AGE ESTIMATION OF THE HUMAN SKELETON

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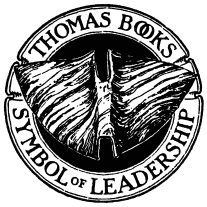

CHARLES C THOMAS • PUBLISHER, LTD.
Springfield • Illinois • U.S.A.

Published and Distributed Throughout the World by

CHARLES C THOMAS • PUBLISHER, LTD.
2600 South First Street
Springfield, Illinois 62794-9265

ISBN 978-0-398-07949-9 (hard)
ISBN 978-0-398-07950-5 (paper)

Library of Congress Catalog Card Number: 2010016116

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Printed in the United States of America
MM-R-3

Library of Congress Cataloging in Publication Data

Age estimation of the human skeleton / edited by Krista E. Latham, Ph.D. & Michael Finnegan, Ph.D., D-ABFA, with a foreword by Jane E. Buikstra, Ph.D., D-ABFA and Stanley J. Thine, Ph.D., D-ABFA.
p. cm.
Includes biographical references and index.
ISBN 978-0-398-07949-9 (hard)–ISBN 978-0-398-07950-5 (pbk.)
1. Human skeleton–Analysis. 2. Human skeleton–Growth. 3. Human body–Composition–Age factors. 4. Forensic athropology. 5. Forensic osteology. 6. Dental anthropology. I. Latham, Krista E. II. Finnegan, J. Michael. III. Buikstra, Jane E. IV. Rhine, Stanley, V. Title.

GN70.A34 2010
614'17–dc22 2010016116

To the memory of:
Alice M. Brues (1913–2007)
and
Sheilagh T. Brooks (1923–2008)

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FOREWORD

In ascertaining that a set of remains are both human and of medicolegal significance, the forensic anthropologist absorbs many impressions. These form an instant conclusion, a skeletal gestalt. However, most practitioners agree that creation of a biological profile should be undertaken in a very compartmentalized fashion, independently assessing sex, age, ancestry and stature. Later, one can more fully evaluate other attributes; ante-, peri- and postmortem trauma, state of health and other idiosyncratic features that might be useful in narrowing down the search for identity, and for attributes that would illuminate time since death, cause of death and other matters of medicolegal interest.

Aging younger individuals has traditionally depended upon an assessment of the maturation of the skeleton; the appearance of centers of ossification, epiphyseal fusion, development and eruption of the teeth, and in the very young, direct measurement of the bony elements. In older individuals the age estimation process has focused on degeneration of the skeleton as reflected in various joints of the body, such as the pubic symphysis, auricular surface and cranial sutures. Each of these continues to be the focus of ever-closer analytical scrutiny.

In the past few decades there has been a growing interest in assessing age by an analysis of the fine structure of bones and teeth. It may seem that this continued finer focus provides an alternate, more exotic, hardware-dependent and time-demanding analysis. Yet, not all of these methods will be used on a single case. Instead, we have an ever-expanding galaxy of potential approaches that can be selectively applied to any case.

Clearly, no single criterion is adequate for estimating age. Any estimate of age (or any other quality) is made more reliable and accurate by employing multiple approaches with multiple bones. While age may be estimated from the state of the pubic symphysis (for example), it is dangerous to place all of one's eggs in that–or any other–single basket. Evaluation of multiple bones through a combination of anthropometric, anthroposcopic and histological means offers convergent conclusions from methodologically independent sources, and thus the most robust results.

This volume effectively illustrates that the study of human osteology in a forensic context continues to become both wider and deeper.

STANLEY RHINE

INTRODUCTION

Age Estimation of the Human Skeleton represents a collection of some of the latest research in age at death estimation indicators of human skeletal remains using dental, gross morphological, histological and multifactorial techniques. The papers represent scientific research that has been conducted and presented at scientific forums within the past several years, and encompasses age estimation methods from all life-stage categories, including: fetal, subadult, and adult. This book will serve as a convenient starting point for practical and research applications.

INSPIRATION FOR THE VOLUME

This volume arose from various symposia at recent Mountain, Desert and Coastal Forensic Anthropologists meetings, focusing on methods of age estimation from the human skeleton. The symposia were organized by the editors, who noticed a great deal of research being conducted on this topic. The editors also recognized a need for an up-to-date book on aging human skeletal remains, as the last text available for this purpose was compiled in 1989, and significant scientific advances have been made since that time. There are several books available that have one or two chapters devoted to skeletal aging techniques. However, the full spectrum of techniques cannot be covered in one or two chapters and an entire volume on this topic is needed.

THE MOUNTAIN, DESERT AND COASTAL FORENSIC ANTHROPOLOGISTS

The Mountain Desert & Coastal Forensic Anthropologists meeting (MD&C) celebrates its thirtieth anniversary in 2010. From the beginning, MD&C has served as a forum to foster the presentation of new research and a continuing discussion of pertinent topics surrounding skeletal biology and forensic anthropology. This volume celebrates that legacy.

Looking Back

MD&C officially met for the first time in 1981 with nine attendees at the Southern Utah State College's mountain cabin. The first three meetings focused on regional variation of human skeletal remains, and resulted in the first MD&C inspired publication: *Skeletal Attribution of Race* (Gill and Rhine, 1990). These early accommodations were very rustic and remote, a combination that kept attendee numbers small and meetings very informal.

The MD&C meeting location changed to the Lake Mead Lodge in Boulder City, Nevada in 1986. With the change of venue came more attendees and the need for more organization. By 1988 the number of attendees rose to 41 and by 1989 MD&C had its first official schedule of presentations and first annual t-shirt. In 1991, *The Connective Tissue* became the official journal of the Mountain, Desert and Coastal Forensic Anthropologists.

The silver anniversary of MD&C was celebrated in 2005 with 37 attendees. By this time the atmosphere had shifted to a more balanced group of forensic anthropologists and eager students. The number of individuals wanting to present new or refined research grew to the point that a moderator was required to keep track of time. The Lake Mead Lodge closed its doors in 2008, and MD&C had to move to yet another location in Boulder City. Younger attendees try to maintain the original intent of the MD&C founders, while adapting to changing times. As attendee numbers rise and fall from year-to-year, one thing remains the same: MD&C is a favorite meeting for many anthropologists (historical information summarized from various volumes of *The Connective Tissue*).

Looking Ahead

MD&C was created as a way to gather forensic anthropologists and their advanced graduate students from the mountain, desert and coastal western part of the United States together in a friendly informal atmosphere to discuss the field of forensic anthropology. As attendee numbers have grown and demographics have changed, so has the face of the meeting. However, MD&C remains consistent in bringing out the best in its attendees. MD&C is distinct from other meetings with its informal attire and no titles attitude. This creates an environment where old and young, experienced and naive, debate and share ideas. A glance at regular attendees of the past and present reveal a long list of able-bodied forensic anthropologists. The first 30 years of MD&C have inspired numerous researchers and two volumes, and it is expected that there is still much to come.

K.E.L.

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A HISTORY OF METHODOLOGY IN THE ESTIMATION OF AGE AT DEATH FROM THE SKELETON

DOUGLAS H. UBELAKER

The history of the methodology of estimating age at death from the human skeleton is complex and incorporates a large and diverse literature. Given the limited space available for this section, I have chosen to focus only on key thematic developments as presented in landmark synthetic works. Special attention is devoted to the development of approaches based on newly recognized anatomical areas and perspective, which continued to influence research in later times. This approach, by necessity, limits literature coverage and indicates that some key individual studies are not examined exhaustively.

THOMAS DWIGHT'S PIONEER STUDIES

The work of Thomas Dwight (1843–1911) represents a useful entry point into the history of age at death estimation. T. D. Stewart (1901–1997) considered him to be the "father of forensic anthropology in the United States (Stewart, 1979, xii) since he became involved in forensic cases and made significant early contributions to the field. Working in Boston, Dwight conducted research and taught anatomy for decades, holding the Parkman Professorship of Anatomy at Harvard. Although he made significant research contributions to methods of age estimation (Dwight, 1881, 1890a,b) his reputation in forensic anthropology became established through his key prize-winning publication in 1878 *The Identification of the Human Skeleton, A Medico-Legal Study*. Given its historical prominence, this essay presents a useful platform to launch this examination of the history of age estimation.

Although Dwight's essay was general in nature, it addressed key points in age estimation that continue in importance today. Much of the most relevant discussion is presented in Chapter IV (Dwight's volume) entitled "The Age." In his introduction

to this chapter, Dwight noted that age can "rarely be given with any great accuracy" (Dwight, 1878:36). He highlighted the importance of sex difference in aging and that different methods apply to different general stages of life. Dwight recognized an immature stage up to age 25 in males and 22 in females, a young adult stage extending to about age 30, a mature stage from 30 to 60 and the "senile" stage "which may begin at a very variable period" (Dwight, 1878:37). For the immature stage, he stressed bone size and epiphyseal union, noting differences between beginning and final fusion and recognizing considerable variation in the timing of development. Dwight was so impressed with the likely variation that he refused to put these data in tabular form noting "The fact is, that the careful observations of some hundreds of skeletons of known ages, needed to settle this point, are yet to be made" (Dwight, 1878:37–38). This attitude contrasts with views presented in various anatomy texts of the time and such a cautious approach likely contributed to the honor Stewart later bestowed upon him.

Dwight also called attention to age changes in his young adult, mature, and senile stages, but was similarly concerned that variation was extensive and solid research needed to be completed. In a cautionary statement regarding cranial suture closure, which was later overlooked by others, he noted "the closure of the sutures which usually begins in the mature stage is another of those signs that are too variable to be depended on" (Dwight, 1878:38). He also cautioned of the variability in third molar eruption "they are like the trains of some railroads, due when they arrive" (Dwight, 1878:39).

In summary, Dwight's essay departed from texts of the time and likely won the award and Stewart's praise not because of the wealth of dogma, but because he called attention to how little was really known about variation in age progression and the need for research.

H. H. WILDER (1890–1971)

A professor at Smith College in Massachusetts, Wilder's name is closely linked with methodology relating to personal identification issues, including facial approximation. Trained as a zoologist in Europe, he became involved in forensic issues late in his career and coauthored a key synthetic work on personal identification (Wilder and Wentworth, 1918). Although much of Wilder's volume focuses on fingerprint analysis and other aspects of soft tissue identification, it contains a robust section entitled "identification of fragmentary, decomposed or dried remains; identification of bones and teeth." This particular section (Chapter VI in Wilder's volume) includes summary information on age estimation that reveals developments in thinking by that time.

Like Dwight, Wilder called attention to variation but was much more willing to offer specifics for age changes in bones and teeth. According to Wilder "the age of a

person under twenty-five may be quite definitely calculated from the skeleton, or even, occasionally, from a single bone" (1918:85). The Wilder and Wentworth publication (1918:87) provides a chart listing the fusion of the coracoid process of the scapula with the "main bone" at puberty, fusion of the basilar synchondrosis at the 16th year, fusion of the "three parts of the os innominatum" by the 18th–20th year and fusion of the iliac crest by the 25th–28th year. Dental eruption is discussed but not dental formation. Criteria for estimating age in the adult years focuses on obliteration of the cranial sutures, shifts in the mandibular angle and "the reduction of the angle between the neck, and shaft of the femur" (Wilder and Wentworth, 1918:88). Wilder does not discuss the database that such opinions are based upon and fails to echo Dwight's cautionary appeals for additional research.

HRDLIČKA'S "ANTHROPOMETRY" (1920)

Although Aleš Hrdlička (1869–1943) was known primarily for his contributions to other areas of anthropology (Stewart, 1940), he also made significant and pioneering efforts in forensic applications (Ubelaker, 1999). In an early synthetic work, which became a standard reference work for practicing physical anthropologists, Hrdlička (1920) addressed age estimation from skeletal remains. In this work, Hrdlička summarized basic age changes discussed by others above but stressed factors which in his considerable experience were especially useful. For the early adult years he emphasized the regularity of fusion of the basilar synchondrosis and reported age ranges of one to five years for complete fusion at various bone sites. He called attention to population variation in the timing of tooth eruption and dental wear. Hrdlička noted the age changes in cranial suture closure and suggested that considering suture closure and dental wear together, "we may correctly estimate the age of the adult subject to within, perhaps, ten years" (1920:99).

Hrdlička also noted "the pubic articulation shows important changes with age" (1920:98). Although no detail is provided, he cited a recently published study by T. Wingate Todd (1885–1938) "Age changes in the Pubic Bone" (1920) in the *American Journal of Physical Anthropology*. Since Hrdlička was editor of that journal at the time, he likely had an early exposure and positive impression of the content in that key article. This seminal article by Todd resulted from the then recent assemblage of anatomical collections of known age at death at the Anatomical Laboratory of Western Reserve University in Cleveland, Ohio, and set the stage for later developments in age estimation from the pubic symphysis.

Hrdlička's *Practical Anthropometry* published in 1939 presents a revised version of his 1920 publication and a glimpse at the minimal developments in age estimation methodology in the intervening 19 years. This version differs little from the previous volume, but provides a more specific guide to age changes in dental attrition. The previously mentioned quote in regards to age estimation from cranial sutures and

dental observations was modified to suggest an accuracy of "within less than ten years" (1939:47). For detail on recent research developments, Hrdlička refers readers in a footnote to publications by Todd (1930) on the pelvis and Graves (1922) on the scapula. Hrdlička also called attention to the importance of osteophytosis in age evaluation but presented no detail.

KROGMAN'S "GUIDE" (1939)

Historians of forensic anthropology (e.g., Stewart, 1979) have identified Wilton Marion Krogman's 1939 publication as a key development in the field. For the first time, Krogman (1903–1987) assembled important information on human identification from skeletal remains for publication in an outlet oriented toward law enforcement. The publication revealed to that community the value of scientifically-oriented analysis of human skeletal remains in the identification process. Although much of the general information is presented in a manner similar to publications by Hrdlička and others cited above, Krogman presented greater detail. He presented age information on different stages of cranial suture closure (begin, rapid, final) and added information on the dates of appearance of ossification centers.

In contrast to Hrdlička's publications, Krogman presented considerable detail on age changes at the pubic symphysis. He called attention to the gradual loss of billowing on the symphyseal face as well as the formation of "nodules," pitting and erosion. Krogman also noted how the use of x-rays could be valuable, highlighting changes seen in four stages of below 25 years, between 26 and 39, between 40 and 55 and over 56 years. Since the text is not referenced, it is not clear if Krogman's information was derived from the literature and/or from his own research.

STEWART'S EDITION OF HRDLIČKA'S *PRACTICAL ANTHROPOMETRY* (1952)

Following Hrdlička's retirement and death, T. D. Stewart published a revision of the classic reference work *Practical Anthropometry.* Although he kept Hrdlička's name in the title, Stewart put his own mark on the volume by significantly updating much of the information. Changes were minimal in the skeletal aging section with the most significant addition being a footnote calling attention to the then recent publication (1950) of the *Radiographic Atlas of Skeletal Development of the Hand and Wrist by Greulich and Pyle.*

MCKERN AND STEWART'S *SKELETAL AGE CHANGES IN YOUNG AMERICAN MALES* (1957)

In 1954, T.D. Stewart traveled to Kokura, Japan to participate in a military identification effort of United States soldiers killed during the Korean conflict. Data on various skeletal age changes were collected during the identification process on 450 young American males. These data later became the basis for the classic monograph published in 1957. In assembling these data, Stewart recognized the need for information derived from new samples in order to capture information on the vast range of human variation. He also recognized the existing paucity of data on relatively young individuals since most of the available anatomical collections were comprised of older adults. Stewart also suspected that most of the reported age ranges for various skeletal indicators were too restricted and did not take adequate account of the range of variation and the various stages of development and expression of the traits examined. The military sample offered a partial remedy to many of these issues.

Although the study was restricted to males, it represents an historical leap forward in that it examined age changes in greater detail than had been the case previously. For example, observations on cranial suture and epiphyseal closure were broken down into individual sutures and epiphyses and by four stages of closure (in addition to no closure). This approach yielded unique data on age variation in closure as well as information on population variation.

In their treatment of the pubic symphysis, McKern and Stewart decided to abandon the typological approach advanced earlier by Todd (1920, 1921) in favor of a more dynamic formula process. The authors were impressed with the approach taken by William Herbert Sheldon (1898–1977) in his efforts to study human physique. Sheldon's (1940) somatotype formula utilized three components of seven grades to characterize individual body type. Incorporating a simplified version of this concept, McKern and Stewart settled on the three component, five-subdivision system that was eventually published and widely utilized. This system recognized that the various components of the symphyseal face do not always occur in the same pattern and sequence as suggested by the Todd system.

KROGMAN'S *THE HUMAN SKELETON IN FORENSIC MEDICINE* (1962)

This classic text represents the first major synthesis of methodology in age estimation. Although the volume covered many aspects of forensic anthropology, 93 pages were devoted to the estimation of age at death. In contrast to his 1939 publication, the 1962 volume is very well referenced, so much so that it is difficult to separate Krogman's own data and opinions from the compilation from the literature. Reflecting his career interest in growth and development, the section on "the earlier years" is uniquely comprehensive for its time, presenting detailed information on

bone formation and a summary of the already complex literature on epiphyseal formation and closure. Absent from this section is information on dental development and eruption, keeping with the emphasis on the "skeleton" implied in the title. Although little totally new information is presented in the text, it presents for the first time an exhaustive survey of the published literature with insightful commentary from a very experienced practitioner.

Krogman dedicated the book to T. Wingate Todd "with whom I studied and from whom I learned." Thus it is not surprising that Todd's work is prominently presented in the volume. He presented both the Todd, and McKern and Stewart systems of assessment of the symphysis pubis, but commented "with the basic work of Todd and the refinements introduced by Brooks and by McKern and Stewart, the pubic symphysis takes it place as the most reliable indicator of age in the human skeleton" (1962:105). Although Krogman provides considerable discussion of variation of age indicators, much of the data presented seem to be overly concise even by standards of the time. He concludes the aging sections with the statement referring to the third and fourth decades "using pubic symphysis plus other skeletal criteria, I'd venture an accuracy of plus or minus two years" (1962:111).

STEWART'S *ESSENTIALS OF FORENSIC ANTHROPOLOGY* (1979)

As with Krogman's 1962 volume, a major segment (62 pages) of Stewart's synthetic volume focused on methodology relating to the estimation of age at death. In contrast to the Krogman volume, Stewart included a carefully selected literature review, which reflected his sense of the most appropriate techniques available. In addition to the approaches to immature age estimation included in the Krogman volume, Stewart added a robust discussion of dental formation and eruption, noting the importance of teeth in age estimation of the young.

For adult estimation, Stewart included the then recent study of Gilbert and McKern (1973), which extended the McKern and Stewart system of evaluating the pubic symphysis to females. He also provided detail from the literature and his own research on arthritic type change in joints, histological dental approaches, studies of change in cancellous tissue, and bone microstructure including Ellis R. Kerley's (1924–1998) studies of age changes in histological features of compact bone (Kerley, 1965, 1969, 1970). The volume is distinctive from previous works in: (1) producing methodology focusing on a broader range of anatomical structures, (2) increasing awareness of variation in most age changes, and (3) the need to be selective in consulting the supportive published literature.

SUMMARY

In this survey of historical developments in methodology to estimate age at death from skeletal remains several trends are apparent. The most obvious development is the gradual recognition through research that different areas of the skeleton convey distinct information on age change. For adults, the early reliance on dental attrition and cranial suture closure gradually shifted as new techniques came on line. While evaluation of the pubic symphysis barely was discussed in Hrdlička's time, it gradually began to dominate adult age estimation with later research efforts by Todd, McKern and Stewart, and Gilbert and McKern. Clearly the discussion of histological methods, which are so prominently featured in Stewart's 1979 volume, were not on the radar screen of earlier synthesizers.

Another clear development is the gradual recognition of the importance of variation in age estimation and its resulting impact on error. In hindsight, modern forensic anthropologists likely would consider the very early attempts at age estimation to be overly precise with insufficient recognition of the actual error involved. This early naïve precision was a product of the available data and lack of research on samples of more diverse origins and of greater age range. Gradually such research has been conducted with the growing perception of human variation in most of the attributes developed.

Another trend apparent in the literature examined here is the increasing awareness of the need for additional research and access to larger and more diverse samples. While Dwight recognized aspects of this need, real progress had to await the acquisition of suitable samples of individuals of known age at death. Such samples were gradually assembled either by the careful curatorial efforts of anatomists such as T. Wingate Todd or the more opportunistic data collection by T. D. Stewart in his human identification efforts.

An additional recognizable pattern involves more complex and sophisticated methodology. Approaches have a growing tendency to recognize that different methods are more appropriate and effective for different age ranges. Increasingly, methodology calls for combining different approaches with the realization that combined approaches are frequently more effective than isolated ones.

Although these developments play prominent roles in the history outlined here, they do not stop with Stewart's 1979 synthesis. These trends continue into more recent periods and play dominant roles in the material presented in this volume. Existing efforts to improve methodology in the estimation of age at death build on the accomplishments and revelations of past initiatives. Many of the developments recognized as being important by our academic ancestors remain key today.

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ACKNOWLEDGMENTS

The editors would like to acknowledge all those who have participated in the Mountain Desert and Coastal Forensic Anthropologists (MD&C) meetings over the past thirty years. MD&C provides a forum for the presentation and discussion of scholarly work in the field of forensic anthropology, and it was at MD&C that the majority of these papers were originally presented and at which the inspiration for this volume was realized.

We would like to extend our gratitude to Drs. Bruce Anderson, Jerry Melbye and P. Willey for reviewing the material and providing feedback regarding the papers in this volume, and to Amandine Eriksen for designing the cover illustration. Our thanks to those individuals who assisted with the preparation of the volume, especially Elizabeth DeVisser, Elena Madaj, Megan Madonna and Imran Musaji. We also wish to acknowledge the patience and support of our friends and family during the preparation of this volume.

Finally, the editors would like to thank the contributors to this volume for their hard work and efforts. It has been a pleasure working with you all over the past two years. Our gratitude to Mr. Michael Thomas of Charles C Thomas Publisher, Ltd. for his patience and assistance throughout this process.

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Chapter 1

DENTAL AGING TECHNIQUES: A REVIEW

JEREMY J. BEACH, CHRISTOPHER W. SCHMIDT, AND RACHEL A. SHARKEY

INTRODUCTION

Determining the age at death for skeletal remains has always been a primary concern of the biological anthropologist and dental remains, in particular, can play a central role in assessing the age of an individual. Teeth are usually available to the anthropologist for the construction of a biological profile because they are durable and preserve very well, even when other aspects of the skeleton have long since decomposed. Their ubiquity in archeological and forensic contexts has led to a plethora of literature regarding dental aging techniques. This chapter provides a summary of some of those techniques in an effort to assist biological anthropologists in distilling the vast literature that currently exists, but, by no means constitutes an exhaustive reporting of all techniques, regardless of their efficacy. Instead, we have chosen to highlight some of the more useful approaches to aging teeth, both past and present as the intended audience includes biological anthropologists, professional and student, as well as those in forensic odontology and forensic dental anthropology (e.g., Schmidt, 2008).

Usually, the first stage of any skeletal study is the determination of the biological profile, which minimally consists of the individual's age, sex, and ancestry. The indicators used to create the biological profile, of course, depend on those anatomical landmarks that are present at the time of the study. The fact that tooth enamel is nearly 100 percent mineral makes it an extremely durable substance. The density of enamel also makes it quite impervious to many taphonomic effects. As a result, tooth crowns are usual-

ly present for anthropological examinations. In addition, the root structures of teeth are housed in the alveolar bone of the mandible and maxillae, which protect them from degradation. Thus, entire dentitions are often available for age determination.

Dental aging techniques can be broken down into two major categories. The first of these categories is centered on the developmental changes that occur to the human dentition while the teeth are growing and emerging into the oral cavity, and the second involves the degenerative changes that occur once the teeth have erupted and begin to wear down.

DEVELOPMENTAL AGING TECHNIQUES

Hard Tissue Formation

Tooth formation begins very early in the life of an individual. By six weeks *in utero* tooth primordia are lining up along the margin of what will soon be the embryonic mouth. These buds are derived from the same embryonic tissues that make the skin, thus teeth are a function of both the skin and the skeleton. Over time the cells in the buds make the shape of the tooth and eventually enamel and dentin are placed down to form the crown and root, respectively. Thus, a fetus that is no more than a few months old has dental hard tissues present in both its upper and lower jaws. By the time a baby is born, all of its deciduous crowns have either formed or are in the process of forming, and even one adult tooth crown, that of the first molar, is in the initial stages of development.

Documenting the sequence of dental formation is an avenue of research that has been greatly studied in the past, and of these earlier studies Moorrees et al. (1963a, b) is probably the best known. This radiographic study looked at the formation of both the coronal and radical portions of the permanent dentition as well as the eventual apical closure. From these observations, Moorrees and colleagues (1963a, b) came up with a standard rate and sequence of formation that could be used to estimate age more precisely than using eruption alone. The method involves scoring each tooth for its developmental stage, then comparing those scores to values representing a particular age. For example, a deciduous first incisor crown that is fully formed and is recovered adjacent to a deciduous second incisor crown that is only three-fourths complete is consistent with a single individual aging to less than 6 months old. But, if a complete deciduous second molar is found in associa-

tion with these two teeth, then suspicion might be raised that more than one individual is present because deciduous molars usually do not complete their formation until after the age of two. Thus, the analyst determines an MNI or minimum number of individuals represented in any assemblage simply by inventorying the teeth. Should a particular tooth be present more than once, or should teeth of disparate developmental age be found commingled, the dental inventory will show that more than one person is present.

The chronological development of dental hard tissues is not a uniform process that is identical in all populations. Differences have been noted between groups of different ethnic backgrounds (Harris and McKee, 1990; Harris, 2007; Blankenship et al., 2007). In particular, Harris and McKee (1990) noted that tooth mineralization of populations of African ancestry from the American south maturated at a significantly faster rate than comparable populations of European ancestry by about as much as 5 percent. This is why it is so vitally important that the biological anthropologist be well experienced and versed in how human variation is manifest in the human skeleton and dentition. Improper application of dental aging techniques can lead to inappropriate assessment of a biological profile.

The Demirjian (1973, 1976, 1980) technique of scoring dental maturity has been frequently applied for aging individuals of unknown age within the realm of forensic science (TeMoananui et al., 2008; Tunc and Koyuturk, 2008; Rózylo-Kalinowska et al., 2008; Martin-de las Heras et al., 2008). The technique was intended as a measure of maturity of the dentition of younger individuals. Each tooth in the dentition is scored on an ordinal scale and from these values a composite score is computed that represents the overall developmental state of the individual. While this approach has been valuable in those instances where the dentition is complete, as Hillson (1996) points out, this methodology is not applicable when some teeth are missing, as is the case in certain archeological populations where tooth loss due to cavities or extreme wear is common. Moreover, when the Demirjian technique was applied to populations other than those with which Demirjian developed his standard, it was found that the methodology tended to overestimate age (Moananui et al., 2008; Tunc and Koyuturk, 2008; Rózylo-Kalinowska et al., 2008).

Dental Eruption

Schour and Massler's well-known 1941 and 1944 studies detail the eruption sequences of the human dentition by establishing 22 eruption stages and their