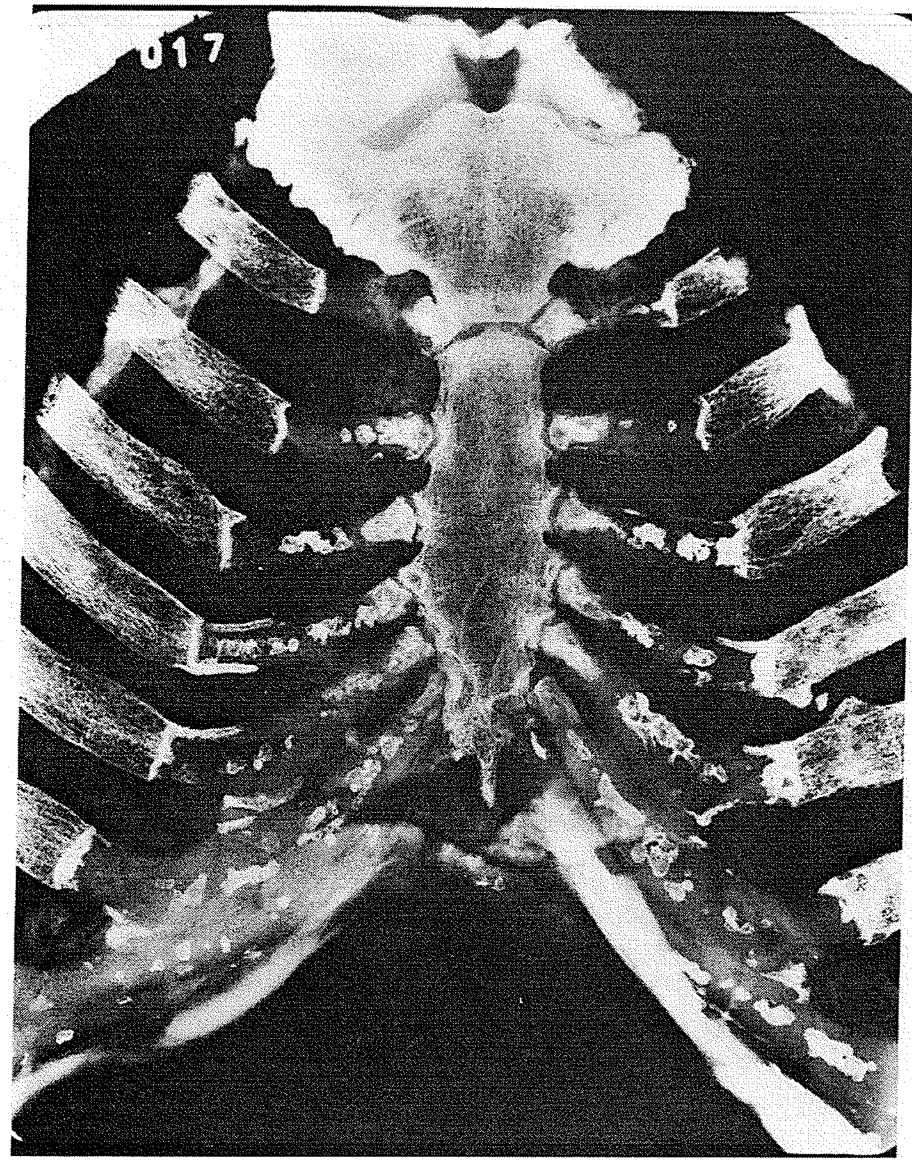

Figure 20: Ossification Pattern Type I (Indeterminate)

Reproduced from McCormick et al., 1985, page 188, Figure 13.

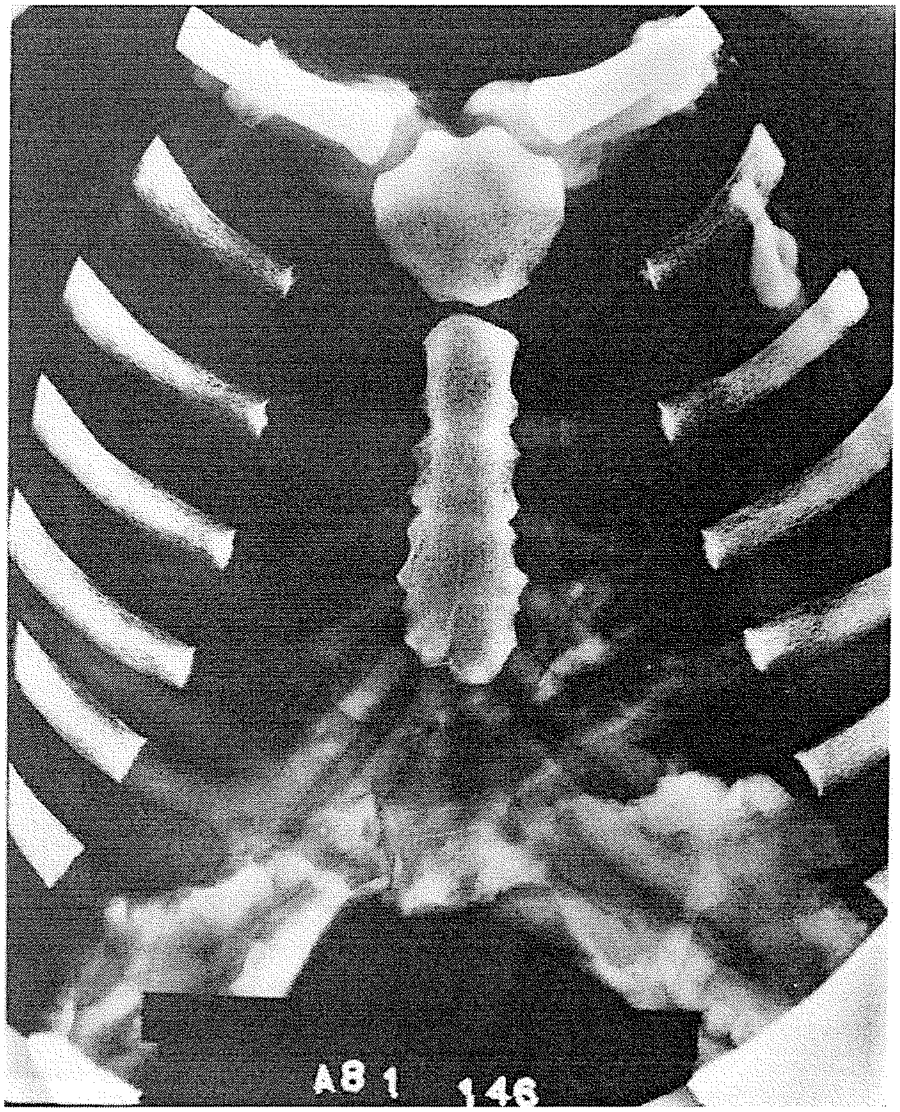

Figure 21: Ossification Pattern Type X

Reproduced from McCormick et al., 1985, page 191, Figure 15.

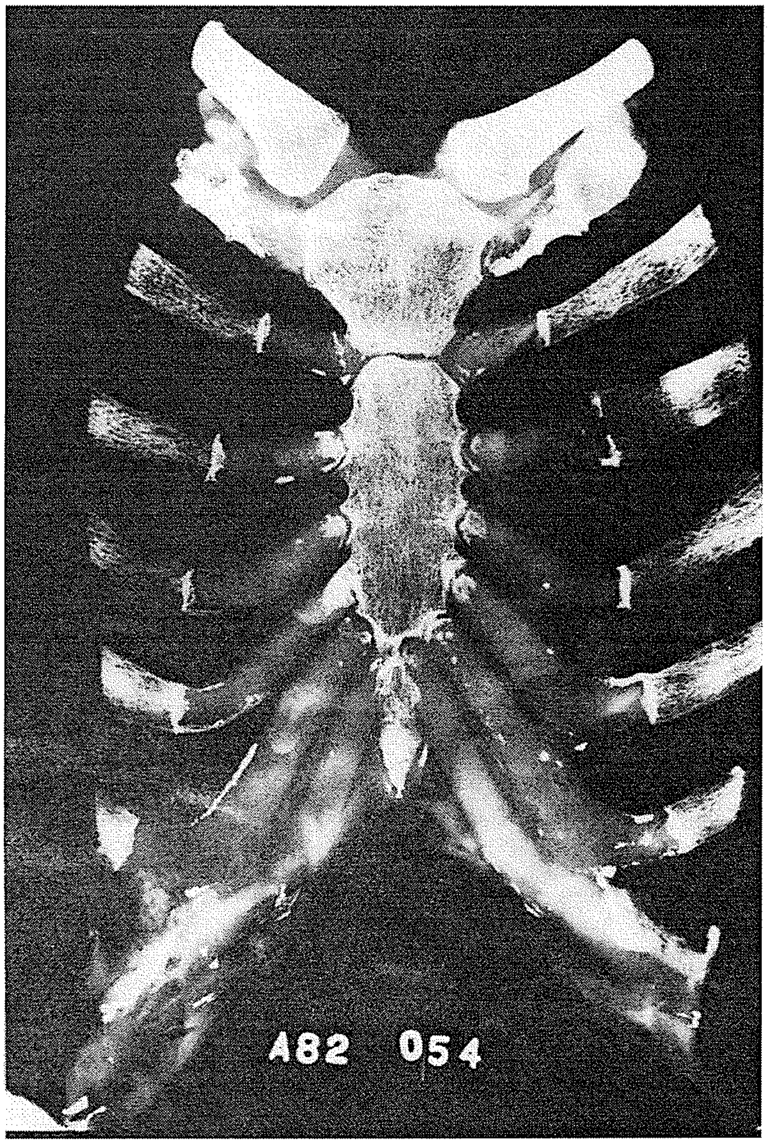

Figure 22: Ossification Pattern Type Y

Reproduced from McCormick et al., 1985, page 190, Figure 14.

Indeterminate patterns consisted of an ossification pattern with both male and female patterning yet without a definite dominance of one sex predictive pattern over the other. The ossification configurations are typically combinations of B and C with E or H. Types A, F, and G are not present. As Types A and F are highly sex specific patterns their presence would disallow the consideration of indeterminate patterning. These occurred in about 6% of adult chest plates.

Null patterns were seen in young adults. These included a Null Pattern X, which was defined as having no ossification and Null Pattern Y with ossification limited to parasternal and first rib cartilage. Approximately 9.0% of cases exhibited a null pattern.

McCormick, Stewart, and Langford (1985) developed an algorithm based on their experience and bias to aid sex estimation. Male Type E and female Types B and C were assigned a semi-quantitative value of 1+ to 3+ depending on the amount and type of costal cartilage ossification. A 1+ value represents minimal changes marginally assignable to a masculine or feminine type, a 2+ value represents recognizable, characteristic patterning in moderate quantities, and a 3+ value represents heavy to massive patterning. For example, the very sex-specific female Type A pattern was always given a 3+ value. This was also the case with the typical male Types F and G. The values represented in part the author's experiences as well as the observation that in this population the higher values for ossification in females are more sex specific than for males.

Indeterminate, null and weak male/female Types B, C, and E (1+, 2+ female patterning or 1+ male patterning) were automatically considered female if the manubrial length was less than 46 mm. All null, indeterminate and weak male/female Types B, C, and E (1+, 2+ male or 1+ female) were considered male if manubrial length was 60 mm or greater.

Type H cases were given a feminine estimate only if manubrium-corpus area was less than 4700 mm^2 or if the fourth rib width was less than 15 mm and manubrial length was less than 50 mm. Type D cases were assigned estimates by manubrium-corpus length, less than 152 mm were feminine and greater than 152 mm were masculine.

Null patterning or X and Y Type cases were considered female if two of the three following criteria were satisfied. A manubrium-corpus area less than 5000 mm^2 and/or a corpus width between the second and third ribs less than 124 mm and/or a fourth rib width less than 15 mm. It is not specifically stated as such but it is assumed that McCormick et al. (1985) would automatically consider that if two of the three criteria were not met the individual would be presumed male.

Using only sex-specific patterning 79.2% of cases were assessed with an accuracy rate of 92.0%. As found previously it was also noted that sex-specific patterning increased with age. In the 20-25 year age group 50.6% of cases exhibited patterning sufficient to be recognizable. This increased to 93.1% in the 60 or older age group.

With the use of sternal length sexing was possible in 67.2% of the cases which fell outside of the gray zone of 143 to 157 mm. Accurate sex was predicted in 94.3% of those cases. A cutoff of 148 mm (148 mm or over being indicative of male sex and less than 148 mm female) was used giving an overall accuracy of 85.2% for the entire study population. The indeterminate zone was 143 to 157 mm. Males less than 25 years had statistically shorter sternal lengths than the entire male study population. Males in older groups had average sternal lengths much closer to the average for the entire male study population. Females in the age group of 20-21 years had significantly shorter sternal lengths than the entire female study population. Females in older groups had no statistically significant difference from the entire female study population.

In a review of 196 cases McCormick et al (1985) found the fourth rib width to be more sex predictive than ribs two, three, or five. This parameter showed sexual dimorphism for 71.8% of the study population. The indeterminate widths were 15 and 16 mm. If the indeterminate widths were excluded sex could be accurately predicted in 91.5% of the cases. The addition of the fourth rib to the algorithm increased the overall accuracy to greater than 95% when applied to the entire population. A cutoff of 16 mm (16 mm or greater predicting male, less than 16 mm indicating female) gave an accuracy rate of 84.6% for the study population.

Corpus width at the second intercostal interspace reflected the sexual dimorphism seen with the other morphometric parameters, but alone is a rather weak sex predictor because of the large indeterminate range. If used alone, excluding the indeterminate range, 36.3%

cases yielded a sex predictive value of 88.3%. It is best utilized in computing the manubrium-corpus area estimate. When this is added to the algorithm the gladiolar width at the second interspace was of value in a few cases. It had an indeterminate range of 20-27 mm.

Sternal area was sex predictive in 67.6% of cases. The overall predictive value was 93.0% when the neutral zone was excluded. When used alone with a cutoff of 5400 mm^2, the sternal area yielded an accuracy of 85.6%. The indeterminate or neutral zone neutral zone was 4976-6041 mm^2.

With the use of the algorithm McCormick et al. (1985) were able to correctly predict sex in 97.1% of the cases with a 95% confidence interval of 96.1% to 99.8%. On a double blind study one author accurately sexed 99% of the x-rays and another individual with no training in anthropology or forensic pathology accurately sexed 97% of the x-rays.

Using the eight ossification patterns alone sexing was possible in 84.4% of the total cases, with 90.9% predictive values. According to the authors the ossification patterns used, as evaluated from a review of the clinical, biochemical, and necropsy results, are not disease related. Ossification patterns and quantities may also be used as age predictors. If both ossification patterns and sternal length were used sexing was correctly assessed in 94% of the study sample.

All of the parameters appear to have some sex predictive capabilities. In some cases the use of only one parameter could determine sex accurately (particularly costal cartilage ossification) while others were better used in concert with other techniques, i.e., corpus width. If all parameters were used with the empirically derived algorithm, accuracy rates ranging from 97% were achieved. McCormick, Stewart, and Langford (1985) have not noted any population affinity limited or predictive feature within this study population.

EFFECTS OF PATHOLOGY ON OSSIFICATION OF THE THORACIC AREA

By the mid-40s the general consensus on the ossification of costal cartilages was that they were so common they were scarcely worth mentioning (Kerr and Gillies, 1944). However, some researchers attempted to link costal cartilage ossification with pathological influences such as arteriosclerosis, tuberculosis, nutritional, metabolic, and endocrine states under genetic control (Vastine et al., 1948). Horner (1949) studied the premature calcification of the costal cartilages and its association with pathological conditions. Previous research had attempted to find associations between tuberculosis and calcification (Kading, 1923), calcification in the blood vessels and the rib cartilage (Huyssen, 1924), a connection with malnutrition, osteoporosis, gallstones, and kidney stones (Falconer, 1938) but according to Horner (1949) none of these studies offered a satisfactory conclusion. As previously stated general beliefs of the day were that this condition was a common affliction of the aging process. Finding that calcification occurred in individuals in their second and third decades of life with no other evidence of premature aging Horner believed there must be some other influence. Early stage rib cartilage calcification had been found to occur centrally and proceed outwards to be deposited peripherally (King, 1939). King (1939) put forth the assumption that the minor trauma of breathing, i.e., muscle contracture against rib, was the impetus for calcification, which would explain why the first costal cartilage calcifies long before the others as the entire chest area suspends from this rib. Horner also believed that the calcification of the first costal cartilage occurred so routinely that it must be regarded as a normal process. Found in males as early as 17 years and in females at age 19 years it may be completely calcified by age 35 and 45 years respectively. As well, the first rib was noted at times to be completely calcified when no other cartilage was.

Horner (1949) took radiographs of the right upper abdomen of 300 patients. This view was used in order to detect an appreciable amount of costal cartilage calcification since, excluding the first rib, calcium was found to be first deposited in the lowest cartilage, those that anastamose, or connect with each other rather than with the sternum. The deposit was noted to be equal bilaterally. Population affinity was ruled out as a factor. The radiographs were initially assessed according to the presence or absence of significant degrees of calcification and then divided into age groups by decades. It was found that the percentage of those with calcium deposits steadily increased with age, with little difference between males and females. The most marked increase occurred in the fourth decade in both sexes with the most marked calcification not necessarily found in the oldest individuals. It was also noted that while most calcification appeared to proceed quite slowly, in some it was of a considerable amount at an early age only to progress gradually later on. Horner suggests a link between these younger individuals and certain significant occurrence of menstrual disorders, obesity, and complaints not due to organic disease.

SUMMARY

Aging an adult skeleton is in most cases a very difficult task generating quite extensive age ranges, while estimating sex in the adult (if the pelvis and the skull are available) may have accuracy rates of up to 98% (Krogman and Iscan, 1986). Utilizing only the thoracic area for age determination has met with its most success in the gross examination of sternal rib ends (Iscan, 1985; Iscan and Loth, 1984, 1985, 1989; Iscan et al, 1984, 1985). This may be partially due to the great variability of sternal fusion rates, which is similar to that of cranial suture patterns (Stewart, 1954; Stewart and McKern, 1957). However fusion of the sternum, or actually lack of fusion, may be useful in indicating a young individual, although this is not entirely definitive. The opposite is true for determining sex. While sex usually needs to be known before sternal rib analysis the metric analysis of the sternal area in sex estimation has been studied and utilized for quite some time (Dwight, 1881; McCormick and Stewart, 1983). This requires an appropriate reference population as there may be a great deal of variability in these measurements between populations (Jit et al., 1980, McCormick and Stewart, 1983). The gray area in these techniques is usually quite extensive as well (Jit et al., 1980). This may be overcome by using a concert of measurements instead of just length or width (Stewart and McCormick, 1983)

The use of radiographic imaging as an aid in growth related studies (Todd, 1930; Flecker, 1932; Hill, 1939; Francis et al., 1939; Greulich and Pyle, 1959; Pyle and Hoerr, 1969), investigation of trauma (Knight, 1980), or pathology (Maples, 1984; Caffey, 1950) was the initial impetus for its use in degenerative analysis (McCormick, 1980; McCormick and Stewart, 1983; Stewart and McCormick, 1983; McCormick et al., 1985; McCormick and Stewart, 1988). Determination of sex using costal calcification patterns can be very accurate if the typical male and female patterns exist, namely Types A, F, and G. However, Types B, C, D, E, H, I, X, and Y are not as exact and benefit greatly from the use of metric analysis. The accuracy rates of these "Types" may also be improved if they can in some way be coupled with other features and their indications. Cartilage to sternum and rib attachment changes, degree of osteoporosis or bone demineralization, and costo-manubrial border changes may be useful if present. Age estimation may also benefit if used in correlation with these features as well as calcification amounts and types.

Previous studies have not provided any substantial evidence for pathological or population affinity influences on calcification amounts or patterns. However, some have suggested that there appears to be a difference in calcification rate between Negroids and Caucasians (Trotter, 1934; Michelson, 1934; McCormick, 1980). Additionally, it is also a well-documented phenomenon that females are affected at younger ages, more frequently, and more seriously by osteoporotic processes than are males (Rubin and Farber, 1988). This may influence calcification in significant manners as well as affecting bone demineralization assessments between the sexes.

In conclusion, the aforementioned studies show at the very least that sex and age estimates from radiographs of the thoracic area are a useful adjunct to traditional methods. As well as being relatively unaffected by ancestry and pathology (except osteoporosis), they offer a simple, quick, and non-invasive alternative when a rapid sex and age estimation is needed.

CHAPTER 3

MATERIALS AND METHODS

MATERIALS

All radiographs were obtained from medico-legal autopsy cases performed at the Health Sciences Centre, Winnipeg, Manitoba, Canada. No individual under the age of 18 years was examined. The autopsy samples were selected sequentially from OCME cases undergoing complete post-mortem examination and were x-rayed in a Faxitron cabinet immediately after removal from the individual. In total 1199 adult autopsies were performed by the Office of the Chief Medical Examiner (OCME) at all facilities during the period of January 1, 2001 to December 31, 2001. The 130 radiographs used in this analysis were collected over a ten-month period from August of 2000 to March of 2001. It was hoped that this extended time period would provide the broadest possible age ranges as well as greater parity in sex. No previous knowledge of the individual's age, sex, or population affinity was known to the researchers prior to examination.

Figures 23 and 24 present the age and sex distribution of the entire sample.

Figure 23: Male Age Distribution
Entire Sample

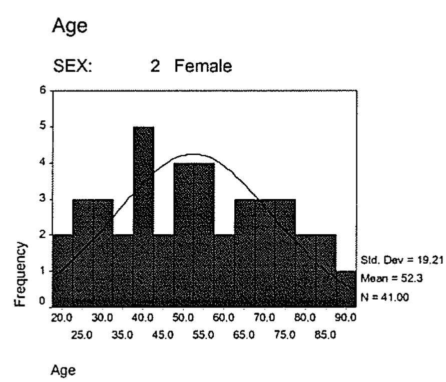

Figure 24: Female Age Distribution
Entire Sample

As can be seen from the above data the distribution is normal except for a small right end skew within the male sample.

METHODS

Research Design

The primary focus of this research is to evaluate the usefulness and reliability of specific radiographic methods that utilize costal cartilage patterns of calcification, costal manubrial border changes, rib end changes, and sternal fusion, size and length as tools in estimating age and determining sex from the adult human skeleton. The principal studies in this field examined are those of McCormick (1980), Stewart and McCormick (1983, 1984), McCormick and Stewart (1983, 1988), McCormick et al. (1985) and Barres et al. (1989). As such, the design selected for this study is a combination of the methods set down previously by these researchers.

The chest plates from 130 subjects of known manner of death, cause of death, age, population affinity, and sex were removed during postmortem investigation of the chest cavity. The area removed and subsequently X-rayed consisted of the costal cartilage and when available 2 to 6 cm of the terminal ends of the first through seventh ribs, as well as the entire sternum with its associated soft tissue. Chest plate radiographs were taken using a Hewlett Packard X-ray Faxitron series (cabinet model 43855*) at 40 kV using Kodak Diagnostic Film Ready Pack X-Omat TL. All measurements were taken to the nearest millimeter with the use of a Mitutoyo Sliding Caliper (accurate to ±0.05 mm).

The radiographs were examined for (1.) location, pattern, and extent of costal cartilage ossification; (2.) cartilage-to-sternum attachment change; (3.) rib-to-cartilage attachment changes; (4.) shape of the costo-manubrial junction; (5.) fusion of the manubrium; ossification of the first rib; (6.) cupping of the sternal rib ends; (7.) degree of bone demineralization or osteoporotic changes; and (8.) ossification of the xyphoid. Sternal measurements were also taken. The methods used are as described in the literature review of McCormick (1980), Stewart and McCormick (1983, 1984), McCormick and Stewart (1983, 1988), McCormick et al, (1985), and Barres et al. (1989). (For a more detailed description of methods please see Appendix A).

To test for inter-observer error three researchers besides the author independently scored the films using the aforementioned criteria without prior knowledge of age, sex, or population affinity. Instructions were written and contained within a template booklet (Appendix B) arranged by the author from criteria and examples supplied by the aforementioned researchers. The booklet also contains a recording sheet (Appendix C). The four examiners include the author, (results taken from run two, researcher #1), a forensic pathologist, (researcher #2); a law enforcement forensic identification specialist (with no medical or radiographic training), (researcher #3); and, a radiologist with approximately 40 years of experience, (researcher #4). The latter three examiners assessed the same 20 randomly selected radiographs in sequential order. Only the author completed the measurement section of the assessment due to the negligible amount of subjectivity of this exercise with results entered on separate recording sheets (Appendix D).

The age and sex distribution of the sub-sample of radiographs is presented in Figures 25 and 26.

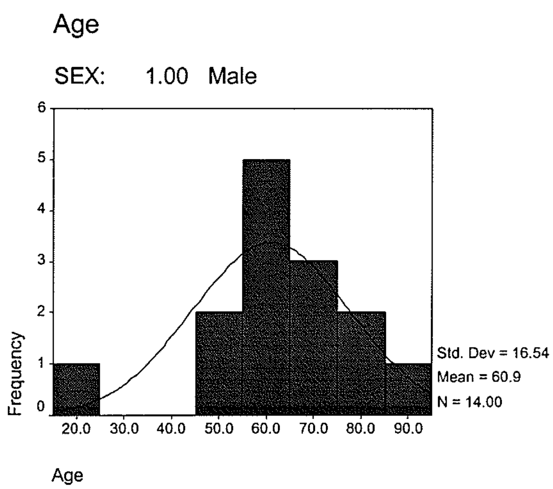

Figure 25: Age Distribution OCME Sub-Sample Males

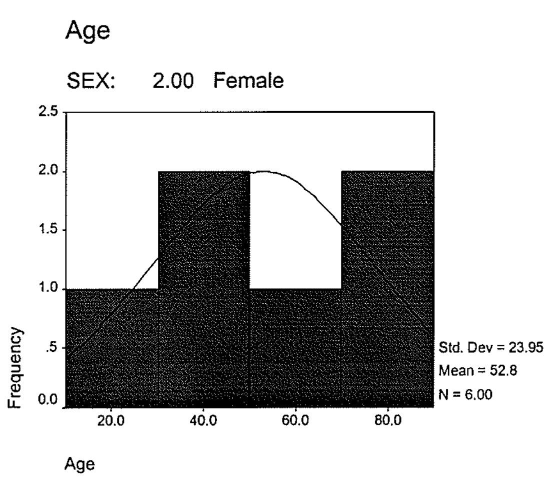

Figure 26: Age Distribution OCME Sub-Sample Females

The complete sample is comprised of 89 males and 41 females. The sub-sample closely parallels this ratio with males represented 14 times and females six. Males outnumber females by approximately two to one in both cases that allowed for the generation of a representative sub-sample. The age range is also representative of the original sample. Males ranged from 18 years, the cut-off point for adults, to 89 years, the greatest age within the complete study sample. Females ranged from 19 years, the youngest in this category, to 80 years of age, eight years less than the oldest individual within the entire female sample.

To test for intra-observer error the author completed two evaluations of the material. After a one-month time lapse the author performed a second assessment of the radiographs. The one-month time lapse was done to prevent recognition of the radiographs and memory of the first evaluation.

Reliability

Inter-Observer and Intra-Observer Error

Reliability is either internal or external. External reliability, or inter-observer error, is a measure of external consistency (McClave and Dietrich, 1988), or the agreement rate of between independent researcher choices. Within this research sample four examiners will be used to test for degree of inter-observer reliability.

Internal reliability or intra-observer error is simply the extent to which data that is measured at one time is consistent with data measured at another by the same individual.

The test-retest method will be used to measure the reliability/intra-observer error of the applicable methodologies.

Effects of Population Affinity

Table 7 summarizes the ethnic distribution of this sample with respect to sex.

Table 7: Distribution of Sex and Population Affinity

Ethnic Affiliation	Male	Female
Caucasian	40	14
Native American	16	8
Negroid	1	0
Mongoloid	1	1
Unknown	31	18
Total	89	41

Negroid and Mongoloid individuals are represented in only three cases thus any possible ethnic differences in these categories will not be significant due to the very small sample size. The groups consisting of Caucasian, Native, and Unknown individuals comprise the largest subsections. However, being "unknown" in itself renders an investigation into this category for ethnic-related differences ineffectual. In that respect, only Caucasian and Native American categories will be tested for significant differences, which may be manifest within the thoracic area. Figures 27 and 28 present the age distribution of the Caucasian and Native individuals.

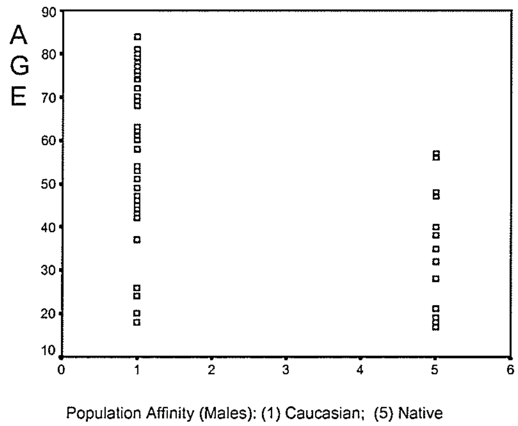

Figure 27: Age Distribution (1) Caucasian and (5) Native Males

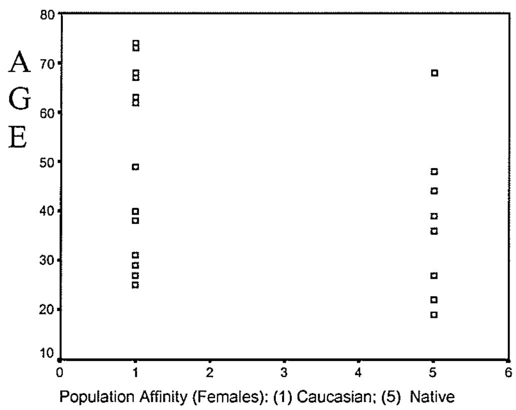

Figure 28: Age Distribution (1) Caucasian and (5) Native Females

Independent samples t-tests indicate no significant differences between Caucasian or Native male and female individuals with respect to metrical parameters ($p>0.05$).

Bone Density, fusion of the manubrium, cartilage to sternum attachment changes, c Bone Density, fusion of the manubrium, cartilage to sternum attachment changes, cartilage mineralization, and rib to cartilage attachment changes were next examined for population affinity differences. Independent sample t-tests indicate no significant differences between Caucasian and Native female individuals with respect to Barres et al.'s five thoracic features ($p>0.05$). However, there appears to be significant differences between Caucasian and Native males with respect to bone demineralization ($t=3.761$; $df=52$; $p<0.001$), cartilage-to sternum attachment changes ($t=3.211$; $df=55$; $p=0.002$), and cartilage mineralization ($t=2.830$; $df=55$; $p=0.006$). This may be explained by the small sample size as well as by the age distribution. As shown in Figure 27, Native males are much younger in age than are Caucasian males. As well, Caucasian males are represented by almost 2 ½ times more individuals than are Native males. Thus, the results of this test are probably affected by the above reasons and will be disregarded in future analysis.

Ossification amounts of the first costal cartilage, peristernal and second through seventh costal cartilage, costo-manubrial border changes, rib-end changes, osteoporotic changes, and extent of xyphoid ossification were next examined for changes related to ethnic affinity.

There are no statistically significant differences between Caucasian and Native females. Males appear to have significant differences with respect to second to seventh costal cartilage changes ($t=1.342$; $df=55$; $p=0.004$), rib-end changes ($t=3.416$; $df=7$; $p=0.011$), and osteoporotic changes ($t=2.609$; $df=51$; $p=0.012$). However, as before, these results are most likely affected by the great difference in ages and sample size of the two sub-groups as well as the generally small sample size as a whole. These results will also be treated as suspect and will not factor into future analysis.

Effects of Pathology

Pathological influences on the ossification of the thoracic area have been noted by some researchers to occur in individuals with advanced osteoporotic degeneration (Falconer, 1938), arteriosclerosis, tuberculosis and nutritional, metabolic, endocrine influences (Vastine et al., 1948), as well as muscle contracture against the ribs from breathing (King, 1939).

As Figures 29 and 30 note the majority of individuals examined in this sub-sample experienced a natural death [Office of the Chief Medical Examiner (OCME) Annual Review, 2000). While it is entirely likely and most probable that the individuals who died in a manner other than natural were experiencing certain disease processes during the end of their lives, their sample size is too small to be significant within this study. Of the natural deaths it cannot be determined with any certainty with the data available whether these individuals were suffering from the any of the effects that the previous researchers have put forth as influencing the natural processes of thoracic ossification. Thus effects of pathology will not be examined within this study sample further.

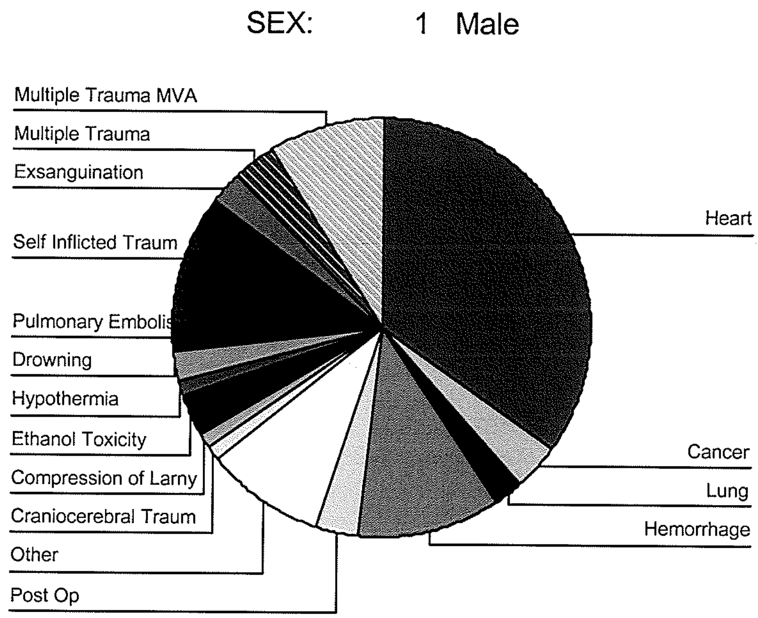

Figure 29: Cause of Death Distribution within Male OCME Sample

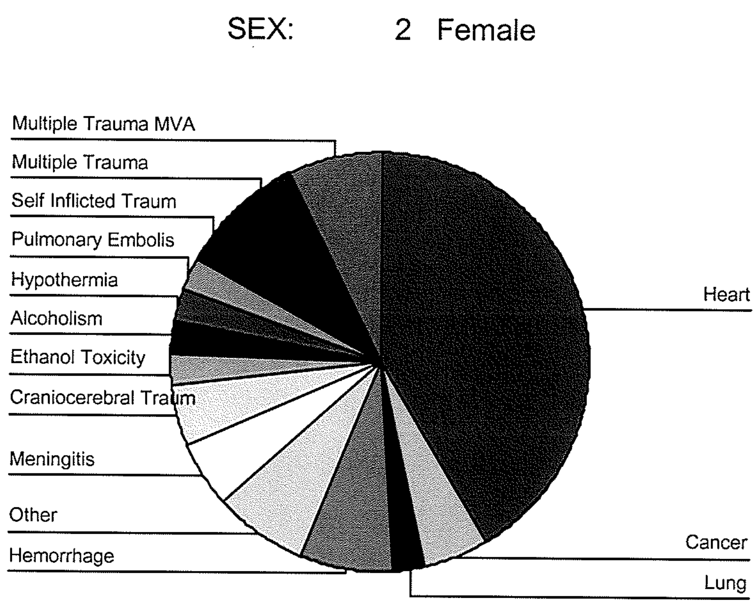

Figure 30: Cause of Death Distribution within Female OCME Sample

CHAPTER 4

RESULTS

INTER-OBSERVER ERROR

Barres et al.: Five Thoracic Features

Tables are generated detailing each researchers chosen score for Barres et al.'s five thoracic features: bone demineralization, BD; fusion of the manubrium, FM; cartilage to sternum attachment changes, CS; cartilage mineralization, CM, and rib to cartilage attachment changes, RC. Individuals are shown in order of increasing age. In order to test for significant differences between researchers, Kendall's W tests are done to rank scores with respect to specific researchers. The Kendall's W statistic assesses concordance between ranked categorical data for multiple observers. It has a value of between 0 and 1 with 1 being complete concordance. The p-value provides an assessment of the statistical significance of concordance, much like a correlation. The Kendall's W test is not differentiated as to sex because of the small sample size, especially among females, thus all results quoted are for combined sex unless otherwise stated.

The results of Kendall's W test are presented in Table 8. In all cases, there is significant concordance between the scores of all researchers.

Table 8: Kendall's W Test for Measure of Agreement of Ranking of Ordinal Variables for bone demineralization, BD; fusion of the manubrium, FM; cartilage to sternum attachment changes, CS; cartilage mineralization, CM, and rib to cartilage attachment changes, RC, both sexes

Kendall's W Test Coefficient of Concordance				
Both Sexes	W	Chi Square	Df	P
Bone Demineralization	0.737	56.038	19	<0.001
Fusion of the Manubrium	0.868	65.952	19	<0.001
Cartilage to Sternum Attachment	0.451	34.277	19	0.017
Cartilage Mineralization	0.851	64.701	19	<0.001
Rib to Cartilage Attachment	0.820	62.334	19	<0.001

Ossification Patterns and Score

Ossification pattern assessment was done using criteria supplied by McCormick et al., (1985). Researcher agreement and accuracy rates with respect to ossification pattern type, and ossification score was assessed using Kendall's W test analysis and rates and scores are presented in Tables 9 to 14. Sex determination was assessed using cross-tabulation Chi-square analysis.

Table 9: Independent Researcher Ossification Pattern and Score Assessment, Predicted Sex.

Ossification Pattern and Score Comparison, Predicted Sex				
		Male		
Age	**Researcher One**	**Researcher Two**	**Researcher Three**	**Researcher Four**
#1: 18 yrs	X-0-Male	X-0-Male	X-0-Male	X-0-Male
#2: 47 yrs	F-3-Male	F-3-Male	F-3-Male	E-1-Male
#3: 51 yrs	Y-0-Male	Y-0-Male	Y-0-Male	Y-0-Male
#4: 57 yrs	F-3-Male	F-3-Male	I-0-Indeterminate	E-1-Indeterminate
#5: 58 yrs	E-3-Male	E-3-Male	E-3-Male	E-3-Male
#6: 59 yrs	E-2-Indeterminate	G-3-Male	D-0-Male	E-2-Indeterminate
#7: 59 yrs	Y-0-Male	B-1-Female	X-0-Male	Y-0-Male
#8: 61 yrs	I-0-Indeterminate	I-0-Indeterminate	I-0-Indeterminate	E-1-Indeterminate
#9: 66 yrs	G-3-Male	G-3-Male	G-3-Male	E-2-Indeterminate
#10: 66 yrs	E-3-Male	E-1-Male	D-0-Male	E-1-Indeterminate
#11: 69 yrs	E-2-Indeterminate	B-1-Indeterminate	D-0-Male	B-2-Indeterminate
#12: 76 yrs	E-3-Male	E-1-Male	D-0-Female	G-3-Male
#13: 77 yrs	E-3-Male	G-3-Male	I-0-Indeterminate	G-3-Male
#14: 89 yrs	A-3-Female	F-3-Male	A-3-Female	A-3-Female
		Female		
Age	**Researcher One**	**Researcher Two**	**Researcher Three**	**Researcher Four**
#1: 19 yrs	C-1-Indeterminate	I-0-Indeterminate	F-3-Male	Y-0-Female
#2: 36 yrs	E-1-Female	E-2-Female	C-1-Female	C-1-Female
#3: 49 yrs	F-3-Male	F-3-Male	A-3-Female	F-3-Male
#4: 54 yrs	C-2-Indeterminate	F-3-Male	C-1-Indeterminate	Y-0-Female
#5: 79 yrs	A-3-Female	F-3-Male	A-3-Female	A-3-Female
#6: 80 yrs	A-3-Female	F-3-Male	A-3-Female	F-3-Male

Table 10: Kendall's W Test Coefficient of Concordance for Measurement of Agreement of Ranking of Costal Cartilage Ossification Patterns, Undifferentiated as to Sex

Kendall's W Test Coefficient of Concordance				
Both Sexes	W	Chi Square	df	P
Ossification Pattern	0.566	43.043	19	0.001
Ossification Score	0.678	51.536	19	0.000

Table 11: Chi-square Test for Measurement of Agreement of Calculated Sex Results between Researchers

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.265[a]	6	.394
Likelihood Ratio	6.376	6	.382
Linear-by-Linear Association	1.578	1	.209
N of Valid Cases	80		

a. 8 cells (66.7%) have expected count less than 5. The minimum expected count is 4.25.

Table 12: Independent Researcher Sex Prediction Accuracy Percentages

Males				
Classification	Researcher One	Researcher Two	Researcher Three	Researcher Four
Male	71.4%	78.6%	64.3%	50.0%
Indeterminate	21.4%	14.3%	21.4%	42.9%
Female	7.1%	7.1%	14.3%	7.1%
Females				
Classification	Researcher One	Researcher Two	Researcher Three	Researcher Four
Female	16.7%	16.7%	33.3%	16.7%
Indeterminate	33.3%	16.7%	00.0%	50.0%
Male	50.0%	66.7%	66.7%	33.3%

Table 13: Independent Researcher Ossification Pattern and Predicted Age Range for Males

Ossification Pattern and Predicted Age Range				
Male				
Age	Researcher One	Researcher Two	Researcher Three	Researcher Four
#1: 18 yrs	X-18-30 yrs	X-18-30 yrs	X-18-30 yrs	X-18-30 yrs
#2: 47 yrs	F-30-65 yrs	F-30-65 yrs	F-30-65 yrs	E-30-80 yrs
#3: 51 yrs	Y-20-40 yrs	Y-20-40 yrs	Y-20-40 yrs	Y-20-40 yrs
#4: 57 yrs	F-30-65 yrs	F-30-65 yrs	I->30 yrs	E-> 30 yrs
#5: 58 yrs	E-30-80 yrs	E-30-80 yrs	E-30-80 yrs	E-30-80 yrs
#6: 59 yrs	E-30-80 yrs	G->65 yrs	D->30 yrs	E-30-80 yrs
#7: 59 yrs	Y-20-40 yrs	B-30-65 yrs	X-18-30 yrs	Y-20-40 yrs
#8: 61 yrs	I->30 yrs	I->30 yrs	I->30 yrs	E-30-80 yrs
#9: 66 yrs	G->65 yrs	G->65 yrs	G->65 yrs	E-30-80 yrs
#10: 66 yrs	E-30-80 yrs	E-30-80 yrs	D->30 yrs	E-30-80 yrs
#11: 69 yrs	E-30-80 yrs	B-30-65 yrs	D->30 yrs	B-30-65 yrs
#12: 76 yrs	E-30-80 yrs	E-30-80 yrs	D->30 yrs	G->65 yrs
#13: 77 yrs	E-30-80 yrs	G->65 yrs	I->30 yrs	G->65 yrs
#14: 89 yrs	A->50 yrs	F-30-65 yrs	A->50 yrs	A->50 yrs

Table 14: Independent Researcher Ossification Pattern and Predicted Age Range Female

Ossification Pattern and Predicted Age Range				
Female				
Age	Researcher One	Researcher Two	Researcher Three	Researcher Four
#1: 19 yrs	C->30 yrs	I->30 yrs	F-30-65 yrs	Y-20-40 yrs
#2: 36 yrs	E-30-80 yrs	E-30-80 yrs	C->30 yrs	C->30 yrs
#3: 49 yrs	F-30-65 yrs	F-30-65 yrs	A->50 yrs	F-30-65 yrs
#4: 54 yrs	C->30 yrs	F-30-65 yrs	C->30 yrs	Y-20-40 yrs
#5: 79 yrs	A->50 yrs	F-30-65 yrs	A->50 yrs	A->50 yrs
#6: 80 yrs	A->50 yrs	F-30-65 yrs	A->50 yrs	F-30-65 yrs

Within the male sub-sample ossification pattern type is the same among all four reviewers only with respect to the 18-, 51-, and 58-year-old male individuals. The first was assessed as having no ossification, or pattern X, the second as showing only para-sternal and/or first rib ossification, or pattern Y, and the last type E ossification (Table 9). In the female sub-sample (Table 9) at no time did all four researchers agree on an ossification pattern.

Kendall's W tests generate results that indicate there is moderate agreement among researchers with respect to ossification pattern selection (Table 10) in the sample undifferentiated as to sex.

Within the male sub-sample six specific males were selected as demonstrating more typical female ossification patterning than male-type ossification. This occurred ten times between all researchers (Table 9 and 12). However, in only five cases were male individuals miss-classified as female, or at a rate of between 8.9% for the entire male sub-sample, or between 7.1% and 14.3% among specific researchers (Table 12). Using no metric criteria, a Type F male was assessed as exhibiting Type A (automatic female) patterning by researchers #1, #3, and #4. Using metric data a male was selected as exhibiting Type D patterning by researcher #3 and a male was selected as exhibiting Type B patterning by researcher #4. Ossification patterns A and F are initially easily confused due to the centralized patterning of both types, a typical female characteristic but seen in type F males due to the advanced stage of ossification. Attention must be paid to the linear peripheral ossification and "Swiss-cheese" aspect of Type-F, not seen among Type-A individuals. After more exposure to the technique however the writer has found that this is easily corrected. An indeterminate identification was generated 14 times (Table 9).

Researcher #2, the forensic pathologist, achieved the greatest accuracy rate with respect to the accurate sexing of male individuals, however, Researcher #1, the author, did not misclassify more individuals than the former, but classified more as indeterminate. Researcher #3, the police identification officer miss-classified the most individuals. Researcher #4, the radiologist, had the highest percentage of indeterminate individuals. This may be related to Researchers 4's greater experience in the analysis of radiographic images that may cause him to be more critical in his analysis. However, all four researchers were fairly consistent and achieved approximately similar results with respect to misclassification. This suggests either a high learning curve with respect to this technique, or the fact that Type-A and Type-F ossification patterns initially appear very similar. In future analysis this may be rectified by using metric analysis as well as ossification pattern in making a final determination of sex.

Within the female sample a determination of female was generated by all four researcher's results only once in the 36-year-old female, even though typical male patterns were chosen by twice by two researchers. This was achieved by using metric parameters to make the final correct determination. Of the six female individuals examined and 24 probable patterns, a typical male-type pattern was chosen ten times. Without metric analysis a determination of male was made eight times. With metric analysis a determination of female was made two times. Once again, this appears to be related to the fact that initially Type-A and Type-F patterns are confused. This occurs here six times. However, upon closer examination, the 49-year-old female is too young at this age to fit the typical pattern for Type-A ossification. With this information and reexamination of the radiograph the pattern appears to be more typical of a Type-B, or "crab-claw" type pattern, which is also more consistent with this age. An accuracy rate among all examiners of 50% was achieved in this sub-sample. Misclassification occurred 33.3% of the time while an indeterminate assessment occurred at a rate of 16.7%.

Correct classification of female individuals was rare with only researcher three managing to be accurate more than once. Researchers were also not consistent in their shared analysis except in the case of the 36-year-old female. Misidentification as male was usual with indeterminate classification ranging from 0% to 50.0%. In general, this method is unable to accurately estimate sex in this sub-sample.

Chi-square tests indicate that there is no significant difference between researchers with respect to determination of sex using ossification pattern selection (Table 11).

Ossification amount for males is scored fairly consistently among examiners, especially when the same pattern was also selected. However, there is a significant difference in score assessment generated between researcher #4 with researchers #1 and #3. When differing ossification patterns were chosen ossification scores varied more. This is specifically the case in the 47-year-old male who was chosen by three examiners to be a Type-F individual, an automatic score of three, and by one examiner as a Type-E individual, with a possible score of between one and three for ossification amount. In cases such as these the differences in score amount are misleading. The Type-F individual may have a limited amount of ossification but because the Type-F is very highly sex specific they automatically are scored as a three. The actual extent of the ossification amount however may be more reflective of a one or two, especially to inexperienced examiners. This is also the case with the 59-year-old male who is miss-classified as a female Type-D pattern, a pattern type which does not get an ossification score, and the 77-year-old Indeterminate pattern male, a pattern type which also does not receive an ossification score. The only real difference in scores with a magnitude greater than two points is seen in the 66- and 76-year-old males with Type-E ossification scored as three and one by different researchers. The score of one chosen by researcher #2 may be indicative of a lack of experience and exposure to this type of pattern. Researcher #3's score differences are again probably affected by a lack of specific medical training. In conclusion, ossification score differences among male individuals appears misleading at first but are fairly consistent among examiners when analyzed more closely.

Within the female sample Type-A and -F ossification patterns among the 49-, 79-, and 80-year-old females automatically generate an ossification score of 3, thus the amount is consistent among all four examiners. The Type-F pattern is also chosen by Researcher #3 for the 19-year-old and Researcher #2 for the 54-year-old individuals. This accounts for most of the disparity in score amount between examiners. Ossification amounts for the 19-, 36-, and 54-year-olds differ by only one point among examiners.

The Kendall's W test generates results indicating that there is more agreement between researchers with respect to ossification score selection than there would be by chance thus indicating a significant degree of consistency in ossification amount ranking (Table 10).

Age ranges for the male sub-sample included an 18-year-old individual who was chosen as a Type-X, or absence of ossification, by all investigators (Table 13). Type-Y ranged from age 51 to 59 in this sub-sample. Excluding misclassifications such as the Type-A and Type-B, sex specific male patterning was manifest among individuals between 47 to 89 years of age. However, according to some of the examiners non-sex specific patterning was also present among individuals up to the age of 77 years.

Table 14 lists ossification pattern with respect to age among females. The youngest individual at 19 years of age was chosen by Researchers #1, #2, and #4 to represent Types–C, -I, and –Y patterning and as such exhibited minimal to moderate amounts of non-sex-specific calcification. Researcher #3 chose the Type-F ossification pattern as representative of the 19-year-old female, generating an automatic ossification score of three. However, distinctive sex-specific patterning appears to predominate primarily between the ages of 49 to 80 years. The 49-year-old individual, more indicative of Type B as mentioned previously, appears to have been miss-classified by all examiners as Type-A or Type-F. Thus the relatively low age of 49 years may be questionable for definitively sex-specific patterning.

Ossification Features

Ossification features were tested using Kendall's W test for measure of agreement of ranking of ordinal variables between researchers. The tests were done undifferentiated as to sex due to the small size of the sample. Bar graphs were generated of specific features differentiated as to sex to see how researchers were differing and to what extents. Tables were generated of specific features in order to contrast researcher scores. There was no improvement in researcher agreement when cases were analyzed in sequence thus all graphical representation was done with cases in order of increasing age.

First Costal Cartilage

First costal cartilage ossification rates among male and female individuals were visible to researchers in only 0% to 21% of examined cases, thus no significant analysis with respect to this feature and inter-observer error was done.

Second to Seventh Costal Cartilage, Costo-Manubrial Border Changes, Rib-End Changes, Osteoporotic Changes

All features showed significant concordance in score assessment between researchers except for xyphoid ossification (Table 15).

Table 15: Second to Seventh Costal Cartilage, Costo-Manubrial Border Changes, Rib-End Changes, Osteoporotic Changes, Inter-Observer Error Results

	2nd to 7th Costal Cartilage	Costo-Manubrial Border Changes	Rib-End Changes	Osteoporotic Changes
Kendall's W	0.784	0.822	0.834	0.711
df	19	19	19	19
P value	0.000	0.000	0.000	0.000

Xyphoid Ossification

Xyphoid ossification was assessed using guidelines supplied by McCormick and Stewart (1988). Figures were generated displaying researcher ranking in order of increasing age and differentiated as to sex (Figures 31 and 32).

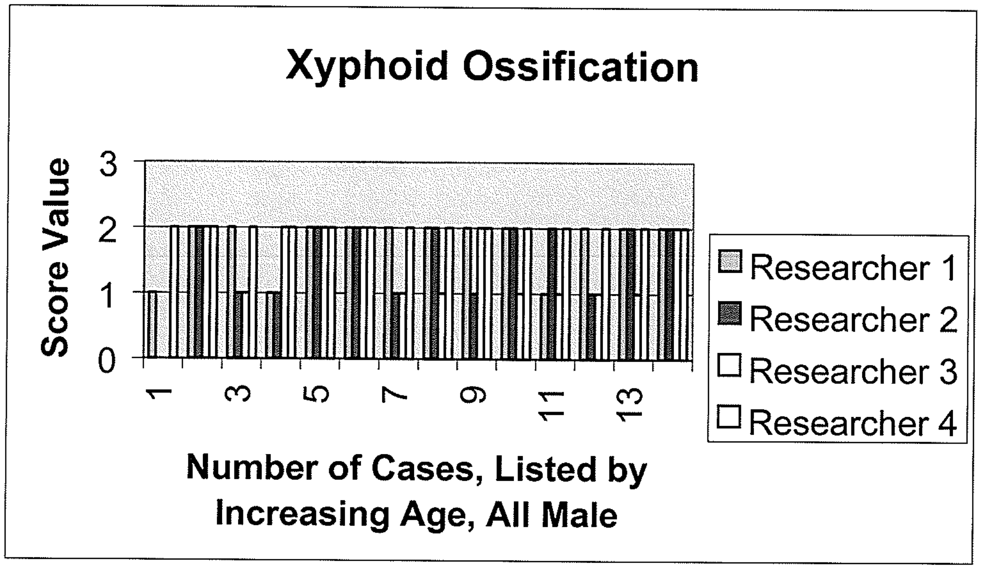

Figure 31: Researcher Results of Extent of Xyphoid Ossification among Males

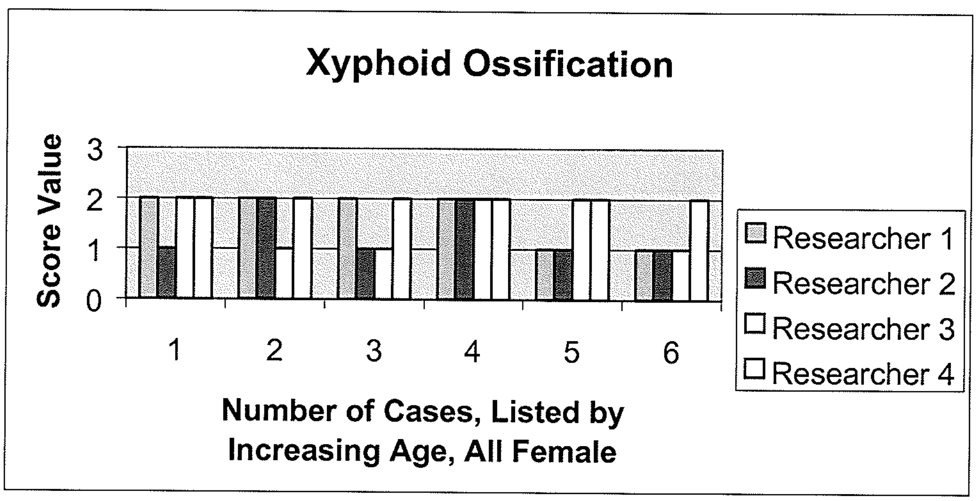

Figure 32: Researcher Results of Extent of Xyphoid Ossification among Females

As can be seen in Figures 31 and 32 extent of xyphoid ossification within the male sub-sample is consistently scored by examiners on four occasions. Within the female sample score assessment differs by only one point among examiners with researchers selecting the same score once.

Kendall's W statistics generate results which indicate score assessment between researchers is poor and no different than what would be expected by random chance (W=0.378; df=19; p=0.070).

INTRA-OBSERVER ERROR

The entire data set of radiographs was examined twice by the author in corresponding order using analogous criteria and templates. The second analysis was done four weeks after the first analysis was completed. This time lapse prevented recognition of most of the individual radiographs and memory of the first evaluation.

Barres et al.: Five Thoracic Features

Bone demineralization among the male study sample differs by as great as three points between runs with consistency of score assessment not improving with experience. Chi-square results show a statistically significant difference in score assessment between runs ($\chi^2 = 10.036$; $df = 4$; $p = 0.04$).

There is a great difference between the choice of scores 3 and 5 between the runs. In particular score 5, the greatest amount of demineralization as detailed in Barres et al.'s template, is not chosen at all within run one but selected on seven occasions within run two (Table 16).

Table 16: Male Bone Demineralization Scores and Autopsy Number, Runs One and Two

Autopsy Number	Age	BD Score Run One	BD Score Run Two
00A398	89	5	2
00A448	72	5	3
01A018	77	5	4
01A038	46	5	3
01A101	60	5	4
01A116	84	5	4
01A119	76	5	4

Bone demineralization among the female study sample also differed by as great as three points between runs with consistency of score assessment unchanged with experience. Chi-square results show no statistically significant difference between score assessment and run (χ^2= 4.278; df = 4; p = 0.37). If the sample is tested undifferentiated as to sex Chi-square measures indicate a significant difference between runs (χ^2=10.145; df=4; p=0.038).

Scoring of fusion of the manubrium for males differed by as great as three points between runs, however this only occurred initially. In the female sample scores differed by as great as four points, however this occurred only once. Both male and female samples showed improved consistency between runs with experience. Chi-square results show no statistically significant difference between runs for either sample (Male: χ^2= 2.756; df = 4; p = 0.59; Female χ^2= 2.987; df=4, p = 0.56).

Cartilage to sternum attachment changes in males differed by up to one point and in females by up to two points. The male sample showed greater consistency in scoring than the female sample throughout the sub-set. Chi-square results show no statistically significant difference in scoring between runs for either sex (Male: χ^2= 4.326; df = 4; p = 0.36; Female: χ^2= 2.280; df = 4; p = 0.68).

Male cartilage mineralization scores differed by up to two points, however this only occurred twice early in the sample. Female scores differed by up to one point. Both sexes showed the same level of consistency in scoring throughout the sample. Chi-square results show no statistically significant difference in score assessment between runs for either sex (Male: χ^2= 4.286; df = 4; p = 0.40; Female: χ^2= 1.670; df = 4; p = 0.80).

Male and Female rib-end assessment was not visible at times and differed by as much as five points between runs. However, this was due to the fact that in the second run these individuals were scored as unreadable. There is no change in assessment with experience in both sexes and Chi-square results show no statistically significant difference between runs for either (Male: χ^2= 3.563; df = 4; p = 0.47; Female: χ^2= 2.110; df = 4; p = 0.72).

Ossification Patterns and Score

Cross-tabulation tests and Chi-square analysis was done on both evaluations of ossification pattern selection differentiated as to sex in order to determine the frequency of pattern selection and intra-observer error rates.

Male calcification pattern analysis is fairly consistent over the entire sample differing only 18 out of 89 times. The differences are distributed equally throughout the sample showing no improvement with experience. Most differences in pattern selection occurred in the patterns Type F, G, I, X, and Y. Chi-square results show no statistical significant difference between runs (χ^2=4.201; df = 9; p = 0.90).

Female calcification pattern selection is not very consistent differing 17 out of 41 times. However, ten of these differences occur in the first half of the analysis suggesting some improvement with experience. No one pattern differs more in selection than any other. Chi-square results show no statistically significant difference between run one and two (χ^2=4.297; df = 8; p=0.83), however, this may be due to the small sample size. If the Chi-square test is done on the entire sample undifferentiated as to sex there is also no significant difference between runs (χ^2=7.284; df=10; p=0.70)

Ossification score was also assessed using Chi-square measures. While the number of radiographs chosen to exhibit a recognizable amount of ossification in the male sample was fairly similar the score assigned to these radiographs differed 19 times out of 54 possible occasions at a rate of 35%. This difference occurs fairly evenly throughout the sample suggesting little change of assessment with experience. Chi-square results show no statistically significant differences between runs (χ^2=0.121; df = 2; p = 0.94).

The number of radiographs chosen to exhibit a scoreable ossification amount was also very similar between runs in the female sample but calcification scores differed 13 times out of a possible 24 at a rate of 54%. There are fewer differences in the latter half of the sample suggesting improvement with experience. Chi-square results show no statistically significant difference between runs (χ^2=0.022; df = 2; p = 0.99).

With respect to sex determination the first evaluation saw five males misidentified as female and 31 individuals determined to be unclassifiable using ossification pattern and amount. First evaluation results for females show that of 41 individuals six were mis-classified and 13 were indeterminate. Run two results for males are actually quite similar with only five individuals mis-classified and 26 of indeterminate sex using these techniques. Females in the second evaluation were mis-classified five times and indeterminate 13, again quite similar to the first examination. However, both sexes exhibited a small degree of increased accuracy in the second evaluation with respect to sex determination. In the female sample correct determination increased and the male sample had less indeterminate scores.

Of the mis-classified males in run one, two were due to a misclassification of a Type F pattern as Type A and three had weak sex-specific patterns (ossification scores of 1+ or 2+) that utilized metrical parameters that placed them in female categories. Of the five mis-classified males in the second run one was due to a Type A-Type F mix-up and four were metrically assessed as female because of weak sex-specific patterning. Of the six mis-classified females in run one, three were mis-classified due to the Type A-Type F mix-up and three were metrically mis-classified, again because of weak sex-specific patterns. The second run mis-classified two females of Type A as Type F or male patterning and three mis-classified due to metric parameters. Chi-square measures do not indicate a significant difference between runs with respect to calculated sex (Male: χ^2 =0.718; df=2; p=0.664; Female: χ^2 =0.945; df=2; p=0.113).

According to McCormick and Stewart (1988) ossification pattern is correlated to specific age ranges. Table 17 indicates the number of individuals with a specific pattern that fell into an inaccurate age grouping and their true age.

Table 17: Run One Ossification Pattern and Inaccurate Estimated Age Range

Ossification Pattern and Inaccurate Estimated Age Range					
Run One			Run One		
Male			Female		
Age Range	# Inaccurate Age Range	True Age	Age Range	# Inaccurate Age Range	True Age
H >18			H >18		
D, I >30			D, I >30		
A >50			A >50	1	44
C >60			C >60	1	49
G >65	1	50	G >65		
X 18-30	4	32, 44, 49, 52	X 18-30	2	32, 34
Y 20-40	8	42, 48, 49, 59, 60, 68, 77, 78	Y 20-40	3	62, 65, 73
F 30-65	4	76, 78, 80, 89	F 30-65	7	19, 29, 67, 68, 80, 86, 88
E 30-80	3	26, 29, 84	E 30-80	1	27
Run Two			Run Two		
Male			Female		
Age Range	# Inaccurate Age Range	True Age	Age Range	# Inaccurate Age Range	True Age
H >18			H >18		
D, I >30			D, I >30	1	29
A >50			A >50		
C >60			C >60		
G >65	2	50, 58	G >65		
X 18-30	3	32, 44, 52	X 18-30		
Y 20-40	13	42, 47, 48, 49, 49, 51, 58, 59, 60, 68, 70, 77, 78	Y 20-40	5	49, 62, 65, 69, 73
F 30-65			F 30-65	5	19, 67, 68, 86
E 30-80	4	26, 28, 29, 84	E 30-80		

Predicted age range mis-categorizes age in the male group of run one 20 times out of 89 individuals (22.5%) (Table 17). In the female group in the first evaluation age range is incorrect 15 times in 41 individuals (36.6%). In run two males are mis-categorized 22 times out of 89 individuals (24.7%) and females 11 times out of 41 individuals (26.8%). Between the evaluations quite often the same individuals are being mis-grouped. In the male sample 15 of the same individuals are mis-aged in both runs. In the female sample seven of the same individuals are mis-aged in both runs. The majority of errors occur within the Type X, 18-30 year range, Type Y, 20-40 year range, Type E, 30-80 year group, and Type F, 30-65 year group. Type X and Y tend to underestimate age while Types E and F both underestimate and overestimate. There is no great difference between runs with respect to generating probable age ranges.

Ossification Features

Bar graphs were generated of specific features differentiated as to sex to see how evaluations were differing and to what extents. Tables were generated of specific features in order to contrast the two run scores.

First Costal Cartilage

First costal cartilage was assessed using Chi-square measures and bar graphs (Figure 33).

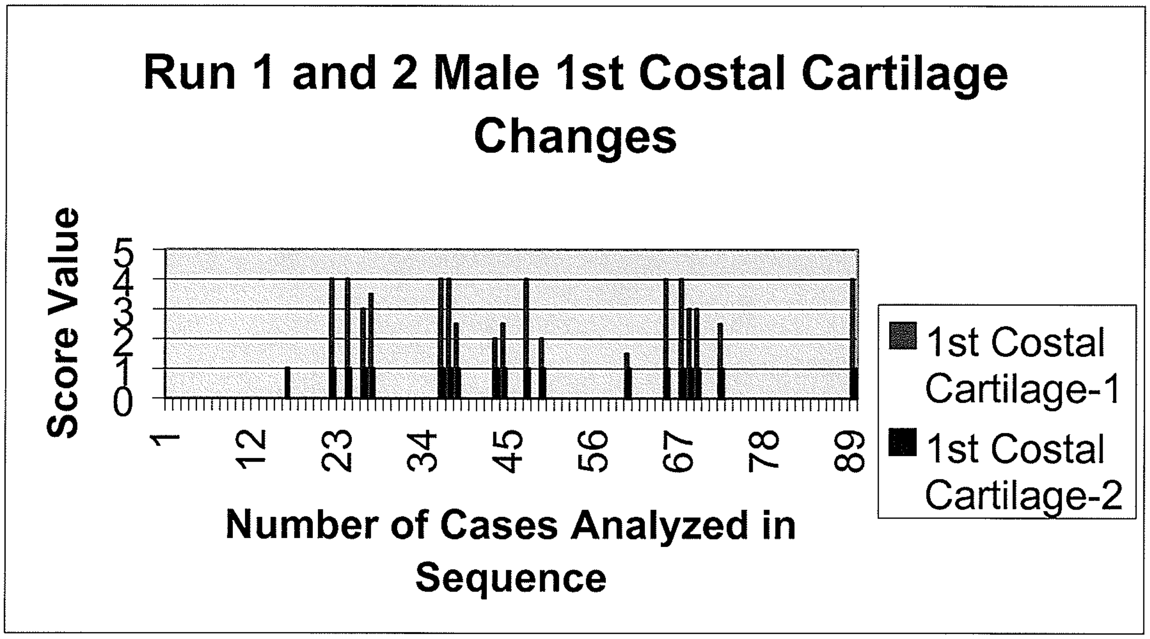

Figure 33: Run One and Two Male First Costal Cartilage Scores in Sequence

Male first costal cartilage changes were only viewable between 18 and 19 times (depending on run number) and all individuals were scored differently (Figure 33). Chi-square results show a significant difference between the runs (χ^2=37.000; df=6; p=0 .00).

Female first costal cartilage changes were only visible on two occasions thus no further analysis was undertaken with respect to this procedure.

Second to Seventh Costal Cartilage

Second to seventh costal cartilage ossification was assessed using Chi-square measures and bar graphs as follows (Figures 34 and 35).

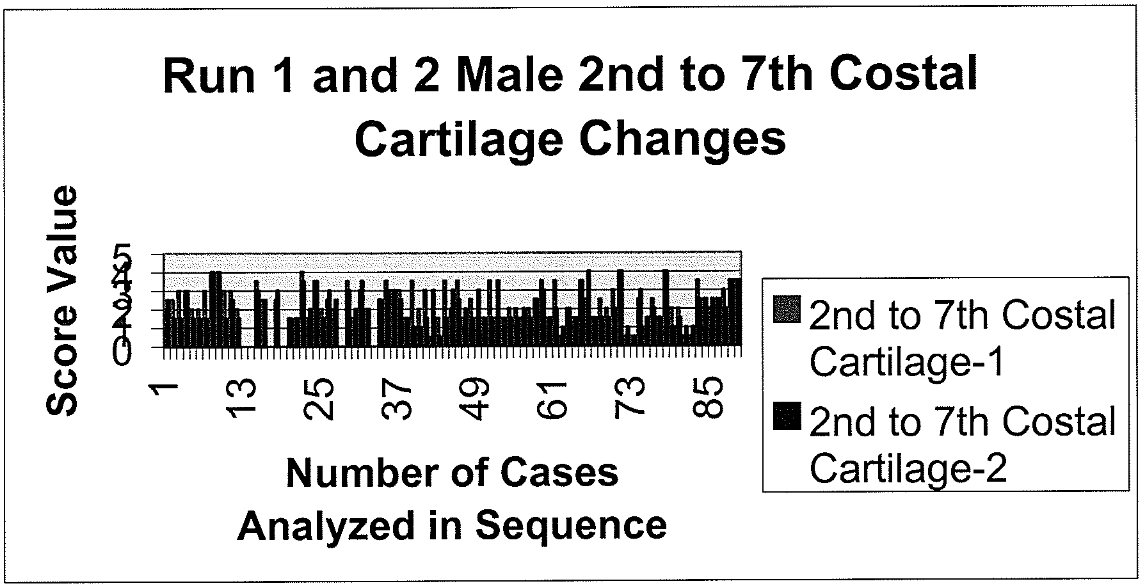

Figure 34: Run One and Two Male 2nd to 7th Costal Cartilage Changes, Cases in Sequence

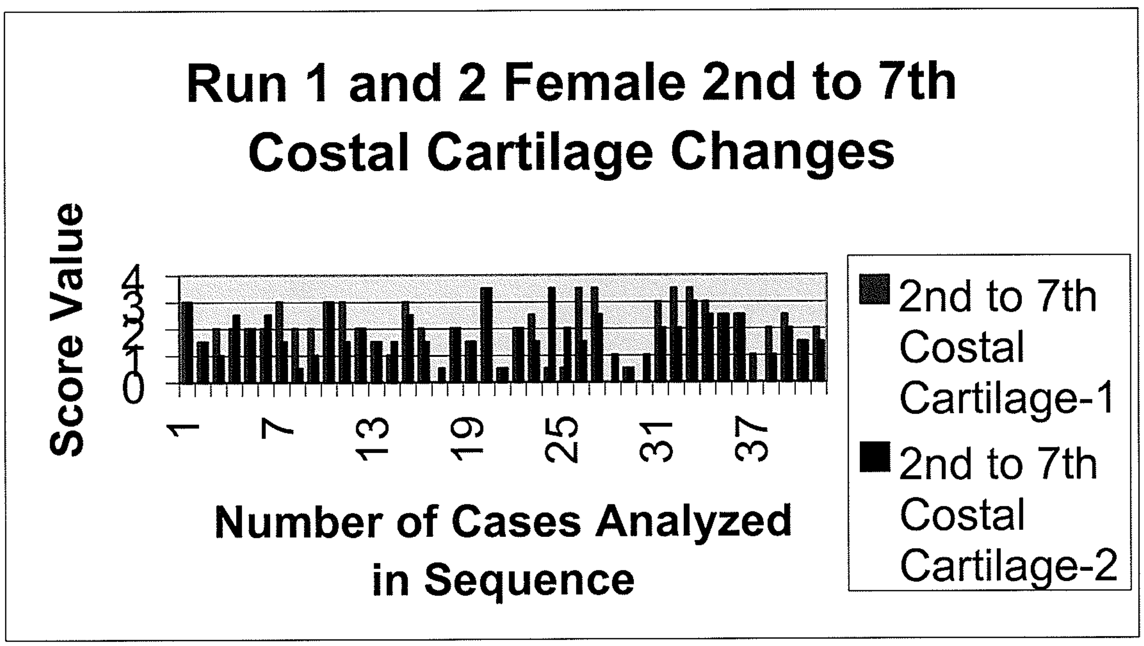

Figure 35: Run One and Two Female 2nd to 7th Costal Cartilage Changes, Cases in Sequence

In the male sample 31 of 89 (35.0%) cases between the two evaluations had second to seventh costal cartilage scored differently (Figure 34). However, only 12 of these cases differed by more than 0.5 to one point. Consistency of scoring does not appear to increase with experience. Chi-square results show no significant difference between the runs (χ^2=14.004; df = 8; p = 0.082).

In the female sample 25 out of 41 cases were scored differently between the runs (Figure 35). Of these, seven had a greater than 0.5 to one point difference between the runs. An increase in consistency does not occur with experience. Chi-square results show no significant difference between the runs (χ^2=10.056; df = 7; p = 0.19.).

Costo-Manubrial Border Changes

Costo-manubrial border changes were assessed using Chi-square measures and bar graphs as follows (Figures 36 and 37).

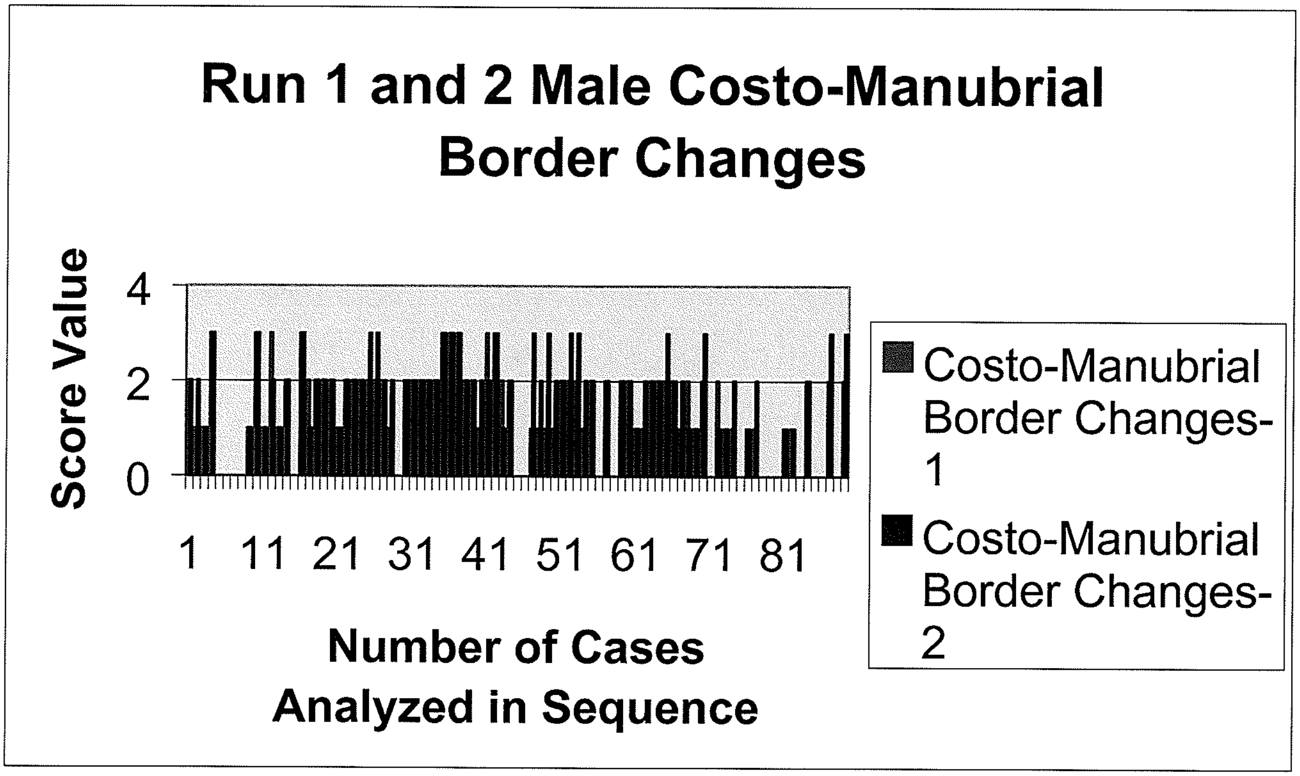

Figure 36: Run One and Two Male Costo-Manubrial Border Changes, Cases in Sequence

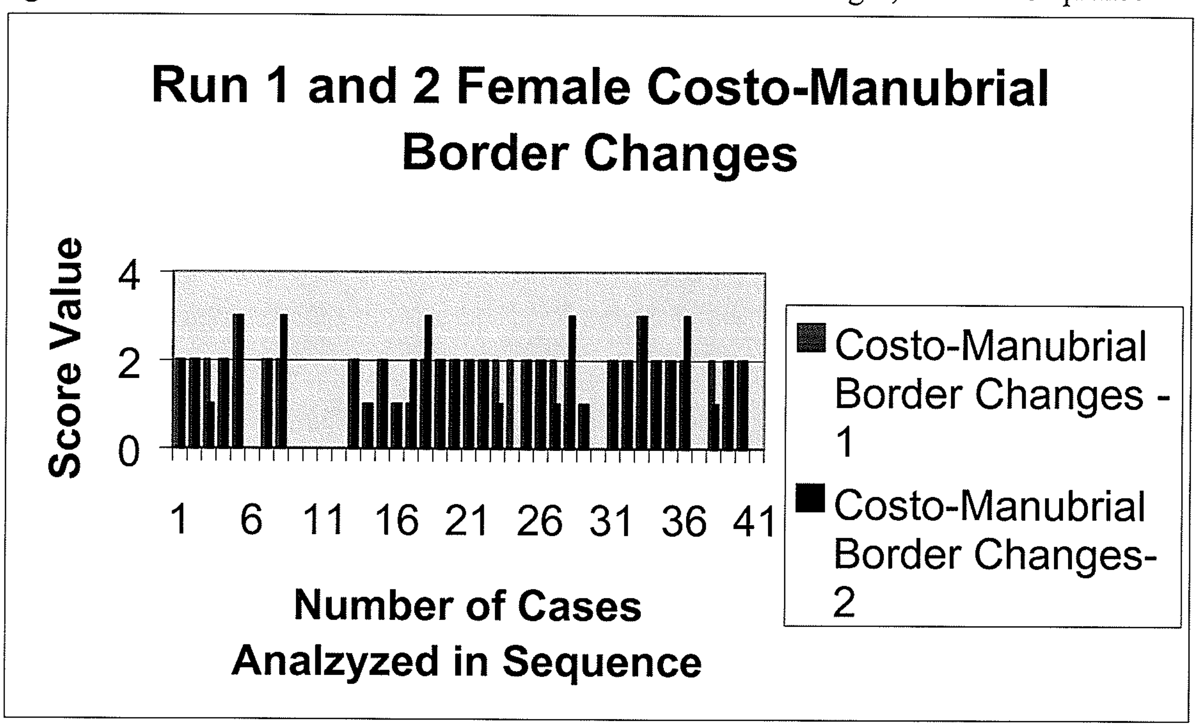

Figure 37: Run One and Two Female Costo-Manubrial Border Changes, Cases in Sequence

Male costo-manubrial border changes differed in 23 out of 70 possible cases at a rate of 33% with greater than a one-point difference occurring twice between evaluations (Figure 36). There is no improvement in consistency of score with experience. Chi-square results show no significant difference between runs one and two using this technique in the male sample (χ^2=4.146; df = 2; p = 0.13).

Female costo-manubrial border changes differ ten times out of a possible 33 cases at a rate of 30% with no difference greater than one point between evaluations (Figure 37). There is no change in consistency with experience. Chi-square results show no statistically significant differences between runs one and two using this technique in the female sample (χ^2=4.195; df = 2; p = 0.12).

Rib-End Changes

Male rib-end changes were only visible on 18 radiographs and females on seven radiographs. Thus, due to the small sample size Chi-square analysis was run on the sample un-differentiated as to sex.

Male rib end changes differed 11 out of a scored 18 times (61.1%) and there was no recognizable trend due to the small sample size. Females were scored differently six times out of seven (85.7%). Chi-square results of both sexes show a statistically significant difference between runs (χ^2=7.482; df = 2; p = 0.002). This is due to the small sample size.

Osteoporotic Changes

Osteoporotic changes were assessed using Chi-square analysis and bar graphs as presented in Figures 38 and 39.

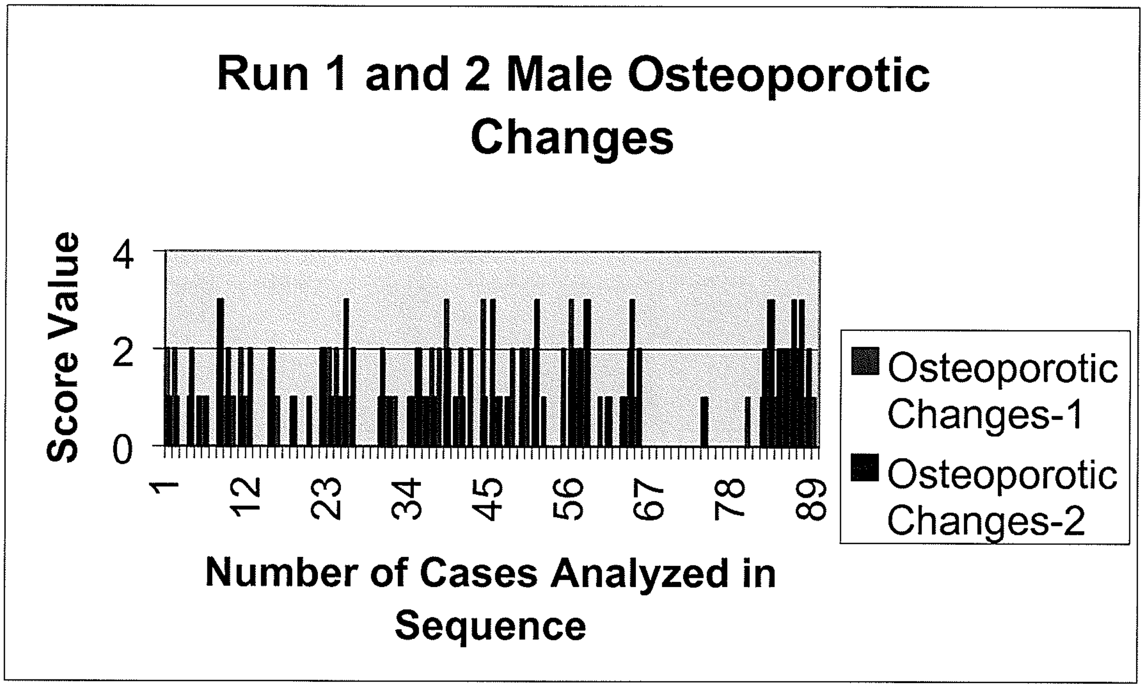

Figure 38: Run One and Two Male Osteoporotic Changes, Cases in Sequence

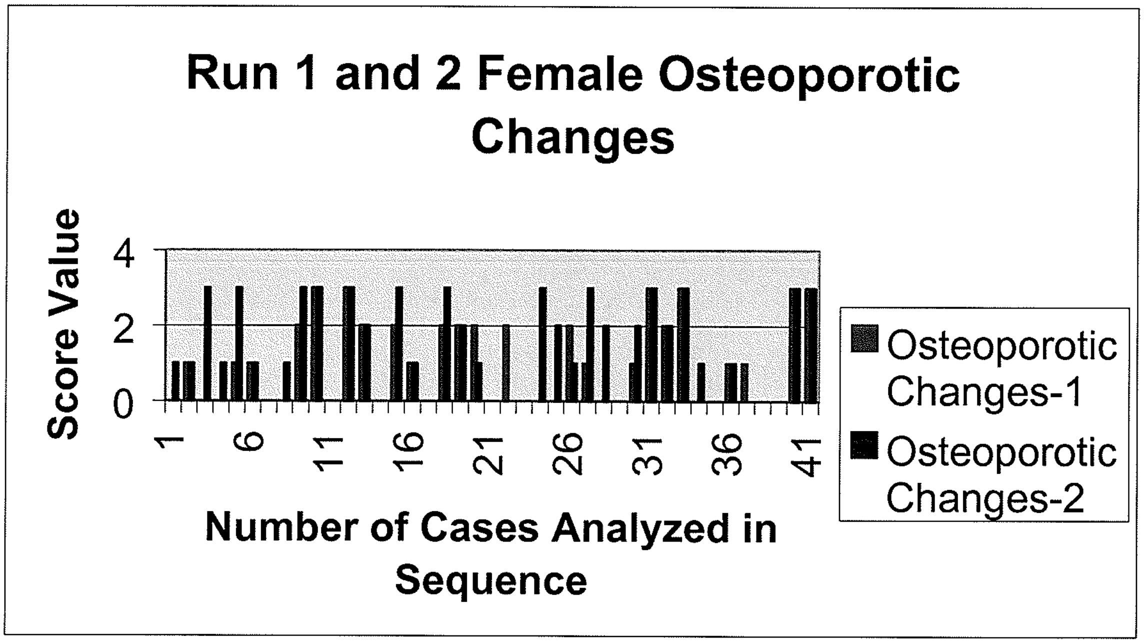

Figure 39: Run One and Two Female Osteoporotic Changes, Cases in Sequence

Male osteoporotic changes differed 40 times out of a possible 81 (49.4%) (Figure 38) however, 30 of these differences were only of one point. There was no increase in consistency over time. Chi-square results show no statistically significant difference between runs (χ^2=0.961; df = 3; p = 0.81).

Female osteoporotic changes were scored differently 18 out of 41 possible times (43.9%) (Figure 39). Twelve of these scores only differed by one point. There was no increase in consistency over time. Chi-square results show no significant difference between runs (χ^2=4.601; df = 3; p = 0.20).

Xyphoid Ossification

Male xyphoid ossification was only scored differently on two occasions out of 89 radiographs (2.2%). Chi-square results indicate no statistical difference between runs (χ^2=0.025; df=1; p = 0.50). Female xyphoid ossification was scored differently once out of 41 possible attempts (2.4%). Chi-square results indicate no statistically significant difference between runs (χ^2=0.050; df=1; p = 0.50).

REPLICABILITY AND ACCURACY

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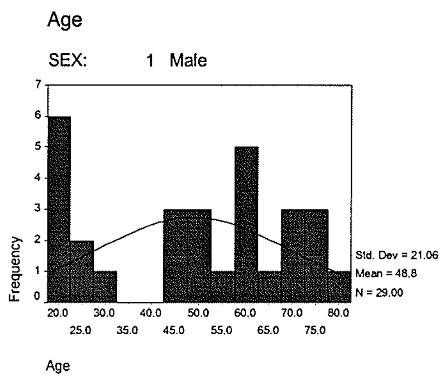
Barres et al.'s (1989) multiple linear regression formula is applied to my sample to compare age estimation data with documented age. Only 40 cases (29 male and 11 female) had all five variables, (i.e., Bone Demineralization-BD, Fusion of the Manubrium-FM, Cartilage to Sternum attachment changes-CS, Cartilage Mineralization-CM, and Rib to Cartilage attachment changes-RC), and were used to create new linear regression equations to test Barres et al.'s equation for estimation of age. Age and sex breakdown of this sample is presented in Figures 40 and 41.



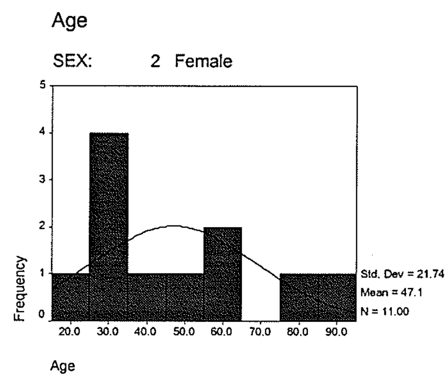
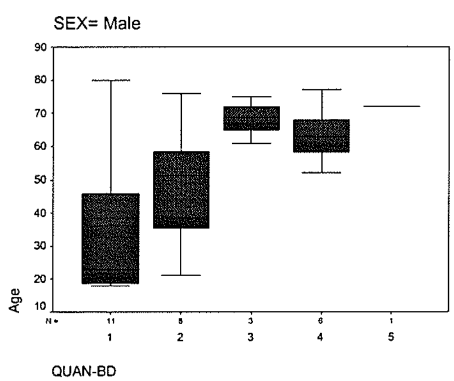


Figure 40: OCME Male Age Distribution Sub-Sample for Barres' Features

Figure 41: OCME Female Age Distribution Sub-Sample for Barres' Features

The male and female age distribution in the sub-sample is fairly evenly distributed except for a positive skew with respect to male individuals (Figures 40 and 41).

The pattern of age-progression with respect to Barres et al.'s five variables is presented in Figures 42 to 51.



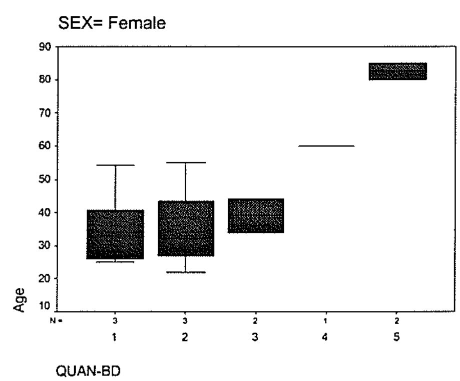


Figure 42: OCME Male Bone Demineralization Sub-Sample

Figure 43: OCME Female Bone Demineralization Sub-Sample

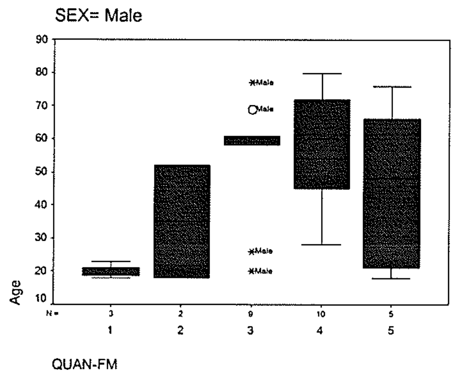


Figure 44: OCME Male Fusion of the Manubrium Sub-Sample

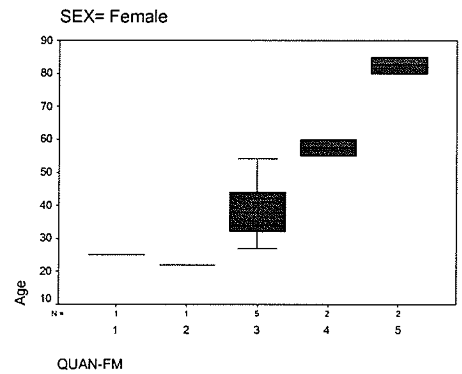


Figure 45: OCME Female Fusion of the Manubrium Sub-Sample

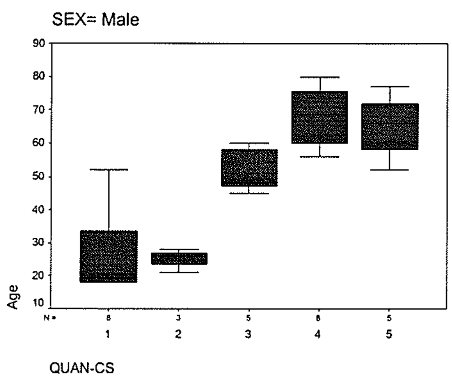


Figure 46: OCME Male Cartilage to Sternum Attachment Changes Sub-Sample

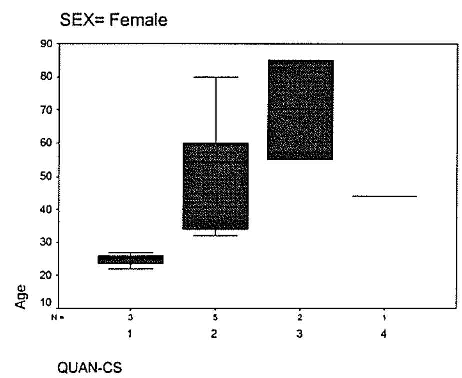


Figure 47: OCME Female Cartilage to Sternum Attachment Changes Sub-Sample

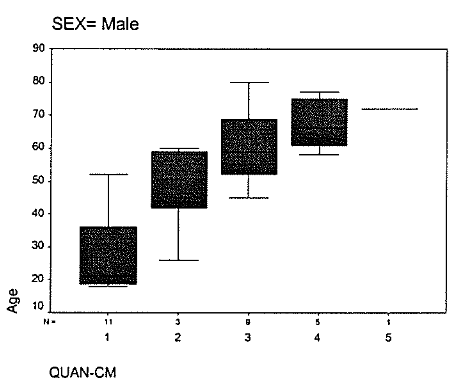


Figure 48: OCME Male Cartilage Mineralization Sub-Sample

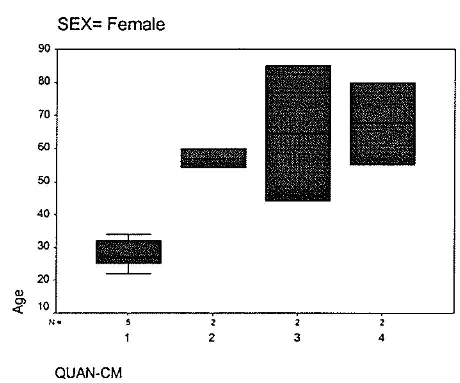
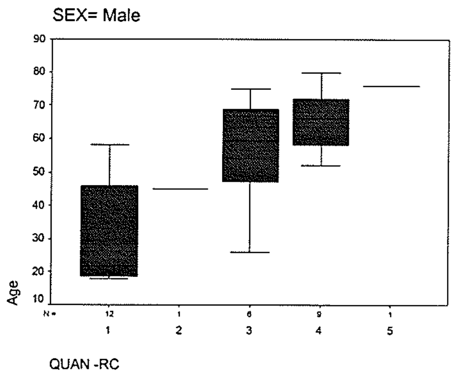


Figure 49: OCME Female Cartilage Mineralization Sub-Sample



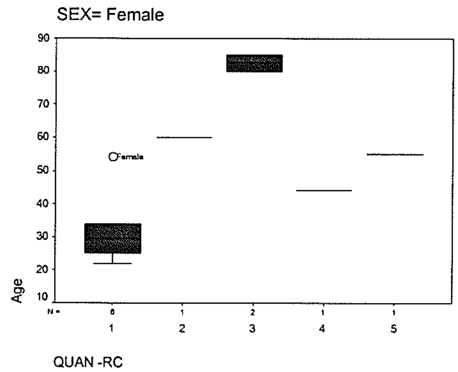


Figure 50: OCME Male Rib-End Changes Sub-Sample

Figure 51: OCME Female Rib-End Changes Sub-Sample

As can be seen from Figures 42 to 51, stage distribution is not evenly distributed in many of the variables with respect to the ages present. Male and female bone demineralization (BD) stages appear abnormal, however, female bone demineralization is more positively associated with age in the sub-sample than it is the male sub-sample. Both male and female manubrium fusion stages (FM), female cartilage to sternum attachment changes (CS) and female rib to cartilage attachment changes (RC) also appear unevenly distributed within the sub-sample. Box plots in all cases, (except female RC for which the sample size is too small), show a general trend towards higher stage number with increasing age. However, there is an overlap between stages adjacent to each other in all cases except male CS stage one, two, and three, female CS stage one and two, and male RC stage one and three. This may be due to the small sample size. However, in no case does stage one overlap with stage five, although in male FM it comes quite close. Again this indicates a tendency for there to be no real difference between stages except when comparing the very early with the very late age groups. The middle stages appear to fall within a large gray area where a great deal of overlap occurs generating no great significant differences between these groups. Pearson correlation coefficient tests are run on the variables differentiated as to sex with results as shown in Table 18.

Table 18: Barres et al. Features Pearson Correlation Coefficient Test

	Male					Female					Combined Sex
Barres' Features	BD	FM	CS	CM	RC	BD	FM	CS	CM	RC	RC
Pearson Correlation	0.47	0.32	0.73	0.65	0.72	0.73	0.66	0.36	0.34	0.56	0.68
P Value	<0	0.02	0	0	0	0	0	0.02	0.03	0.07	0

Female bone demineralization and fusion of the manubrium show greater correlation with increasing age than do male. Male cartilage-to-sternum attachment changes, rib-end-changes, and cartilage mineralization show greater correlation to increasing age than the same three of the female sub-sample. All are significant except the female rib-to-cartilage attachment changes. If undifferentiated as to sex the correlation for rib-end changes is also significantly correlated.

Paired sample t-tests were done comparing estimates of age using Barres et al.'s regression equation to true age. Barres et al. (1989) do not spilt their sample as to sex in the generation of their regression equation or in their analysis. Due to the small sample size of the OCME sub-population (N=40) this will also be the case with the OCME data and regression equation.

A scatter plot of Barres et al.'s age estimate compared with true age was generated and differentiated as to sex (Figure 52).

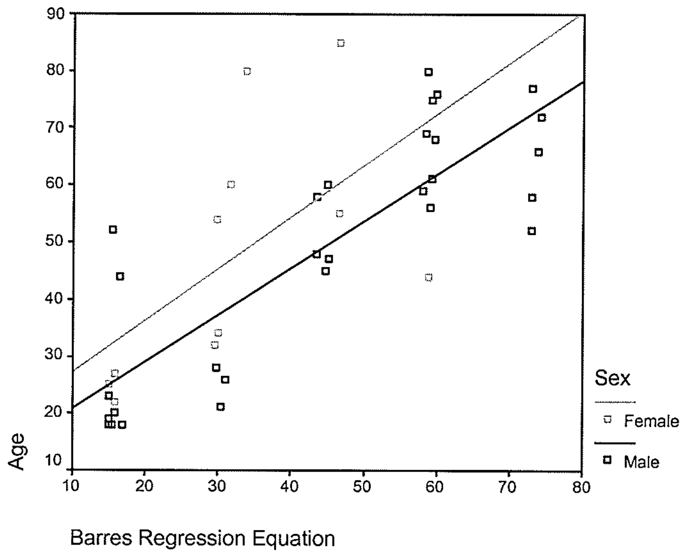


Figure 52: Scatter Plot of Barres et al. Age Estimates versus True Age

A regression equation was next generated using data from the 40 individuals in the OCME study population and results are summarized in Table 19.

Table 19: OCME Data Regression Equation Coefficients

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	6.775	6.286		1.078	.289
	QUAN-BD	2.436	2.160	.155	1.128	.267
	QUAN-FM	3.155	1.918	.176	1.645	.109
	QUAN-CS	2.623	2.925	.177	.897	.376
	QUAN-CM	8.169	4.033	.484	2.025	.051
	QUAN -RC	-.325	3.210	-.022	-.101	.920

a. Dependent Variable: AGE

A scatter plot of true age compared to the OCME regression equation estimate of age was generated (Figure 53).

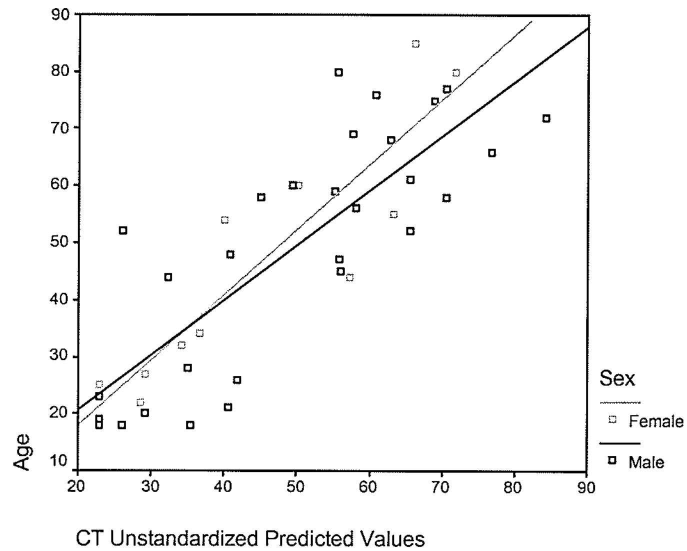


Figure 53: Scatter Plot of OCME Regression Equation Age Estimate versus True Age.

Barres et al. (1989) achieved a standard error of +/- 8.43 years for both sexes with a 95% confidence interval of +/- 17 years in their analysis. Paired samples t-tests of predicted age using Barres et al.'s equation versus true age, indicate a significant difference with respect to the male and female study population (t= 3.345; df=39; p=0.002). Figure 57 does show a positive correlation between the age estimate generated by Barres et al.'s equation and the true age of the sample for both sexes. OCME unstandardized predicted value for age also shows a positive correlation with respect to estimated age and true age for both sexes (Figure 53). Unfortunately, the 40 individual sub-sample size is too small to hold back a test group from the OCME sample to test the validity of the OCME regression equation.

An analysis of variance is run on the sub-sample group to see if any of the variables or sex may be significantly affecting the age estimation (Table 20).

Table 20: Analysis of Variance for Effect of Variables Bone Demineralization, Fusion of the Manubrium, Cartilage to Sternum Attachment Changes, Cartilage Mineralization, Rib-End Attachment Changes, and Sex

Tests of Between-Subjects Effects

Dependent Variable: Age

Source	Type II Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	15847.891[a]	30	528.263	3.595	.024
Intercept	93315.600	1	93315.600	635.036	.000
QUANBD	204.737	3	68.246	.464	.714
QUANFM	343.319	4	85.830	.584	.682
QUANCS	836.815	4	209.204	1.424	.302
QUANCM	356.069	3	118.690	.808	.521
QUANRC	327.496	4	81.874	.557	.700
SEX * QUANBD	1.475	1	1.475	.010	.922
SEX * QUANFM	4.775	1	4.775	.032	.861
SEX * QUANCS	.000	0	.	.	.
SEX * QUANCM	.000	0	.	.	.
SEX * QUANRC	.000	0	.	.	.
Error	1322.509	9	146.945		
Total	110486.000	40			
Corrected Total	17170.400	39			

a. R Squared = .923 (Adjusted R Squared = .666)

(Post hoc tests are not performed for Cartilage Mineralization because at least one group has fewer than two cases).

Analysis of variance results indicate that none of the stages are significantly affected by sex. Cartilage-to-sternum attachment changes (CS), cartilage mineralization (CM), and cartilage-to-rib attachment changes (RC), have too small of a sample size when differentiated as to sex to render a value. Results indicate that all five variables have greater significance at younger stages as compared to those of older age groups. The earlier stages, i.e., one and two are significantly different in all cases from all other stages except with respect to fusion of the manubrium. The middle and older age group stages, i.e. stages three, four and five are as a rule not significantly different from those closest to them or anything after stage two. These results may be affected by the small sample size of this sub-population.

Sternal Metrical Assessment and Sex Predictive Value

Metrical assessment of the sternum with respect to sex differentiation is tested using criteria supplied by McCormick et al. (1985). McCormick et al.'s results of their 1985 analysis are listed in Tables 21 and 22.

Table 21: McCormick et al. (1985) Metric Results

Sex	Feature	N	Range	Minimum	Maximum	Mean	Std. Deviation
Male	Manubrium length	698				55.6	5.6
	Sternal length	698	54	120	174	161.6	12.2
	4th rib width	698	>7	12	>19		
	Costal II and III	698	>16	<19	>35		
	Sternal area	698				6,380	926
Female	Manubrium length	435				50.3	5.1
	Sternal length	435	53	120	173	138.3	10.8
	4th rib width	435	<8	<11	19		
	Costal II and III	435	>16	<19	>35		
	Sternal area	435				4,752	689

Table 22: McCormick et al. (1985) Predictive values for parameters alone and algorithm

	Prediction category	Predictive value	Cases sexed	% of study population
Patterning	Male	.926	555	
	Female	.909	342	
	All	.920	897	79.2
Sternal length	Male	.969	453	
	Female	.906	308	
	All	.943	761	67.2
Sternal area	Male	.973	446	
	Female	.869	320	
	All	.930	766	67.6
Fourth rib	Male	.928	570	
	Female	.885	244	
	All	.916	814	71.8
Gladiolar 2nd interspace	Male	.885	366	
	Female	.867	45	
	All	.883	411	36.3
Algorithm	Male	.987	694	
	Female	.959	439	
	All	.971[1]	1133	100.0

[1]95% confidence interval of algorithm for study population: .961 x .978.

As noted in Tables 21 and 22 McCormick et al. (1985) do not publish results for some of their required measurements, however, the minimum and maximum ranges for sternal length for males and females in their sample is quite different from the OCME sample but the mean and to some extent the standard deviation for males is quite similar to the OCME study population. While the mean for females is not as close to OCME data the standard deviation is almost exact.

An independent samples t-test is run on all OCME measurements for indications of statistically significant differences between the sexes. In all cases of male and female measurements within the OCME sample there is a significant statistical difference.

In McCormick et al's 1985 study, sternal length alone accounted for accurate sexing in 761 out of 1133 cases or 67.2% which lay outside of the 143-157 mm gray zone. Correct sexing occurred in 94.3% of these cases. Using a cutoff of 148 mm (>/= 148 mm = male; < 148 mm = female) they achieved an accuracy rate of 85.2% in their study sample. They also found males less than 25 years of age to have statistically shorter sternal lengths than the entire male population. Starting at age 26-27 years males have average sternal lengths closer to the entire sample. Females were noted to have significantly shorter sternal lengths in the 20 – 21 year age group with the older groups starting at age 22 – 23 years displaying no statistical difference. With only nine males under the age of 26 years and one female under the age of 22 years there does not appear to be any great positive relationship between age and sternal length in the OCME sample (Figure 54). For males the sternal length ranged from 101.35 mm to 199.75 mm with a mean of 163.84 mm. However, the low value of 101.35 mm appears to be an aberrant size with the next shortest male sternum measuring 135.80 mm.

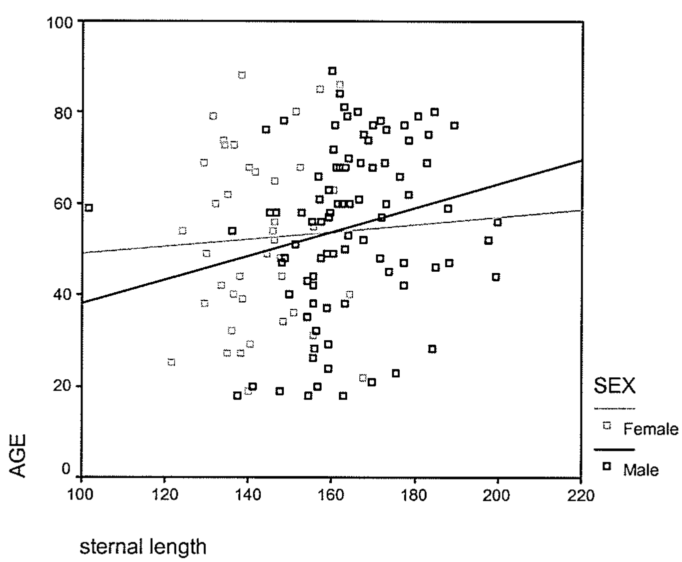


Figure 54: OCME Sample Sternal Length Compared to True Age

Using McCormick et al. (1985) metric parameters for thoracic dimensions and sex assessment cross-tabulation tests were run on the OCME data in order to determine the frequency at which the correct sex was able to be determined (Tables 23 and 24).

Table 23: OCME Sample Sex Determination from Sternal Length, (>/= 148 mm male; < 148 mm female) using McCormick et al. (1985) Criteria

Sex * MSL Sternal Length One Crosstabulation

			MSL Sternal Length One		
			Male	Female	Total
Sex	Male	Count	80	9	89
		% within Sex	89.9%	10.1%	100.0%
		% within MSL Sternal Length One	87.9%	23.1%	68.5%
		% of Total	61.5%	6.9%	68.5%
	Female	Count	11	30	41
		% within Sex	26.8%	73.2%	100.0%
		% within MSL Sternal Length One	12.1%	76.9%	31.5%
		% of Total	8.5%	23.1%	31.5%
Total		Count	91	39	130
		% within Sex	70.0%	30.0%	100.0%
		% within MSL Sternal Length One	100.0%	100.0%	100.0%
		% of Total	70.0%	30.0%	100.0%

Table 24: OCME Sample Sex Determination from Sternal Length (< 143 mm = Female; > 157 mm = Male; 143.001 to 156.999 = Indeterminate) using McCormick et al. (1985) Criteria

Sex * MSL Sternal Length Two Crosstabulation

			MSL Sternal Length Two			Total
			Male	Female	Indeterminate	
Sex	Male	Count	63	4	22	89
		% within Sex	70.8%	4.5%	24.7%	100.0%
		% within MSL Sternal Length Two	94.0%	14.8%	61.1%	68.5%
		% of Total	48.5%	3.1%	16.9%	68.5%
	Female	Count	4	23	14	41
		% within Sex	9.8%	56.1%	34.1%	100.0%
		% within MSL Sternal Length Two	6.0%	85.2%	38.9%	31.5%
		% of Total	3.1%	17.7%	10.8%	31.5%
Total		Count	67	27	36	130
		% within Sex	51.5%	20.8%	27.7%	100.0%
		% within MSL Sternal Length Two	100.0%	100.0%	100.0%	100.0%
		% of Total	51.5%	20.8%	27.7%	100.0%

Using McCormick et al's 1985 cut off point of 148 mm accurate prediction of the sex of the OCME male sample occurred 80 (90%) times out of 89 with a wrong sex assigned 9 times (10%). For the female sample the accuracy rate was 73% or 30 times out of 41 with a wrong determination made 11 (27%) times. In total the correct sex was assigned 110 times out of 130 individuals at a rate of 85%. Using McCormick et al's (1985) values for sex specific sternal lengths ((<143 mm = female; > 157 mm = male; 143.001 to 156.999 = indeterminate) accurate prediction of the sex of the OCME sample occurred 63 (70.8%) out of 89 times for male individuals with an indeterminate sex selected on 22 (24.7%) occasions and the wrong sex assigned four (4.5%) times. For females accurate sex prediction occurred 23 times (56%) out of 41 with four (9.8%) individuals inaccurately determined to be male and an indeterminate estimate generated on 14 (24%) occasions. The total individuals sexed correctly using this technique was 86 out of 130 individuals at a rate of 66%. Disregarding the gray zone 86 out of 94 individuals were correctly assessed at a rate of 91%.

McCormick et al., (1985) also found the 4th rib width to be sexually dimorphic in 71.8% or 814 out of 1133 individuals in their population. When they excluded the indeterminate widths of 15 mm to 16 mm they were able to accurately predict sex in 91.5% of 814 cases (69 cases were inaccurately sexed). If they used a cut off point of 16 mm (>/= 16 mm = male) they were able to predict sex accurately 84.6% of the time for 1133 individuals. Table 25 lists 4th rib width data using the OCME population.

Table 25: OCME Sample 4th Rib Width Sexual Dimorphism; (>/= 16 mm = male) using McCormick et al., (1985) Criteria

Sex * MCLRib Crosstabulation

			MCLRib		
			Male	Female	Total
Sex	Male	Count	63	8	71
		% within Sex	88.7%	11.3%	100.0%
		% within MCLRib	91.3%	24.2%	69.6%
		% of Total	61.8%	7.8%	69.6%
	Female	Count	6	25	31
		% within Sex	19.4%	80.6%	100.0%
		% within MCLRib	8.7%	75.8%	30.4%
		% of Total	5.9%	24.5%	30.4%
Total		Count	69	33	102
		% within Sex	67.6%	32.4%	100.0%
		% within MCLRib	100.0%	100.0%	100.0%
		% of Total	67.6%	32.4%	100.0%

Only the >16mm analysis was carried out with respect to the OCME study population due to the negligible indeterminate area of the test. Using McCormick et al.'s (1985) demarcation point in my data sample males were accurately sexed 63 times out of a possible 71 (89%) (Table 25). A miss-classification occurred eight times out of 71 at a rate of 11%. Females were accurately sexed 25 times out of 31 (81%) and miss-classified six times (19%). In total 88 out of 102 individuals (86%) individuals were accurately sexed.

McCormick et al. (1985) found the corpus width at the second intercostal interspace to be reflective of the sexual dimorphism seen with the other variables, however, when used alone it was a weak indicator of sex because of its large indeterminate range. Excluding its 20.0 mm to 27.0 mm indeterminate range they were able to assess 411 cases with a sex predictive value of 88.3%. (Please note: The range for the corpus width at the second costal interface for males was 19.85 mm to 65.00 mm with a mean of 29.83 mm. The unusually high 65.00 mm width was seen within the same male individual with the abnormally short sternal length. The next highest measurement for this area in the male sample was 44.20 mm). Table 26 presents OCME sample 2nd costal II and III interspace data.

Table 26: OCME Sample Costal II and III Interspace; (<20.0 mm = female; >27.0 mm = male; 20.0 mm to 27.0 mm indeterminate) using McCormick et al., (1985) Criteria.

Sex * MSL Costal II and III Width Crosstabulation

			MSL Costal II and III Width			
			Male	Female	Indeterminate	Total
Sex	Male	Count	67	1	21	89
		% within Sex	75.3%	1.1%	23.6%	100.0%
		% within MSL Costal II and III Width	91.8%	16.7%	41.2%	68.5%
		% of Total	51.5%	.8%	16.2%	68.5%
	Female	Count	6	5	30	41
		% within Sex	14.6%	12.2%	73.2%	100.0%
		% within MSL Costal II and III Width	8.2%	83.3%	58.8%	31.5%
		% of Total	4.6%	3.8%	23.1%	31.5%
Total		Count	73	6	51	130
		% within Sex	56.2%	4.6%	39.2%	100.0%
		% within MSL Costal II and III Width	100.0%	100.0%	100.0%	100.0%
		% of Total	56.2%	4.6%	39.2%	100.0%

For III and III intercostal interspace width in the OCME sample using McCormick et al.'s (1985) data male individuals were accurately sexed 67 times out of 89 (75%) with a misclassification occurring once (1%) and an indeterminate classification occurring 21 (24%) times (Table 26). Females were accurately sexed five times out of a possible 41 (12%) occasions with a misclassification occurring six (15%) times and indeterminate classifications occurring 30 times (73%). If the gray area is ignored, males were accurately assessed 67 out of 68 times (99%) and females five out of 11 (45%). In total 72 individuals out of the 79 (91%) that were not contained within the gray zone were accurately sexed.

McCormick et al. (1985) found sternal area also reflected a sexual dimorphism. The area was sex predictive in 766 cases with an indeterminate area of 4976 mm^2 to 6041 mm^2

yielding a predictive value of 93.0% when this area was excluded. When the cutoff point was placed at 5400 mm^2 (>/= 5400 mm^2 = male) sternal area yielded an accuracy of 85.6%. Table 27 and 28 lists OCME data sternal area results.

Table 27: OCME Sample Sternal Area; (<5400 mm^2 = female; >/= 5400 mm^2 = male) using McCormick et al., (1985) Criteria

Sex * MSL Area One Crosstabulation

			MSL Area One		
			Male	Female	Total
Sex	Male	Count	80	9	89
		% within Sex	89.9%	10.1%	100.0%
		% within MSL Area One	90.9%	21.4%	68.5%
		% of Total	61.5%	6.9%	68.5%
	Female	Count	8	33	41
		% within Sex	19.5%	80.5%	100.0%
		% within MSL Area One	9.1%	78.6%	31.5%
		% of Total	6.2%	25.4%	31.5%
Total		Count	88	42	130
		% within Sex	67.7%	32.3%	100.0%
		% within MSL Area One	100.0%	100.0%	100.0%
		% of Total	67.7%	32.3%	100.0%

Table 28: OCME Sample Sternal Area (<4976 mm^2 = female ; >6041 mm^2 = male; 4976 mm^2 to 6041 mm^2 = indeterminate) using McCormick et al., (1985) Criteria

Sex * MSL Area Two Crosstabulation

			MSL Area Two			
			Male	Female	Indeterminate	Total
Sex	Male	Count	67	6	16	89
		% within Sex	75.3%	6.7%	18.0%	100.0%
		% within MSL Area Two	94.4%	20.7%	53.3%	68.5%
		% of Total	51.5%	4.6%	12.3%	68.5%
	Female	Count	4	23	14	41
		% within Sex	9.8%	56.1%	34.1%	100.0%
		% within MSL Area Two	5.6%	79.3%	46.7%	31.5%
		% of Total	3.1%	17.7%	10.8%	31.5%
Total		Count	71	29	30	130
		% within Sex	54.6%	22.3%	23.1%	100.0%
		% within MSL Area Two	100.0%	100.0%	100.0%	100.0%
		% of Total	54.6%	22.3%	23.1%	100.0%

For sternal area in the OCME population using gray area data 67 out of 89 (75%) males were accurately sexed and six (7%) were mis-classified, Sixteen (18%) fell in the indeterminate zone (Table 27 and 28). Females were accurately sexed 23 out of 41 times (56%) and miss-classified four times (10%) with an indeterminate number of 14 (34%). Disregarding the gray zone individual males were accurately sexed 67 out of 73 times (92%) while females were accurately sexed 23 out of 27 times ((85%). In total 90 individuals were accurately sexed out of 100 (90%) possible individuals. Using McCormick et al.'s demarcation point of 5400 mm^2 males were accurately sexed 80 out of 89 times (90%) and females 33 out of 41 (80%).

Binary logistic regression analysis was run on the four variables that were found to be significant with respect to determining sex in McCormick's et al. (1985) population. Results are presented in Table 29.

Table 29: OCME Sample Binary Regression Analysis on Variables Sternal Length, 4th Rib Width, Costal II and III Interspace Width, and Sternal Area

Classification Table[a]

Observed			Predicted		
			Sex		Percentage Correct
			Male	Female	
Step 1	Sex	Male	67	4	94.4
		Female	2	29	93.5
	Overall Percentage				94.1

a. The cut value is .500

Using all four variables sex is accurately predicted in the OCME sample at an accuracy rate of 94.4% for males and 93.5% for females (Table 29).

Forward step-wise (conditional) binary regression analysis was done on the same four variables as shown in Table 30.

Table 30: OCME Sample Binary Stepwise Forward (Conditional) Analysis on Variables Sternal Length, 4th Rib Width, Costal Interspace II and III Width, and Sternal Area

Classification Table[a]

Observed			Predicted: Sex: Male	Predicted: Sex: Female	Predicted: Percentage Correct
Step 1	Sex	Male	66	5	93.0
		Female	7	24	77.4
	Overall Percentage				88.2
Step 2	Sex	Male	68	3	95.8
		Female	3	28	90.3
	Overall Percentage				94.1

a. The cut value is .500

Using binary regression step-wise forward analysis both costal interspace II and III width and sternal length are rejected and 4th rib width and sternal area are retained as best models for predicting sex (Table 30). As sternal length and costal interspace II and III width are the two measurements that make up sternal area in this analysis this is expected. The sex-prediction accuracy rates rise for males to 95.8% but drop for females to 90.3% using just the two variables (Table 30).

Ossification Pattern and Metrical Assessment

Guidelines detailed in Chapter 3 and Appendix A were used to estimate sex using metric data when the ossification pattern was not sufficient to do so. Table 31 shows the distribution of each specific pattern type and the calculated sex using pattern and metric parameters.

Table 31: OCME Sample Distribution of Calcification Pattern which Used Metrical Parameters and Final Sex Determination

Sex	Distribution of Pattern Types using Metrical Analysis							
Male	B (2)	C (3)	D (4)	E (5)	H (8)	I (9)	X(10)	Y(11)
Total		1	1	23	1	8	9	18
Calculated Sex Male			1	4		2	6	18
Calculated Sex Female		1		1			2	
Calculated Sex Undetermined				18	1	6	1	
Female	B-(2)	C-(3)	D-(4)	E-(5)	H-(8)	I-(9)	X(10)	Y-(11)
Total		6	1	6		4	3	10
Calculated Sex Male							1	1
Calculated Sex Female		2	1	3		1	2	6
Calculated Sex Undetermined		4		3		3		3

Of the 91 individuals (70.0%) whose selected calcification patterns made use of metric assessment in order to determine sex, 61 were male and 30 were female (Table 31). Of these, four males (6.6%) were inaccurately determined to be female, 26 males (42.6%) were classified as undetermined, and 31 males (50.8%) were correctly classified as male. Of the female sample two (6.7%) were inaccurately classified as male, 13 (43.3%) were classified as undetermined, and 15 (50.0%) were classified correctly. Within the entire population that used pattern type as well as metric evaluation the correct sex was determined 46 times (50.5%), inaccurate sexing occurred six times (6.6%), and an indeterminate sex was selected 39 times (42.9%).

Radiographs that were either not sex specific or only vaguely so included Null Types X and Y, Indeterminate or Type I, Type D, and Type H (Table 31). McCormick et al. (1985) observed that while sex-specific ossification is much less advanced in younger adults than in middle age, sex-specific patterning, including D, occurred in 41 out of 81

(50.6%) of their cases in the 20 to 25 year age range. Their data found more sex-specific patterning to increase with age, with the 60 years or older age group, 379 out of 407 (93.1%) displaying sex-specific patterning. Table 32 presents the type of patterning in McCormick et al.'s 1985 sample.

Table 32: Distribution of Patterns Types in McCormick et al. (1985) Study Population

	Males	McCormick	Females	McCormick	Total	McCormick
Type D-4	1-1.1%	6-0.9%	1-2.4%	21-4.8%	2-1.5%	27-2.4%
Type H-8	1-1.1%	21-3.0%	0-0.0%	9-2.1%	1-0.8%	30-2.7%
Type I-9	8-9.0%	50-7.2%	4-9.8%	25-5.7%	12-9.2%	75-6.7%
Type X-10	9-10.1%	75-10.7%	3-7.3%	27-6.2%	12-9.2%	102-9.2%
Type Y-11	18-20.2%		10-18.8%		28-21.5%	
Total X, Y	27-30.3%		13-31.7%		40-30.8%	

In the OCME data set a Type B pattern with a score of 3+ (specific to females if scored as 3+) is seen as early as 19 years of age. However, other sex-specific patterning, Types D and H included, (which do not receive ossification scores), appear as early as age 20 (Type H) and age 26 (Type E). Both of these occur in male individuals. Age ranges for sex-specific patterning are listed in Table 33.

Table 33: OCME Sample Male Ossification Pattern Type and Age Range Distribution

Male	Costal Cartilage Ossification Pattern										
Age yrs.	A-1	B-2	C-3	D-4	E-5	F-6	G-7	H-8	I-9	X-10	Y-11
18-20								1		5	
21-25										1	2
26-30					3						1
31-35					1					1	
36-40					2						2
41-45					4					1	1
46-50					3	2	1				4
51-55			1		2					1	1
56-60					7	2	1		2		3
61-65					3				1		
66-70				1	4		1		2		2
71-75					3		1		1		
76-80					6		2		2		2
81-85					1		1				
86-90	1										
Total	1	0	1	1	39	4	7	1	8	9	18
Female	Costal Cartilage Ossification Pattern										
Age yrs.	A-1	B-2	C-3	D-4	E-5	F-6	G-7	H-8	I-9	X-10	Y-11
18-20		1									
21-25										2	
26-30			1							1	1
31-35											3
36-40					4						1
41-45		1			1				1		
46-50						1			1		1
51-55		1	1		1				1		
56-60			1	1							
61-65					1						2
66-70		1	1			1					1
71-75			1						1		1
76-80	2										
81-85	1										
86-90		1	1								
Total	3	5	6	1	7	2	0	0	4	3	10

Sex specific patterning in specific age-groups are presented in Table 34 as follows:

a.) number of individuals within each age group

b.) percentage of a sex-specific ossification pattern within age group

c.) percentage of a non-sex specific ossification pattern within age group

Table 34: OCME Sample Sex-specific Ossification Pattern Distribution Percentages

Age Yrs. Males # of Cases	a.) # Individuals Present	b.) % Sex-Specific Pattern	c.) % Non-Sex-Specific Pattern
18-20	6	17%	83%
21-25	3	0%	100%
26-30	4	75%	25%
31-35	2	50%	50%
36-40	4	50%	50%
41-45	6	67%	33%
46-50	10	60%	40%
51-55	5	60%	40%
56-60	15	67%	33%
61-65	4	75%	25%
66-70	10	60%	40%
71-75	5	80%	20%
76-80	12	67%	33%
81-85	2	100%	0%
86-90	1	100%	0%
Total	89	61%	39%
Age Yrs. Females	a.) # Pattern Types	b.) % Sex-Specific Pattern	c.) % Non-Sex-Specific Pattern
18-20	1	100%	0%
21-25	3	0%	100%
26-30	3	33%	67%%
31-35	3	0%	100%
36-40	5	80%	20%
41-45	3	67%	33%
46-50	3	33%	67%
51-55	4	75%	25%
56-60	2	100%	0%
61-65	3	33%	67%
66-70	4	75%	25%
71-75	3	33%	67%
76-80	2	100%	0%
81-85	1	100%	0%
86-90	2	100%	0%
Total	41	59%	41%

Although the number of individuals contained within each age range is not equal Tables 33 and 34 show a general tendency towards an increase in percentage of sex-specific ossification patterns with age. Figure 55 graphically represents the frequency of sex-specific and non-sex-specific ossification correlated to age.

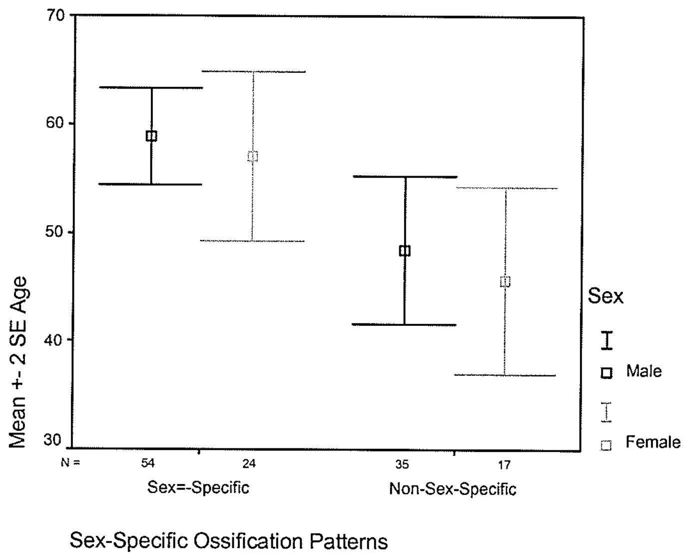


Figure 55: OCME Sample Sex-Specific Ossification Pattern and Age Distribution

While the sample size is not evenly distributed as to age between the sexes nor the age ranges and there is overlap it is apparent that the majority of sex-specific ossification is occurring within the older age groups in both sexes.

With respect to costal cartilage ossification pattern alone, 39 (30.0%) out of 130 cases were of sufficient quantity and specific type to determine sex. Using only the ossification pattern, correct sexing was achieved in 27 out of 28 (96.4%) male cases (one was miss-classified as female) and in eight out of 11 (72.7%) female cases (three were miss-classified as male). Together correct sexing was achieved in 35 out of 39 cases, or 89.8% of the time. This is close to McCormick et al.'s 1985 success rate in that they achieved accurate sexing at a rate of 92.0% on 897 individuals whose ossification patterning was of sufficient quantity and type (this percentage rate is undifferentiated as to sex) using a sample size of 1133 cases.

Figures 56 and 57 present the range of ossification amount with respect to age of both sexes.

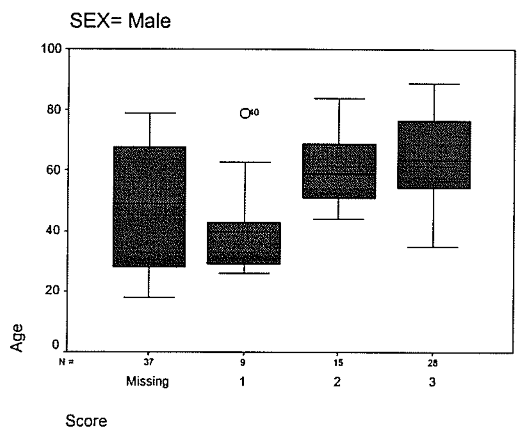


Figure 56: OCME Sample Male Ossification Score

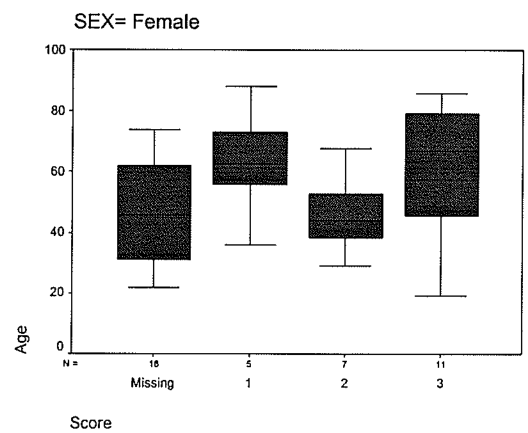


Figure 57: OCME Sample Female Ossification Score

As can be seen from the Figures 56 and 57 the greatest number of individuals are those without a scored ossification amount in both sexes (54 individuals have patterns that are not scored as to ossification amount). Male ossification amount displays a small trend towards higher ossification with age. The female sample, although smaller, displays a great deal of overlap between stages with no discernable trend towards increased ossification with age. Chi-square measures are used to test the significance between sex and ossification scores.

Chi-square results indicate no significant difference between the sexes with respect to ossification score (χ^2=0.170; df=2; p=0.918). An ANOVA is done on this sample to measure significance between score and age (Table 35).

Table 35: ANOVA Comparing OCME Sample Ossification Score and Age

ANOVA

Age

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1959.473	2	979.736	3.723	.029
Within Groups	18949.807	72	263.192		
Total	20909.280	74			

As can be seen from Table 35 there is a significant difference between ossification scores and age.

McCormick et al., Age Estimation

McCormick, Stewart and Langford, (1985) do not rely heavily on age estimation from costal cartilage ossification patterns Types C, D, E, H, I, and Y except as a general guideline to age range. Types A, B, F, G, and X are more consistent and more confidence is placed in age estimates when these patterns are expressed. Calculated age will be assessed using the criteria set out in Table 36 as related to specific ossification patterns. These age ranges are not specifically assigned by McCormick et al. (except for Type A), but are a synthesis by the writer of their findings of specific pattern types and the age minimums and maximums put forth in their 1985 study (Table 36).

Table 36: Estimated Age from Ossification Pattern Assessment using McCormick et al., (1988) Criteria

	Ossification Patterns										
	A	B	C	D	E	F	G	H	I	X	Y
Age	>50	30-65	>30	>30	30-80	30-65	>65	>18	>30	18-30	20-40

Table 37 shows the frequency at which these age ranges and patterns appear within the OCME sample as well as the true age of the individuals.

Table 37: OCME Sample Age Range Frequency and True Age

Sex	Ossification Pattern and Age Range (Years)							
Male	>18 Type H	>30 Type D	>50 Type A	>65 Type G	18-30 Type X	20-40 Type Y	30-65 Type F	30-80 Type E
Ossification Pattern Type: # in Accurate Age Range	1	9	1	5	6	5	4	36
Ossification Pattern Type: # in Inaccurate Age Range				2	3	13		4
True Age in Years				50, 58	32,44, 52	42,47,48, 49, 49,51, 58,59,60, 68,70,77, 78		26, 28, 29, 84
Total	1	9	1	7	9	18	4	40
Female	>18 Type H	>30 Type D	>50 Type A	>65 Type G	18-30 Type X	20-40 Type Y	30-65 Type F	30-80 Type E
Ossification Pattern Type: # in Accurate Age Range		10	3		3	5	3	7
Ossification Pattern Type : # in Inaccurate Age Range		1				5	4	
True Age in Years		29				49, 62, 65 69, 73	19,67, 68, 86	
Total	0	11	3	0	3	10	7	7

As noted in Table 37 errors in age category assignment generally occur within the Type Y group. While this may be somewhat related to the wrong pattern choice on the part of the observer this is unlikely, due to the minimal amount of ossification this particular type exhibits. The Type F-Type A error once again affects results negatively. If the correct pattern had been chosen in these cases all but one Type A individual would have fallen into the correct age grouping. If this factor is taken into account 67 (75%) out of 89 males were correctly classified as to age group and 22 (25%) of males were wrongly classified. Within the female sample (taking into account the wrong pattern assessment of Type F and Type A) 34 (83%) out of 41 females were put into the correct age group and seven (27%) were inaccurately placed. However, the age ranges of most of these groups are extremely wide, most notable Types C, D, E, H, and I.

Ossification Features

McCormick and Stewart (1988) performed a blind age estimate on 929 cases using criteria developed from 705 cases in their series of 863 individuals (158 were excluded as there were no consistent specific criteria for age estimations over the age of 65 years at the time). The sequence of the development of age related changes visible radiographically had been correlated with gross bone and cartilage morphology by McCormick and Stewart and an estimated age appears to have been an educated guess based on their own bias and experience. They calculated a linear regression line using these estimates of age upon which they tested a different set of 863 radiographs and came up with an average underestimation of 1.5 years and a standard deviation of 8.2 years. As this data was a culmination of their own particular experiences and bias it is un-testable in this sample, thus features are only evaluated for significance with age and utility for prediction of age.

First Costal Cartilage

In McCormick and Stewart's 1988 study on age related changes of the human thoracic area they found that the first costal cartilage ossified at a rate and pattern distinctively different from the lower costal cartilage. In males they found slight or trace (0.5) ossification to occur as early as age 15 to 19 years with heavy ossification (4+) occurring within ages 45 to 49 years and up. For females slight or trace (0.5) also occurred as early as 15 to 19 years with heavy (4+) not appearing in their sample. At ages 40 to 44 years however, a score of 3.5 is apparent. Unfortunately, in the OCME sample the first costal cartilage was not visible for 109 individuals. The remaining 20 displayed no ossification. Thus, further analysis of this feature and it's utility for age assessment will not be undertaken.

Second to Seventh Costal Cartilage

In McCormick's (1980) preliminary observations regarding age-related ossification of the costal cartilage he has noted that this feature is a common event among adults and is roughly correlated to age. Every specimen of his initial sample exhibited at least slight mineralization if they were over the age of 25 years. Before 25 years it was rarely present except in trace amounts. He notes dense mineralization is unlikely to occur before the age of 50 years and relatively uncommon before age 60. However, comparatively small amounts of mineralization may also be present on those over 60 years making age estimation based on light mineralization alone (1.5+ to 2+) highly suspect. In the OCME study population second to seventh costal cartilage ossification was scored using McCormick's (1980) template from 0 to 4+. As shown in Figure 58 ossification rates tend to follow the same pattern as described by McCormick with a general trend towards increasing amounts with age but with some individuals of both sexes displaying light mineralization at ages over 60 years. In McCormick and Stewart's 1988 study on age related changes they found that peristernal, rib-end, and central ossification increased with age at different rates. Chi-square measures are run on the second to seventh costal cartilage ossification data and results indicate no significant difference between the sexes in this study population (χ^2 =10.391; df=8; p=0.239).

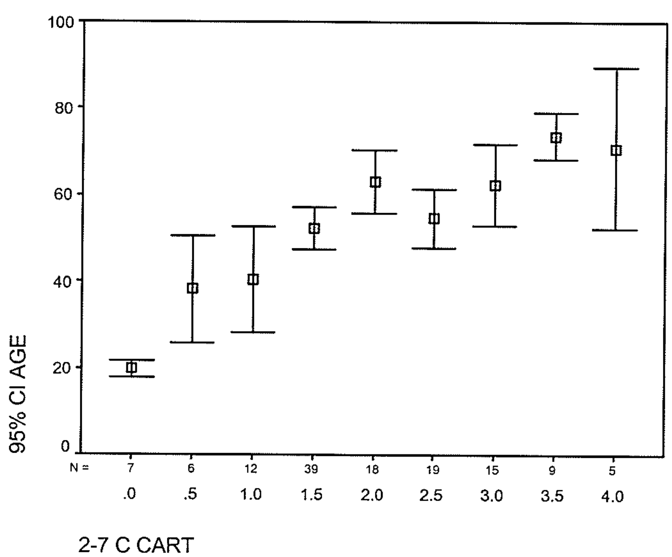


Figure 58: OCME Sample Error Bar Graph 2nd to 7th Costal Cartilage (Both Sexes)

An ANOVA is run on the sample (undifferentiated as to sex) to determine if there are significant differences with respect to second to seventh costal cartilage changes and age (Tables 38).

Table 38: OCME Sample ANOVA 2nd to 7th Costal Cartilage Changes and Age

ANOVA

Age

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	19468.976	8	2433.622	11.454	.000
Within Groups	25707.955	121	212.462		
Total	45176.931	129			

ANOVA results indicate a significant difference with age in second to seventh costal cartilage ossification rates (Table 38). Post hoc analysis shows that the overall trend of this feature is to display the greatest significant differences between earlier stages with distinctions tapering out among the higher stages. After stage 2.0 the stages are not as dissimilar from the higher scores or from those immediately next to them, namely stages 2.5, 3.0, 3.5, and 4.0.

Costo-Manubrial Border Changes

McCormick and Stewart (1988) found a smooth costo-manubrial border to indicate an age less than 25 years, slightly irregular 25 to 35 years, and distinctly irregular over 35 years of age. Using the OCME sample box plots are generated of each sex to note the degree of overlap between the stages (Figures 59 and 60).

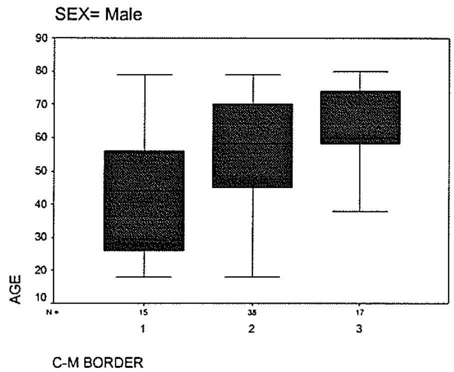


Figure 59: OCME Sample Male Costo-Manubrial Border Changes

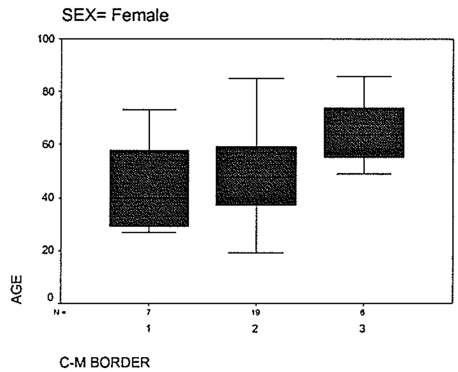


Figure 60: OCME Sample Female Costo-Manubrial Border Changes

There is a great deal of overlap between all stages in both sexes (Figures 59 and 60). Chi-square measures test the OCME data on costo-manubrial border changes to determine if there are any significant differences between the sexes as the box plots are extremely similar.

There is no significant difference between male and female costo-manubrial border changes (χ^2 =0.402; df=2; p=0.818). As there is no significant difference between the sexes with regards to this analysis future testing will be done undifferentiated as to sex. An error bar graph shows a great deal of overlap between the stages however, the means are quite distinct (Figure 61).

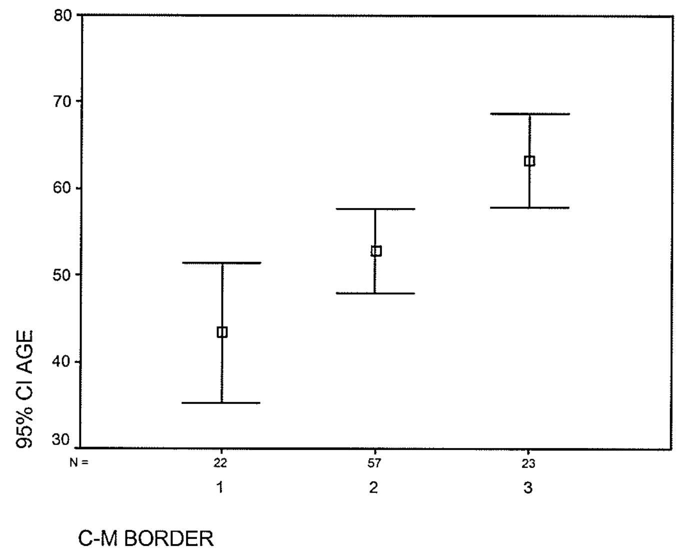


Figure 61: OCME Sample Error Bar Graph Costo-Manubrial Border Changes

A General Linear Model (GLM) (Table 39) shows significant differences in age between each group and age.

Table 39: OCME Sample GLM Test of Costo-Manubrial Border Changes

Tests of Between-Subjects Effects

Dependent Variable: AGE

Source	Type II Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4464.940[a]	2	2232.470	7.379	.001
Intercept	287897.657	1	287897.657	951.636	.000
V37	4464.940	2	2232.470	7.379	.001
Error	29950.403	99	302.529		
Total	322313.000	102			
Corrected Total	34415.343	101			

a. R Squared = .130 (Adjusted R Squared = .112)

Rib-End Changes

McCormick and Stewart (1988) found the sternal rib end to become prominently flared beginning in the 40-year age group with an increase in depth of depression of the rib end as well as irregularity of the rib edges with age. They also found this to be more accentuated in males, especially those with ossification Type E changes. Chi-square measures test if there are any significant differences with respect to sex for rib-end changes within the OCME sample.

There is no significant difference between males and females with respect to rib end changes (χ^2 =5.379; df=2; p=0.068). Future analysis will be done with no differentiation as to sex. An error graph is generated to note the position of the means and degree of overlap of the stages (Figure 62).

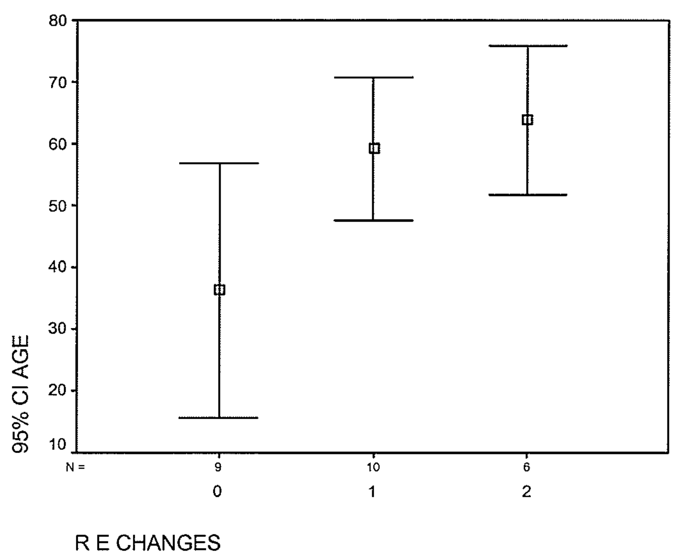


Figure 62: OCME Sample Error Bar Graph Rib-End Changes

The means are clearly separated between stages one with two and three however, there is a great deal of overlap and the means of two and three are very similar. A General Linear Model (GLM) test is run to determine if there are significant differences between the stages with age (Table 40).

Table 40: OCME Sample GLM Test of Rib-End Changes

Tests of Between-Subjects Effects

Dependent Variable: AGE

Source	Type II Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3598.971[a]	2	1799.486	4.551	.022
Intercept	67704.040	1	67704.040	171.245	.000
V38	3598.971	2	1799.486	4.551	.022
Error	8697.989	22	395.363		
Total	80001.000	25			
Corrected Total	12296.960	24			

a. R Squared = .293 (Adjusted R Squared = .228)

Results indicate significant differences in age between each rib-end stage and age (Table 40). Post hoc tests reveal significant differences only between stage zero and one (p=0.020) and zero and two (p =0.015).

Osteoporotic Changes

McCormick and Stewart (1988) found densely packed trabeculation in the sternum and rib ends to be typical in the younger age groups within their sample (not specific as to which groups). They found significant changes to occur frequently in the rib ends of females in the late 30's and in the early 40's for males, progressing to the sternum in the

40's for females and the 50's for males. They do not supply definitive data for these changes. Bar graphs are generated with respect to the OCME sample and osteoporotic changes to determine degree of overlap between stages (Figures 63 and 64).

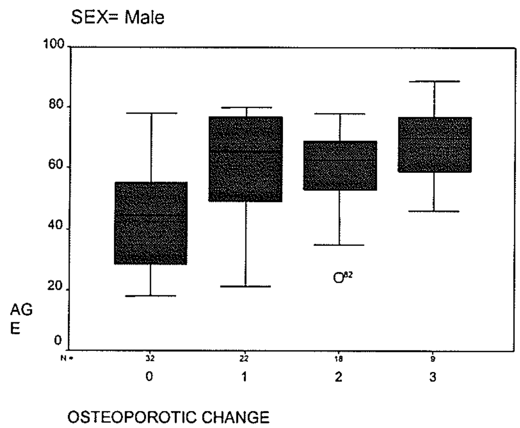


Figure 63: OCME Sample Male Osteoporotic Changes

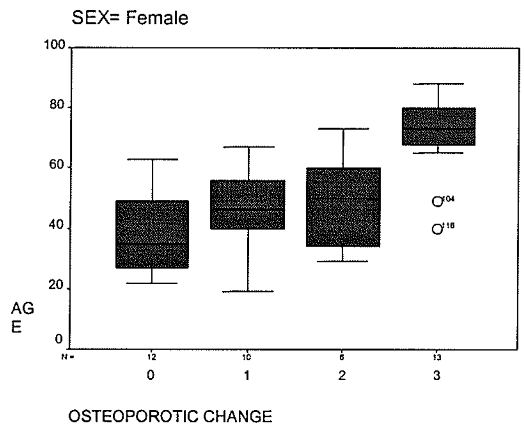


Figure 64: OCME Sample Female Osteoporotic Changes

There appears to be differences between male and female stages as seen in Figures 63 and 64. There is a general trend for increase in osteoporotic score with increasing age in both sexes, however, there is more of a separation between stages in the female sample. The female sample also shows two distinct outliers in the stage three categories while males have one distinct outlier in the stage two categories. All stages except female stage three show some degree of overlap. Chi-square measures test to determine if there are any significant differences between the sexes.

There is a significant difference between the sexes with respect to osteoporotic change (χ^2=8.071; df=3; p=0.045) thus future analysis will be done differentiated as to sex. An ANOVA (Table 41) shows significant differences in age with osteoporotic change and age for both males and females (p<0.001).

Table 41: OCME Sample ANOVA Test for Osteoporotic Changes

ANOVA

Age

Sex		Sum of Squares	df	Mean Square	F	Sig.
Male	Between Groups	7821.317	3	2607.106	9.737	.000
	Within Groups	20616.239	77	267.743		
	Total	28437.556	80			
Female	Between Groups	7370.963	3	2456.988	12.301	.000
	Within Groups	7390.256	37	199.737		
	Total	14761.220	40			

Post hoc tests show no significant differences between all stages in the male sample except with zero and all others (p= <0.001) indicating only significance between absence of change and all levels of change. The female sample shows significant differences between stage three and all others. This would indicate only very advanced female demineralization is significant in this sample with respect to age (p = <0.004).

Xyphoid Ossification

McCormick and Stewart (1988) found the xyphoid process to show the first evidence of ossification in males of their mid-teens, but this was variable and not customary until their late teens. Complete or largely complete ossification was rare until the late 20's in both sexes and fusion with the sternum sometimes absent even in the very aged individuals. A box graph is generated to compare means and overlap of the stages within the OCME sample (Figure 65).

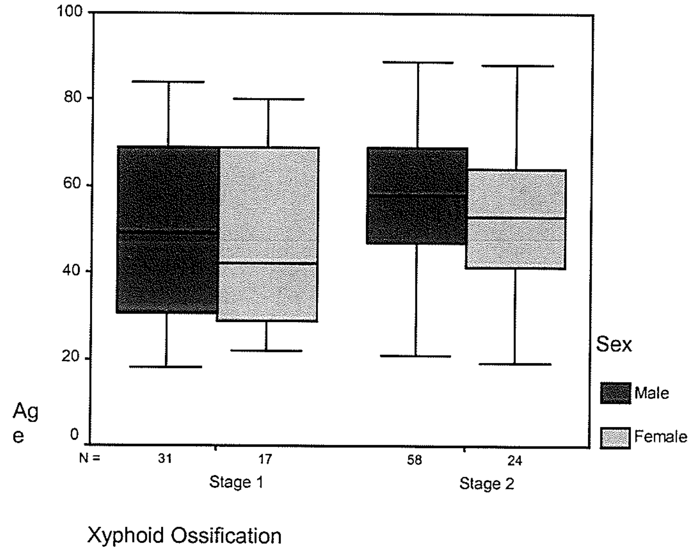


Figure 65: OCME Sample Box Plot Xyphoid Ossification Stage and Age

Figure 65 shows an extreme amount of overlap between the stages and the sexes with respect to xyphoid ossification. There is also no stage zero present. Chi-square measures are done on this sample population to test if ossification of the xyphoid is significantly different between the sexes.

There are no significant differences between xyphoid ossification with respect to sex (χ^2=0.530; df=1; p=0.467). As there are only two groups in this analysis and the overlap of stages is so great with respect to age no further testing will be done on this feature with respect to age determination.

Multiple Variables

Using only the three variables that were significant with respect to age in the OCME analysis, second to seventh Costal Cartilage Changes; Costo-Manubrial Border Changes;

and Osteoporotic Changes, a Generalized Linear Model (GLM) was run to determine which variables contributed best to the model with respect to age significant changes (Table 42).

Table 42: OCME Sample GLM Test for Significance of Variables to True Age

Tests of Between-Subjects Effects

Source	Type II Sum of Squares	df	Mean Square	F	Sig.
Corrected Model					
Intercept	272473.000	1	272473.000	1470.517	.000
2nd to 7th Costal ca	7990.784	8	998.848	5.391	.000
Osteoporotic	2867.875	3	955.958	5.159	.003
Costo-manubrial	270.254	2	135.127	.729	.485
Error	15379.124	83	185.291		
Total	306469.000	97			
Corrected Total	33996.000	96			

a. R Squared = .548 (Adjusted R Squared

Variables second to seventh costal cartilage changes and osteoporotic changes are significant different with respect to increasing age (Table 42). An ANOVA test is done using only these two variables and a scatter plot is generated using the predicted value for age against the true age (Figure 66).

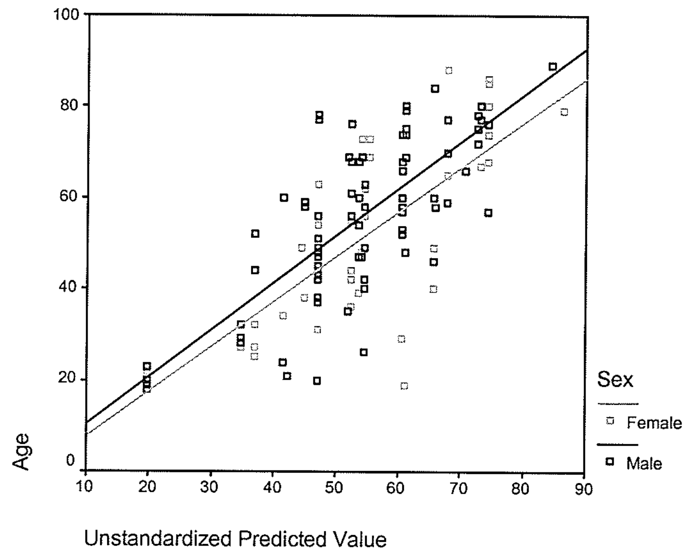


Figure 66: OCME Sample Scatter plot Predicted Value for age using 2nd to 7th Costal Cartilage Changes and Osteoporotic Changes plotted against True Age

The previous three variables are now tested using ANOVA tests but differentiated as to sex (Table 43).

Table 43: OCME Sample ANOVA Test of 2nd to 7th Costal Cartilage Changes, Costo-Manubrial Border Changes, Osteoporotic Changes, Differentiated as to Sex

Tests of Between-Subjects Effects

Dependent Variable: Age

Sex	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Male	Corrected Model	17116.426[a]	13	1316.648	10.171	.000
	Intercept	73967.183	1	73967.183	571.394	.000
	TSCOSTCA	8871.812	8	1108.976	8.567	.000
	CMBORD	335.458	2	167.729	1.296	.283
	OSTEO	1479.161	3	493.054	3.809	.015
	Error	6601.974	51	129.450		
	Total	214665.000	65			
	Corrected Total	23718.400	64			
Female	Corrected Model	6648.672[b]	11	604.425	3.614	.006
	Intercept	38626.586	1	38626.586	230.937	.000
	TSCOSTCA	2433.809	6	405.635	2.425	.063
	CMBORD	1163.625	2	581.812	3.478	.051
	OSTEO	2188.396	3	729.465	4.361	.016
	Error	3345.203	20	167.260		
	Total	91804.000	32			
	Corrected Total	9993.875	31			

a. R Squared = .722 (Adjusted R Squared = .651)

b. R Squared = .665 (Adjusted R Squared = .481)

In this case variables second to seventh costal cartilage and osteoporotic changes were significantly different with respect to increasing age in the male sample (Table 43). Only osteoporotic changes were significant in the female sample but this is due to the small sample size of this population. As such, both second to seventh costal cartilage and osteoporotic variables are tested differentiated as to sex and predicted value for age is generated and plotted on a scatter plot versus true age for the sample (Figure 67).

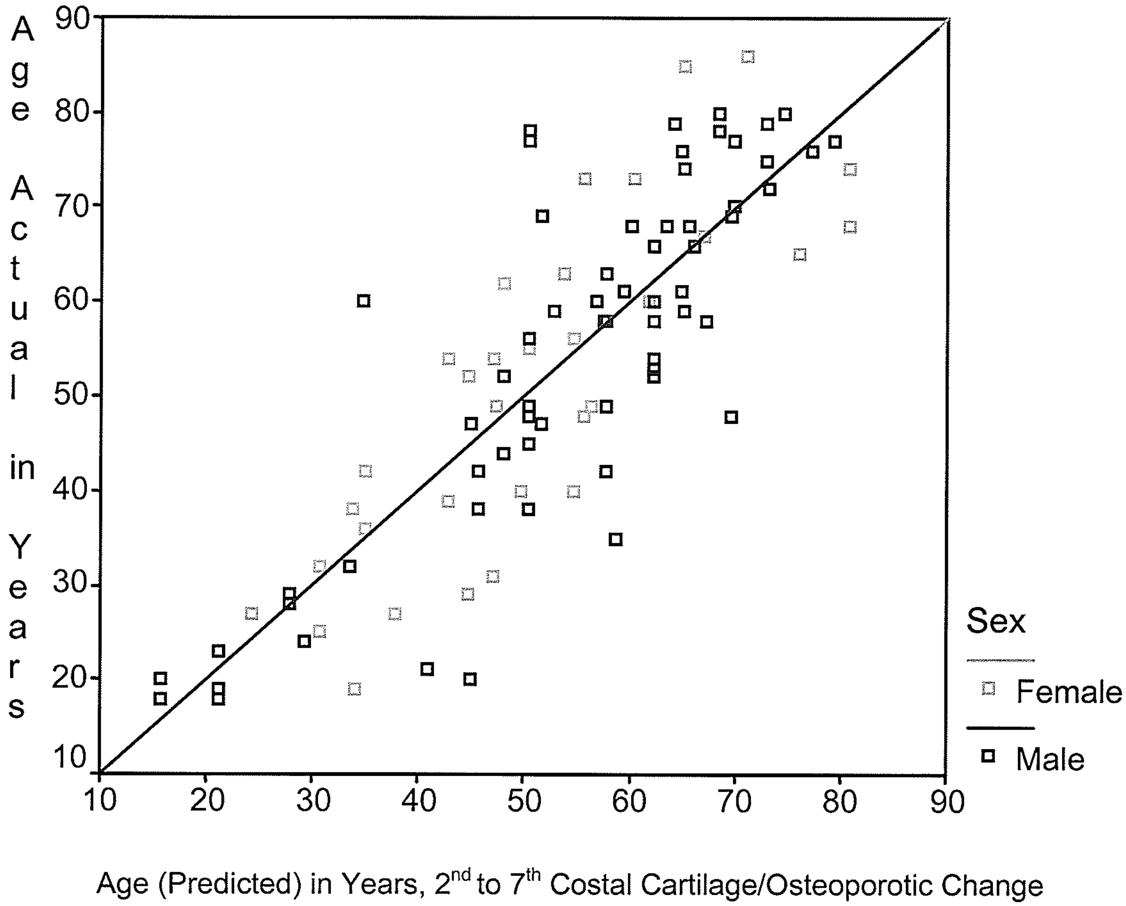


Figure 67: OCME Sample Predicted Value for Age Using 2nd to 7th Costal Cartilage and Osteoporotic Changes, Differentiated as to Sex

As can be seen from the above figure there is a positive relationship between predicted age and true age using variables second to seventh costal cartilage and osteoporotic changes.

CHAPTER 5

DISCUSSION

The human skeleton undergoes morphological and histological changes with age. Both of these are used in the estimation of age at death in the adult skeleton (Dwight, 1890; Stewart and McKern, 1957; Brooks and Suchey, 1990). Morphological aging methods of the adult skeleton focus on processes of remodeling and deterioration and as such the techniques employed to evaluate these changes can be very subjective and subject to high degrees of inter-, and to a lesser extent, intra-observer error. The following sections discuss the results found with respect to the tested methodologies and their incidence of inter- and intra-observer error. Also noted are any results obtained with regard to this type of error from the original studies.

INTER- AND INTRA-OBSERVER ERROR

The researchers selected to test for inter-observer error included the author, a forensic pathologist, a forensic identification officer, and a radiologist. All have had various degrees of exposure to scientific analysis, medical or forensic, with differing concentrations and applications. The forensic pathologist was chosen as one of the main focuses of this study was to determine the utility of radiographic examination of the thoracic area in order to make a quick and less labor intensive determination of sex for use in forensic cases of unknown or presumed identity. In most cases this would utilize the services of a pathologist, at least initially. The police service identification officer was chosen in order to test how well an individual with some forensic training, but no osteological or radiographic experience, would be able to replicate the results of the more medically experienced individuals. And finally, a radiologist was selected to assess if the technique would be as consistent and accurate when tested by a more experienced and critical observer of radiographic material. Kendall's W tests were utilized to examine if significant differences in researcher score selection was present.

To test for intra-observer error the author evaluated the entire set of radiographs 4 weeks after the first examination, utilizing the standard test re-test method of analysis. A graphical representation of the results as well as statistical analysis differentiated as to sex using Chi-square tests was then presented in sequential order of examination.

Barres et al. (1989): Five Thoracic Features

Correspondence of score assessments using Barres et al.'s (1989) method did not improve in the OCME sample when cases were analyzed for results in the same sequence that the four researcher examined them. This may suggest a high learning curve for this type of analysis, a small learning curve in that it was learned and applied successfully early in the analysis, or that the sample was not big enough to generate this type of distinction. As there was no significant increase in accuracy with experience all case were analyzed in this section with respect to increasing age of the individuals being examined.

Barres et al. (1989) assessed between-judge agreement or inter-observer error by comparing the linear correlation coefficient computed for each feature and for each possible couple of judges on the entire set of observations. They state that all the scored features within their sample show good between-judge reproducibility, as these coefficients of correlation are all strongly positive. In the OCME study, inter-observer error was assessed using a Kendall's W test that measures the agreement of ordinal rankings of variables across cases. All results except those for cartilage to sternum attachment changes (CS) were near the value of one indicating high agreement between researchers across cases. Cartilage to Sternum changes rendered a W value of 0.451 (p=0.017), indicating poor agreement between researchers across cases. With this exception, the use of Barres et al.'s template to score radiographic stages of specific features did not differ significantly between researchers for the sub-sample population. Researcher #4, the radiologist, displayed the highest amount of disagreement in ranking with all the examiners which suggests the technique is amenable to individuals with less radiographic experience, as would most likely be the case if it were utilized in the previously mentioned forensic scenario.

While Barres et al. (1989) did test for intra-observer error within their sample they did not use the standard test retest method. Instead they allowed their judges to examine the radiographs once without a template and then again three months later with a template which had been reproduced through the grading of features which the three observers had initially agreed upon as to score. This is not a true test of intra-observer error in that the first evaluation somewhat dictated the latter, however, they did state that the template only generated a small increase in reproducibility and allowed for more ease in scoring.

With respect to intra-observer error in the OCME sample Chi-square results indicate there is a significant difference in bone demineralization scoring between runs in the male sample while the female sample is statistically similar between runs. This is due to the small sample size of the female sample. When the Chi-square analysis is done undifferentiated as to sex the results indicate once again that there is a significant difference between runs. These differing results between runs may indicate the test is too subjective to be used consistently. It may also indicate that after one complete assessment of the radiographs the examiner had a better idea of the degrees of expression of bone demineralization within their sample and what constituted a stage and assessed, subconsciously, to that standard with less emphasis on the Barres et al. template ratings. As well, stage three on the Barres et al. template was not included in their publication allowing for a great deal of subjectivity in this regard.

Manubrium fusion scores also differed by as great as three points between runs in males and by as great as four points in females but there was a definite trend towards consistency with experience in both samples. If the sample is split into three sections, male consistency percentages rise from 51.7% in the first third to 80.0% in both the second and last third of the sample. Female percentages for consistency rates rise from 30.8% in the first third to 71.4% in the middle third to 85.7% in the last third. Males were scored similarly 63 times (70.8%) and females 26 times (63.4%). Chi-square results for both indicate no statistically significant differences between runs in ranking.

Chi-square tests on cartilage to sternum attachment changes and cartilage mineralization changes indicated there were no significant differences between the runs in either sex. Differences between examinations of rib-end changes were hard to assess, as many radiographs did not contain the necessary data. However, within the visible male and female samples scores could differ by as much as five points and there was no increase in consistency over time. Chi-square tests indicated no significant differences between runs in the male and female samples. The numbers for male and female individuals are simple not large enough to show any statistical significance and these results are probably not valid. This coupled with the low reproducibility of this section indicate an unacceptable amount of intra-observer error for this feature.

Barres et al.'s (1989) feature assessment appears to be very subjective and generates a large degree of intra-observer error with respect to bone demineralization stages. This may have been affected by the nature of the test-retest method itself in that the observer subconsciously assessed their entire sample on the first evaluation and ranked it according to their parameters and extremes as opposed to Barres et al. This would not have been noticeable in Barres et al.'s test as they used the initial parameters and degrees of demineralization within their sample to construct a template in order to assess the same sample a second time. Fusion of the manubrium, cartilage to sternum attachment changes, and cartilage mineralization results did not generate any significant degree of intra-observer error between examinations. This may be because of the less subjective nature of these techniques, especially with regards to manubrial fusion. As well, the template may have encompassed all or most of the extremes in variation of the stages, again permitting less subjectivity with regard to ranking these stages. With a cumulative percent of 75.6% of individuals over the age of 40 years, (an age where there is a general increase in ossification) the radiographs may also have been more amenable to higher degrees of precision and consistency in stage assignment due to the increased visibility of said features. Rib-end examination was unfortunately not visible so frequently and hence the sample size so small that any statistical outcome should be considered unsound. In addition, I (as well as the other researchers) found Barres et al.'s template and lack of explicit written instructions to be frequently confusing. One does not know whether to score just the area they have shown on the template or the entire area in question. This is the case with all of the features. For example, was the degree of bone demineralization assessed using the entire sternal area (body and manubrium) or just the segment they have included in their template? Why is the third stage three of bone demineralization omitted? Is it the manubrium that you are asked to score for degree of fusion to the body of the sternum, or the entire sternum? Barres et al. state "fusion of the pieces of the manubrium" and show the entire body of the sternum and the lower edge of the manubrium in four of five stages. For cartilage-to- sternum attachment changes, is it the entire area that is scored or just the two ribs on the left side, and if so which two ribs are they? Why is the first stage for cartilage mineralization also omitted? And, finally, for rib-to-cartilage attachment changes, is it all of the affected ribs or just the one rib they have indicated in their template? Is that the fourth rib or another rib? While it may be easy to assume some of the answers to these questions the researcher should not be required to do so. Clearer and more in depth instructions would have eliminated all or most confusion and a great deal of subjectivity in this analysis.

McCormick et al. (1985): Sex Determination

McCormick et al. (1985) use specific ossification patterns of the costal cartilage and dimensions of the sternum which are evident on radiographs to assign sex to unknown individuals. While some of these ossification patterns are extremely sex-specific, others are not and rely on metric dimensions of the sternum as well as ossification pattern to assist in the determination of sex. For those radiographs with an absence of or very limited ossification metric evaluation was used exclusively to determine sex. They developed an algorithm within this study based on their own experiences that they also utilize to determine sex of these unknown individuals. In this regard they attempt to correlate radiographically visible thoracic costal cartilage patterns with sex through the creation of this empirically derived algorithm using ossification patterns and four metric determinations.

To test for inter-observer error McCormick et al. (1985) had enlisted the services of an individual who had had no training in anthropology or forensic pathology. They had instructed the individual briefly, given him/her an initial draft of their 1985 paper, and asked that the person sex 200 consecutive chest plates. This yielded an accuracy rate of 97%. They make no note of how many of these radiographs were accurately sexed using only pattern assessment, pattern assessment and metric evaluation, just metric data, or the algorithm they had developed. As this percentage is equal to their own accuracy rate when all of their parameters are used, (specifically 4^{th} rib width, sternal length and area, corpus width, ossification pattern, and algorithm), one assumes all parameters were used in the test subjects analysis. If this is correct pattern assessment reproducibility between examiners was basically untested as many of their cases were correctly sexed using metrics alone: (sternal length sex predictive in 67.2% of cases rendering 94.3% accuracy; 4th rib width sex predictive in 71.8% of cases rendering 91.5% accuracy; corpus II and III interspace width sex predictive in 88.3%; sternal area sex predictive in 67.6 % of cases rendering 93.0% accuracy; ossification pattern sex predictive in 79.2% of cases rendering 92.0% accuracy; algorithm sex predictive for 100% of cases rendering 97.1% accuracy). They do not state how many of these individual radiographs overlapped, i.e. metric assessment of one or more parameters was applicable and consistent in sex determination as compared with ossification pattern, or if one technique generated different results from another or which technique had the highest accuracy rate. They do state however, that their algorithm correctly sexed 97.1% of their entire population. This becomes even more important when one goes on to uncover that the algorithm they have developed is based primarily on their own experience and ability to assess thoracic area patterning and is basically just a measure of how good a guess they are able to make with respect to sex determination. This in essence renders the test totally non-replicable on a sample outside their own using different judges with differing levels of experience and bias. Hence, within the present study the algorithmic parameters were not evaluated. In the OCME sample inter-observer error was tested using Kendall's W test and Chi-square analysis.

Ossification pattern selection between researchers for the male sample was very consistently scored, however the female sample was not as constant. Some of the more obscure and least sex-specific patterns, such as Types C and D, or patterns with ossification scores of only one or two, caused the most amount of disagreement between judges. This may indicate ossification pattern reliability between researchers increases directly with amount of ossification patterning which in turn should be positively correlated with age. Thus one would expect to see more consistent results as the sample ages. This was not the case with the male or the female sample. Indeed, ossification pattern and sex determination appears to be more consistent within the younger age groups indicating that the metric assessment is more consistent and accurate in its results within this sub-sample. However, the dismal female sample results can be explained by an initial confusion as to what constituted a Type A pattern and a Type F pattern (this was also the case with the 89 year-old-male individual who was scored as a female Type A by three researchers). Of three female Type A individuals three researchers scored these cases as Type F males. If this initial pattern confusion could have been cleared up initially the success rate for consistency and accurate sex determination in the female sample would have risen greatly. Nineteen out of 24 possible choices of pattern type would have been similar and correct sex determination would have risen to between 66.7% to 83.3% depending on the researcher. However, different pattern selection did not necessarily render a wrong estimate of sex. Metric parameters were used when pattern type was not a strong male or female type (strongly sex-specific types include A, F, and G, and E with an ossification score of 3). Correct sex determination in the weak sex-specific group occurred between 50.0% and 80.0% in the male group and between 33.3% and 100.0% in the female sample. As a whole, correct sex assignment occurred between 50.0% and 78.6% for males and 16.7% and 33.3% for females. If you negate the "Indeterminate" individuals correct sex was determined between 81.8% and 91.7% for males and 20.0% to 80.0% for females.

Kendall's W results indicate there is no significant difference between ossification pattern selection between researchers. Cross-tabulation Chi-square test results also indicate that sex determination using this technique did not generate significantly different results between judges.

Ossification score assessment appears to become more consistent with age of the population. However, this is a bit misleading as older individuals may exhibit different ossification pattern types, such as Types A, F, and G, (patterns frequently found among the more aged population), but similar ossification scores, as Types A, F and G each receive an automatic ossification score of three. Kendall's W test indicates that there are no significant differences between researchers in ranking of ossification scores.

McCormick and et al. (1985) do not test their method for sex determination from thoracic radiographs for intra-observer error. In the OCME sample each individual radiograph was re-examined using the same parameters and guidelines four weeks after the initial evaluation and intra-observer error was tested using Chi square analysis on the sample differentiated as to sex.

Ossification pattern selection in the male sample was fairly consistent differing only 18 out of 89 times. Chi-square analysis did not show any statistically significant differences between evaluations. Most of these differences (12) occurred between the selection of patterns of little or no ossification, namely Type I, or the indeterminate pattern, Types C and D, minimal sex-specific patterning, Type E, minimal to moderate ossification with scores of one or two, Type X, no ossification, and Type Y, parasternal and first rib ossification only. It is significant that the selection of patterns of little or no ossification caused the majority of differences. The criteria for selection of these patterns may need more clarification or expertise to recognize. Type F and Type G were also not consistently selected which may be related to the fact that the Type G pattern is just a more intense or later version of Type F. Female ossification pattern differences were similar as well in that the majority of disagreement occurred between patterns of little ossification (eight) times. Type A and F were also inconsistently chosen, for the previously noted Type A-Type F pattern confusion. Ossification amount was also tested using Chi-square analysis and no significant differences between evaluations for either sex was noted.

Predicted sex from ossification pattern selection and metric parameters were fairly consistent in accuracy rates between evaluations. The number of males mis-classified remained constant at five in both evaluations but the number of indeterminate individuals was less by five in the second evaluation. Female misclassification dropped from six in run one to five in run two but the number of indeterminate individuals remained constant. There was no significant difference indicated between runs with respect to calculated sex.

McCormick and Stewart (1988): Age Estimation

In this 1988 study McCormick and Stewart attempt to correlate the sequence of development of degenerative changes visible on radiographs of the human thoracic area to gross bone and cartilage changes to stages of increasing age. They calculated a linear regression line from a sub-series of 929 cases that were blindly evaluated by one of the researchers who estimated age using parameters set out by the authors in a subsequent study of 863 individuals. They found an average underestimation of 1.5 years occurred with a standard deviation of 8.2 years. However, once again their results are not testable as the equation was based on their experience and ability to estimate age using criteria put forth from one of their earlier studies. They do not test for inter-observer error in this study sample.

In the OCME sample age range was consistent among researchers even when differing patterns were selected, primarily because of the large age span that each pattern could occur in. In total, only six age ranges out of 56 male individuals (10.7%) with respect to all researchers did not encompass the true age of the individual. The female sample was not as accurate with the age range projected not encompassing true age on nine occasions out of a possible 24 (37.5%). Once again however, the results were affected by the mis-classified Type F and A patterns. If these are negated the age range would have encompassed true age 18 times out of 24 or 75.0%.

In conclusion, when the ossification pattern is a weak sex-specific pattern such as Type C, D, or E with ossification scores of one or two, researchers had the most inconsistency in pattern selection. This occurred most frequently among middle-aged individuals. However, accurate sex determination usually occurred in these cases because metric evaluation was also undertaken. Younger individuals with null type patterning as well as older individuals with strongly sex-specific patterning were more consistently scored between researchers. These younger and older individuals were also generally sexed accurately as the null Types also make use of metric analysis and the older individuals have very strong sex-specific patterns. This was not the case however with many of the Type A and F individuals in the OCME sub-sample, as these patterns were initially unclear to all the researchers. Because of the very wide age ranges age estimation was also very consistent, as it was almost impossible not to fall somewhere in between the widely separated values.

McCormick and Stewart (1988) did not test for intra-observer error in their study. Within the OCME sample ossification pattern and age range predictions were fairly consistent between evaluations. In total, only 20 (22.5%) of male individuals in the first evaluation and 22 (24.7%) in the second did not fall into the correct age category. Within the female sample 15 (36.6%) individuals in run one and 11 (26.8%) individuals in run two were not placed in the appropriate age range. Once again, a partial reason that the female results were less accurate lies in the fact that Types A and F were more confusing to the researcher and harder to differentiate in the first evaluation than they were in the second. There are no great differences in age range selection between evaluations.

Ossification Features

First Costal Cartilage

First costal cartilage ossification rates among male and female individuals were not visible to researchers in the majority of radiographs thus no significant analysis with respect to this feature and inter-observer error could be attempted.

With respect to intra-observer error first costal cartilage ossification rates among male and female individuals were also not visible in the majority of radiographs. Those that could be tested were assessed using Chi-square measures that indicated there were significant differences between evaluations with respect to the male sample. The female sample was not analyzed due to its small sample size.

Second to Seventh Costal Cartilage

With respect to inter-observer error ossification of the second to seventh costal cartilage for both the male and female sub-sample generated complete agreement between researchers on two occasions. This occurred at both extremes of the ranking system, the complete absence of ossification and the highest score-able amount of ossification. This is to be expected in cases with a total lack of ossification, however the most extreme cases were generally not consistently scored between judges. The most consistency in score assessment occurred in the older age groups in both sexes. Kendall's W statistics generate results which indicate score assessment between researchers is not significantly different between researchers. Chi-square measures with respect to intra-observer error tests indicated no significant differences between runs in either sex for second to seventh costal cartilage changes.

Costo-Manubrial Border Changes

With respect to inter-observer error within both sex sub-groups most researchers found the costo-manubrial area to be frequently non-scoreable thus, the sample size was smaller than usual. However, Kendall's W statistics indicate there were no statistically significant differences between researchers. Intra-observer error Chi-square measures for costo-manubrial border changes also did not indicate any significant differences between the two evaluations.

Rib-End Changes

Rib–end changes were for the most part not visible within the inter-observer error sub-sample and when they were they were they frequently did not display any appreciable change to researchers. Kendall's W results indicate there are no significant differences between researchers in judging this feature, but because of the small sample size these results should be treated cautiously. Lack of visible rib-ends was also the case within the entire sample and Chi-square measures indicated a significant difference between evaluations with respect to intra-observer error. However, once again these results should be used cautiously due to the small sample size with respect to this feature.

Osteoporotic Changes

While Kendall's W statistics render results that indicate there are no significant differences between observers with respect to osteoporotic change there appears to be a great deal of subjectivity in score assessment between judges with this feature, except in cases of extreme change. At times the differences are greater than two points. This may be related to the fact that of all the features analyzed in this section, this is the only one that does not have a template with which to compare stages with but makes use of the entire sub-sample as guidelines for scoring. As such, it may be even more subjective in nature than the other exercises. With respect to intra-observer error male and female osteoporotic changes were scored differently between evaluations almost half of the time (44.6%). However, most of this variation was of only one point and Chi-square measures indicated no significant differences between the runs.

Xyphoid Ossification

With respect to inter-observer error Kendall's W test results indicate no significant differences between judges. However, the extent of xyphoid ossification is debatable among some researchers, especially when partial or complete ossification is represented.

While this type of analysis may initially appear to be quite straight forward, either there is no ossification, some, or complete, it appears there may have been an error in communication. After a review of the 20 radiographs it appears that some individuals were scoring whether or not the xyphoid was indeed fused to the body of the sternum as well as, or in spite of, being partially or totally ossified. As fusion may never occur within an individual and is variable with respect to age this may have affected the results somewhat and statistical outcomes should be treated cautiously.

Xyphoid ossification results are the most consistently scored features in tests of intra-observer error with only two male (97.8%) individuals differing and one female (97.6%) in both evaluations. Chi-square measures indicate no significant difference between runs. To this researcher this feature was one of the least subjective to score, i.e., the xyphoid was either not present, partially ossified or completely ossified, hence the high degree of consistency.

REPLICABILITY AND ACCURACY

Barres et al. (1989): Five Thoracic Features

Barres et al.'s (1989) study presented their method for estimating age at death using quantitation of radiographic features visible on thoracic radiographs. They have created a regression equation that they found able to estimate age within +/- 8.4 years. As previously noted there are difficulties utilizing Barres et al.'s methodology in that instructions are at times vague and templates are incomplete which makes replication of their techniques problematic on occasion, but overall the basic methods are quite simple to follow and recreate.

Barres et al. (1989) found that of the features that they were evaluating, the coefficients of correlation between true age and a given feature varied between judges but were consistently ranked in the same order for the three strongest coefficients: cartilage-to-sternum attachment changes, rib-to-cartilage attachment changes, and sternal fusion. Age and bone demineralization and cartilage mineralization were the weakest whoever the judge in their male sample. Their female sample generated the opposite results with bone demineralization and cartilage mineralization the two best predictors, however they have noted the smaller female sample size and higher age may be affecting these results. Within the OCME sample only the author's results for the five variables were tested for ranking of correlation coefficient. Like Barres et al.'s results male bone demineralization displayed a minimal to moderate correlation with age but fusion of the manubrium, one of their most positive correlations, was in the OCME male sample the lowest or least positively correlated to age. Cartilage-to-sternum and rib-end changes were also positively ranked like the Barres et al. data but cartilage mineralization only moderately so. For females bone demineralization was ranked highest, similar to Barres et al.'s results, followed by fusion of the manubrium, rib-end-changes, cartilage-to-sternum attachment changes and cartilage mineralization. The latter three displayed only minimally positive correlations to age. Unlike the Barres et al. sample however, the mean age in the OCME sub-sample is quite similar between the sexes; males 48.8 years, females 47.1 years, but the male sample contained 29 individuals while the female sample only 11.

Barres et al's (1989) regression equation was tested against the OCME sample to determine how accurate it would be at predicting age of another study population. The results indicated it is not a good model for predicting age in the OCME sample (df=39; SE=14.227; 95% c.i. = 2.997,12.168; p=0.002). The scatter plot of Barres et al. predicted age and the OCME regression equation predicted age plotted against true age showed a positive correlation both. However, Barres et al. had frequent and widely scattered outliers while the OCME plot was more tightly fitted about the true age line. Unfortunately, the sub-sample was too small to hold a group back to test the accuracy of the OCME regression equation in aging unknown individuals.

Barres' et al. (1989) like McCormick (1980) found a positive correlation with bone demineralization and age for both males and females. The OCME data shows the same tendency but with a higher correlation of bone demineralization and age in the female sample than in the male. This may be related in someway to the tendency for females to develop and exhibit osteoporotic changes sooner and more intensely than males of similar age. This is especially interesting here in that males outnumber females almost three to one and are slightly older in this sub-sample. Barres et al. also noted a high degree of correlation with rib-end changes among males of increasing age that supported results published by Iscan et al. (1984). This is also the case with the OCME sample male rib-end changes. Female rib-end changes are not significant with respect to age in this sample, however, this may be due in part to the small sample size tested here. If Chi squared measures are done on the two sexes together, the correlation coefficient is still moderately high at 0.677 and the p value is significant.

Sternal Metrical Assessment and Sex Predictive Value

Numerous investigators have used the sternal area and its metric dimensions as aids in the determination of sex. McCormick et al cite Dwight, (1881; 1890); Paterson, (1904); Pons, (1955); Ashley, (1956); Stewart, (1979), Jit et al., (1980); and Stewart and McCormick, (1983) as some of the individuals who have used using sternal (manubrium and body) length as a useful sex predictor. All of these studies dealt with different population bases and had different limits for male and female ranges. Accuracy rates ranged from 89% (Pons, 1955) to 76.7% for males and 80.4% for females of an European population; 77.6% for males and 84.6% for females of an African population (Ashley, 1956) to 72.12% for males and 62.5% for females of a North Indian population (Jit et al., 1980). In Stewart and McCormicks' 1983 study on sex and sternal length they found sex predictive values of 0.95, 0.90, and 0.80 for a study population of 617 individuals. The range of 143 to 157 mm had a predictive value that could be less than 80% accurate. When they combined sternal length with ossification pattern they were able to sex 85% of all adults. Over all, 84.4% of their 617 cases were correctly sexed. Mahakkanukrauh (2001) studied 260 Thai sterna (174 male and 86 female) and found only the length of the body of the sternum to be sex predictive. She sexed 90.8% of males and 40.7% of females with an accuracy rate of 74.2%. This is also probably a fairy homogenous study population. In McCormick et al's 1985 study they combine five sternal metric parameters with sex-specific ossification patterns of the costal cartilage to determine sex. However, they generate quite accurate results with sternal measurements alone as previously noted. Within the OCME study sample sternal assessment is also quite accurate, alone, and coupled with sex-specific ossification patterns. While McCormick et al. (1988) state that sternal length, 4th rib width, and sternal area when used alone are the stronger sex predictors of the five metric parameters, the OCME data indicates that if 4th rib width and sternal area are used together to predict sex they are able to sex 78.5% of the study population with accuracy rates of 95.8% for males and 90.3% for females. This is on a very heterogenous population and is consistent with success rates of other adult macroscopic sexing methods (apart from the os coxae and skull) such as Iscan and Miller-Shaivitz's (1984) method for sexing the femur and tibia (86% to 94% accurate depending on population affinity and element used), and Stewart's (1979) results for the scapula (87%) and vertical head diameter of the humerus (91%).

McCormick et al. (1985): Sex Determination

When ossification pattern alone was used to sex the OCME population the accuracy rate was not especially high. While it was fairly respectable (correct sexing was achieved in 35 of 39 cases or 89.8%), McCormick et al., (1985) achieved accurate sexing at a rate of 92.0% on 897 individuals. The number of individuals in the OCME sample who could be sexed using costal cartilage ossification pattern alone was quite low, only 39 (30.0%) of the 130 cases. Using ossification pattern and metric parameters, correct sexing was only determined 46 times (50.5%) out of 91 individuals. This is partially because the gray area when using McCormick et al.'s criteria is so large that indeterminate sex is predicted at almost the same frequency, as a determination of sex is, in this case 39 times (42.9%). Inaccurate sexing occurred six times (6.6%). A large number of these indeterminate cases are created as McCormick et al. have used manubrial length to separate males from females in Type I and weak male/female types (1+, 2+ female patterning or 1+ male patterning) and weak male/female types (1+, 2+ male or 1+ female patterning) instead of their more accurate sex-predictive measurements such as sternal area or 4th rib width. As mentioned previously, McCormick et al.'s algorithm was not tested as it was created reflecting the sex determination capabilities borne through the experiences of its creators.

McCormick et al (1985) found sex-specific patterning to increase with age in their sample by approximately 50% presence, starting in the 20 to 25 year age group and increasing to 93% by and after the age of 60 years. In the OCME sample this increase in sex-specific patterning with age is also apparent, albeit on a smaller scale. While rare, sex-specific patterning is present as early as 19 years in a female who displays a Type B pattern with 3+ ossification. The earliest sex-specific patterning in the male sample is seen in a 20-year-old male who displays a Type H pattern. As per McCormick et al's data however, sex-specific ossification is not prevalent until after the age of 25 years in both sexes and of greatest frequency after the age of 30 years (Figures 68 and 69).

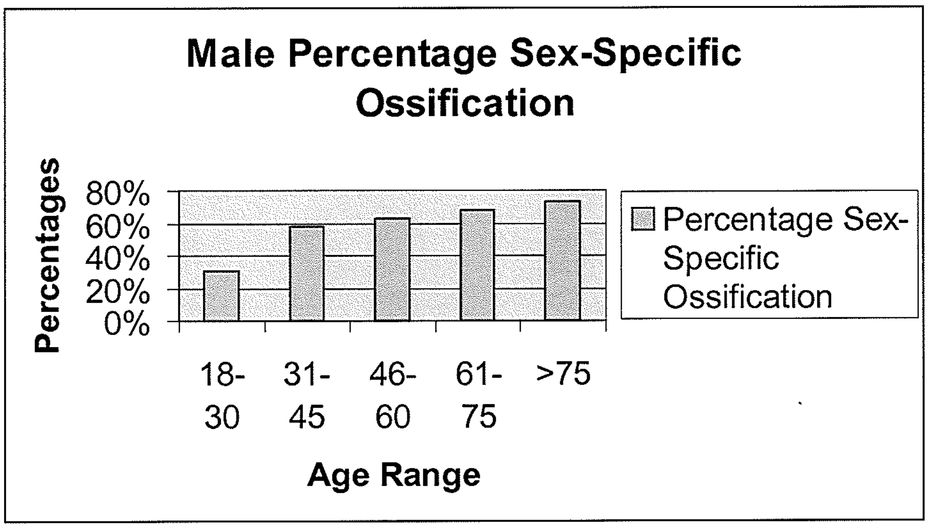


Figure 68: Male Sex-Specific Ossification Patterns

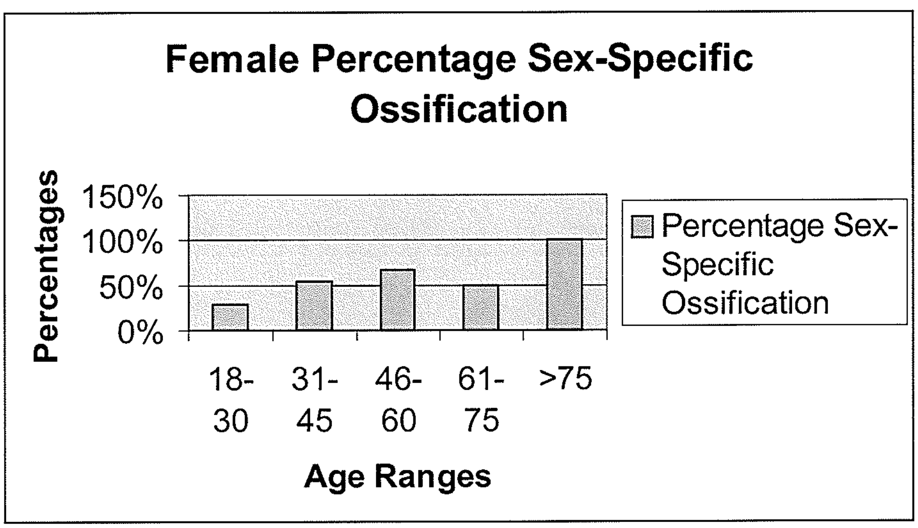


Figure 69: Female Sex-Specific Ossification Pattern Frequency

Similar to McCormick and Stewart's 1983 study ossification pattern in the OCME sample was also distinctly different between the sexes. Males exhibited Type E patterns on 39 occasions (females seven) and had four Type F patterns and seven Type G patterns. Both very sex-specific male type ossification patterns. A Type F pattern was noted in two females but this is attributed to the initial Type A-Type F confusion. Taking this into account Type A appeared at a frequency of 12.2% within the OCME sample, similar to McCormick et al's findings of 15% frequency rate of type A pattern in their 1985 study population. Typical female patterns, or Type A and B were noted three and five times respectively. Type A was noted once in a male individual, again because of the Type F-Type A confusion. All of these patterns tended to occur in late middle age or after at least the age of 40 years, except for the 19-year-old female with Type B3+. Male ossification also tended to exhibit linear patterning (as seen in the predominance of the Type E, and later Type F and G patterns) and female the central type ossification (as noted in the Type A and B patterns). Male ossification tended to be denser as found in the number of Type E3+ patterns and Types F and G which again, tended to occur in late middle age, or after the age of 40 to 45 years. While female sex-specific ossification did occur as early as 19 years of age and Type C as early as 26 to 30 years, the sample size is too small to say that female ossification was resoundingly earlier than males, although the indications are that this may be the trend. Unlike McCormick et al's 1985 findings, there was no significant difference between the sexes with respect to ossification score in the OCME sample. This may be due to the sample size or to a particular behaviour of this sample.

McCormick and Stewart (1988): Age Estimation

As previously noted the linear regression line McCormick and Stewart (1988) have created to estimate age is not testable on another sample due to the fact that it was created using their own personal experience and bias. Thus ossification patterns and features were evaluated for their occurrence within specific age ranges, their significance with increasing age, and their utility as predictors of age range alone as well as with other features.

The use of ossification pattern alone in the OCME sample tended to generate very wide age ranges and seemed to be most useful when specific sex-related ossification patterns were present. However, only as a greater than or less than age ranking method. For example, if a female presented with a Type A pattern the individual is greater than 50 years of age. As well, Type G, which was also found only in individuals over the age of 50 years. Both of these results are similar to those found by McCormick and Stewart in 1988. Type X, unlike McCormick and Stewart's results, appears within the OCME sample as late as age 52 years in one male individual. Other ossification patterns have age ranges so variable and wide that the use of their patterning as an estimate of age is of very limited utility, except perhaps as an adjunct to other aging changes.

Ossification score also showed limited utility as an age predictor. Although it was significant as to age the stages that were significant were only one and three and there was a great deal of overlap between stages one and three with stage two. This may be useful in determining ages of younger or older individuals but not as effective with middle-aged adults.

Ossification Features

First Costal Cartilage

First costal cartilage was not visible so frequently within the OCME sample that it was not tested for sex and age significant changes.

Second to Seventh Costal Cartilage

McCormick found in 1980 that second to seventh costal cartilage ossification was a common event among adults and was roughly correlated to age. Every individual he examined over the age of 25 years exhibited at least slight mineralization, some individuals even in their 60's had only minimal amounts. Dense mineralization was uncommon until at least after the age of 50 years. This was also the case in the OCME sample with one 52-year-old male exhibiting no ossification. There was also a tendency for a great deal of overlap between specific stages, with most differences between earlier and later stages, while those immediately next to each other showed little divergence. There was also no distinctive difference between the ossification amount within the male and female sample. As McCormick noted this makes age estimation based only upon these parameters suspect, especially when only minimal ossification is present. This feature, along with ossification pattern, is also best used in concert with other criteria in attempting age estimates.

Costo-Manubrial Border Changes

Costo-manubrial border changes also displayed a great deal of overlap between stages but a general tendency of increasing border irregularity with age. Once again there is no significant difference between the male and female sample but there are significant differences between all three stages. Once again, the morphological changes of this area are too variable within the OCME sample to predict age with any great degree of accuracy but may be used with other features to estimate a range.

Rib-End Changes

Unlike many previous researcher results (Iscan and Loth, 1984; Iscan, 1985; Dupras and Pfeiffer, 1987) rib-end changes in the OCME population do not display any significant differences with respect to sex in the OCME sample. This may be due to the small sample size of this feature as it was unclear on many radiographs, making the already small female population even smaller. As well, the rib-end stages that were visible overlapped to a great extent within the entire sample. Statistical analysis found no significant difference with age or sex in the OCME sample.

Osteoporotic Changes

T-tests indicate a significant difference between the sexes with respect to osteoporotic change. These changes display greater separation between stages in the female than in the male sample with a general trend towards increased demineralization and age in both sexes. However, only the very advanced female demineralization is noted as significant in the OCME sample. This may be due to the small sample size of this population or the result may have been affected by the feminine tendency of experiencing osteoporotic changes earlier and more intensely than males (Urist, 1962; Rubin, 1988). As well, while the earlier stages tend to overlap a great deal in the OCME sample, the female stage three is distinct, suggesting this feature may be utilized in the estimation of a "greater than" age range for female individuals.

Xyphoid Ossification

Xyphoid ossification and fusion rates have been proven to be notoriously unreliable as an age indicator by many investigators (Stewart, 1954; Krogman and Iscan, 1986; McCormick and Stewart, 1988), and generally serve only as a very rough indicator of age range in the majority of cases. This is also the case in the OCME sample with stages one and two almost completely overlapping each other in both sexes making this feature un-testable for it's utility as an aid in age estimation.

Multiple Variables

Second to seventh costal cartilage change, costo-manubrial border change, and osteoporotic change were all shown to be significant with respect to increasing age in the OCME sample. An analysis of variance run to determine which variables contributed best to the model with respect to age significant changes indicated that second to seventh costal cartilage and osteoporotic changes were most valuable and these two were again tested. Results indicated an extremely positive relationship between predicted age and true age using these two variables. Unfortunately, the sample size was too small to hold back a group to test the utility of these features to estimate an age range.

CHAPTER 6

CONCLUSIONS

The purpose of this research was to evaluate methods previously developed for aging and sexing unknown adult individuals using radiographs of the thoracic area. Morphological age changes are the standard methodology for estimating age in the adult skeleton. These consist of processes of bone remodeling and degeneration, both typical and age-related, use-related, sex-specific, and pathological (Meindl and Lovejoy, 1985; Brooks and Suchey, 1990). All of these techniques are highly subjective and generate wide age-ranges, and tend to underestimate the age of older individuals. Aging the adult individual becomes even more difficult when faced with an incomplete body. If only a skull is available, age ranges are notoriously broad and to a great extent unreliable. However, if the pelvis and cranium are available sex determination of an adult individual can be made with 98% accuracy (Krogman and Iscan, 1986). Obviously sex determination is more difficult if presented with only a long bone or some other single element. As well, most methods have been developed for use on dry bone (especially metric assessment) and at the very least require a partially if not totally defleshed body. In the majority of forensic situations, this is not the case. Most individuals requiring a forensic examination to determine at the very least identity, come to the Medical Examiner's office in varying stages of decomposition. Initially it may be a straightforward procedure to initiate identification processes if the body is relatively fresh. In these cases fingerprints, visual confirmation, unique physical characteristics, dental records, or past medical procedures may be used. However, on occasion an individual may be too decomposed to utilize the first three methods. The latter two are also not always available or records may be difficult to locate. While DNA is still the only absolute method for determining sex, it is an expensive and time-consuming procedure, and will not give you an age range. Defleshing an entire body is something most pathology departments do not have the facilities to undertake nor the experience. As well, it is not a pleasant task in itself. Any technique that may facilitate a rapid, simple, and inexpensive determination of sex and estimate of age is thus extremely important in such situations (McCormick et al., 1985; McCormick and Stewart, 1988). As well, this non-intrusive method may be utilized on individuals of historic significance who are not amenable to destructive processes such as defleshing or histological procedures that require bone samples.

In the OCME study, the thoracic area was assessed for age and sex related changes that may be seen on radiographic images. A concentration was placed on the replicability of age and sex determination techniques as illustrated primarily in the studies of, McCormick (1980), McCormick and Stewart (1983, 1988), McCormick et al., (1985), Stewart and McCormick (1983, 1984), and Barres et al. (1989)

Barres et al. (1989) created a regression formula that allowed them to estimate age at death from the quantification of five features visible on radiographs of the thoracic area. They achieved a 95% confidence interval of +/- 17 years. This is similar to results found by Iscan et al (1984) who estimated age of white males utilizing phase analysis of ribs. However, Barres et al. believe their method may be preferable in some instances in that it does not necessitate the special processing of specimens that Iscan's method requires. In the OCME sample, Barres et al.'s template allowed for less subjective score assessment on the part of the four judges than did the osteoporotic feature evaluation, which required the entire OCME sample be used as a representative guideline. Barres et al.'s manubrial fusion rate results were also more consistently scored than were xyphoid fusion assessments between all four judges. Cartilage-to-sternum attachment changes and cartilage mineralization changes were less accurate using Barres at al.'s template than were score assessments using McCormick and Stewart's (1988) ossification pattern templates. This suggests that McCormick and Stewart's study with respect to ossification patterns may be more a detailed and representative study of the entire range of expression with regards to these features. This would be consistent with McCormick and Stewart's much larger sample size (1,965 as opposed to Barres et al.'s 55 individuals). Inter-observer consistency was significantly different with respect only to bone demineralization, which may indicate this may be the most subjective of Barres et al.'s feature assessments. With all features the more extreme cases, those of little or no change or those with the greatest degree of change, displayed the highest degree of uniformity with respect to score ranking among examiners. All of these results indicate, as would be expected, that templates increased inter-observer consistency. As well, as is the case in many gross subjective scoring techniques, the intermediate zones suffered the most from inconsistencies between researchers.

A test of Barres et al.'s (1989) regression formula on the OCME sample found significant differences (df=39; p=0.002) between true age at death and predicted age. However, Barres et al. as well as OCME results found a positive correlation between feature ranking and increasing age at death, indicating the features do exhibit a quantifiable change with increasing age in both samples. Unfortunately, the OCME sample was too small to hold back a test population to test its regression equation with respect to true age estimation.

Using McCormick et al's 1985 ossification pattern methodology inter-observer error was high among researchers in that they often differed in their choice of pattern type in both the male and female OCME samples, but metric analysis generated consistent and accurate sex determination. The study suffered from a Type A-Type F pattern confusion which directly influenced accuracy results within the small inter-observer error sample. However, inter-observer error was not significantly different with respect to ossification pattern selection and sex determination.

OCME sample ossification pattern types were consistent with results found by McCormick et al. (1985) with respect to sex distribution. An accurate determination of sex was generated in 35 of 39 cases or 89.8%, (McCormick et al. achieved accurate sexing at a rate of 92.0% on 897 individuals). However, the number of individuals who could be assessed using this technique was low, only 39 (30.0%) of the 130 cases. A combination of ossification pattern and metric assessment accurately predicted sex 46 times (50.5%) out of 91 individuals. McCormick et al. use manubrial length to determine sex of weakly sex-specific patterned individuals. They did not test this measurement for sex-related significance in the usual manner but justify their use of it as a criteria for determining sex by stating that the individuals sectioned in this way had the expected ossification scores. In essence this is again un-testable because the scores and algorithm they are utilizing have been established through their own experience. This technique, in turn creates a huge gray area and a lot of indeterminate results. If the more accurate and sex-predictive measurements such as sternal area or 4th rib width are used the accuracy rate increases greatly as does the number of individuals who may be assessed with this criteria. A cumulative percent of 94.1 individuals were accurately sexed using sternal area and 4th rib width in the OCME sample.

OCME results are similar to McCormick et al. (1985) in that sex-specific patterning was found in both studies to increase with age. These patterns are also distinctly different between sexes in both studies with the typical male linear marginal subperichondral ossification prevalent in the male sample and typically female central subperichondral ossification prevalent within the female sample (>90% predictive value).

The results of this analysis indicate that, if ossification pattern is present, and it is of a sex-specific type such as the typical female Type A and/or the typical male Type F or G, an accurate determination of sex may be made without using other parameters. However, one must be absolutely clear on the differences between the often initially confusingly similar Type A and Type F patterns, to make that type of judgement. Due to the ease and rapidity of taking sternal measurements such as 4th rib width and sternal area, it would be unwise to not use these as an adjunct to sex determination along with patterning. If the patterning is of a weak sex-specific type or there is little or no ossification, metric assessment alone is required and has been shown within the OCME sample to be extremely accurate. Because of the increase in sex-specific ossification type with age, most notably the aforementioned Types A, F, and G, these may also be more successfully utilized as a greater than indicator of age, i.e., greater than 50 years, as well as a corroborator of sex when coupled with metric assessment.

The similar degrees of ossification over a wide age span during the middle years limits this features utility as a valuable method of age estimation. The occurrence of limited ossification in older individuals and the finding of dense ossification within the OCME sample in relatively young individuals also makes age estimation based on this feature suspect. Age estimation using ossification pattern, while positively correlated to age in some instances, most notably recognizable sex-specific pattern type, generated only very wide age ranges, on par and at times less precise than the wide ranges generated through cranial suture analysis. This technique may be best suited as a corroborative technique or adjunct to other methods.

First costal cartilage ossification was unfortunately not visible so often within the OCME sample that little can be said of it's utility as an age or sex-related indicator. Second to seventh costal cartilage ossification and osteoporotic change however were visible in the majority of cases and results indicate a general trend of increasing ossification correlated with increasing age. The latter more prevalent in the female sample. However, the utility of these techniques is again, like ossification pattern analysis, probably best suited as a corroborative tool to be used with other methods of age estimation.

Costo-manubrial border, rib-end changes, and xyphoid ossification displayed a great deal of stage overlap, limiting their utility as age predictive features. There was a general increase change in the first two features, however, the OCME sample may have been too small, especially with respect to the often non-viewable rib-end changes, to render an accurate determination with respect to these features usefulness in age estimation.

Of the features analyzed in this section only second to seventh costal cartilage ossification, costo-manubrial border, and osteoporotic changes were noted to be significant with respect to age and were tested further. It was found that osteoporotic changes and second to seventh costal cartilage ossification generated an extremely positive relationship between increasing predicted age and true age.

RECOMMENDATIONS

In conclusion, results of this study support the findings of previous researchers (McCormick, 1980; McCormick and Stewart, 1983, 1988; McCormick et al., 1985; Stewart and McCormick, 1983, 1984; Barres et al., 1989) in that the specifically identified features of the thoracic area visible radiographically and tested within the OCME population sample did demonstrate quantifiable changes which can be positively correlated with increasing age. As well, certain features and patterns were found to be significant with respect to sex. Of the features tested bone demineralization, cartilage mineralization, osteoporotic changes, and second to seventh costal cartilage changes were the most successful in terms of significance with respect to age and sex. Future analysis of a larger population base may allow regression equations to be generated which in turn may produce estimates of age ranges for adult individuals with greater precision and less standard error. Cartilage-to-sternum attachment changes, one of the highest correlations with age within the Barres et al. (1989) sample, was only moderately successful in this analysis. This may be due to the sample size or specific behavior of this population itself. As this is also a very active area in terms of growth and aging, future testing on a larger population base would also be indicated with this feature. As would be expected, fusion of the manubrium and xyphoid ossification, both proven to be variable and inconsistent indicators of age in many previous studies, behaved similarly within this sample and offered little to the success of any of the methodologies in terms of age prediction. First costal cartilage ossification, rib-end changes, and rib-to-cartilage attachment changes are also proven areas of extensive growth and age-related modification and may have been useful indicators of age if they would have been visible more often within this sample. Again, these areas would benefit from more analysis.

With respect to ossification pattern analysis and estimate of age and determination of sex, results were quite similar to those found by McCormick at al. (1985), and McCormick and Stewart (1988). However, age ranges were so wide that this technique may best be utilized as a corroborative tool and/or as an indicator of a greater or less than age range. Digital analysis of the amount of costal ossification may enable better predictors of age to be generated in that specific amounts, not discernable or quantifiable by gross examination, may be captured on digital analysis and manipulated accordingly. As well, pattern type may also be a useful determinate of age and sex in future research using digital image analysis, in that pattern selection is at times quite a subjective technique and patterns unseen or unnoted by gross visual examination may be distinguished digitally.

Metric analysis of the sternum was the most successful technique in this study in that it generated very precise determinates of sex using only three very simple and rapidly taken measurements from radiographs of the thoracic area. These are easily taught and reproduced and require little or no special processing of remains, unique equipment, or extensive anthropological knowledge. Future research may include a collaboration of these measurements with digitally evaluated ossification patterns and amounts, as well as feature assessment to increase accuracy rates of sex prediction and perhaps better delineate estimates of age range.

REFERENCES

Aegerter, A.G., and Kirkpatrick, J.A.
1975 ***Orthopedic Diseases.*** W.B. Saunders Co. Philadelphia

Ashley, G.T.
1956 **The human sternum. The influence of sex and age on its measurements.** Journal of Forensic Medicine. Vol. 3. pp. 27-43.

Barres. Denir R., Durigon, Michel, and Paraire, Francois.
1989 **Age Estimation from Quantitation of Features of "Chest Plate" A-Rays.** Journal of Forensic Sciences. Vol. 34. No. 1. pp. 228-233.

Bass, William
1987 ***Human Osteology-A Laboratory and Field Manual***. Missouri Archaeological Society, Columbia MO.

Black, T.K. III
1978 **A new method for assessing the sex of fragmentary skeletal remains in femoral shaft circumference.** American Journal of Physical Anthropology. Vol. 48. pp. 227-231.

Brooks, S.T., and Suchey, J.M.
1990 **Skeletal Age Determination Based on the Os Pubis: A Comparison of the Ascadi-Nemeskeri and Suchey-Brooks Methods**. Human Evolution. Vol. 5. pp. 227-238.

Caffey, J.
1950 ***Pediatric X-ray Diagnosis.*** 2nd Edition. Yearbook Publishers, Chicago, Illinois.

Chilvarquer, I., Katz, J.O., Glassman, D.M., Prihoda, T.J., and Cottone, J.A.
1991 **Comparative Radiographic Study of Human and Animal Long Bone Pattterns.** Journal of Forensic Science. Vol. 32. pp. 145-154.

Dupras, T.L., Pfeiffer, S.K.
1986 **Determination of sex from adult ribs.** Canadian Society of Forensic Sciences Journal. Vol. 29. pp. 221-231.

Dwight, T.
1881 **The sternum as an index of sex and age.** Journal of Anatomy. Vol. 15. pp 327-330.

1890 **The sternum as an index of sex, height, and age**. Journal of Anatomy. Vol. 24. pp. 527-535.

Elkeles, A.
1966 **Sex Differences in Calcification of Costal Cartilages**. Journal of American Geriatric Society. Vol. 14. pp. 456-462.

Epker, B.N., and Frost, H.M.
1965 **A histological evaluation of bone resorption and formation according to the kind of bone surface involved.** Anatomy Record. Vol. 152. No. 2. pp. 129-135.

Evans, K.T., and Knight, B.
1981 ***Forensic Radiology.*** Blackwell Scientific Publications. Oxford, London.

Falconer, B.
1938 **Calcification of Hyaline Cartilage in Man.** Archives of Pathology. Vol. 26. pp. 942-955.

Fazekas, I.G. and Kosa, F.
1978 ***Forensic Fetal Osteology.*** Budapest, Okadeniai Kiado.

Fischer, E.
1955 **Verkaklungsformen de Rippenknorper.** As cited in Determination of Sex by Costal Cartilage Calcification. Navani et al. American Journal of Roentgeneology. Vol. 108. No. 4. pp. 771-774.

1975 As cited in Costochondral ossification and aging in five populations. Semine and Damon. Human Biology. Vol. 47, pp. 101.

Flecker, H.
1932 **Roentgenographic Observations of the Times of Appearance of the Epiphyses and their Fusion with the Diaphyses.** Medical Journal of Australia. Vol. 67. Pp. 118-164.

Frances, C.C., Werle, P.P., and Behm, A.
1939 **The Appearance of Centers of Ossification from Birth to Five Years.** American Journal of Physical Anthropology. Vol. 24. Pp. 273-299.

Fully. G. and Dehouve, A.
1965 **Renseignements apportes dans ls Determination de l'age par l'etude anatomique et radiologique du sternum et des cotes.** As cited in Age Estimation from Quantitation of Features of "Chest Plate" X-Rays. 1988. Denis R. Barres et al.. Journal of Forensic Sciences. Vol. 34. No. 1. pp. 228-233.

Gilbert, B.M.
1973 **Misapplication to Females of the Standard for Aging the Male Os Pubis.** American Journal of Physical Anthropology. Vol. 38. pp. 39-40.

Gilbert, B.M. and Mckern, T.W.
1973 **A Method for Aging the Female Os Pubis.** American Journal of Physical Anthropology. Vol. 38. pp. 31-38.

Greulich, W.W., and Pyle, S. I.
1959 ***Radiographic Atlas of Skeletal Development of the Hand and Wrist.*** Stanford, Illinois. Stanford University Press.

Harris, H.A.
1933 ***Bone Growth in Health and Disease: The Biological principles Underlying the Clinical, Radiological, and Histological Diagnosis of Perversions of Growth and Disease in the Skeleton.*** London Oxford University Press.

Hately, W., Evison, G., and Samuel, E.
1965 **The pattern of ossification in the laryngeal cartilages: a radiological study.** British Journal of Radiology. Vol. 38. p 585.

Hill, A.H.
1939 **Fetal Age Assessment by Centers of Ossification.** American Journal of Physical Anthropology. Vol. 24. pp. 251-272.

Horner, John L.
1949 **Premature Calcification Of The Costal Cartilages: Its Frequent Association With Symptoms Of Non-Organic Origin**. Radiology. Vol. 108. No. 4. pp. 186-193.

Huyssen, C.A.
1924 **Schweiz. Med. Woch.** *In Premature calcification of the costal cartilages.* Horner, 1970. Radiology, 1970. Vol. 108. pp. 186-193.

Iscan, M.Y., and Loth, S.R.
1984 **Metamorphosis at the Sternal Rib End: A New Method to Estimate Age at Death in White Males.** American Journal of Physical Anthropology. Vol. 65. pp. 147-156.

Iscan, M.Y.
1985 **Osteometric analysis of sexual dimorphism in the sternal end of the rib.** Journal of Forensic Sciences. Vol. 30. pp. 1090-1099.

Iscan, M.Y., and Loth, S.R.

1985 **Determination of Age from the Sternal Rib in White Males: A Test of the Phase Method.** Journal of Forensic Sciences. Vol. 31. No. 1. pp. 122-132.

1989 **Osteological Manifestations of Age in the Adult.** In *Reconstruction of Life From the Skeleton.* Alan R. Leiss.

Iscan, M.Y., Loth, S.R., and Wright, R.K.

1984 **Age Estimation from the Rib by Phase analysis: White Males.** Journal of Forensic Sciences. Vol. 29. No 4. pp. 1094-1104.

1985 **Age Estimation from the Rib by Phase Analysis: White Females.** Journal of Forensic Sciences. Vol. 30. No. 3. pp. 853-863.

Iscan, M.Y., and Miller-Shaivitz, P.

1984 **Determination of Sex from the Tibia.** American Journal of Physical Anthropology. Vol. 64. pp. 53-57.

1986 **Sexual dimorphism in the femur and tibia.** In Reichs (ed.) *Forensic Osteology: Advances in the Identification of Human Remains.* Springfield, Illinois.

Jaffe, H.L.

1958 ***Tumours and Tumerous Conditions of Bones and Joints.*** Philadelphia. Lee and Febiger.

Jit, I., Jhingan, V., and Kulkarni, M.

1980 **Sexing the Human Sternum**. American Journal of Physical Anthropology. Vol. 53. pp. 217-224.

Kading, K.

1923 **Roentgenstrahlen.** In *Premature calcification of the costal cartilages.* Horner, Radiology, 1970. Vol. 108. pp. 186-193.

Kelley, M.A.

1978 **Phenice's Visual Sexing Technique for the Os Pubis: A Critique.** American Journal of Physical Anthropology. Vol. 48. pp. 121-122.

Kerr, H.D., and Gillies, C.L.

1944 ***The Urinary Tract, A Handbook of Roentgen Diagnosis.*** Yearbook Publishers. Chicago.

King, J.B.

1939 **Calcification of the costal cartilages.** British Journal of Radiology. Vol. 12. pp 2-12.

Knight, B.
1980 **Forensic Pathology**. In Eckert (editor) ***Introduction to Forensic Sciences.*** Mosby, St. Louis.

Kozielec, Tadeusz
1973 **A Roentgenometric Study of the Process of Ossification of the Human Sternum.** Folia Morphologica. Vol. 32. No. 1. pp. 125-148.

Kreitner, K, F., Schweden, S.J., Riepert, T., Nafe, B., and Thelen, M..
1998 **Bone Age Determination Based on the Study of the Medial Extremity of the Clavicle.** European Radiology. Vol. 8. No. 7. pp. 1116-1122.

Krogman, W.M.
1962 ***The Human Skeleton in Forensic Medicine.*** Springfield, Illinois. Charles C. Thomas.

Krogman, W.M., and Iscan, M.Y.
1986 ***The Human Skeleton in Forensic Medicine.*** Springfield, Illinois. Charles C. Thomas.

Lanzkowsky, P.
1968 **Radiological Features of Iron Deficiency Anemia.** American Journal of Diseases of Children. Vol. 116. pp. 16-29.

Mahakkanukrauh, Pasuk
2001 **Thai Sternum and Sexing**. Journal of the Science Faculty of Chiang Mai University. Vol. 28 (1). pp. 39-43.

Maples, W.R.
1984 **The Identifying Pathology.** In Rathbun and Buikstra (editors) ***Human Identification: Case Studies on Forensic Anthropology.*** Springfield, Illinois.

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

McCormick, W. F., and Stewart, J. H.
1983 **Ossification Patterns of Costal Cartilages as an Indicator of Sex.** Archives of Pathology and Laboratory Medicine. Vol. 107. pp. 206-210.

1988 **Age Related Changes in the Human Plastron: A Roentgenographic and Morphologic Study**. Journal of Forensic Sciences. Vol. 33. No. 1. pp. 100-120.

McCormick, W.F., Stewart, J.H., and Langford, L.A.
1985 **Sex Determination from Chest Plate Roentgenograms.** American Journal of Physical Anthropology. Vol. 68. No. 2. pp. 173-196.

McClave, J.T., and Dietrich, F.H.
1988 ***Statistics.*** Fourth edition. Dellem Publishing, San Francisco.

Meindl, R.S., and Lovejoy, C.O.
1985 **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. pp. 57-66.

Michelson, N.
1934 **The Calcification of the First Costal Cartilage Among Whites and Negroes.** Human Biology. Vol. 6. pp.

Morgan, T.A., and Harris, M.C.
1953 **The Use of X-Rays as an Aid to Medico-legal Identification.** Journal of Forensic Medicine. Vol. 1. pp. 28-38.

Navani, S., Shah, J.R., and Levy, P.S.
1970 **Determination of Sex by Costal Cartilage Calcification.** American Journal of Roentgenology, Radium Therapy and Nuclear Medicine. Vol. 108. No. 4. pp. 771-774

Office of the Chief Medical Examiner. Government of Manitoba, Canada, Department of Justice
2000 ***Office of the Chief Medical Examiner, Annual Review, 2000***, A.T. Balachandra, MBBS, FRCPC, FCAP, Chief Medical Examiner, Winnipeg MB

Ortner, D.J., and Putschar, W.G.J.
1985 ***Identification of pathological conditions in human skeletal remains.*** Washington. Smithsonian Institution Press.

Owsley, D.W., and Mann, R.W.
1990 **Medicolegal case involving a bear paw.** Journal of American Podiatric Medical Association. Vol. 80. No. 11. pp. 623-625.

Paterson, A.M.
1904 ***The Human Sternum.*** Williams and Northgate, London.

Pons, J.
1955 **The sexual diagnosis of isolated bones of the skeleton.** Human Biology. Vol. 27. pp. 12-21.

Purkait, R.
2001 **Measurements of Ulna-A New Method for Determination of Sex.** Journal of Forensic Science. Vol. 46. Pp. 924-927.

Pyle, S.I., and Hoerr, N.L.
1969 ***A Radiographic Standard Reference for the Growing Knee.*** Springfield, Illinois. Charles C. Thomas.

Reichs, K.J.
1986a ***Forensic Osteology: Advances in the Identification of Human Remains.*** Charles C. Thomas, Springfield, Illinois.

1986b **Forensic Implications of Skeletal Pathology: Ancestry.** In Reichs (editor) 1986. *Forensic Osteology: Advances in the Identification of Human Remains.* Charles C. Thomas, Springfield, Illinois.

Rist, E., Gally, L., and Trocme, C.
1928 **L'ossification des cartilages costaux dans l'espece humaine.** As cited in Ossification Patterns of Costal Cartilages as an Indicator of Sex. W. McKormick and J. Stewart. 1983. Archives of Pathology and Laboratory Medicine. Vol. 107.

Rubin, E., and Farber, J.L.
1988 ***Pathology.*** J. B. Lippincott Company. Philadelphia, Pennsylvania.

Sanders, C.F.
1966 **Correspondence: Sexing By Costal Cartilage Calcification**. British Journal of Radiology. Vol. 39. pp. 233-234.

Sassouni, V.
1955 **Roentgenographic cephalometric analysis of cephalo-facio-dental relationships.** Joutnal of Forensic Science Society. Vol. 2. P. 429.

Sedlin, E., Frost, H.M., and Villanueva, A.R.
1953 **Variations in Cross-section Area of Rib Cortex with Age.** Journal of Gerontology. Vol. 18, pp. 9.

Steele, D.G., and Bramblett, C.A.
1988 ***The Anatomy and Biology of the Human Skeleton.*** Texas A and M University Press

Stewart, T.D.
1954 **Metamorphosis of the Joints of the Sternum in Relation to Age Changes in Other Bones.** American Journal of Physical Anthropology. Vol. 12. No. 3. pp. 519-535.

1979 ***Essential of Forensic Anthropology.*** Charles C. Thomas, Springfield Illinois.

Stewart, J.H., and McCormick, W.F.
1983 **The Gender Predictive Value of Sternal Length.** American Journal of Forensic Medicine and Pathology. Vol. 4. pp 217-220.

1984 **A Sex- and Age-Limited Ossification Pattern in Human Costal Cartilages.** Journal of Clinical Pathology. Vol. 81. pp. 765-769.

Stewart, T.D., and McKern, T.W.
1957 **Skeletal Age Changes in Young American Males**. Quartermaster Research and Development Center.

Todd, T.W.
1930 **Age Changes in the Pubic Bone: VIII Roentgenographic Differentiation.** American Journal of Physical Anthropology. Vol. 14. Pp. 255-271.

Trotter, M.
1934 **Synostosis between manubrium and body of the sternum in whites and negroes.** American Journal of Physical Anthropology. Vol. 18. No. 3. pp. 439-442.

Urist, M.R., Zaccalini, P.S., MacDonald, N.S., and Skoog, W.A.
1962 **New approaches to the problem of osteoporosis.** Journal of Bone and Joint Surgery. Vol. 44B. pp. 464-484.

Vastine, J.H., Vastine, M.F., and Arango, O.
1948 **Genetic influence on osseous development with particular reference to deposition of calcium in costal cartilages**. American Journal of Roentgeneology and Radium Therapy. Vol. 59. pp. 213-221.

White, Tim D.
1991 ***Human Osteology***. Academic Press, Inc.

APPENDIX A

The methods used are detailed as follows:

Sex Determination

Measurements (As described in McCormick et al., 1985, figure 27 in Appendix D; table 4, figure 15 in text)

1. **Manubrium-corpus (manubrium-body of the sternum) length.**

- Sternal length is defined as the sum of the manubrium and corpus lengths. The xyphoid process is excluded because of its great variability in size and shape (McKern and Stewart, 1957). The length of the sternum is measured by a vertical line from the most anterior and superior aspect, a point between the jugular and clavicular notches, to the manubriosternal joint. The body of the sternum length is measured by a vertical line extending from the manubriosternal joint to the xyphosternal joint. The total manubrium-corpus length is the sum of the two vertical sublines.

2. **Fourth rib width.**

- This is the transverse diameter measured by a line perpendicular to a tangent to the costal margin and immediately lateral to the costal fossa. Either the right or left rib may be used. If the sides are not identical, the measurement nearer to the gray indecisive zone of 15–16mm 4th rib width should be used.

3. **Corpus sterni (body of the sternum) width midway between costal notches II and III.**

- The minimum width of the corpus sterni is obtained by measuring a horizontal line midway between costal notch II and III. Occasionally sterna have asymmetric notches. In these cases, the separation of vertical lines tangent to the innermost portions of the interspace was measured.

4. **Manubrium-corpus (sternal) area.**

- The sternal area index is defined to give a rough estimate of the area occupied by the manubrium and corpus. It is the product of the manubrium and corpus sterni lengths times the average of the three widths:
    1.) The manubrium width at the first costal notch midpoint.
    2.) The corpus width midway between second and third costal notches.
    3.) The corpus width midway between the fourth and fifth costal notches.

Patterns of costal cartilage ossification. (As described in McCormick, 1980, McCormick and Stewart, 1983, 1988; Stewart and McCormick, 1983, 1984; McCormick et al., 1985; McCormick and Stewart, 1988; figures 2 to 15 in Appendix A; figures 8 to 22 in text).

Female Ossification Patterns:

Ossification Type A: (figures 2 and 3 in Appendix A; Figure 8 in text)

- Consists of centrally placed, smoothly contoured globules of ossification in the central portions of costal cartilages. Can be heavily mineralized.
- Typically these globular foci have smooth, rounded contours which contrast sharply with the surrounding cartilage and are relatively radioluecent.
- Do not involve sterno-chondral junctions or immediately subperichondral cartilage. There are no peripheral linear bands of ossification.
- Never found in females under the age of 50 years. When present in significant amounts diagnostic of elderly females, likely in their 70's.
- Never found in males.

Ossification Type B [or Navani's Type II (central)]: (Figures 3 and 4 in Appendix A; figure 9 in text)

- Consists of pyramidal-shaped central tongues of ossification beginning in the costal fossa. The base of the pyramid is parallel to the costal fossa and the apex points toward the sternum. Ossification can be abundant and may partially obscure this pattern. As well, a "crab-claw" configuration of central costal mineralization is often present.
- Relatively dense sheets of costal cartilage mineralization, non-globular and non-central. Irregular sheets of ossification beginning in the subperichondral location and often marked at the costochondral junction.

- Found in younger individuals than Type A, seen in ages 15 to 79 years but most frequent in ages 30 to 65.

Ossification Type C: (figure 5 in Appendix A; figure 16 in text)

- Central fragmental costal cartilage ossification without the costal fossa ossification pyramids. The foci of ossification in these individuals is often small, irregular, and sharply angular.
- Generally can only be used to assess age as greater than 30 years due to minimal amount of sex-specific patterning but ossification greater than Type X.

Ossification Type D: (figure 6 in Appendix A; figure 17 in text)

- A moderate amount of mineralization is present at both the costal fossa and the articulations of the sternum and costal cartilage. Occasional ossification spurs may extend from the costal fossa along the superior costal cartilage.
- Generally can only be used to assess age as greater than 30 years due to lack of sex-specific patterning but ossification greater than Type X.

Male Ossification Patterns:

Ossification Pattern E: (figures 7 and 8 in Appendix A; figure 18 in text)

- Characterized by heavy ossification of the inferior and superior costal cartilage margin. The articulations of the sternum and costal cartilage are almost always ossified.

- Subperichondral tongues of new bone extending out from the rib ends. Peripheral subperichondral (ie, marginal) linear ossification. Calcification is mainly confined to the upper and lower margins of the costal cartilage.
- The most typical male pattern.
- Of greatest frequency in ages 30 to 80 years but may occur as young as 20 and old as 99 years, although rare.

Ossification Pattern F: (figure 9 in Appendix A; figure 10 in text)

- Resembles "Swiss-cheese" and has sheet-like, centrally located ossification with regularly arranged, small, round, radioluecent defects.
- Noted infrequently in individuals as young as 20 years of age but of greatest frequency in individuals 30 to 65 years of age.

Ossification Pattern G: (figures 10 and 11 in Appendix A; figure 11 in text)

- Consists of truly massive costal cartilage ossification. The articulations of the sternum and costal cartilage are not mineralized.
- A distinctive male pattern seen predominantly in very elderly men.
- Seen infrequently in individuals as young as 55 years but of greatest frequency in individuals over 65 years of age.

Ossification Pattern H: (figure 12 in Appendix A; figure 19 in text)

- Has a finely granular appearance of costal cartilage ossification. The sternal and costal cartilage articulations have no ossification but a fine, vertical line of mineralization that appears at the costal fossa. The granular or "salt and pepper" ossification is found in the lateral two-thirds of the costal cartilage and has a horizontal, linear distribution.

- No age frequency noted.

Non-sex-specific Ossification Patterns:

Indeterminate Pattern: (figure 13 in Appendix A; figure 20 in text)

- Consists of an ossification pattern with both male and female patterning yet without a definite dominance of one sex predictive pattern over the other.
- The ossification configurations are typically combinations of B and C with E or H. Types A, F, and G are not present.
- Ossification may be too extensive for delineation of any type.
- Ossification may be of both marginal and central type, but too mixed for specific determination.
- Scored as greater than 30 years of age as amount of ossification too extensive for Null Pattern Types.

Ossification Patterns X and Y: (figures 14 and 15 in Appendix A, figures 21 and 22 in text)

- Null patterns are seen in young adults, Null Pattern X, and small numbers of older adults of mixed ages with ossification limited to parasternal and first rib cartilage, or Null Pattern Y.
- Ossification is too minimal for determination.

- Type X found in adult individuals from 18 to 30 years of age. Individuals in their early 30's tend to express more ossification amenable to pattern typing.
- Type Y individuals tend to fall within the 20 to 40 year age range as ossification negates Type X assignment but is not extensive enough for pattern assignment.

McCormick, Stewart, and Langford developed an algorithm based on their experience and bias to aid sex estimation. Their five parameters were assigned positive or negative values according to their occurrence in expected ranges. Values will be assigned as follows:

- Types B, C, and E will be assigned a semi-quantitative value of 1 to 3 depending on the amount and type of costal cartilage ossification.
- A 1 value will represent minimal changes marginally assignable to a masculine or feminine type.
- A 2 value will represent recognizable, characteristic patterning in moderate quantities.
- Types A, F, and G will always receive a 3 value as they represent heavy to massive sex specific patterning.

Indeterminate, X, Y, and weak male/female types (1, 2 female patterning or 1 male patterning) will be considered female if the manubrial length is less than 46 mm. All X, Y, indeterminate and weak male/female types (1, 2 male or 1 female) will be considered male if manubrial length is 60 mm or greater.

Type H cases will be considered female if the manubrium-corpus area is less than 4700 mm^2 or if the fourth rib width is less than 15 mm and manubrial length is less than 50 mm.

Type D cases will be assessed sex using estimates of manubrium-corpus length. Less than 152 mm will be considered female and greater than 152 mm will be considered male.

X and Y patterning cases will be considered female if two of the three following criteria are met:

- A manubrium-corpus area less than 5000 mm2.
- A corpus width between the second and third ribs less than 124 mm.
- A fourth rib width less than 15 mm.

Age Determination (as described in McCormick, 1980; Stewart and McCormick, 1984; McCormick and Stewart, 1988).

First costal cartilage: (Figure 16 in Appendix A; table 3, figure 3 in text)

- This ossification pattern and rate is distinct from the lower costal cartilage. It appears to be enveloped in a "bony case" which appears solid on radiographic examination.
- Ossification first makes an appearance in the early 20's as small globular ossifications along the inferior border of the cartilage of the rib end. As the individual aged these enlarge and coalesce, proceeding from the rib end to sternal

end until solid and trabecular. The fusion line is generally not visible by the fifth decade.

- Heavy ossification occurs more rapidly in males, especially Type F males.
- Ossification amount is scored for males and females as 0 (absent) to 4 (complete).

Second through Seventh costal cartilage: (figure 17 in Appendix A; table 3, figure 1 in text)

- Ossification generally occurs in peristernal, rib end, and central locations.
  - Least sex-predictive ossifications occur in the peristernal area.
    - This happens as early as mid-teens increasing with age. By age 35 there is almost always some visible, especially in males.
    - This type of ossification is of moderate frequency in the early to mid 30's in males and late 30's to early 40's in females.
    - It is predominant in frequency in the over 40 age group.
    - It may be massive in amount by age 60 in both sexes.
- Rib end ossification is very sex-predictive assuming several distinct patterns.
    - Sub-perichondral spurs projecting along the upper and lower rib margins are characteristic of males, first appearing as relatively faint ossifications along the inferior border in the late 20's or early 30's and are generally well developed in males over 50 years of age. Typical Type E patterning.
- Central female-type patterns consist of cone shaped central new bone formation arising with its base parallel to the fossae costa and with its apex towards the sternum. A typical Type B pattern. With increased age these may begin to take on a "crab

claw" pattern. In fourth decade of the life the rib end and peristernal areas will take on a trabeculated appearance. Continuation and fusion along the subperichondral area occurs in the fifth decade accompanied with an obliteration of fusion areas by trabeculation.

- 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 are elongated laterally from a broadly ossified insertion are assigned a 3 value.

Typical Female Type Ossification Pattern or Type A: (figures 2 and 3 in Appendix A; figure 8 in text)

- An ossification pattern in the central portion termed Type A has only been found in females over 50 years of age.

Typical Male Ossification Patterns or Types F and G: (figures 9, 10 and 11 in Appendix A; figures 10 and 11 in text)

- An ossification pattern in the central area often continuous with the rib ends is seen in males only. Type F is visible among males in the third decade of life. Solid appearing costal cartilage, probably the end of this stage and termed Type G are limited to men over 65 years of age.

Costal Manubrial border: (figures 18, 19, and 20 in Appendix A; figure 6 in text)

- A smooth border indicates a probable age of less than 25 years, slightly irregular 25 to 35 years, and distinctly irregular over 35 years.

Rib End Changes: (figure 21 in Appendix A; figure 5 in text)

- The sternal ends of the ribs become flared in the 40's with an increase in cup depth and irregularity of the edges with age. This is more evident in males and often seen with subperichondral spurs along the upper and lower rib margins.

Osteoporotic Changes: (figures 22 and 23 in Appendix A; figure 26 in text)

- Dense trabeculation in the sternum and rib ends is typical in younger age groups. Significant changes may occur in the rib ends in the late 30's for females and early 40's for males. These changes may also occur in the sternum in the 40's in females and in the 50's in males.

Ossification of the Xyphoid Process: (figures 24, 25, and 25 in Appendix A; figure 7 in text)

- Radiographic evidence of ossification in males rarely seen before the late 20's with complete or total ossification very uncommon before this age. Fusion with the body of the sternum is sometimes absent past 60 years of age.

Age Estimation from the Quantitation of Features of Thoracic Radiographs (as described by Barres et al., 1989). (figure 1 in Appendix A; figure 2 in text)

- Bone Demineralization 1 (none) to 5 (heavy)

- Fusion of the pieces of the manubrium 1 (unfused) to 5 (completely fused)
- Rib-to-cartilage attachment changes 1 (none) to 5 (heavy)
- Cartilage mineralization 1 (none) to 5 (heavy)
- Cartilage-to-sternum attachment changes 1 (none) to 5 (heavy)

Calculated age will be assessed using the previous criteria as related to specific ossification patterns as previously described in Table 37.

APPENDIX B

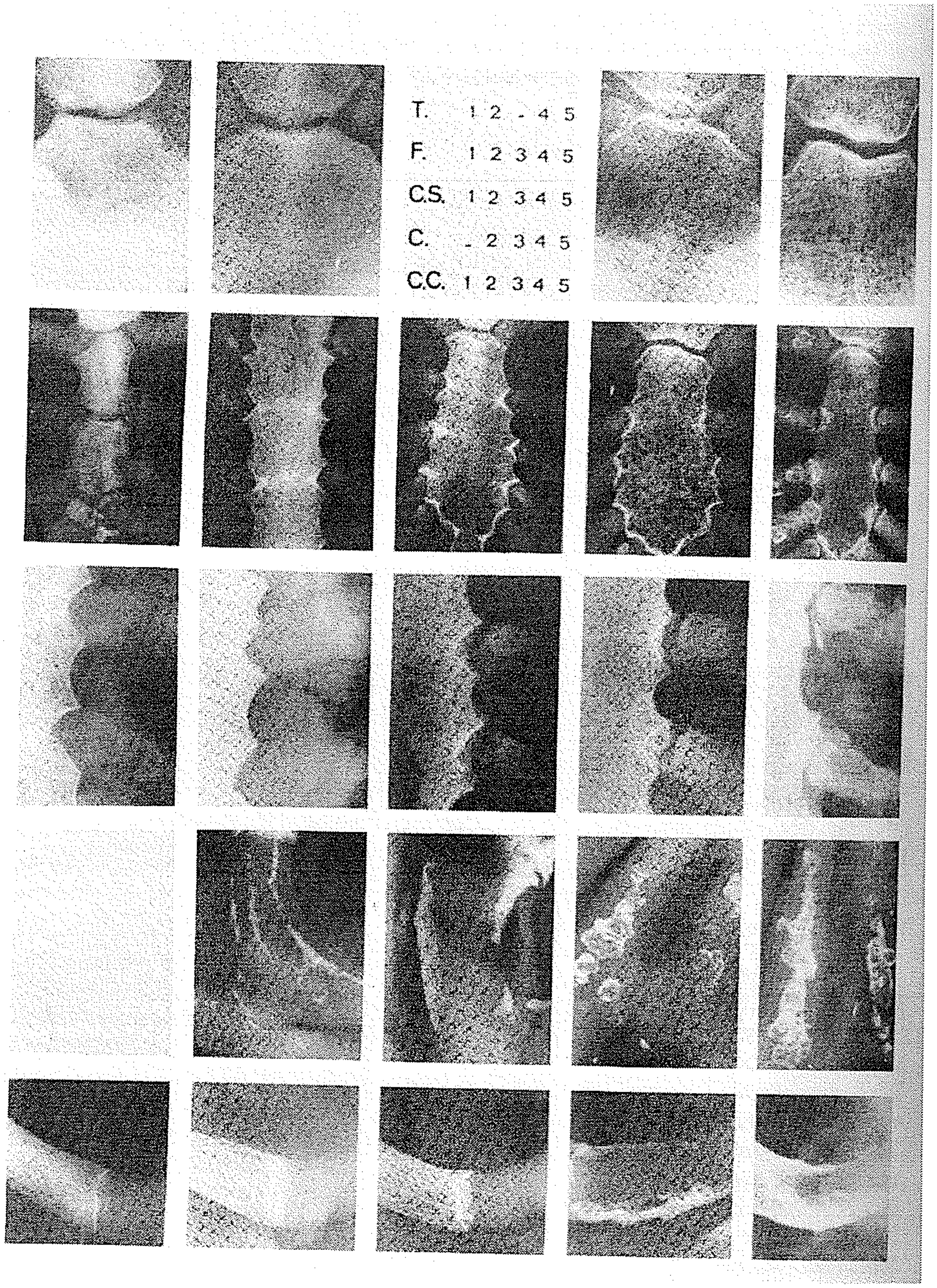
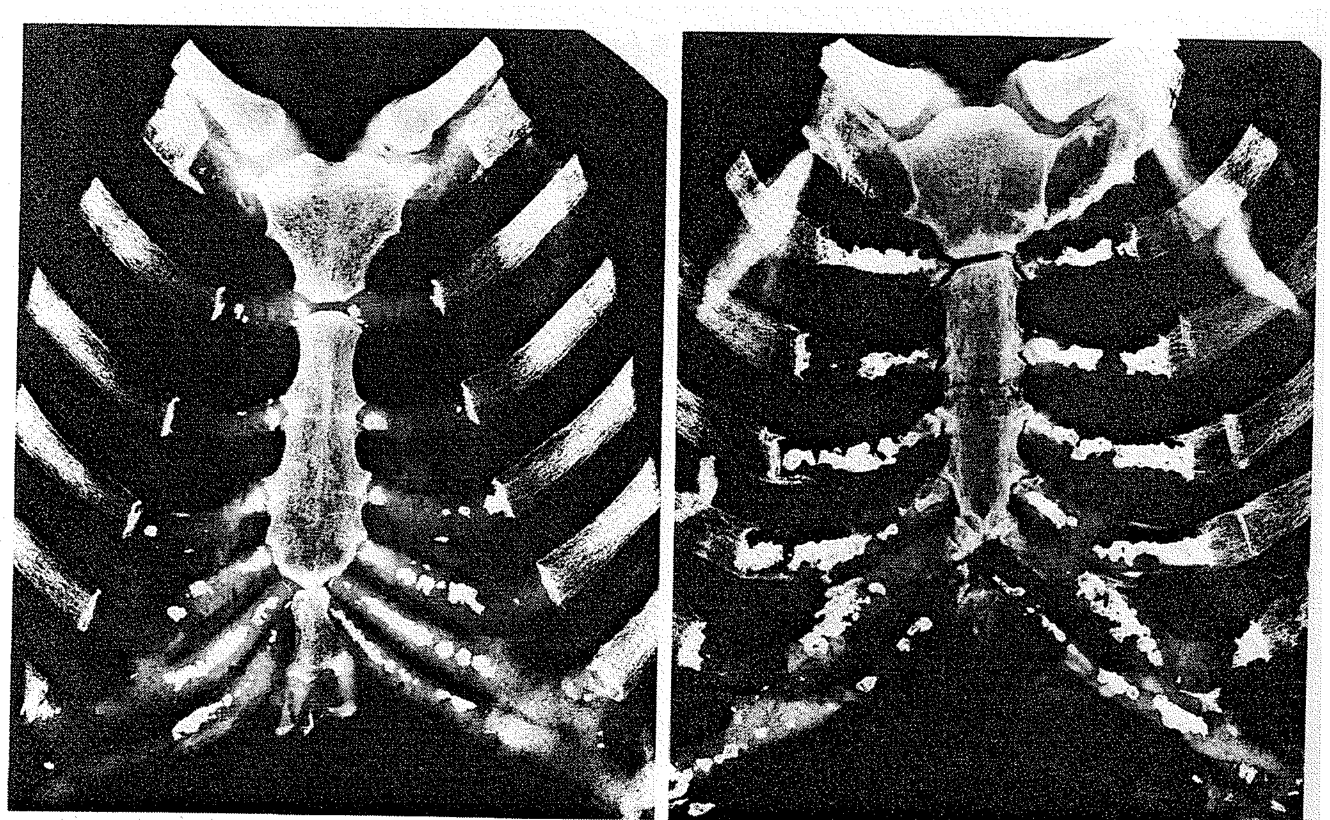


Figure 1: (Figure 2 in text): Photographic Template for Feature Assessment of Chest Plate X-Rays.
Reproduced from Barres et al., 1989, Figure 1, page 230.



Early Type A Ossification Late Type A Ossification

Figure 2 and 3: Early and Advanced Ossification Pattern Type A
Reproduced from Stewart and McCormick, 1984, Figures 1 and 2, page 766.

- Consists of centrally placed, smoothly contoured globules of ossification in the central portions of costal cartilages. Can be heavily mineralized.
- Typically these globular foci have smooth, rounded contours which contrast sharply with the surrounding cartilage and are relatively radioluecent.
- Do not involve sterno-chondral junctions or immediately subperichondral cartilage. There are no peripheral linear bands of ossification.

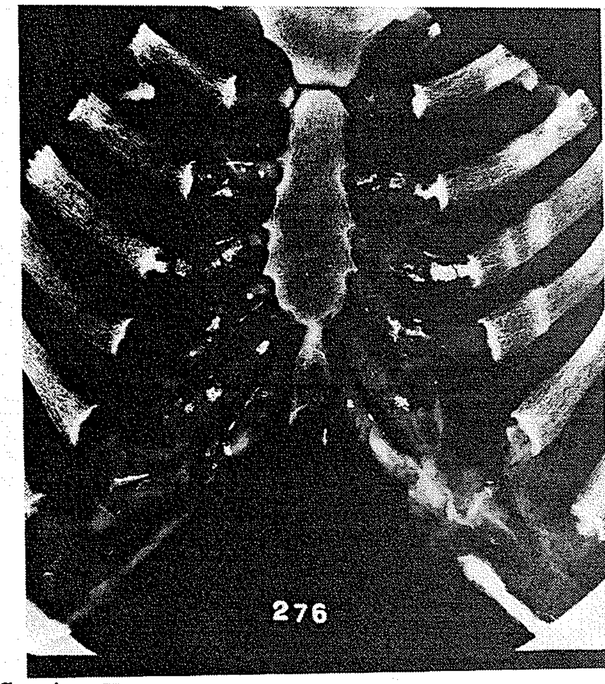


Figure 4: Early Ossification Type B

- Relatively dense sheets of costal cartilage mineralization, nonglobular and noncentral.
- Irregular sheets of ossification beginning in the subperichondral location and often marked at the costo-chondral border.

Reproduced from McCormick et al., 1985, Figure 5, page 178.

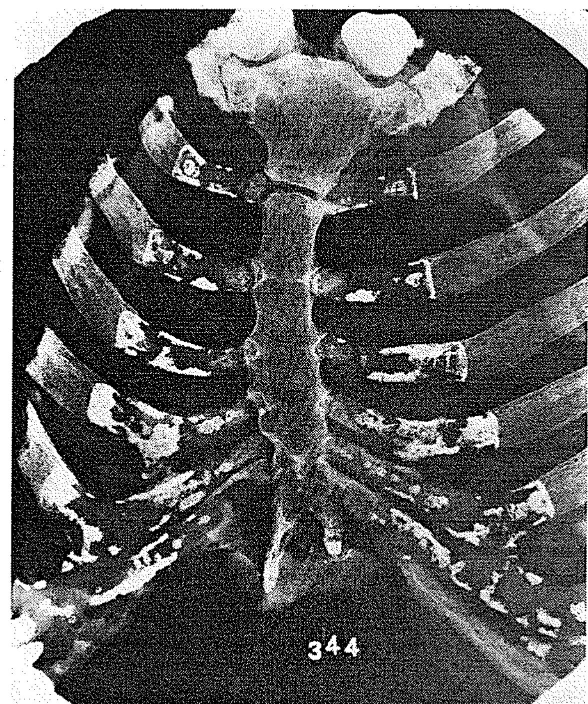


Figure 5: Late Ossification Type B

- Consists of pyramidal-shaped central tongues of ossification beginning in the costal fossa. The base of the pyramid is parallel to the costa fossa and the apex points toward the sternum.
- Ossification can be abundant and may partially obscure this pattern. As well, a "crab-claw" configuration of central costal mineralization is often present.

Reproduced from McCormick et al., 1985, Figure 5, page 179.

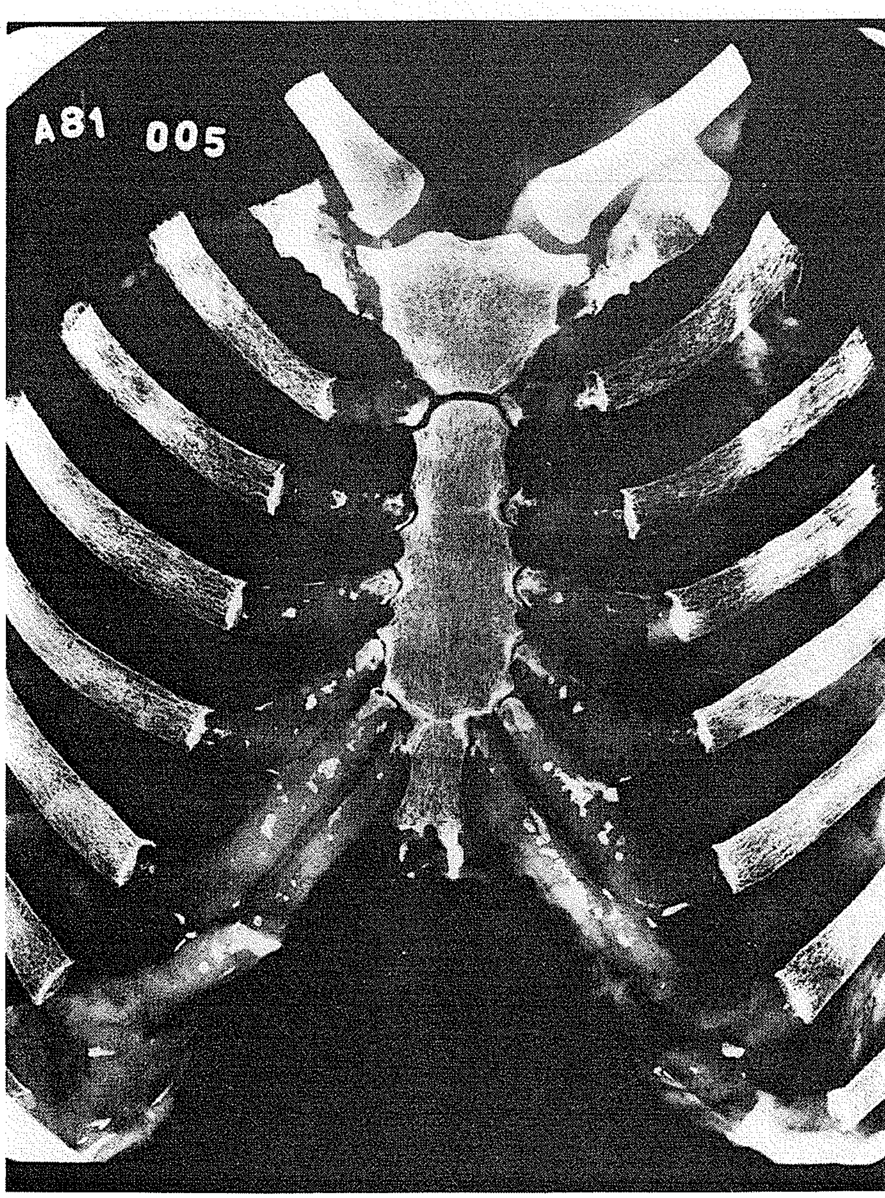


Figure 6: (Figure 16 in text): Ossification Type C

- Central fragmental costal cartilage ossification without the costal fossa ossification pyramids.
- Foci of ossification in these cases are often small, irregular, and sharply angular.

Reproduced from McCormick et al., 1985, Figure 6, page 180.

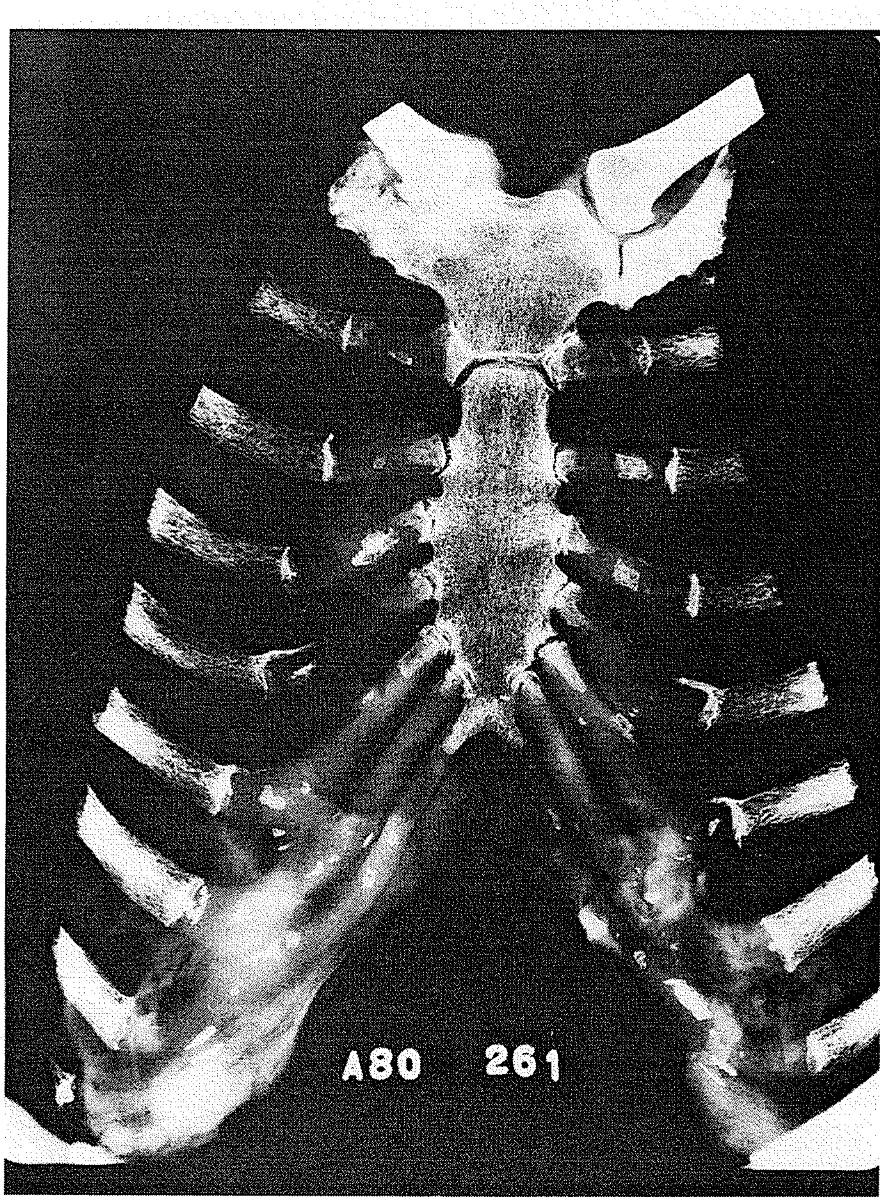


Figure 7: (Figure 17 in text): Ossification Type D

- A moderate amount of mineralization is present at both the costal fossa and the articulations of the sternum and costal cartilage.
- Occasional ossification spurs may extend from the costal fossa along the superior costal cartilage.

Reproduced from McCormick et al., 1985, Figure 7, page 181.

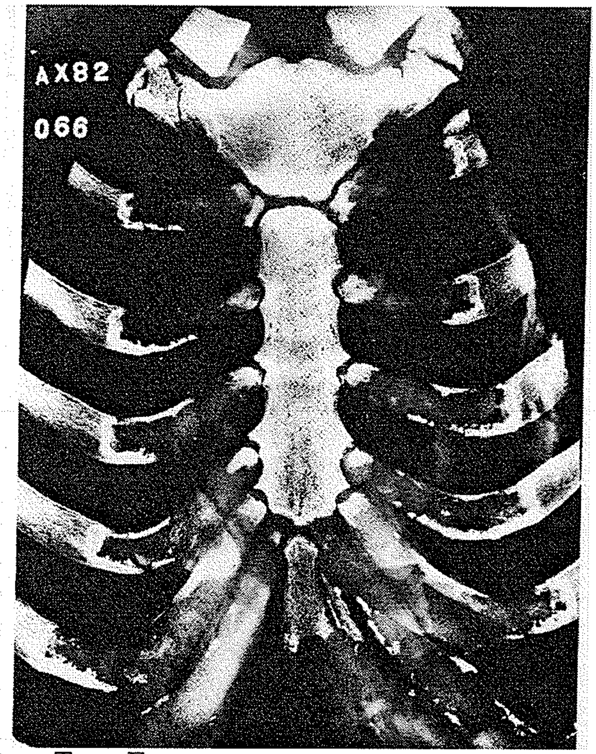


Figure 8: Ossification Pattern Type E

- Characterized by heavy ossification of the inferior and superior costal cartilage margin.
- The articulations of the sternum and costal cartilage are almost always ossified.

Reproduced from Stewart and McCormick, 1984, Figure 7, page 768.

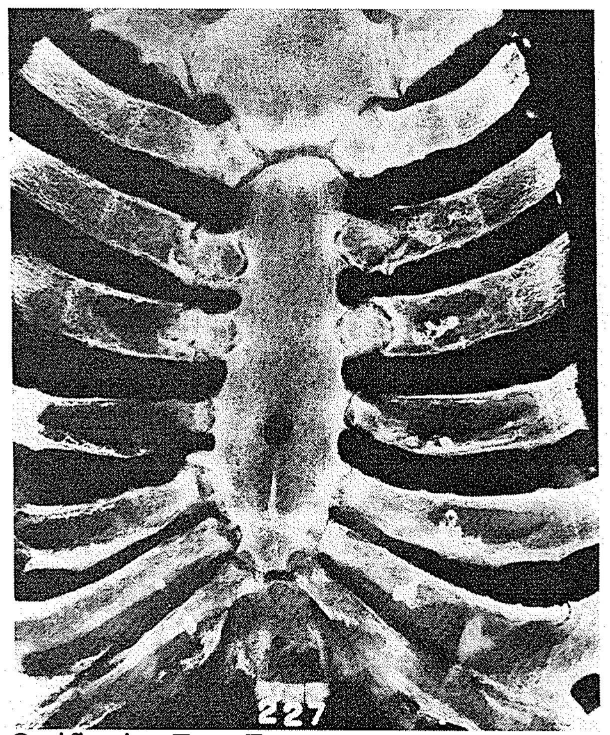


Figure 9: (Figure 18 in text): Ossification Type E

- Subperichondral tongues of new bone extending from out from the rib ends.
- Peripheral subperichondral (i.e.) marginal, linear ossification.
- Ossification is mainly confined to the upper and lower margins of the costal cartilage.

Reproduced from McCormick et al., 1985, Figure 8, page 182.

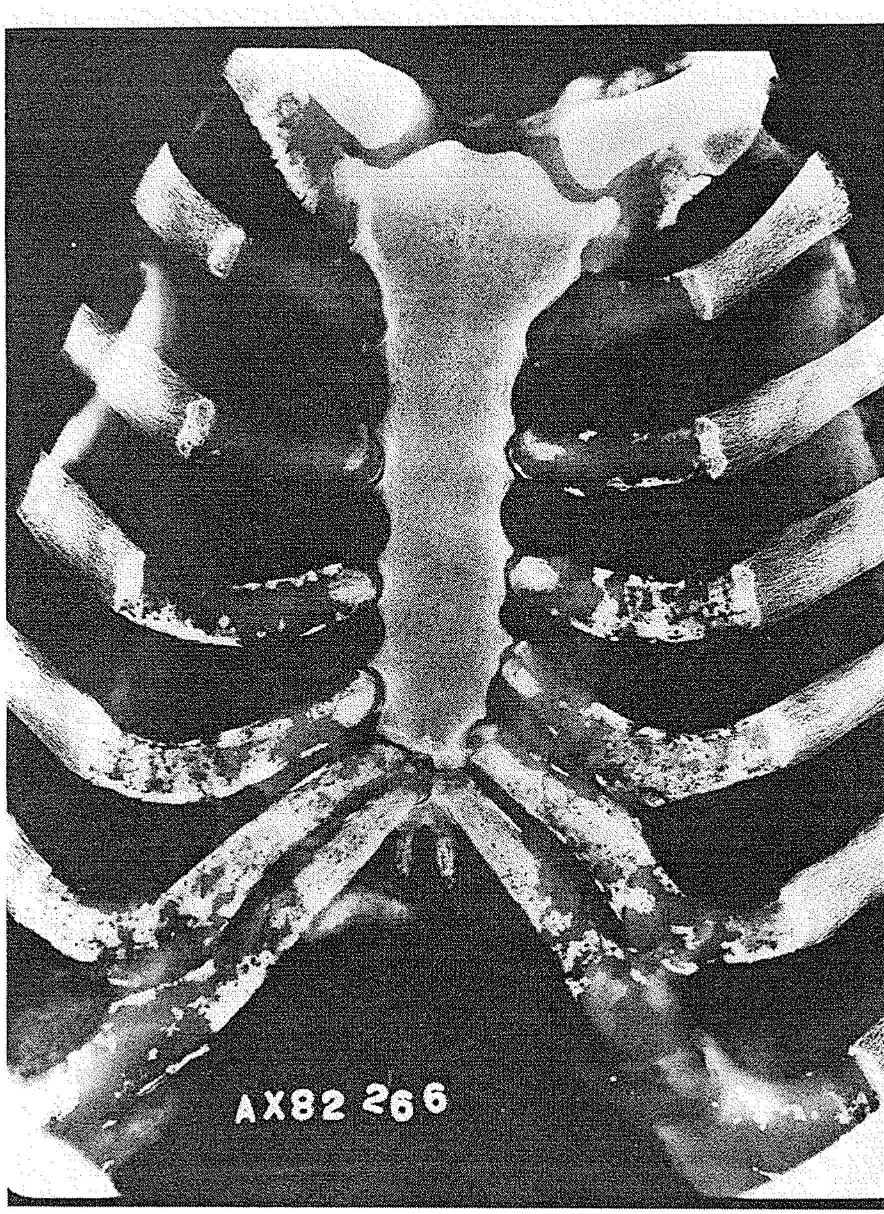


Figure 10: Ossification Type F

- Sheet-like, centrally located ossification with regularly arranged, small, round, radiolucent defects.
- Resembles "Swiss-cheese".

Reproduced from McCormick et al., 1985, Figure 9, page 184.

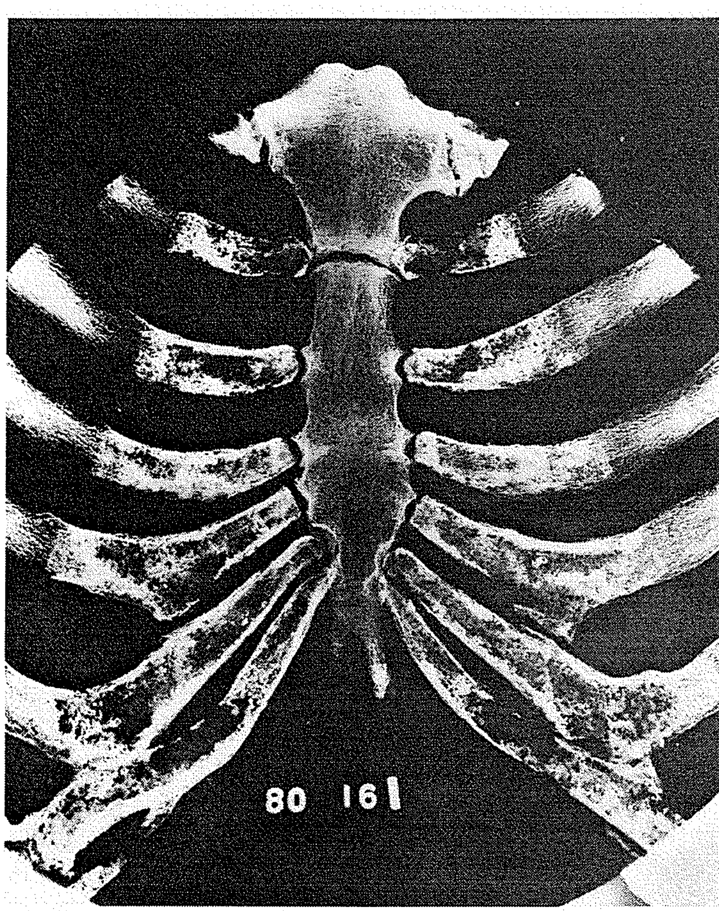


Figure 11: Ossification Type G

- Consists of truly massive costal cartilage ossification.

Reproduced from McCormick et al., 1985, Figure 11, page 186.

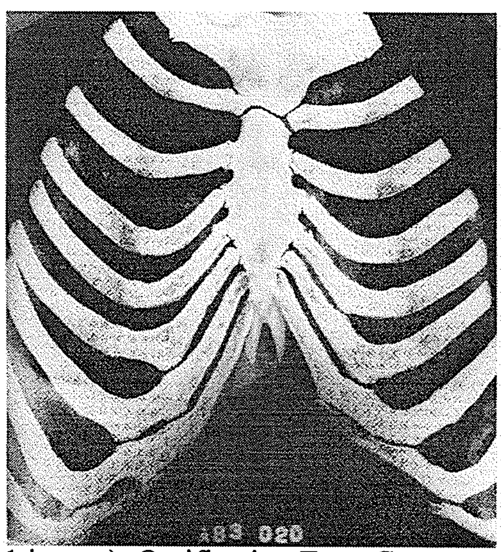


Figure 12: (Figure 11 in text): Ossification Type G

- The articulations of the sternum and costal cartilage are not mineralized.
- May be the end stage of Type F.

Reproduced from McCormick and Stewart, 1988, Figure 14, page 114.

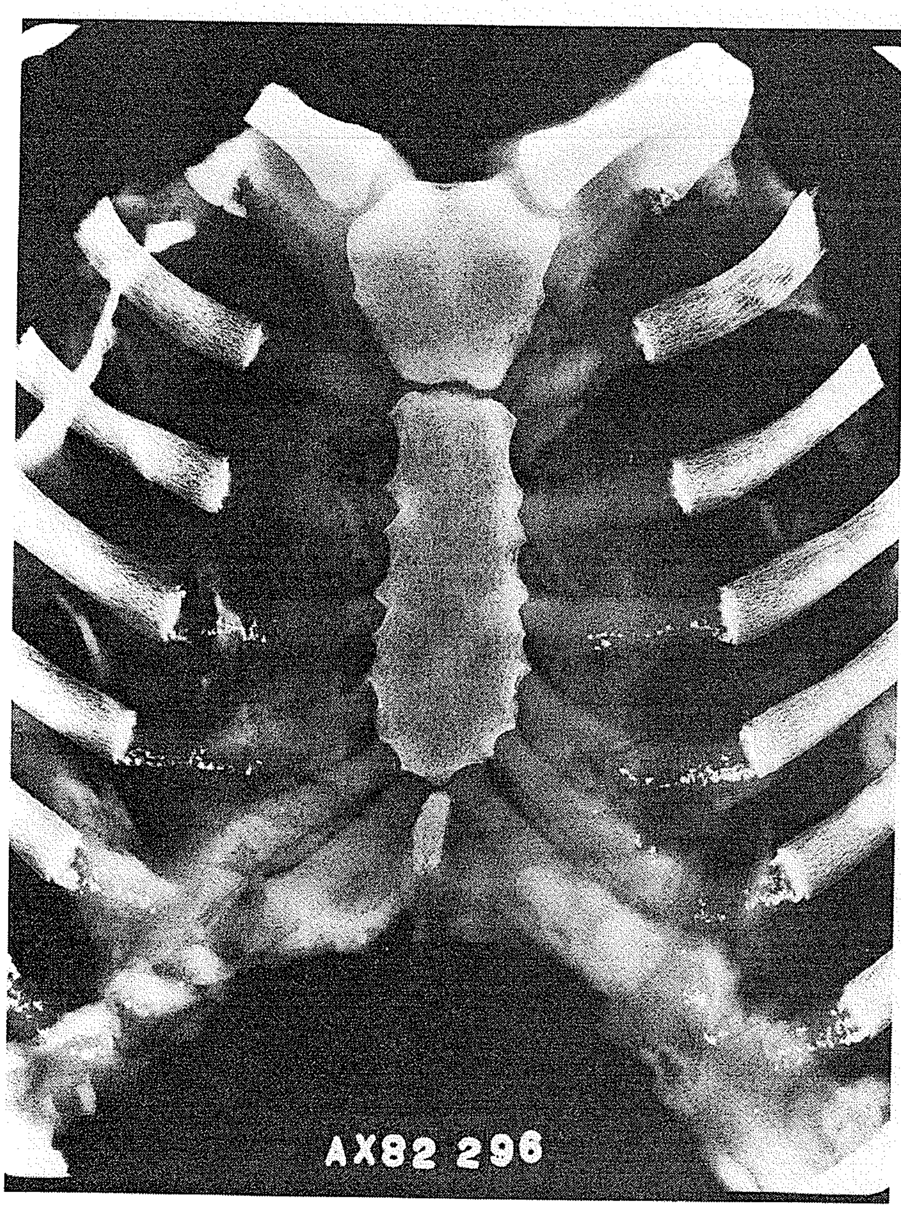


Figure 13: (Figure 19 in text): Ossification Type H.

- Has a fine granular appearance of costal cartilage ossification.
- The sternal and costal cartilage articulations have no ossification but a fine, vertical line of mineralization which appears at the costal fossa.
- The granular or "salt-and-pepper" ossification is found in the lateral two-thirds of the costal cartilage and has a horizontal, linear distribution.

Reproduced from McCormick et al., 1985, Figure 12, page 187.

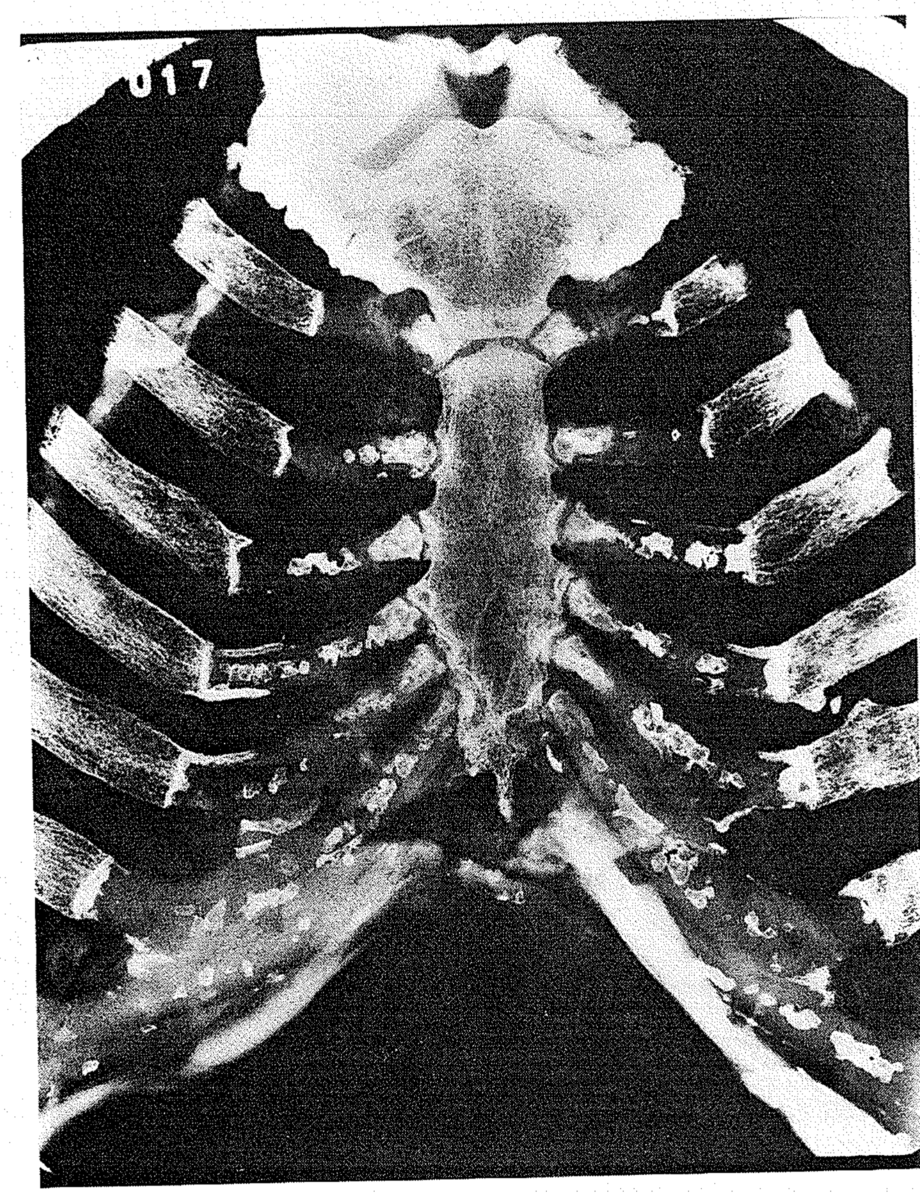


Figure 14: (Figure 20 in text): Ossification Type I (Indeterminate)

- Consists of an ossification pattern with dual patterning yet no clear predominance of either.
- Configurations are typically a combination of B and C with E or H.
- Ossification may also be too extensive for delineation.

Reproduced from McCormick et al., 1985, Figure 13, page 188.

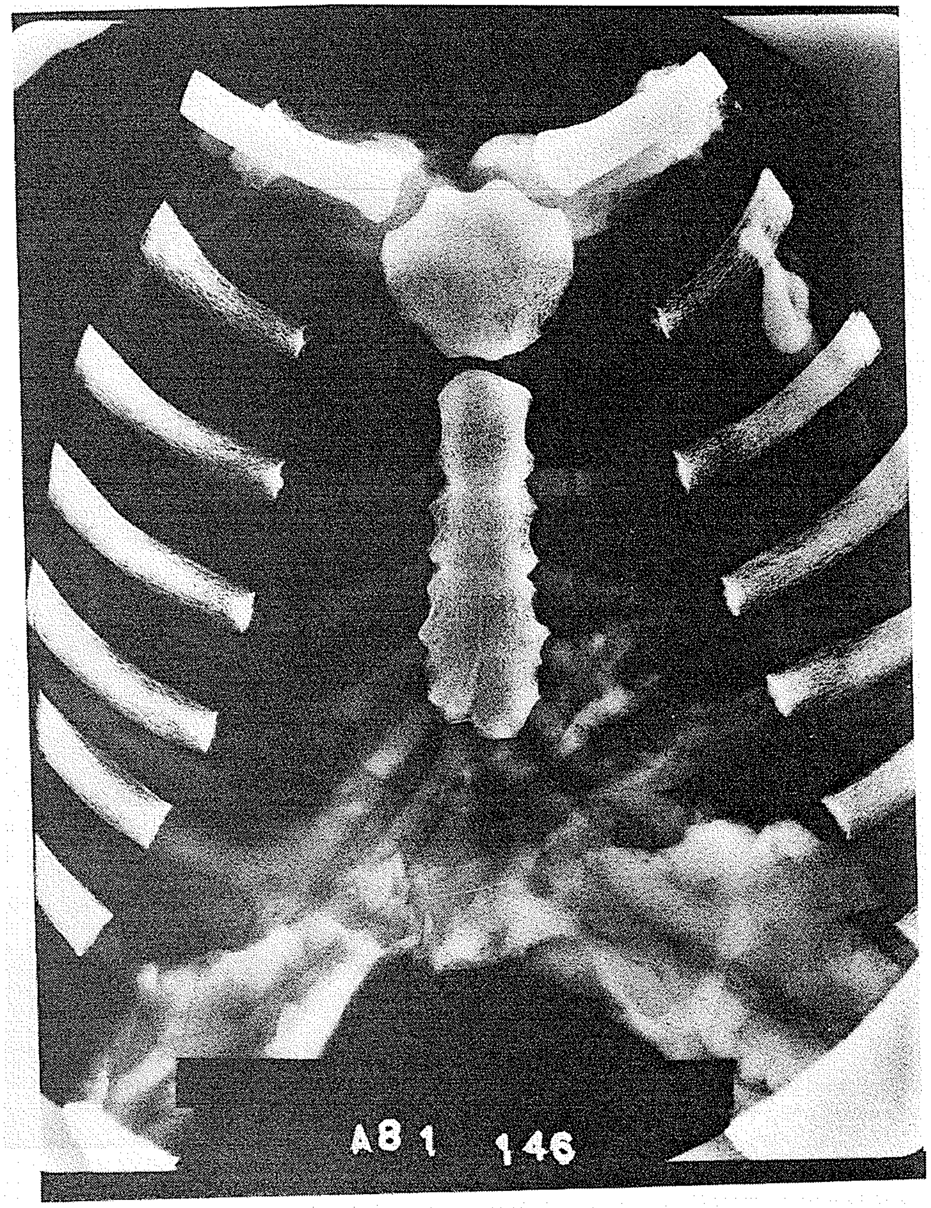


Figure 15: (Figure 21 in text): Ossification Type X

- No ossification of costal cartilages.

Reproduced from McCormick et al., 1985, Figure 15, page 191.

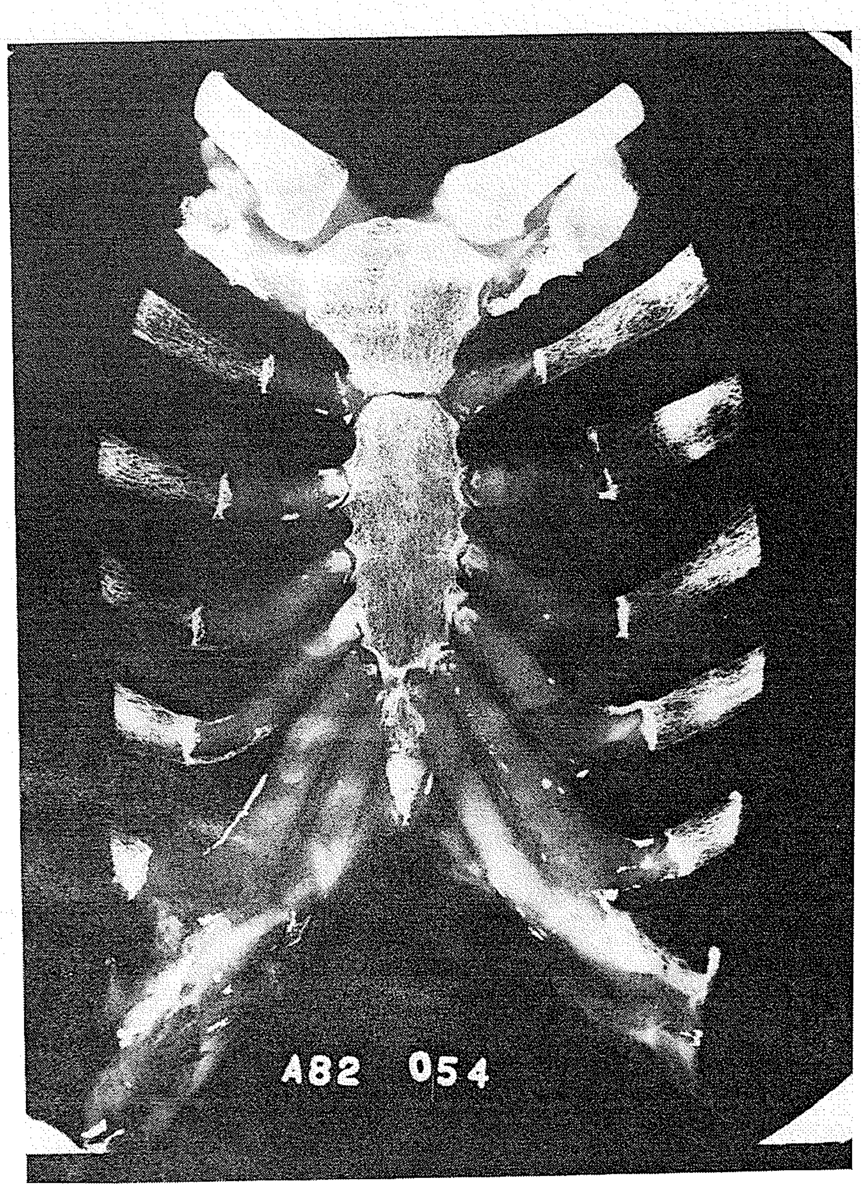


Figure 16: (Figure 22 in text): Ossification Type Y

- Has only para-sternal and/or first rib ossification.

Reproduced from McCormick et al., 1985, Figure 14, page 190.

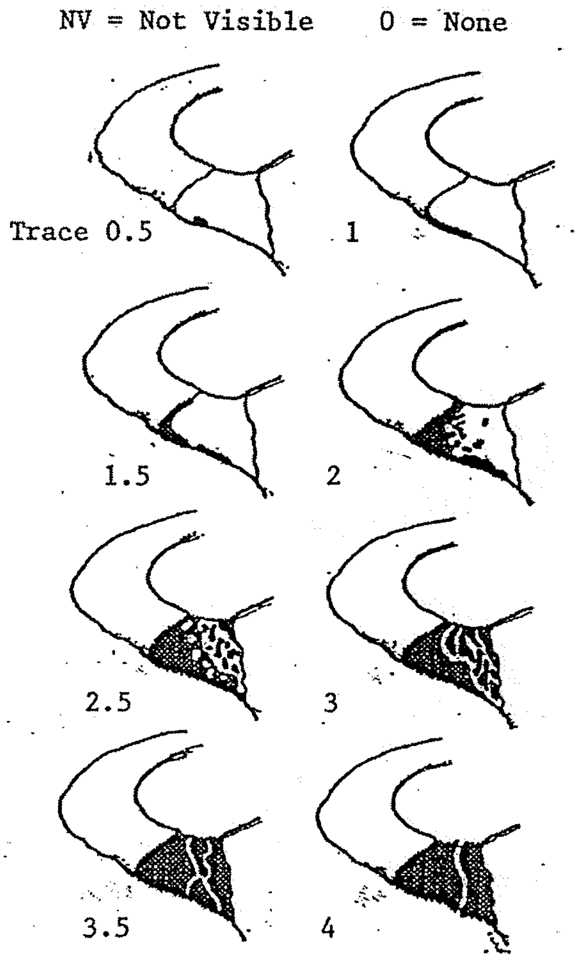


Figure 17: (Figure 3 in text): Schematic diagram of the increasing amounts of first costal cartilage ossification.

- From trace to four, as seen with advancing age. Figure 6, page 107.

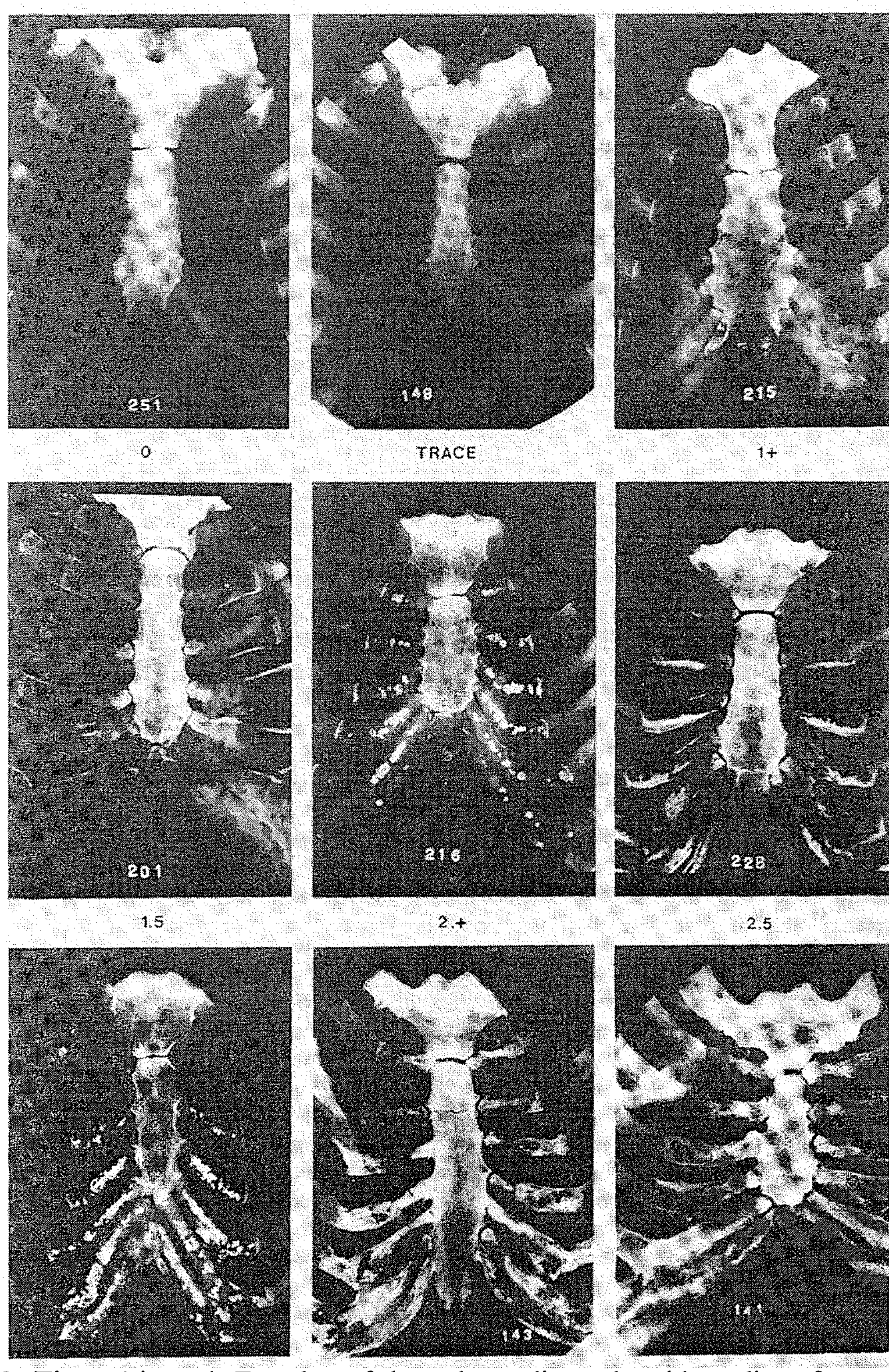


Figure 18: (Figure 1 in text): Template of chest plate radiographs with grading of ossification of costal cartilages.

- From 0 (none) to 4 (very severe).

Reproduced from McCormick, 1980, Figure 1, page 738.

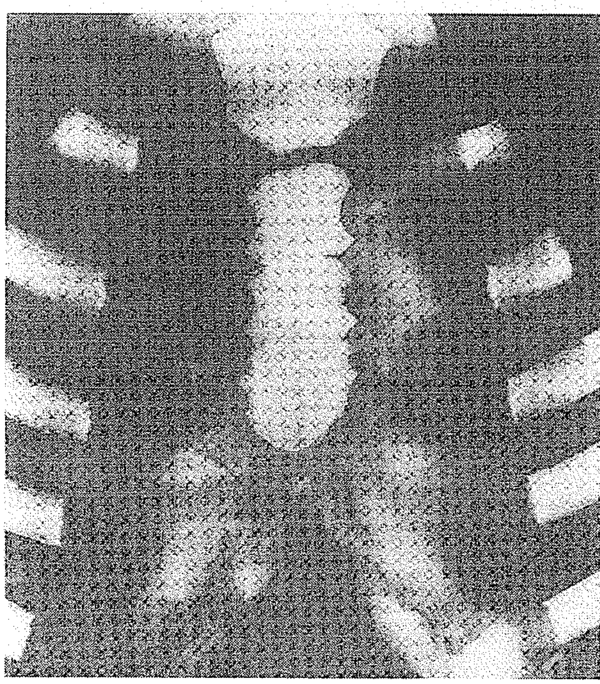


Figure 19: (Figure 6 in text): 1. Smooth contour to manubrium at the costomanubrial junction. Reproduced from McCormick and Stewart, 1988, Figure 15, page 115.

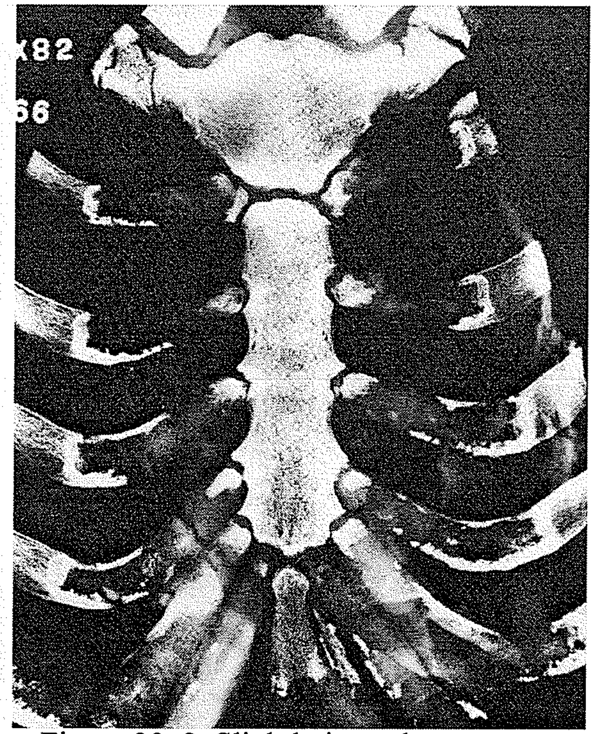


Figure 20: 2. Slightly irregular costo-manubrial junction. Reproduced from Stewart and McCormick, 1984, Figure 7, page 768

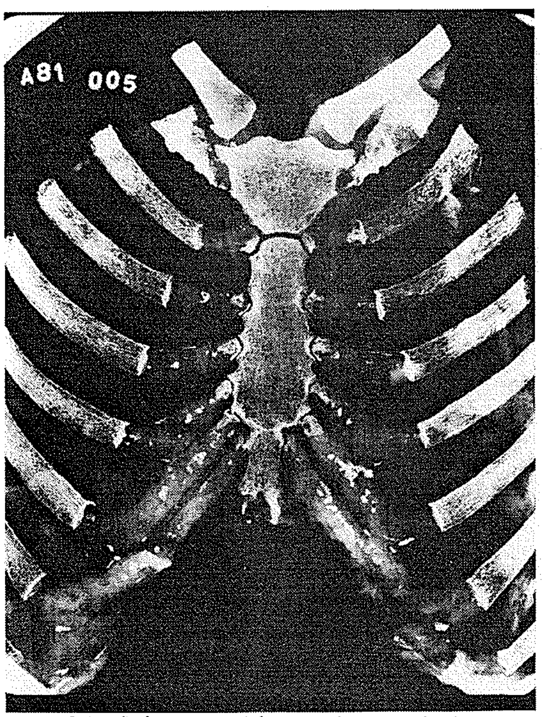


Figure 21: (Figure 16 in text): 3. Distinctly irregular costomanubrial border. Reproduced from McCormick et al., 1985, figure 6, page 180.

Costomanubrial Border
NV = Not Visible
1 = Smooth
2 = Slightly Irregular
3 = Distinctly Irregular

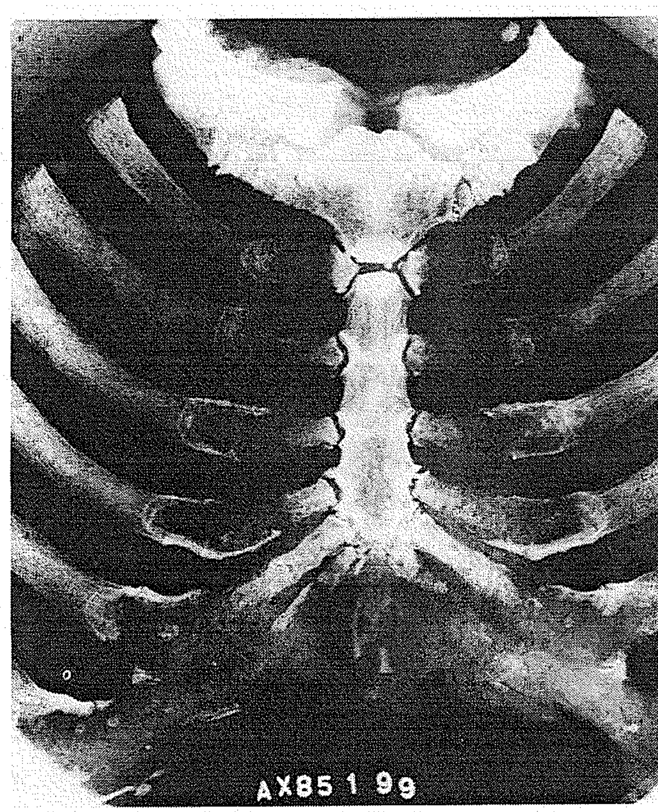


Figure 22: (Figure 5 in text): Deep cupping of the rib ends.

- May be markedly accentuated by rib end spurs.

Reproduced from McCormick and Stewart, 1988, Figure 18, page 118.

Rib-End Changes
NV = Not Visible
0 = No Change
1 = Moderate Change
2 = Marked Change

Osteoporotic Changes

NV = Not Visible
0 = No changes; Dense trabeculation
1 = Minimal changes; Minimal loss of trabeculae
2 = Moderate changes; Moderate loss of trabeculae
3 = Marked changes; Marked loss of trabeculae

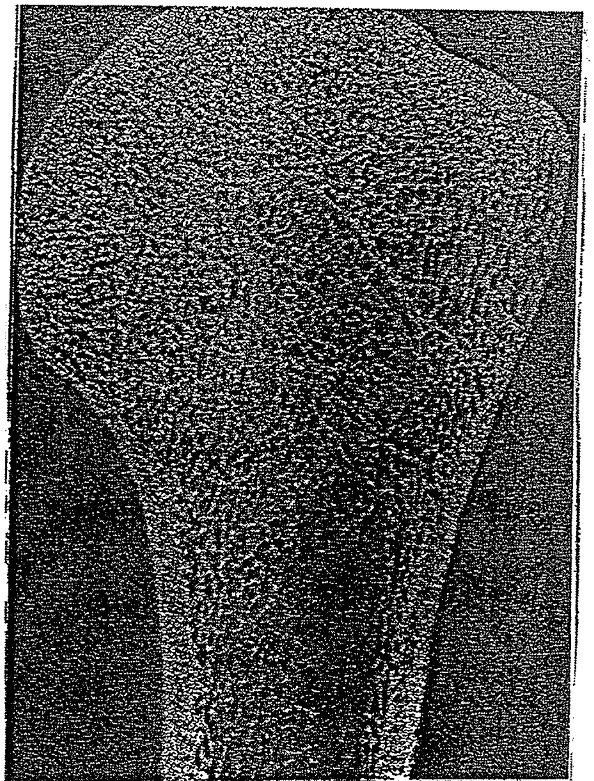


Figure 23: Dense trabeculation.

- No osteoporotic changes.

Reproduced from Krogman and Iscan, 1986, Figure 154, page 172.

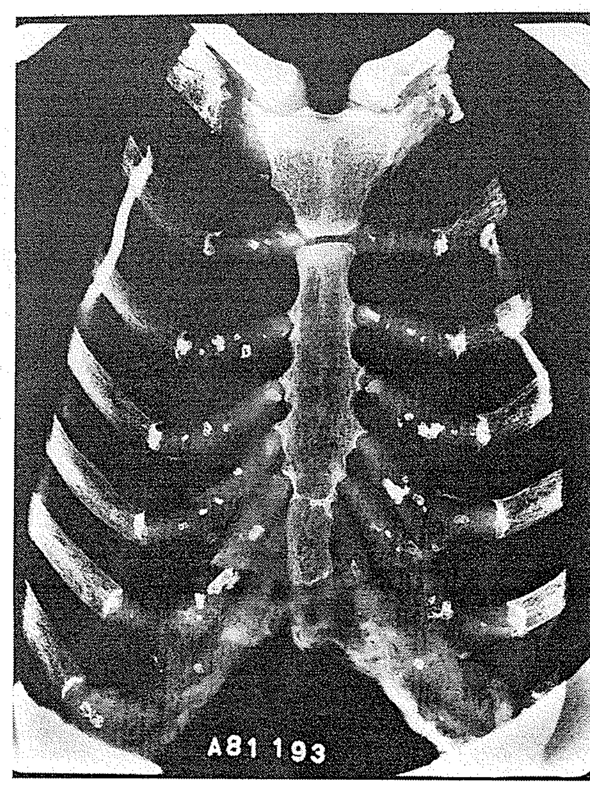


Figure 24: Marked loss of trabeculation.

- Marked osteoporotic changes.

Reproduced from McCormick et al., 1985, Figure 2, page 176.

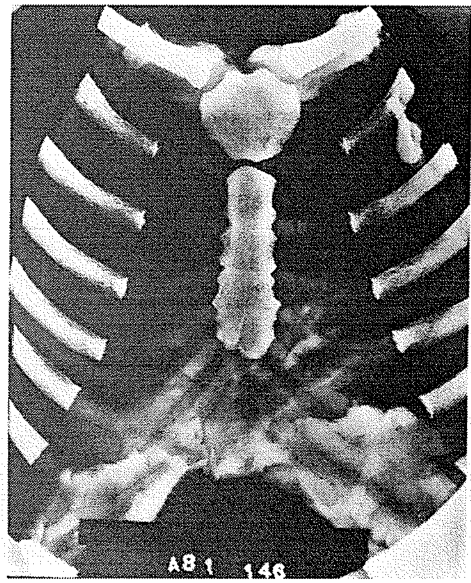


Figure 25: (Figure 21 in text):
0. No ossification of the xyphoid.
Reproduced from McCormick et al., 1985
Figure 15, page 191.

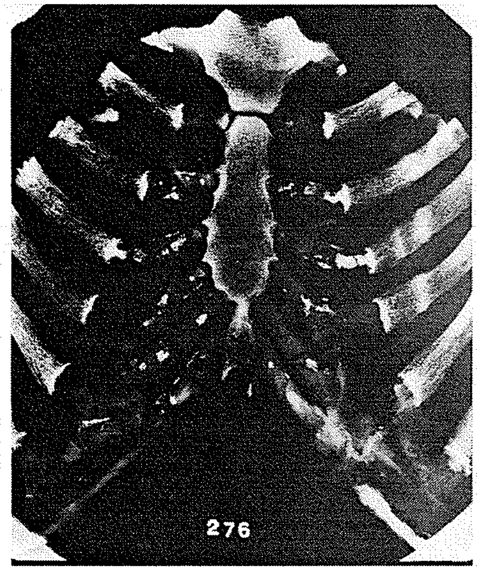


Figure 26: 1. Partial ossification of the xyphoid.
Reproduced from McCormick et al., 1985.
Figure 4, page 178.

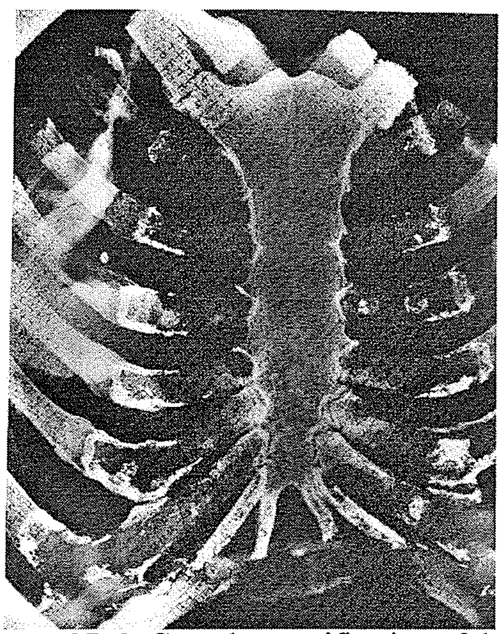


Figure 27: 2. Complete ossification of the xyphoid.
Reproduced from Stewart and McCormick, 1983, Figure 1, page 218

Ossification of the Xyphoid
0 = No ossification
1 = Partial ossification
2 = Complete ossification

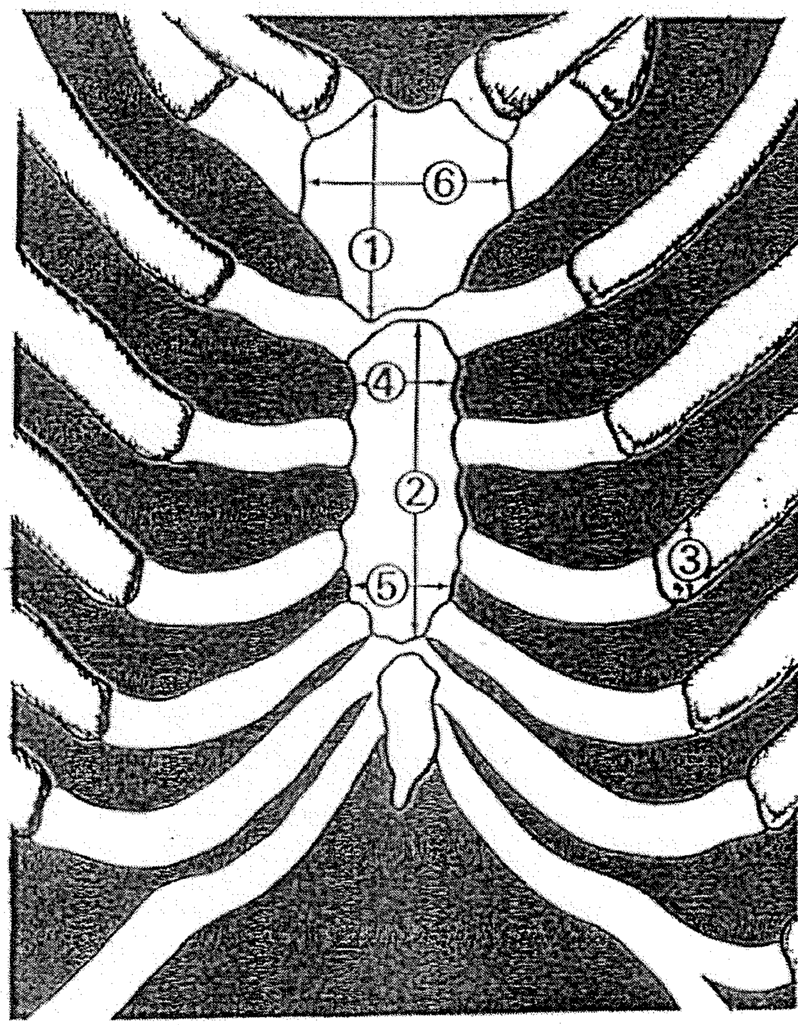


Figure 28: (Figure 15 in text): Drawing of the chest plate area noting the various measurements (mm).

I. Manubrium-corpus length:

Line 1: Length of Manubrium.

Line 2: Length of the corpus.

II. Line 3: Forth rib width.

III. Line 4: Corpus width midway between costal notches II and III.

IV. Manubrium-corpus (sternal) area.

Line 5: Corpus width midway between costal notches IV and V.

Line 6: Manubrium width at the first costal notch midpoint.

Line 4: Corpus width midway between costal notches II and III.

Reproduced from McCormick et al., 1985, Figure 1, page 174.

APPENDIX C

Date: **Autopsy #:** **Name:** **Order** **Time**

1. Quantitation of Five Thoracic Features

A. Bone Demineralization (BD):(standards set per Barres sample): (entire sternum): Figure 1 in Appendix A, figure 2 in text.
1 to 5

B. Fusion of the pieces of the sternum (FM): (score body and manubrium) Figure 1
1 to 5

C. Cartilage-to-sternum attachment changes (CS): (all visible): Figure 1
1 to 5

D. Cartilage mineralization (CM): (all visible): Figure 1
1 to 5

E. Rib-to-cartilage attachment changes (RC): (all visible): Figure 1
1 to 5

2. Ossification Pattern

Ossification amount scored as 1, 2, 3
1= represents minimal changes; represented by small button-shaped scattered foci occupying most of the width of the chondro-mesosternal insertion
2= represents recognizable, characteristic patterning; represented by larger areas with coalescence, these extend completely across the width of the insertion
3= represents heavy to massive patterning; represented by changes covering a major portion of the cartilage area, these are elongated laterally from a broadly ossified insertion

Type A: Figure 2 and 3 in Appendix A.
Always 3

Type B: Figure 4 and 5 in Appendix A
1, 2, or 3

Type C: Figure 6 in Appendix A, figure 16 in text.
1, 2, or 3

Type D: Figure 7 in Appendix A, figure 17 in text.

Type E: Figure 8 and 9 in Appendix A, figure 18 in text.
1, 2, or 3

Type F: (Swiss-Cheese pattern): Figure 10 in Appendix A.
Always 3
Type G: (May be end-stage of pattern F): Figure 11 and 12 in Appendix A, figure 11 in text.
Always 3

Type H: (Salt-and-Pepper pattern): Figure 13 in Appendix A, figure 19 in text.

Indeterminate: (Typically combinations of B and C with E or H): Figure 14 in Appendix A, figure 20 in text.

Ossification Pattern X: Figure 15 in Appendix A, figure 21 in text.

Ossification Pattern Y: Figure 16 in Appendix A, figure 22 in text.

3. Ossification Data

A. First Costal Cartilage Ossification: Figure 17 in Appendix A, figure 3 in text.

NV = not visible; 0 = none; 0.5 to 4 as per template

B. Peristernal and Second through Seventh Costal Cartilage Ossification: Figure 18 in Appendix A, figure 1 in text.

NV = not visible; 0 to 4 as per template

C. Costo-Manubrial Border: (Score left side if possible) Figure 19, 20, 21 in Appendix A, figure 6 and 16 in text.

Side:
NV = Not Visible
1 = Smooth
2 = Slightly Irregular
3 = Distinctly Irregular

E. Rib-End Changes: (Scored as per entire study sample) Figure 22 in Appendix A, figure 5 in text.

NV = Not Visible
0 = No change in cup depth or sternal rib end flaring
1 = Moderate change in cup depth and sternal rib end flaring
2 = Marked change in cup depth and sternal rib end flaring

F. Osteoporotic Changes (score manubrium and body of sternum): (Scored as per entire study sample) Figure 23 and 24 in Appendix A.

NV = Not Visible

0 = No Osteoporotic changes; Dense trabeculation
1 = Minimal Osteoporotic changes; Minimal loss of trabeculation
2 = Moderate Osteoporotic changes; Moderate loss of trabeculation
3 = Marked Osteoporotic changes; Marked loss of trabeculation

D. Ossification of the Xyphoid: Figure 25, 26, 27 in Appendix A, figure 21 in text.

0 = No ossification:
1 = Partial ossification
2 = Complete ossification

Comments:

APPENDIX D

Measurement Data

Date: **Autopsy #:** **Name:** **Order:** **Time:**

Measurements: Table 4, Figure 15 in text, figure 27 in Appendix C

1. **Manubrium-corpus length:**

   Line 1:

   Line 2:

   Total:

2. **Fourth rib width:**

   Line 3:

3. **Corpus width midway between costal notches II-III:**

   Line 4:

4. **Manubrium-corpus area:**

   1. Manubrium width at first costal notch midpoint: Line 6:

   2. Corpus width midway between costal notches II-III: Line 4:

   3. Corpus width midway between costal notches IV-V: Line 5:

Average of 1, 2, and 3: Length x Average Width = Area:

Sternal Length: **Sternal Area:** **Manubrial Length:**

Comments: