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An independent test of the technique of aging skeletal material from the sternal end of the right fourth rib

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An Independent Test of the Technique of Aging Skeletal Material from the Sternal End of the Right Fourth Rib

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ABSTRACT

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An Independent Test of the Technique of Aging Skeletal Material from the Sternal End of the Right Fourth Rib

Dr. Randall R Skelton, Director RS.

The objective of this project is to evaluate the accuracy and reliability of two methods of aging human skeletal remains from the sternal end of the right fourth rib. These methods are called "phase analysis" and "component analysis". The fourth rib was chosen in order to replicate previous research. Aging skeletal remains is one of the primary tasks of the forensic anthropologist, and the information derived from skeletal material can be applied to other disciplines, including paleoanthropology, paleodemography, and other forensic sciences. The results of this research indicate that phase analysis is a better method than component analysis for estimating age from the skeleton.

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CHAPTER I: INTRODUCTION

1.1 Nature and Scope of the Problem

The objective of this research is to examine the accuracy and reliability of determining skeletal age at death using the sternal end of the right fourth rib. This technique was first proposed by Loth, et.al. (1983), and further developed by Iscan et.al (1984a, 1984b, 1985) and Iscan and Loth (1986a, 1986b). This method assesses the metamorphosis of the sternal end of the right fourth rib as an indicator of age at death.

1.2 Forensic Anthropology

Forensic anthropology is concerned with applying the methods, information, and expertise of the physical anthropologist in a legal context. The goal is to assess the identifying characteristics of skeletal remains in order to assist in the individualization of an unknown decedent.

The phrase "forensic anthropology" is inclusive of all aspects of the morphology of the human skeleton, including normal and abnormal variation. Indeed, variation is a key concept to forensic anthropology, as it represents a major element with which we must wrestle when designing and evaluating our normative standards, and when estimating variables on a case by case basis.

Snow (1973a, p. 4) defines forensic anthropology as "the application of the physical anthropologist's specialized knowledge of human sexual, racial, age, and individual variation to problems of medical jurisprudence." This broad definition allows us to expand the breadth of our work beyond merely the identification of human skeletal remains (e.g.: see Stewart 1979, p. ix; see also: Cobb 1952; Camps 1976; Rhine 1984).

The main task of the forensic anthropologist is to provide enough information from skeletal remains to establish adequate parity between those remains and a decedent, and facilitate direct positive or circumstantial identification of the individual represented (Stewart 1979; Rathbun and Buikstra 1984; Krogman and Iscan 1986). This "antemortem biological biography" considers "human skeletonized remains and their environments," as well as the circumstances surrounding death and subsequent deposition (Iscan 1981a, p 10; see also: Warren 1978; Stewart 1979; Iscan 1981b; Snow 1982; Rathbun and Buikstra 1984; Krogman and Iscan 1986; Bass 1987; Steele and Bramblett 1988; White 1991). Each of the variables scrutinized by the forensic anthropologist lends itself, individually and in combination with others, to the potential identification of the decedent.

There are several variables that forensic anthropologists attempt to assess when given skeletal remains and dentition. Age, sex, ancestry (or race), stature, and traumatic and pathological conditions are the necessary prerequisite variables which must be evaluated in order to facilitate the individualization of a decedent. What the bones tell and how they tell it are the primary focus of the forensic anthropologist (Mann et.al. 1970; Snow 1973a, 1973b; Maples 1984; Krogman and Iscan 1986; Bass 1987). Aging human skeletal remains is a primary task of the forensic anthropologist, the main goal of whom is to provide information leading to the individualization of unknown decedents.

The forensic anthropologist is usually a consultant to local, state, or federal medico-legal authorities and law enforcement personnel. Since conventional methods of identification, such as fingerprinting, dental records, and personal recognition often prove inadequate in cases involving skeletonized human remains, the forensic anthropologist brings a specialized perspective to the analysis. This perspective includes distinctive skills and methods, a broad and varied database, and theoretical frameworks which enable the forensic anthropologist to provide medical and legal specialists with information that augments traditional techniques used for identification (Wentworth and Wilder 1932; Brues 1958; El-Najjar and McWilliams 1978; Rathbun and Buikstra 1984; Krogman and Iscan 1986; Bass 1987; Iscan and Kennedy 1989).

The ideas behind forensic anthropology have a long history, dating to the latter half of the 19th century (e.g. Broca 1867; Dwight 1878, 1890; Bertillon 1889; Holl 1898; Kollmann 1898; see also: Wentworth and Wilder 1932; Comas 1960; Stewart 1970; Snow 1982; Rathbun and Buikstra 1984).

Concentrated efforts toward the development of techniques and skills for identifying individuals based on skeletal or dental remains began in earnest in the early part of the 20th century, especially in the 1930s. Much of the field's original information derived from research among specialists in related fields, such as anatomy, biology, medicine, and odontology (Comas 1960; Steinbock 1976; Stewart 1979; Snow 1982; Rathbun and Buikstra 1984). Recognition of the field as a professional discipline was bolstered by the establishment of a Physical Anthropology section of the American Academy of Forensic Sciences in 1972 (Mann and Wood 1970; Kerley 1978; Snow 1982; Rathbun and Buikstra 1984; Rhine 1984).

As a discipline, forensic anthropology demands at least a working knowledge of many spheres of information. Since the human species is quite variable, reliable evaluation of the criteria used in human skeletal analysis requires an understanding or other domains, including: anatomy and physiology, archaeology, comparative osteology, demography, epidemiology, genetics, human paleontology, odontology, paleopathology, skeletal biology, and for certified experts, legal interpretation (Krogman and Iscan 1986; see also: Stewart 1970, 1984; Gilbert 1973; Spitz and Fisher 1973; Rathbun and Buikstra 1984; Rhine 1984; Shipman et.al. 1985; Steele and Bramblett 1988; White 1991). From the methodological standards for archaeological excavation to differentiation between human and non-human remains; from the growth and development of the human skeleton, and the organs and musculature of the human body to the occurrence, transmission, and evidence of both hard- and soft-tissue disease; from the eruption sequences and identification of dentition to the nuances of legal procedure, and evidentiary interpretation and testimony, the forensic anthropologist must possess substantial erudition.

The scope of our understanding and competence ranges between fields of inquiry;

nonetheless, we must recognize our limitations and remain within our area of expertise. This is "critical to the maintenance of our credibility and effectiveness as forensic scientists" (Rathbun and Buikstra 1984. P. 9). These limitations are imposed to a large degree by the extent of individual variability endemic to the human species, and range from interobserver error to incomplete remains and inadequate methods of evaluation.

1.3 Aging in a Forensic Context

Estimating a range for an individual's age at death is an essential part of any forensic investigation. We must not simply give an age range estimate, however; we must be confident that we can provide the most accurate and the most reliable information that we are able.

One problem with forensic anthropology and the methods used in our analyses, including this study, is the heavy reliance upon information obtained from dissecting room and autopsy cadavers, a sample population that is "notoriously biased" (Krogman and Iscan 1986, p. 4; see also Bass 1987). The general notion is that the people available in these venues are representative only of a particular socioeconomic segment of the population, and therefore information derived from their remains is potentially suspect. There are exceptions to this, namely the studies conducted by Snow (1948) and McKern and Stewart (1957) based on army populations, but they are few and have problems of their own. We must proceed as if the data we have are representative to an acceptable degree, even when we know that they probably are not.

1.3a Developmental Changes

Immature skeletal development has been well studied and documented since the early 20th century (Adair and Scammon 1921; Stevenson 1924; Borovansky and Hnevkovsky 1929; Davies and Parsons 1927; Cowdry 1939; Hill 1939; Stewart 1954, 1976; Stewart and Trotter 1954; Fazekas and Kosa 1978; Raisz and Kream 1983a, 1983b; Ubelaker 1987). Radiographic and gross morphological studies have demonstrated the reliability of aging the sub-adult skeleton based upon the ossification of endochodral formations (Fazekas and Kosa 1970; Hall 1978), appearance and development of ossification centers (Borovansky and Hnevkovsky 1929; Francis et.al 1939; Hill 1939; McKern 1957; Fazekas and Kosa 1970), rates of union between epiphyses and diaphyses (Davies and Parsons 1927; Borovansky and Hnevkovsky 1929; Todd 1930; Francis et.al. 1939; McKern 1957; Fazekas and Kosa 1970), dental eruption sequences (Stewart 1934, 1963; Kronfeld 1935; Garn, et.al. 1959; Fazekas and Kosa 1970), linear growth rates of long bones (Todd 1931; 1933; Lacroix 1951; Fazekas and Kosa 1970; Yoshino et.al 1989), and sex differentials (Garn et.al 1966; Hall 1978; Perzigian and Jolly 1984; Rao and Pai 1988). One of the ideas illustrated by the study of immature skeletal growth is that techniques based upon development are relatively more dependable than those based upon atrophic or degenerative change (Fazekas and Kosa 1970; Pansky 1979; Shipman et.al. 1985; Reichs 1986).The sequences and timing of developmental processes are well documented and understood, and in the absence of pathological condition, we can be quite precise in our estimates of age for individuals who have not yet attained skeletal maturity.

1.3b Degenerative Changes

Degenerative or atrophic processes are much more individually variable than developmental changes, however. It is very difficult to establish adequate standards for aging the adult skeleton, and we cannot be as exact in our age estimates when dealing with post-maturity skeletal material (Krogman and Iscan 1986; Bass 1987).

Age ranges discernable from patterns of change on the bony structures tend to widen as the body ages. Certain components of the skeleton can be reliable into the fifth decade of life; many, however, are unreliable as early as 25 years of age, or even younger. Many factors, both internal and external can affect physiology, which in turn can affect the patterns of calcification, resorption, deposition, and gross morphological change. This variability can extend to the extreme.

1.4 Methods for Estimating Age

Traditional techniques for aging the adult human skeleton consist of: (1) histological methods; (2) radiological methods; and (3) direct morphological methods. Each method is "differentially preferred, [and] they also have their limitations and present certain difficulties" (Iscan et.al. 1984a, p. 1095).

1.4a Histological Analysis

Results have been excellent in the field of histology, providing very accurate methods of assigning age to skeletal remains. Kerley (1965) and Ahlqvist and Damsten (1969) both provided sound and precise methods for determining age from microscopic analysis (see also: Bouvier and Ubelaker 1977). Epker and Frost (1965) and Epker et.al. (1965) concluded that there is excellent correlation between the processes of resorption and formation of various bone surfaces and the age of "metabolically normal" individuals (p. 202). Later work, including Carlson et.al. (1970), Frost (1976), Kerley (1984), Poole et.al. (1984), Stout (1986), Stout and Paine (1992), Dudar (1993) and Stout et.al. (1994) have furthered work on histological methods. Methods currently in use include histo-morphometry or "osteon counting," (that is, microscopic analysis concentrating on the presence of complete osteons, partial osteons, and the amounts of lamellar bone and non-Haversian systems within the cortex of long bones) (Fangwu 1983; Kerley and Ubelaker 1978; Ortner 1975; Thompson 1979, 1981; Dudar et.al. 1993; Stout et.al 1993); quantification of the thickness and density of cortical bone (Schranz 1959; Thompson and Gunnes-Hay 1981; Burr and Peotrowski 1982; Erickson 1991); Haversian canal areal quantification (Thompson and Gunnes-Hay 1981); and the areal quantification of cortical bone (Erickson 1991; for work specifically on cortical area quantification of ribs, see Sedlin et.al. 1963).

By evaluating microscopic structure of bone, the investigator can assign age at death information with a very high degree of accuracy. The drawbacks of histological analysis remain, however. Success has been achieved, but the invasive methods and destruction of bone which are necessary to the procedures of microscopic analysis, and the expense of equipment and expertise required, prevent many investigators from pursuing such analysis. This effectively limits the utility of histological analysis. A recent study (Stout 1988, p. 124) also indicates that "there are a number of methodological and physiological factors that can affect the reliability of histological methods now available for age estimation." These caveats must be considered when undertaking histological analysis of skeletal remains.

1.4b Radiological Analysis

Radiological or radiographic (roentgenographic) techniques utilize X-ray technology to view ossification patterns. The results from this field of endeavor have been less successful than with histological analysis. Michelson (1934), King (1939), Acheson (1954), and Fischer (1955) were pioneers of evaluating the calcification of costal cartilage from radiographic films, and the endeavor has continued to the present (see: Lagemann 1972; Semine and Damon 1975; McCormick 1980, 1982; Murphy et.al. 1980; Saternus and Koebke 1981; Koebke and Saternus 1982; Markert et.al 1983; Turovtsev 1984; McCormick and Stewart 1988; Barres et.al. 1989; Teale, et.al. 1989; Lynnerup et.al. 1990; Barchilon et.al. 1996). Some success has been forthcoming in this field: X-ray examinations have been shown in a few instances to provide tolerable accuracy in the estimation of age at death, but expense, equipment and expertise can distance these methods from some investigators, and the reliability of X-ray analysis in general cannot be considered sufficient. Radiographic studies also require an intact chest plate, including the cartilage, which is generally not possible when dealing with skeletonized forensic material or material in a prehistoric context.

1.4c Morphological Analysis

Morphological, or direct, examinations provide the most accessible methods for estimating variables from the human skeleton. They afford the most rapid and convenient techniques for analyzing skeletal remains from unknown individuals. There are limitations to morphological examinations, as well, however, including interobserver error, human variability, health and disease status, occupation, and environmental degradation of bony tissue. Suchey (1979), Lovejoy et.al (1985a), Bedford et.al. (1993), and Dudar et.al. (1993) found that errors in analysis and experience of the analyst were inversely correlated. Iscan et.al (1984b, p. 155) found that "individual variation increased after the third decade", and previous researchers, including Kerley (1970), McCormick and Stewart (1957), McKern (1970), McKern and Stewart (1957), Sedlin et.al. (1963), Semine and Damon (1975), Steinbock (1976), Suchey (1979), Snow (1983), and Suchey et.al. (1984) confirm that various elements of the human skeleton exhibit marked variability in various decades of life. Couple this with the problem of interobserver error, and inaccuracies in the estimation of human skeletal remains can be compounded. For this reason, development and testing of techniques is paramount for success in the field, and training new members is equally important.

1.4.1 Loci for Determining Skeletal Age

Initial research into morphological change and its relationship to age concentrated on the skull and the rate of closure of cranial sutures as a way to determine an individual's age at death, but experts soon realized that individual variability limited this as an accurate technique. New areas of the skeleton subsequently were examined as potential sites for age analysis: the dentition, the scapula, the vertebral column, the pubic symphysis, the auricular surface of the os coxae, and recently, ribs.

1.4.1a The Skull

The first investigations into the problem of aging adult human skeletal material concentrated on the rate of closure of the cranial sutures. Both ecto- and endocranial sutures were evaluated, and both were found to correlate with aging. (Dwight 1890b; Parsons and Box 1905; Todd and Lyon 1924, 1925a, 1925b, 1925c; Martin 1928; Wentworth and Wilder 1932; Montagu 1938; Hrdlicka 1939; Cobb 1952). The degree of individual variability in the rate of closure, however, mitigates against any reliable estimate of age. Todd and Lyon (1924) themselves observed that even their own investigations did not support "the uncontrolled use of suture closure in [the] estimation of age" (p.379; see also: Singer 1953; Brooks 1955; McKern and Stewart 1957; Nemeskeri et.al 1960;

Powers 1962; Stewart 1968; Kerley 1970, 1972; Brothwell 1981; Lovejoy et.al 1985a; Krogman and Iscan 1986; Bass 1987; Mann et.al. 1987). Endocranial sutures, especially the medio-anterior sutures, are the most effective cranial indicators (McKern and Stewart 1957; Johnson 1976; Krogman and Iscan 1986), but even here, predictive power is undependable at best. The relationship between suture closure and age is only a general one. Onset and progress are both highly erratic, and therefore suture closure "as either direct or supportive evidence for skeletal age identification, is generally unreliable" (McKern and Stewart 1957, p 37).

Other indicators of age found on the skull have been proposed. Todd (1924, 1939), Cobb (1952) and Roche (1953) each mentioned the thickness and texture of the skull as a potential morphological component to be evaluated. Neither has been substantiated by systematic testing or statistical analysis, and their reliability is suspect at the very least. Lines of muscular attachment were also investigated, as were the development of venous sinuses, Pacchionian depressions (pits on the interior of the cranium, associated bilaterally with the sagittal suture), and the grooves formed by the meningeal artery (Todd 1924, 1939; Cobb 1952). None were found to accurately reflect age at death (Moore 1955; Stewart 1968; Vlcek 1974; Krogman and Iscan 1986). The skull has been generally abandoned as a useful aging site, unless it is the only available skeletal component, or is used as a corroborative agent.

1.4.1b Dentition

Early methods of assessing age at death from the dentition focused on "changes occurring in the dental tissues" such as "attrition of the enamel, sclerosis of the dentin, denticles in the pulp, deposition of cementum, continuous eruption of the teeth and alterations in the periodontal structures" (Gustafson 1950, p. 45). Histological, radiographic and morphological techniques have all been assessed as to their respective viability for accurately aging human dentition (Schour and Massler 1944; Stewart 1963; Molnar 1971; Ubelaker 1978; Brothwell 1981)

Eruption sequences have been well documented and the corresponding age ranges have been established for subadult remains (Schour and Massler 1944; Fazekas and Kosa 1970; see also: Ubelaker 1978; Brothwell 1981; Krogman and Iscan 1986, pp 352-375; and Bass 1987). Aging the adult specimen, however, is somewhat more difficult.

Current methods forensic anthropologists use for adult age estimation based on the teeth rely primarily on the analysis of tooth morphology: dental calcification and dental attrition (Krogman 1927; Schour and Massler 1944; Gustafson 1950; Burns and Maples 1976; Johnson 1976; Ubelaker 1978; Brothwell 1981; Lovejoy 1985). Dental calcification is assessed through radiographic films: calcification occurs from the crown to the neck to the root. Schour and Massler (1944) developed an excellent illustrated method of visual analysis based on three stages of dental development: deciduous, mixed, and permanent dentition, covering four periods of an individual's life: infancy, early childhood, late childhood and adolescence and adulthood.

Dental attrition assesses the occlusal wear evident on dental remains, including the incisal edge and elevation of the cusps (Gustafson 1950; Butler 1972; Ubelaker 1978; Brothwell 1981; Lovejoy 1985; Lovejoy et.al 1985a; Krogman and Iscan 1986; Bass 1987). It is a valuable tool for age estimation, but tends to be population specific. Attempts have been made to evaluate dental attrition among members of diverse populations, but most work has been done (and most success has been found) with homogenous groups. The consensus is that "cultural, dietary, pathological and traumatic factors affect the wear pattern differentially" and "make the development of an age standard very difficult" (Krogman and Iscan 1986, p. 361; see also: Molnar 1971).

The forensic anthropologist is an observer of the morphology of dentition, but not an interpreter. The use of modern dental techniques (that is, clinical data which can be used for identification) remains only in the purview of the forensic odontologist. As an indicator for the anthropologist, dentition is a corroborative agent, rather than a diagnostic tool (Gustafson 1966; Ubelaker 1978; Brothwell 1981; Krogman and Iscan 1986; Bass 1987).

1.4.1c The Scapula

The scapular epiphyses provide accurate information to about age 25, based upon epiphyseal union. Following maturity, however, lipping and atrophic processes (which occur at the margin of the glenoid fossa, the clavicular facet, the acromial process), and the development of vascularity and "pleating" of the bone are the only means by which we can evaluate age at death from this bone, and these can give only limited and general indications of age (Graves 1922; Todd 1939; Cobb 1952; Stewart 1954, 1968; Stewart and Trotter 1954; Angel 1984, Angel et.al 1986).

1.4.1d The Vertebral Column

The vertebral column also provides only limited indication of age; there is a general linear relationship between osteophytosis ("vertebral lipping") and advancing age. Stewart (1958, p. 149) concluded that "osteophytosis by itself does not permit close aging of skeletons," and Howells (1965) evaluation of Stewart's data indicated the same.

The physiological variation of osteophytosis, its genesis and extent, is mitigated or exacerbated by lifestyle factors, as well. The presence of disease may affect the growth of osteophytes or may mimic the appearance of osteophytes (Steinbock 1976; Ortner and Putschar 1981); occupations which require an excess of pressure, weight, or strain on the back can trigger early development of bony growth on the spinal bodies (Allbrook 1956; Obysov and Mardonov 1969; Acsadi and Nemeskeri 1970; Ortner and Putschar 1981); and trauma can initiate the early development of osteophytosis itself, or arthritic conditions which can lead to the formation of bony growths on the vertebral bodies (Wells 1964; Steinbock 1976; El-Najjar and McWilliams 1978; Ubelaker 1978; Krogman and Iscan 1986; Bass 1987). Therefore, the presence or extent of osteophytosis is not an accurate factor for determining age at death. The bones of the spine, including cervical, thoracic, lumbar and sacral bodies, are best suited for corroborative evidence, rather than effective, reliable diagnostic criteria (Weisl 1954; Allbrook 1956; Stewart 1958; Howells 1965).

1.4.1e The Pubic Symphysis

The pubic symphysis is very valuable as an age indicator until the fifth decade; thereafter, it is essentially unusable (Hanihara 1952; McKern and Stewart 1957; Gilbert and McKern 1973; Hanihara and Suzuki 1978; Suchey 1979; Zongyao 1982; Snow 1983; Meindl et.al. 1985b; Suchey et.al. 1985; Angel et.al. 1986).

Todd (1920, 1921a, 1921b, 1921c, 1921d, 1930a) introduced and tested the technique of phase analysis for the pubic symphysis, and developed a very effective method of determining age. McKern and Stewart (1957) refined the techniques set forth previously, and attempted to account more directly for observed variation, and subsequent tests by Brooks (1955), Gilbert and McKern (1973), Zongyao (1982) and Meindl et.al. (1985b) have verified the applicability of the pubic symphysis as a locus of reasonably accurate age estimation, although the tendency of the technique seems to be a slight overestimate of real age, "especially in the .later decades of life." However, since the phases are arranged "in lustra of five years, the five-year spread is enough to cover any overlap" (Krogman and Iscan 1986, p. 154). In addition to normal variation, the stresses of pregnancy and child birth can complicate accurate estimation of age from the pubic symphysis.

1.4.1f The Auricular Surface

The phase method of aging skeletal remains has also been applied to the auricular surface of the coxals with appreciable success (Sashin 1930; Iscan and Derrick 1984; St. Hoyme 1984; Lovejoy et.al. 1985b). The articular facet between the sacrum and the coxals, the auricular surface and its accessory components can be useful elements in the estimation of age. Texture, shape, density, porosity, billowing, and granularity of the bone are all considered as they pertain to the auricular surface itself, as well as to the apex, the preauricular surface, the retroauricular area, and the superior and inferior demifaces.

The auricular surface is another valuable tool for the forensic investigator, but like the pubic symphysis, tends to be reliable primarily through the fifth decade. There may also be some differences in morphology based upon ancestry and sex, and pregnancy seems to affect the rate of change of the bone.

1.4.1g Additional Sites used in Aging Skeletal Material

Supplementing the sites and methods listed above are additional bones and processes that may prove to be necessary in cases of fragmentation, degradation, or incomplete recovery of remains. These include: (1) the union of the pelvic components (pubis, ilium, and ischium), which normally occurs in the subadult, and the union of the pelvic epiphyses, which appear in the teens and complete union around 23 years of age. These epiphyses are found on the ilium, and the ischial tuberosity and ramus (McKern and

Stewart 1957; Stevenson 1924); (2) the degree of union of long bone epiphyses and diaphyses (Stevenson 1924; Cowdry 1939; Stewart and Trotter 1954; Acsadi and Nemeskeri 1970; Angel et.al. 1986; Krogman and Iscan 1986); (3) union of the clavicular epiphyses, which normally occurs between 18-25 years of age (Stevenson 1924; Todd and D'Errico 1928; Todd 1930b, 1930c, 1933; McKern and Stewart 1957); and (4) changes in the sternum, including union of the sternal bodies, development of foramina in the sternum, and growth and calcification of the xiphoid process (Dwight 1890a; Martin 1928; Ashley 1956; McCormick 1981; Sun et.al. 1995).

Histological studies of aging correlates have been applied to cortical bone from various locations, including the femur, ulna, radius, and the sternum (Kerley 1965; Ahlqvist and Damsten 1969; Carlson et.al 1970); and radiological studies have been applied to the humerus, femur, pubic symphysis, the clavicle, and the bones of the wrist, shoulder and knee (Hansen 1954; Schranz 1959; Acsadi and Nemeskeri 1970). The intent of these studies is to enrich the state of knowledge of the disciplines involved with the examination of human skeletal remains. Building upon the work that has preceded them, recent scholars have added an impressive array of techniques for the analysis of the human skeleton, but much remains to be done: testing known and employed techniques; developing and testing new and innovative techniques; and educating the next level of students as to competent execution of skeletal examinations, and to the potentials and pitfalls of the disciplines involved.

One point that authors have emphasized in conjunction with the burgeoning knowledge of skeletal change is the excellent results generally obtained by a combined assessment of variables. This "multifactorial" approach looks at an aggregate of all features available, integrates methods where possible, and provides a much more reliable and accurate evaluation of the remains at hand (McKern 1954; Stewart 1954; Nemeskeri et.al 1960; Lovejoy et.al. 1985; Mensforth and Lovejoy 1985; Meindl et.al. 1990; Vesterby and Poulson 1997). As pointed out by Meindl and Lovejoy (1985, p. 65), "no *single* skeletal indicator of age at death is ever likely to accurately reflect the many factors which accumulate with chronological age, each of which can contribute valuable information to the age estimate. Any indication which both significantly reflects biological age and whose informational content is dependent of other indicators will be useful to a final estimate, whether under forensic or archaeological conditions."

1.4.1h The Ribs

Differences between racial groups in the patterns of ossification of the costo-chondral cartilage have been documented as a potential source of indication since the latter half of the 19th century (Bertillon 1889; Broca 1867; Cologlu 1998; Dwight 1878; Fischer 1955; Iscan et.al. 1987; Koebke and Saternus 1982). Differences between the sexes in the rate and extent of calcification of the costal cartilage have been documented since the early part of the 20th century (Rist et.al. 1928; Michelson 1934; Elkeles 1966; Sanders 1966; Navani et.al. 1974; Werner 1978; Soidekat 1982; McCormick and Stewart 1983; Markert et.al 1983; McCormick and Stewart 1983; Stewart and McCormick 1984; Iscan 1985; Rao and Pai 1988; Inoi 1997; Cologlu 1998).

Documentation of the rib in its developmental stages as an effective indicator of age in infants and children began in earnest in the 1930s (Tchaperoff 1937; Falconer 1938; Hill 1939; King 1939). A general linear pattern between adult age and the ossification of the costal cartilage was first examined on roentgenographic films in the 1920s and 30s (Rist et.al. 1928; Riebel 1929; Michelson 1934; Falconer 1938; King 1939). This early work concentrated on the calcification of the cartilage that separates the ribs from the sternum. Subsequent work examined the morphology of the sternum and the ribs as indicators of sex, which led to investigations of the microscopic structure of these bones and the utility of morphological changes as indicative of age.

In the following decades, the rib was seriously considered as a site of importance, although attention was paid predominantly to radiographic and histologic methods. Many methods for the assessment of age based on ribs have been proposed. Fischer (1955) investigated the calcification of the costochondral cartilage from roentgenographs. Sedlin et.al. (1963) evaluated the area of a grid obscured by the cortex of ribs cut in cross section. Their study found that the minimum area covered by cross sectioned cortical bone occurred in infancy, increased to early adulthood, and dropped off sharply thereafter. Given the normal development of the skeletal elements into early adulthood, and given that bone loss in general tends to increase with advancing age, and given that cortical bone tends to thin with age, their results seem less than striking. Their study, did, however, provide impetus for others. Semine and Damon (1975) studied costochondral ossification data, including chest plate roentgenograms, of adults from five populations and determined that ossification did increase with age, and mineralization may have been more pronounced among those populations studied which had a higher dietetic mineral intake. They also found indications of sex-linked ossification rates as a function of endocrine activity.

McCormick (1980, 1988) and Stewart and McCormick (1984) describe a method of radiographic analysis of the chest plate of a decedent. Working on the assumption that the relatively precise method of aging bone from amino acid racemization (and other microscopic techniques) is only precise when performed by experts who may or may not be available, or may be financially unavailable to most pathologists, McCormick found that his method could provide "acceptable accuracy while obviating the need for great expertise or expense" (1980, p.737). In the absence of an expert physical anthropologist, McCormick's study has some utility, insofar as it indicates a general linear pattern of increasing calcification with advancing age. As a reliable technique with which to assess the age at death of human skeletal remains, it has very little utility. Other authors have presented alternatives to the material above, strengthened the acceptance of techniques listed above, or provided insight into the failings of techniques listed above (see: Horner 1949; Epker and Frost 1965; Epker et.al. 1965; Elkeles 1966; Sanders 1966; Obysov and Mardonov 1967; Nishino 1969; Lagemann 1972; Navani et.al. 1974; Werner 1978; Saternus and Koebke 1981; Koebke and Saternus 1982; Fangwu 1983; Turovtsev 1984).

Building on the work primarily of Sedlin et.al. (1963), Epker and Frost (1965), Epker et.al. (1965), Nishino (1969), Semine and Damon (1975), and McCormick (1980, 1988), Mehmet Yasar Iscan and associates developed a technique of determining age from observed morphological changes in the sternal end of the right fourth rib was proposed.

This technique was first described by Loth et.al. (1983), and elaborated by Iscan et.al. (1984a, 1984b, 1985) and Iscan and Loth (1986a, 1986b) as an additional or corroborative location from which to determine the age at death of human skeletal material. The traditional approach to aging human remains by direct observation relies on only a few specific elements of the skeleton, which in many cases may be missing or damaged, therefore mitigating accurate evaluation of a decedent. New methods of analysis are essential "for cases where available methods are inadequate or inappropriate and corroborative evidence is necessary" (Iscan et.al. 1984a, p. 1094). The present study is an independent assessment of the technique of using the medial end of the right fourth rib as a viable addition to the methods of aging the human skeleton, and I propose the following hypotheses:

H_0) There is no change in the bony shape, structure, or quality of the sternal end of the right fourth rib that will correlate with real age at death (null hypothesis);

H_1) The morphological changes that occur at the sternal end of the right fourth rib are patterned and consistent, and can be correlated with age at death;

H_2) If H_1 is true, then the component method of assigning age based on the morphology of the sternal end of the right 4^{th} rib is more accurate than the phase method; and

H_3) If H_1 is true, then the phase method of assigning age based on the morphology of the sternal end of the right 4^{th} rib is more accurate than the component method.

1.5 The Results of Developing and Testing Procedures

No bit of human remains provides *prima facie* evidence to allow us to unequivocally state the details of the decedent represented, nor does any one method yield highly reliable results in and of itself. We must rely whenever possible on a multifactorial approach to the task of aging the human skeleton. This approach "incorporates age information from as many age indicators as are available for each skeleton" and "has been shown to be a highly reliable method of skeletal aging" (Bedford et.al. 1993, p 287; see also: Lovejoy et.al. 1985; Meindl et.al. 1990). In order that we may be confident in our multifactorial approach to aging the human skeleton, it follows that we must be confident in the techniques which comprise that approach. These techniques require independent tests in order that their veracity may be demonstrated and their efficacy replicated.

Aging from the rib end can provide one more tool for use in the estimation of skeletal age. In the case of complete adult skeletal remains, assessing the skull, the dentition, the components of the pelvis, the rib, and associated corroborative elements will provide highly accurate information, assuming that extreme variation due to pathological or traumatic conditions does not prevail. In the case of incomplete or degraded remains, all components available to the observer must be entered into the evaluation, and the greatest good will derive from the greatest number of ways we can assess the elements available to us. The nature of the problem in the latter case is such that we expect our estimates to encompass the widest possible set of variables which will still provide adequate parity for the individualization of a decedent.

In any case, the experience of the observer and the reliability of the techniques employed are fundamental concerns in the analysis of skeletal remains. Techniques must be proposed, tested, and verified, and made available to other investigators. As these techniques are confirmed, they must be demonstrated in the classroom and laboratory, as well as added to the arsenal of tools of the forensic anthropologist and brought to bear on case material.

CHAPTER II: Materials and Methods

2.1 The Sample

In order to evaluate the methods of determining age from the metamorphosis of the sternal rib end, I harvested specimens from autopsy cadavers at the Montana State Laboratory of Criminal Investigation, under the direction of the Montana State Medical Examiner Dr. Gary E. Dale, who has statutory authority and written permission to collect such samples. The specimens were obtained between 1993 and 1994. Only the right fourth rib was collected, as will be addressed below in the *Discussion* section of this paper. All soft tissue was removed from the bones using a soaking solution of trisodium phosphate and subsequent boiling. All specimens used for analysis were clean and undamaged.

The sample consisted of 57 specimens, and I only included in the analysis those individuals over the age of 15 (therefore, n = 54). Iscan et.al. (1984a, p. 1095) remarked that "the first morphologic changes [...] were not seen in the sternal extremity of the rib until after the age of 16 years", and Iscan et.al (1984b) concluded that morphological change in the rib end only began after age 17. Michelson (1934) found that calcification of the costal cartilage does not begin prior to age 11, while McCormick (1980) and McCormick and Stewart (1988) noted that morphological change in the rib end is not detectable prior to age 15. Within my own sample, simple variation in size notwithstanding, there is no marked change in the morphology of the sternal rib end before age 15. There were only 3 individuals in that age interval, however, which accounted for 5% of the sample. For the purpose of this investigation only individuals over the age of 15 were included.

2.2 Techniques for Analysis

Table 1 shows the frequency of specimens in each age interval. Approximately 82% of this sample was under the age of 50, with the highest concentrations in the twenties (21.0%) and thirties (24.6%). The mean age of the sample was 37 years, the median age of the sample was 35 years. The range in ages, excluding specimens 15 years of age or younger, was from 16 to 89 years.

Table 1. Age Distribution of Sample Specimens

Age Interval in Years	**N**	**%**
0-14	3	5.3
15-19	4	7.0
20-29	12	21.0
30-39	14	24.6
40-49	9	15.8
50-59	6	10.5
60-69	5	8.8
70 & over	4	7.0
Total	57	100.0

I evaluated two methods of analysis: component analysis, as done by Iscan et.al (1984b) (and comparable to the work of McKern and Stewart (1957) and Gilbert and McKern 1973)); and the phase method, as done by Iscan and Loth (1986a, 1986b), and Iscan et.al. (1984a, 1985) (see also Todd 1920, 1921a, 1921b, 1921c, 1921d, 1930a, 1939; Sashin 1930; Brooks 1955, Iscan and Derrick 1984; Lovejoy et.al 1985a; Meindl et.al 1985b).

2.2a Component Analysis

Each rib was examined with the application of three factors, or components, in mind, as described by Iscan et.al (1985b, p. 148). These factors are: (1) pit depth, (2) pit shape, and (3) rim and wall configurations, and are described below. Component analysis is used to quantify the morphological changes which occur at the costochondral junction. These metamorphoses are then assigned to one of six stages within each component, and subsequently totaled scores for each stage are considered. The stages within each component are then used to assign an age range to each specimen. The summary statistics for component analysis appear in Table 2.

Component 1, pit depth, is the "most obvious" of the age related changes in the sternal end of the rib. Maximum depth is measured by holding a depth caliper perpendicular to the point "where the distance between the base of the pit and the anterior or posterior wall is the greatest" (Iscan et.al. 1984b, p. 148). Cranial and caudal extensions of the rib wall are not used in measurement, because of the presence, in many cases, of irregular bony projections. Based upon the depth measurement, the specimen is then assigned to one of the six stages subsumed within the analysis of Component 1. After Iscan et.al. (1984b, p. 148) the six stages are determined as follows:

0. Flat to slightly billowy extremity with no indentation (pit) greater that 1.1 mm
1. Definite pit formation with a depth ranging from 1.1 to 2.5 mm
2. Pit depth ranging from 2.6 to 4.5 mm
3. Pit depth ranging from 4.6 to 7.0 mm
4. Pit depth ranging from 7.1 to 10.0 mm
5. Pit depth of 10.1 mm or more

Component 2 consists of the changes in the shape of the pit. The immature skeleton exhibits no field differentiation or a "slight, amorphous indentation, which, in about 1 year from its first appearance, develops into a structure which is V-shaped" (Iscan et.al 1984b p. 148). The shape is defined by the anterior and posterior walls of the rib, and gradually the bottom of the pit widens from a V-shape to the U-shape characteristic of advancing age. Component 2 is also divided into six stages, as follows:

0. This stage is used for juvenile and adolescent specimens with no pit formation at the flat billowy articular surface
1. A shallow, amorphous indentation (pit) is now present
2. Formation of a V-shaped pit with thick walls
3. The pit assumes a narrow U-shape with thin walls
4. Wide U-shaped pit with thin walls
5. The pit is still a wide U-shape, yet deeper, more brittle, and poorer in texture with some disintegration of bone

(Iscan et.al. 1984a, p. 148)

Component 3 evaluates the metamorphosis of the rim and wall surrounding the pit. Initially the rim is a rounded, regular border which begins to scallop, and "eventually, with advancing age, the rim and walls become increasingly irregular, thin and sharp" (Iscan et.al. 1984b, p. 152). As with Components 1 and 2, Component 3 is divided into 6 categories, as follows:

> 0. The 0 designation is for those specimens with a smooth regular rim and no wall formation
> 1. Beginning walls with a thick, smooth regular rim
> 2. Definitely visible walls that are thick and smooth with a scalloped or slightly wavy rim
> 3. A transitional stage between the regularity in stage 2 and the irregularity in stage 4. The scalloped edges are disappearing and the walls are thinning, yet the walls remain fairly sturdy without significant deterioration in the texture of the bone
> 4. The rim is becoming sharper and increasingly irregular with more frequent bony projections often most pronounced at the cranial and caudal margins of the rib. The walls show further thinning and are less sturdy with noticeable deterioration in texture
> 5. The texture shows extreme friability and porosity. The rim is very sharp, brittle and highly irregular with long bony projections. Occasionally, as the depth of the pit increases, windows are formed in areas where the walls are not complete
>
> (Iscan et.al. 1984b p. 152)

In theory, each stage in a component corresponds to a decade of life; that is, stage 0 reflects the first decade (approximately 0-10 years of age), stage 1 reflects the second decade (11-20) and so on. Biological development doesn't always correspond to our expected statistical outcomes, however, and we must often modify our calculations. Therefore, stage 0 generally encompasses ages up to about 15; stage 1 ages 15 to 20, and by the later stages we see wide fluctuations in the ages of represented specimens, often spanning several decades.

2.2b Phase Analysis

Phase analysis relies on the "distribution of specimens into phases [...] based on changes noted in the form, shape, texture, and overall quality of the sternal rib" (Iscan et.al. 1984a, p 1096; see also: Krogman and Iscan 1986; Iscan 1985; Iscan and Loth 1986a, 1986b; Iscan et.al. 1985, 1987). There are nine phases(0 - 8), and specimens are assigned to each phase based upon the description or quantification of morphological change. As with component analysis, phase analysis begins with the development of a pit in the medial articular facet of the rib, which widens and deepens with age. The rim of the medial wall changes from regular and rounded to irregular and scalloped, and ultimately loses uniformity. In addition to this, the wall surrounding the pit lengthens across the costochondral junction, and the overall texture and quality of the bone deteriorates. The formation and extension of the wall requires one caveat: the caudal and cranial projections of the medial rib are irregular, and generally not useful in analysis. The anterior and posterior walls are the sites of analytical importance.

As age advances, in general, the pit widens and deepens, the wall extends and thins, and the rim sharpens. "The overall texture and quality of the bone itself, dense, smooth, and solid in youth, deteriorate until the bone becomes very thin, brittle, and porous in the elderly" (Iscan et.al. 1984a, p. 1096). The various conditions of the pit, rim, and wall are the criteria used for assigning specimens to one of the nine phases, and subsequently determining an age range.

CHAPTER III: Results

The results of the component analysis and phase analysis are presented in this section.

3.1 Results of Component Analysis

Table 2 contains the descriptive statistics for component analysis, and includes the 95% confidence interval of the mean, standard deviation, and standard error. This is the interval within which I can assert, with 95% probability, the intended parameter (age of the specimen) is contained.

Table 2: Summary Statistics for Component Analysis

Stage or Score	N	Mean Age	SD	SE	95% Conf. Int. of Mean	Age Range
I-Pit Depth						
1*	4	27.3	17.86	8.93	14.7-74.5	17-54
2	14	28.3	6.06	1.62	24.8-31.8	21-45
3*	24	40.7	13.47	2.75	34.9-46.4	27-89
4	10	49.9	10.24	3.24	42.6-57.2	35-65
5	2	60.0	21.21	15.0	29.3-85.7	45-75
Total:	54					
II. Pit Shape						
1	3	18.3	1.15	0.67	15.5-23.2	17-19
2*	14	31.9	16.94	4.53	22.2-41.7	21-89
3	21	36.8	8.02	1.75	33.1-40.4	27-55
4*	14	49.2	8.22	2.19	44.4-53.9	31-65
5	2	69.0	6.60	1.83	41.4-91.3	63-75
Total	54					
III. Rim and Wall Configurations						
1	2	19.5	3.54	2.50	16.4-26.1	17-22
2	10	24.8	3.79	1.20	22.1-27.5	19-29
3*	22	37.2	13.70	2.92	21.3-53.5	26-89
4*	17	46.4	7.39	1.79	42.5-50.2	31-58
5	3	67.7	6.42	3.71	51.7-83.6	63-75
Total	54					
IV. Total Component Scores						
3	2	18.5	2.12	1.50	14.3-37.5	17-20
4	3	20.0	1.48	1.07	16.7-32.8	19-21
5	2	23.0	2.28	2.01	19.1-45.4	21-25
6	5	25.7	2.66	1.08	22.9-28.5	22-28
7	5	29.4	3.91	1.75	24.5-34.3	26-36
8*	5	42.0	26.36	11.78	09.3-74.7	29-89
9	10	36.5	8.18	2.47	31.0-42.1	27-54
10	6	42.5	7.89	2.79	35.9-49.1	33-55
11*	5	46.9	8.67	3.27	38.9-54.9	31-58
12	4	51.2	5.26	2.35	41.7-54.8	44-57
13	3	61.5	4.95	3.50	27.2-95.7	58-65
14	2	67.0	5.66	4.00	26.2-97.8	63-71
15	2	72.0	4.24	3.01	33.8-93.4	69-75
Total	54					

(* designates cells which are recalculated in Table 2A)

(Specimens with a score of 0 for each component were not included in the analysis, and do not appear in the results, as explained above.)

Table 2A shows the adjusted summary statistics for component analysis. Several observations fell at extremes of the various cells; these "outliers", included in the original analysis and in Table 2 above, have been removed from analysis in order to smooth the data. In table 2A, outliers from the analysis of component 1 (pit depth) with a score of 1 have been removed to reflect only the scores of specimens with expected age values. Outliers from the analysis of component 2 with scores of 2 and 4 have also been removed, as have outliers from component 3 with scores of 3 and 4, and outliers from the totaled component scores under the scores of 8 and 11. These outliers are as follows:

Component 1: one specimen with a real age of 54 scored a 1;
Component 2: one specimen with a real age of 89 scored a 2, and one specimen with a real age of 31 scored 4;
Component 3: one specimen with a real age of 89 scored a 3, and two specimens with real ages of 31 and 33 scored 4;
Components in toto: under the score of 8, one specimen with real age of 89 years, and under the score of 11, one specimen with real age of 31 years.

The adjusted results are shown below in Table 2A.

Table 2A: Adjusted Summary Statistics for Component Analysis

Stage or Score	N	Mean Age	SD	SE	95% Conf. Int. of Mean	Age Range
I. Pit Depth						
1*	**3**	**18.3**	**1.15**	**0.67**	**15.5-21.2**	**17-19**
2	14	28.3	6.06	1.62	24.8-31.8	21-45
3*	**23**	**38.5**	**8.93**	**1.85**	**34.7-52.4**	**27-58**
4	10	49.9	10.24	3.24	32.6-67.2	35-65
5	2	60.0	21.21	15.01	29.3-85.7	45-75
Total	**52**					
II. Pit Shape						
1	3	18.3	1.15	0.67	15.5-21.2	17-19
2*	**13**	**27.5**	**4.29**	**1.19**	**24.9-30.1**	**21-36**
3	21	36.8	8.02	1.75	33.1-40.4	27-55
4*	**13**	**49.2**	**8.21**	**2.19**	**44.4-53.9**	**31-65**
5	2	69.0	6.60	1.83	41.4-91.3	63-75
Total	**52**					
III. Rim and Wall Configurations						
1	2	19.5	3.54	2.50	16.4-26.1	17-22
2	10	24.8	3.79	1.20	22.1-27.5	19-29
3*	**21**	**35.0**	**7.59**	**1.66**	**31.5-38.4**	**26-55**
4*	**15**	**48.3**	**5.39**	**1.39**	**45.3-51.3**	**39-58**
5	3	67.7	6.42	3.71	51.7-83.6	63-75
Total	**51**					
IV. Total Component Scores						
3	2	18.5	2.12	1.50	14.3-37.5	17.20
4	3	20.0	1.48	1.07	16.7-32.8	19-21
5	2	23.0	2.28	2.01	19.1-45.4	21-25
6	5	25.6	2.66	1.08	22.9-28.5	22-28
7	5	29.4	3.91	1.75	24.5-34.3	26-36
8*	**4**	**30.3**	**2.50**	**1.25**	**26.3-34.2**	**29-34**
9	10	36.5	8.18	2.47	31.0-42.1	27-54
10	6	42.5	7.89	2.79	35.9-49.1	33-55
11*	**4**	**49.5**	**5.61**	**2.29**	**43.6-65.4**	**41-58**
12	4	51.2	5.26	2.35	41.7-54.8	44-57
13	3	65.0	4.95	3.50	27.2-95.7	58-65
14	2	63.0	5.66	4.00	26.2-97.8	63-71
15	2	75.0	4.24	3.01	33.8-93.4	69-75
Total	52					

(* designates cells which have been recalculated in Table 2A)

(Specimens with a score of 0 of each component were not included in the analysis, and do not appear in the results, as explained above.)

3.2 Results of Phase Analysis

This brings us to the method of phase analysis, a simplified version of component analysis, in which the overall morphology is interpreted as a gestalt. Specimens are still assigned a score, but it is based strictly on the "changes noted in form, shape, texture, and overall quality of the sternal rib" (Iscan et.al. 1984a). The pit is still an important factor in phase analysis, of course, but less significance is assigned to its measurable depth than to its observable extent and shape.

Table 3 shows the descriptive statistics for phase analysis, including the 95% confidence interval, standard deviation, and standard error. Similarly to component analysis, those ribs which were assigned to phase 0 are not included in phase analysis, as no morphological change was detected in specimens under 15 years of age.

Table 3: Summary Statistics for Phase Analysis

Phase	N	Mean	SD	SE	95% Conf. Int. of Mean	Age Range
1	3	18.3	1.54	0.67	15.4-21.2	17-21
2*	8	34.8	22.34	7.90	16.1-53.4	21-89
3*	14	34.6	6.70	1.79	30.8-38.5	27-54
4	10	39.6	4.69	1.48	36.2-42.9	32-47
5*	6	56.2	15.34	6.28	40.0-72.3	31-71
6	4	61.3	8.38	4.19	47.9-74.6	50-70
7	5	62.2	4.87	2.17	56.2-68.3	57-70
8	4	66.0	8.87	4.43	51.9-80.1	55-75

Total 54

(* designates cells which are recalculated in Table 3A)

(Specimens in phase 0 were not included in the analysis, and do not appear in the results, as explained above.)

As with component analysis, outliers occurred in some of the cells for phase analysis. These were:

Phase 2: one specimen with real age 89;
Phase 3: one specimen with real age 54;
Phase 5: one specimen with real age 31.

The outliers were removed from the sample in order to smooth the data, and a second analysis was conducted. The adjusted summary statistics appear in Table 3A.

Table 3A: Adjusted Summary Statistics for Phase Analysis

Phase	N	Mean	SD	SE	95% Conf. Int. of Mean	Age Range
1	3	18.3	1.54	0.67	15.4-21.2	17-21
2*	**7**	**27.0**	**4.65**	**1.75**	**22.7-31.4**	**21-34**
3*	**13**	**33.2**	**3.86**	**1.07**	**30.8-38.5**	**27-39**
4	10	39.6	4.69	1.48	36.2-42.9	32-47
5*	**5**	**61.2**	**10.31**	**4.61**	**48.4-73.9**	**47-71**
6	4	61.3	8.38	4.19	47.9-72.3	31-71
7	5	62.2	4.87	2.17	56.2-68.3	57-70
8	4	66.0	8.87	4.42	51.9-80-1	55-75

Total 51
(* designates cells which have been recalculated for Table 3A)
(Specimens in phase 0 were not included in the analysis, and do not appear in the results, as explained above.)

3.3 Summary

Component analysis, when considered as summed data, provides a reasonable method of age determination. The individual components, however, do not provide such a reliable picture. Component 1, pit depth, is nearly useless beyond the third decade, and components 2 and 3 realize limitations at about the same time. Phase analysis is a simpler technique and provides consistent results to the fifth decade.

CHAPTER IV: Discussion

4.1 Component Analysis

Analysis of the stages of component 1 (pit depth) shows an increase in mean age from 27 to 60. Inconsistencies occurred (see the description of outliers above) at stages 1 and 3, and were adjusted for subsequent analysis. The original statistics for the analysis (see Table 2) indicate that diagnosis of component 1 provides reliable data only for stage 2. The adjusted statistics indicate that stages 1 and 2 are reliable, while divergence begins to widen during stage 3, and the gap increases markedly in stages 4 and 5. Either summary renders analysis of component 1 by itself essentially useless, especially after about age 35. This is consistent with the results reported by Iscan et.al. (1984b).

Analysis of the stages of component 2 (pit shape) shows an increase in mean age from 18 to 69 years, with an average increase of 9 years in stages 1 through 3. Inconsistencies occurred with this component in stages 2 and 4; these were also adjusted for subsequent analysis. The summaries of the initial analysis indicate that stage 1 and 3 are reliable age indicators. The adjusted summaries indicate that stages 1 through 4 provide adequate aging data. This is also consistent with the results Iscan et.al. (1984b) reported.

Analysis of the stages of component 3 (rim and wall configurations) shows an increase in mean age 19 to 67 years, with inconsistencies appearing in stages 3 and 4. The original statistics (Table 2) indicated that reliable aging information can be obtained from stages 1 and 2; beyond that, the gap in age ranges renders this component unreliable at best. The adjusted summaries, however, indicate that stages 1 through 3 are constant and furnish adequate age data, and stage 4 is acceptable as well. Stage 5 of component 3 shows a marked increase in the 95% confidence interval; this stage might prove useful only as corroborating material.

The analysis of the summed component scores (1 + 2 + 3) suggests the relative value of this technique might lie in a total view of the sternal rib end. Individual components are risky as reliable tools for aging, but the sum of the parts seems to be an effective guide. This statement is mitigated by the fact that the sample size in the younger age ranges (approximately 15-22) is too small for adequate statistical viability. Total component scores of 3, 4, and 5, in both the original analysis, and subsequent adjusted analysis, do not provide compelling statistical evidence for the use of this technique in this age range. The limited sample sizes, however, constrain their predictive value. This is also true of the later summed component scores 13, 14, and 15. The sample sizes are similarly limited, and similarly constrain their predictive value. The middle scores, however, demonstrate quite well the efficacy of the summed component scores as a viable aging method. The 95% confidence intervals for scores of 6 through 12 are well within acceptable boundaries for the analysis of the age of a human skeleton. Close scrutiny of the totals reveals, however, that the real value of these sums derives from components 2 and 3. The metric quantification of the depth of the pit is an insignificant and unreliable piece of the rib aging puzzle.

4.2 Phase Analysis

The details of the original phase analysis are not as convincing as those of the subsequent examination. In the original, phase 1, phase 3, and phase 5 show expected results as pertains to the mean ages of each cell, and phases 1, 3, 4, and 7 show reasonable ranges for the 95% confidence interval; beyond that, however, the utility of this method is not convincingly demonstrated by the first statistical run.

The removal of the outliers significantly altered the prognosis for phase analysis: with the exception of phase 5, which retains a high standard deviation and wide 95% confidence interval, and phase 6, for the same reasons, the mean ages progress as would be expected, and the confidence interval also largely reflects expected values.

Phases 6 - 8 have generally large confidence intervals, but this may be due in fact to: (a) the relatively small sample sizes, and (b) the tendency for bone beyond about 30 years of age to vary dramatically. Atrophic changes in bone compel us to increase our age range estimates: in the juvenile skeleton we can estimate age usually within 1-2 years; in the 30s and 30s, we generally can provide ranges within a 5 year estimate; after the 30s, our estimates are usually only viable in decades.

The results of phase analysis for the purpose of this investigation are very encouraging, and suggest that it is a viable addition to the forensic investigator's analytical toolkit.

4.3 A Note on the Outliers

All of the results given above seem to indicate that change in the osseous material of the ribs takes place most rapidly prior to age thirty, which would confirm results obtained by other scholars. Bass (1987), Frost (1963), Hall (1978), Iscan et.al. (1984a, 1984b, 1985) and Iscan and Loth (1986a, 1986b, 1986c) all point to this understanding of the nature of bony metamorphosis. Certainly the development of the bony material of the rib ceases by about 17 years of age, after which time, the processes of degeneration and atrophic change, absorption and resorption, collude to change the cortical bone, and to extend the projections across the costochondral junction. The outliers of the sample are, for the most part, specimens within the age lustra in which we would expect to find the greatest variability. Understanding the nature of variation endemic to the human species is not something from which we ought to shy; rather it is an essential element we must consider when attempting to determine information from human remains. The design, trials, and implementation of methodological agents centers around variation, and its consideration within the analytical matrix.

The outliers in this sample were consistently grouped within the same age ranges for all analyses. This suggests three things:

1) there is consistent observer error; or
2) variation is such that wild extremes can occur; or
3) a combination of these exists.

I cannot discount the existence of observer error, because the standards in place for these techniques are descriptive and subjective. My interpretation of thick walls, or width and shape of a pit, or a scalloped and irregular rim may vary a great deal from that of Iscan, or others. On the other hand, I believe that my training has prepared me for the task of assessing the morphological condition of the sternal rib within the parameters established by Iscan et.al (1984a, 1984b).

The outliers in this sample appear to be extreme examples of the degree to which variation can exist at the same locus between different individuals. As listed above, one specimen with a real age of 54 years scored a 1 on component I. Based upon the results obtained by Iscan et.al. (1984a, 1984b, 1985) and Iscan and Loth (1986a, 1986b, 1986c), this would imply an age of approximately 17-25, and based upon my own results, the expected age would be the about the same. Bearing in mind that this component is strictly a metric measurement of the depth of the pit in the medial wall of the rib, observer error seems inapplicable to this particular specimen. Regarding the other outliers in component analysis, the specifications for analysis were adhered to, predicated on the visual guides found in Iscan et.al (1984a, 1984b, 1985) and Iscan and Loth (1986a, 1986b, 1986c). The outliers found in my sample do not cohere to the standards established.

The possibility of combined extremes of variation and observer error is a real contingency of any forensic analysis, including this study. The ideal forensic investigation would be undertaken by several observers, and results compared to elicit an agreed upon, and most reliable estimate of all elements and variables involved. This approach goes far towards eliminating, or at least substantially minimizing, the effects of observer error and skewed results deriving from variation.

4.4 Discussion Summary

The average values and confidence intervals reported above indicate that the structure of change at the sternal rib end is patterned and consistent, and associates above the average with real age. Phase analysis is a more reliable method based on my observations of this sample than is component analysis. This holds true for the specimens within this sample, especially when considering the adjusted summed component analysis and adjusted phase analysis.

CHAPTER V. Conclusions

5.1 Hypothesis Evaluation

The results of this study indicate that the null hypothesis (H_0) is invalid. There is, in fact, change that occurs in the medial wall of the rib, taking place in the shape, structure, and overall quality of the bony material. It is also evident that these changes do correlate with real age, as well, and are patterned and consistent on average. The first hypothesis (H_1), can therefore be validated on the basis of the results of this study. The patterns elucidated by Iscan et.al. (1984a, 1984b, 1985) and Iscan and Loth (1986a, 1986c, 1986c) hold for the specimens considered herein, and the aging correlates are also compatible.

The second hypothesis (H_2) assumes that if H_1 holds true, then component analysis will be a more effective analytical technique for again skeletal remains than the phase method. When considering the individual components, this is not true. The individual components are inadequate to the task of aging from the sternal end of the right 4th rib. The components considered as a sum provide a respectable degree of accuracy for determining age, but considering the technique as a whole, in comparison to the phase method, component analysis tends to be generally unreliable and indicates that H_2 is untenable.

Based upon the results of this study, hypothesis three (H_3) can be validated. The results given above are a strong indication of the reliability of the phase method as an indicator of age, and a method superior to the component method. Predictive power is strong for the estimation of age at death based upon phase analysis of the morphological changes indigenous to the medial rib.

5.2 Evaluation of Methods

Based upon observations of my own sample, I conclude that there is some difference in reliability between the phase and component methods. Analysis of the individual components is, in general, more highly variable than is ideal for the task of aging skeletal material. Component 1 is essentially ineffectual as an age indicator, while components 2 and 3 have inconstant utility to the fourth decade.

Phase analysis in this study also has its pitfalls, as mentioned above. The relatively small sample size used in this study could be, and probably is, one source of error. Data pertaining to variation will smooth with larger sampling, and provide a more reliable picture of the curve that exists, incorporating more "normal" specimens against the extremes will balance final results, and provide more reasonable data from which to draw conclusions regarding the viability of aging from the rib site. In the short run, however, the data I have provided, coupled with the data from Iscan et.al (1984a, 1984b, 1985) and Iscan and Loth (1986a, 1986b, 1986c), as well as the results derived from other independent tests (Lovejoy et.al 1985a; Russell 1993) confirm that the changes in the medial rib, even considering the variation within my own sample, are practical in their application to aging the human skeleton.

5.3 Further Research

This study, and the research upon which it is based, relies on the availability of the right fourth rib for analysis. As a research device this is reasonable, but real situations may not allow for this availability. Forensic and archaeological case material is often incomplete or damaged, and the right fourth rib may not be available for analysis. Iscan et.al (1984b, p.155) have suggested that the third and fifth ribs "may not significantly differ in morphology from that of the fourth rib and may provide equally reliable results," although this has yet to be systematically tested. Semine and Damon (1975) concluded that the rate of change of the first rib is much faster than the lower ribs; there is definitely potential for supplementary investigation into the possibility of inter-rib variation.

There is also potential for additional investigation regarding bilateral differences found among the ribs, as well as differences due to sex, and differences due to ancestry. Iscan et.al. (1987) have pursued this latter topic to an extent, and several other authors working with homogenous population material have contributed to the understanding of racial variation (Michelson 1934; Hanihara 1952; Semine and Damon 1975; Thompson and Gunnes-Hay 1981; Inoi 1997; Cologlu 1998). There is still room, however, for further investigation into the differences that may occur between populations.

Some effort has gone into the attempt to determine the extent of variability in the ribs based on sex. (Falconer 1938; Horner 1949; Fischer 1955; Elkeles 1966; Garn et.al 1966; Semine and Damon 1975; Iscan and Loth 1986c; Inoi 1997; Cologlu 1998). Differentials in hormonal output are believed to result in variations in the aging patterns found on the rib. This needs further investigation to reify the reliability and accuracy of the techniques of aging from the rib.

5.4 Summary

The objective of this project is to evaluate the accuracy and reliability of two methods of aging human skeletal material from the sternal end of the right fourth rib. These methods are called "Phase Analysis" after Iscan et.al. (1984a), and "Component Analysis" after Iscan et.al. (1984b). The fourth rib was chosen in order to replicate the work of Iscan and associates (1984a, 1984b), who determined that intercostal variation is such that the 3rd and 5th ribs “may not significantly differ in morphology from that of the fourth rib and may provide equally reliable results (Iscan et.al. 1985b, p. 155; see also: Semine and Damon 1975; McCormick and Stewart 1983; Lovejoy et.al 1985a; Loth et.al 1994; Russell et.al. 1993). In fact, further research into intercostal variation and variation between sides is warranted. If it proves to be true that there is little or insignificant bilateral variability, and that there is little or insignificant variability between the 3rd and 5th ribs, then the value of this technique increases. It has not been approached systematically, however, and the studies to which I refer, including this one, all proceed on the assumptions of inconsequential bilateral and intercostal variation. These could prove to be very misleading assumptions.

Variation itself is a fundamental concern of forensic anthropology, and a part of the intent of studies such as this is to account for it and design or assess appropriate models. In the case of the outliers in this study, the variation is such that I cannot account for it. There are factors affecting bone development and degeneration that remain to be systematically researched and applied to the models used in forensic evaluation. These factors include drug, narcotic and alcohol use, altitude adaptations, occupational stresses, functional loading of the skeletal structure, and disease. Research into the effects of these factors on bone has been undertaken in some cases, but remains to be correlated to the interests of forensic anthropology. Altitude adaptations are well documented, for example, but how the stresses involved affect the morphology of the medial wall of the rib has not been methodically carried out. Disease and drug use, and the interaction of both on bone development are additional areas that need to be investigated and documented, in order to mitigate the effects of variation on the outcomes of our examinations. In the case of my own sample, each of the decedents representing the specimens deemed as outliers were using drugs (both prescribed and illicit), ranging from sudafed to flurazepam to dalmane and phenobarbital, and each of them suffered from chronic illness ranging from HIV to seizure disorders to lupus.

An additional problem arises from environmental factors and the degradation of bony material. Older bone tends to increase in friability, and durability within the depositional environment determines which bones and to what extent bones will be recoverable and usable for analysis. This can limit the forensic examination, and can prove problematic for novice investigators. The effects of environmental degradation can seem to mimic the effects of aging (which can lead to abnormally high estimations of age), and can affect the remains of older individuals to the extent that no useful information can be deduced from their remains.

Aging techniques currently in use among forensic anthropologists consist of gross morphological examinations, physiological and histological analysis of osseous material, and radiographic (roentgenographic) examination of bone. Each method presents the analyst with its own set of valuable information and problems of appraisal. Development of new techniques is necessary to the evolution of the discipline, but testing and refining of techniques already in use is equally important. In addition, the techniques used by forensic anthropologists may also apply to archaeology and paleodemography, and can be applied by paleoanthropologists as a supplemental tool in the study of human evolution (Comas 1960; Olivier 1969; Acsadi and Nemeskeri 1970; Brothwell 1981; Ortner and Putschar 1981; Lovejoy et.al. 1985; Mensforth and Lovejoy 1985; Meindl et.al 1986). The value of deriving accurate information from the human skeleton transcends just the interests of the forensic community; our data and methods of analysis can be applied in a number of disciplines. Through the process of verification of the methods in use, we can develop a clearer understanding of the shortcomings and potentials of our work, and we can provide reliable and accurate techniques that directly benefit students, scholars, and researchers in a variety of academic and laboratory settings, as well as medicolegal personnel, and bereaved family members.

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