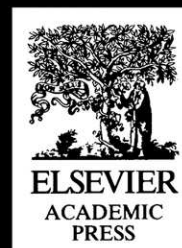




Developmental Juvenile Osteology

Louise Scheuer and Sue Black

Illustrations by Angela Christie



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Ultrasound picture of a fetus *in utero* at 20 week's gestation.

Developmental Juvenile Osteology

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525 B Street, Suite 1900, San Diego, California 92101-4495, USA
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Elsevier Academic Press
84 Theobald's Road, London WC1X 8RR, UK
<http://www.elsevier.com>

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library.

ISBN 0-12-624000-0

Produced and typeset by Gray Publishing, Tunbridge Wells, Kent
Printed in Great Britain by Bath Press, Bath, Somerset
03 04 05 BP 9 8 7 6 5 4 3 2

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Foreword: The Development of Juvenile Osteology

The importance of this volume will be immediately obvious to anyone who has been confronted with fetal or juvenile human osteological material in an archaeological, palaeontological, forensic or physical anthropological context. There is simply no currently available reference work that deals with the fetal and juvenile human skeleton in sufficient detail to be practically useful. Louise Scheuer and Sue Black have recognized a major gap in the field and have responded with a volume that is sure to become a classic wherever there is an interest in the identification and interpretation of the human fetal and juvenile skeleton.

It is perhaps easy, or relatively so, to recognize a need for a major reference work. It is much more difficult to fill that need. Both Scheuer and Black are highly experienced anatomists with many years of classroom and research experience. There is no doubt about their qualifications to carry out this task. But even so, I doubt if at the beginning they realized the enormity of the project they had set themselves or the length of time that would be needed to bring it to fruition. One major obstacle was their conviction that the book must be based on skeletal material of known age to avoid the circularity of discussing age-specific skeletal development on the basis of material that itself was aged using skeletal size or morphology. This proved to be difficult because such skeletal material is so rare and required considerable detective work to bring together. A second obstacle was the wealth of previously published material scattered in many disparate references relevant to many different disciplines and published in many different languages. The bibliography is large, spans 300 years and the information presented therein has been meticulously sorted and summarized. This in itself is a highly valuable contribution to the field. The absolute insistence on documentation and accuracy of both the skeletal and

the contextual information in the book will ensure that it becomes a classic in the field.

In recent times, descriptive anatomy has taken a definite back seat to the various biochemical approaches to skeletal analysis. Among others, these new approaches include DNA analyses that have the potential to uncover the genetic basis of skeletal growth, the sex and possible familial and/or ethnic affiliation of skeletal material and the infectious diseases that the individual suffered in life. There is also the possibility, through stable isotope analysis, of determining the diet of the individual. In many academic departments, topographic anatomists live in the shadow of the perceived cutting-edge importance of these newer biochemical approaches to the understanding and interpretation of skeletal material. There is no doubt that these approaches are important, have enriched the disciplines that deal with the interpretation of skeletal material and have great potential to continue to do so. But there is still much to learn and understand through the study of whole organisms. Macro-anatomy gives much more than context and background for these newer biochemical techniques. It is here that this contribution will provide an invaluable and unparalleled resource.

Archaeologists, forensic pathologists and anthropologists will simply not be able to do without it in the context of recognizing and identifying fetal and juvenile material. It will also be invaluable to anyone interested in human growth and development. For example, in my own field of human palaeontology, there is a growing realization that there have been major changes in the tempo and mode of ontogeny in human evolution and that a good understanding of these ontogenetic patterns will provide significant insight into our own evolution. To date, this work has focused primarily on the dentition, but this volume will

provide the necessary comparative context to facilitate the interpretation of skeletal growth and development in pre-human fetal and juvenile material.

Scheuer and Black have put considerable thought into the organization of this work, making it not only informative, but also accessible and practically useable. The meticulous descriptions of each individual bone are clearly written and logically presented. The 'practical notes' for identification of all bones are invaluable to the field worker, as are the clear and beautifully executed illustrations by Angela Christie.

There is no doubt that this reference will outlive the current generation of researchers. The authors and artist should be congratulated on providing a resource that will facilitate the research of so many current and future scientists whose work touches on the analysis of human fetal and juvenile skeletal material. On behalf of all of us, I offer them a sincere and well-deserved thank you.

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Head of Department of Anthropology
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Preface

It has been our privilege for the past 20 years and more to be involved in both the undergraduate and postgraduate teaching of the anatomy of the developing juvenile skeleton. The motivation to write this book arose from our own personal awareness of the general inadequacy of textbook assistance and indeed the absence of a text that is dedicated solely to the subject. Although, like many of the basic aspects of biological studies, one is certain that the required information will be available somewhere, it is often extremely difficult, costly and time-consuming to track down these original details from individual papers. Many embryological, anatomical and osteological books do summarize some of the facts about the developing skeleton, but there is often a limited amount of additional information on other equally important aspects. Even after extensive literature searches, we are still unaware of a single text in the English language that amasses a reasonable volume of information on this subject.

Regrettably, fetal and juvenile osteology receives little attention in modern-day anatomical, medical, anthropological and forensic teaching. It has been suggested that this might have arisen partly through the profound paucity of suitable teaching specimens, compounded perhaps by a lack of experienced teachers. However, the lack of a dedicated text must be unquestionably one of the fundamental underlying reasons for this regrettable situation. As a result, the developing skeleton has been dubbed somewhat of a 'Cinderella' in the academic osteological world, although it is interesting and encouraging to note that in recent years there is some evidence of a resurgence of research in this area.

When we began to write this book we envisaged a slim field/laboratory manual with a limited amount of additional background information. However, as our literature searches progressed so the book has expanded beyond the boundaries of our initial inten-

tions because we encountered so much information that was, in our opinion, either too important to be omitted or simply too interesting to be ignored.

Our primary aim was to bring together the vast literature on the topic of the developing skeleton and, along with illustrations from our own specimens, to chart the development of each bone from its embryological origin to its final adult form. It has always been our intention that the text will be primarily aimed at physical anthropologists, forensic pathologists, archaeologists and palaeontologists but we hope that it may perhaps prove both interesting and useful to a wider clinical and scientific audience.

While we have attempted to restrict our information to the field of anatomical and osteological details, information on the developing skeleton arises from many diverse literature sources including anatomy, embryology, physical anthropology, palaeontology, pathology, paediatrics, orthopaedics, radiology and orthodontics, to mention but a few. Where possible, we have attempted not to stray too far into the obviously related fields of auxology, biological anthropology or (palaeo) pathology but often this has proved somewhat difficult. During the searches of the literature, especially in the older texts, we have often come across 'little gems' that have fascinated or amused us and we have included these as footnotes throughout the book. In this way we hope that they will not interfere with the flow of the text but will add a little levity to what can often be a 'heavy' read.

We were acutely aware from the outset that the quality of the illustrations would be critical to the value of the text. We soon realized that they would in fact have to be hand-drawn, as photographs proved to be unacceptably inferior in quality due to the variability of the bone specimens in preservation, colour, etc. We were extremely fortunate to discover the exceptional talents of Angela Christie who painstakingly drew every half-tone illustration in the text from actual bone

specimens and subsequently made many adjustments at our exacting request. Uniquely, the majority of the material displayed in this text is of documented age at death and, where appropriate, such information is clearly stated in the legends. In some instances we have included photographs and radiographs, many of which arose from the research projects undertaken by our BSc students throughout the years. Credit is naturally given to their dissertations in the bibliography and although they may not be readily accessible for direct consultation, it is our hope that given time, the details of their work will find their way into the literature.

Apart from our students, there are many other people who have helped us throughout the production of this text. We are especially indebted to our friend and colleague, George Maat from Leiden University, who has read and commented upon the entire text. Leslie Aiello, Tim Cowan, Christopher Dean, Sheila Jones, Mike Moore, Robert Poelmann, Shelley Saunders, and Anthony Wright have also read and commented upon parts of the script and for this we express our most sincere thanks. Helen Liversidge generously gave permission for unpublished data to be quoted. We have also received help with information, specimens and photography from John Norton and Tjeu Gysbers at the Royal Free and University College School of Medicine, Martin Greig of Queen Mary and Westfield College, Sarah Smith of the United Medical and Dental Schools, Gus Alusi and João Campos of the Institute of Otology and Laryngology and Margaret Clegg at University College.

We are grateful to Jamanda Haddock of the Department of Radiology at the Royal Free Hospital for permission to use the ultrasound picture of the fetus *in utero* which was taken by Sally Blackmore.

We are particularly indebted to Detective Chief Superintendent John Bunn, Detective Superintendent Duncan Jarrett, forensic photographer Nick Marsh and Photographic Officers Matt Sprake and Neal Williams of New Scotland Yard for their permission to include some photographic specimens.

For their assistance and invaluable access to various skeletal collections we gratefully acknowledge Theya Molleson of the Natural History Museum, Canon John Oates of St Bride's Church, Professor Almaca and Luis Lopes of the Museu Bocage in Lisbon, Joanna Norris and particularly the St Barnabus excavation team – Joy Pollard, Sheila Gates, Jacqui Bowman, Gerry Doyle and Sarah Smith. Searching the literature has proved to be a monumental task in the production of this text and we wish to thank Professor Peter Vanezis and Maria Vanezis of the University of Glasgow, the librarians at the Royal Free Campus of the Royal Free and University College Medical School, Mark Wilmshurst at the Royal Society of Medicine library and Simon Barker at Aberdeen Royal Infirmary for their help and encouragement. Special thanks are issued to The Anderson Cars Group for invaluable assistance with many practical matters, including photocopying and printing.

We are indebted to Andrew Richford and Graham Allen of Academic Press and especially to Lesley Gray of Gray Publishing for their support and encouragement throughout the production of the text.

However, it is the constant support and encouragement of our husbands, Peter Scheuer and Tom Black, that deserve our most sincere gratitude.

Louise Scheuer
Sue Black

Introduction. A Guide to the Text

It must surely be clear that if we wish to safeguard the interests of our science (physical anthropology), and of those innocents who identify themselves with it, and who by so doing voluntarily condemn themselves to a precarious, albeit interesting life brachiating as it were from one lower income bracket to another, then it is our duty to see to it that they are properly equipped for the work which they wish to do and which so urgently requires to be done.

(Montagu, 1941)

The correct identification of the skeletal components of the juvenile skeleton is critical to the analysis of skeletal remains, regardless of whether they are of archaeological or forensic origin. Without such information it is virtually impossible to establish the number of individuals represented, let alone ascertain their identity. Indeed, a lack of familiarity with immature remains has led, on more than one occasion, to their identification as 'non-human'. Once the remains have been confirmed as human, the next step is usually an attempt to establish the four principal parameters of biological identity (sex, age at death, stature and ethnic affinity). However, with juvenile skeletal remains it is often only the determination of the age at death that can be established with any degree of reliability. Sex determination from juvenile remains is tentative at best and stature is so closely linked to the age of the individual that it is often used to predict it. Race is difficult to establish in the adult, so in the child it is virtually impossible, especially when only skeletal remains are presented.

The main purpose of this book is to describe each individual bone of the skeleton, or indeed different components of a bone, from its embryological origin to the final adult form. It is hoped that this systematic approach will assist the processes of both identification and age determination of the juvenile skeleton.

Chapters 2–4 form an introduction to the juvenile skeleton. **Chapter 2** deals with many of the fundamental issues concerning juvenile skeletal remains including the origin of such material, the various techniques by which it has been studied, the variability of child growth, the dilemma of biological versus chronological age and skeletal versus dental age. **Chapter 3** examines the more specific cellular and vascular nature of bone growth and development. It discusses the ontogenetic development of bone from its mesenchymal origins, through a cartilaginous or membranous template, to its eventual transformation

into bone. Bone growth is considered, as is the influence of its vascularity. **Chapter 4** gives a very brief outline of the early embryological development of the human body as a whole, and sets the scene for the more specific developmental aspects of the skeleton that are discussed in subsequent chapters.

Chapters 5–11 form the core of the text and describe the morphological development of the immature skeleton in a way that permits the ready identification of each skeletal element and thus allows an evaluation of the age at death of the individual. The chapters are arranged in a topographical order, commencing with the axial skeleton and continuing with the upper and then the lower limb girdles and their associated appendages. Each section is essentially separated into four sections – the adult bone, early development, ossification and practical notes.

Each section begins with a description of the **adult bone(s)** but this is far from an exhaustive consideration of the subject as there are many excellent texts written specifically to fulfil this purpose. However, it was deemed necessary to include this section primarily to ensure consistency of terminology used in the subsequent sections on the development and ossification of the bone. Where possible, the accepted standard anatomical planes and terminology have been used throughout, although more commonly used names and others that reflect a historical origin have sometimes been included. Several anomalies of the adult skeleton have been included as this is an important concept that is diminishing as teaching moves away from more traditional methods towards computer models and plastic skeletal teaching aids (Willan and Humpherson, 1999). Whilst it is appreciated that these minor skeletal variants may be of limited clinical value, they can occasionally prove extremely important in the identification of the deceased. In anthropological terms of course, many of these anomalies are referred to as non-metric traits

that may be considered indicative of potential genetic influences (Berry, 1975; Finnegan, 1978). A variety of relevant clinical conditions has also been introduced in this section where they have some bearing on the future development of the bone. Comment has often been made with regards to the value of that particular element in the determination of some parameters of biological identity (sex, race and stature). Whilst this is not the primary aim of this text, it serves only to direct the reader to other sources of reference.

The illustrations of the adult bones are represented by stippled line drawings with muscle attachments indicated. The illustrations throughout the book always depict the right-hand side of the body.

The **early development** of each bone is described directly after the discussion of the adult morphology. Each follows on from the stage previously outlined in Chapter 4 and deals with the specific embryological and early fetal development of that particular bone. This section charts its development from the blastemal condition up to the stage prior to the commencement of ossification. It also includes reference to various congenital conditions and anomalies that may arise during this period and which could subsequently alter the final adult morphology of the bone.

The section on **ossification** describes the development of the bone from the time of appearance of the first centre(s) of ossification up to the stage of final fusion of the epiphyses. In most chapters, this section is separated into three sections—primary centres, secondary centres and pattern of epiphyseal fusion. It is in this section of the book that the illustrations are most important as they not only highlight the earliest stage at which a particular element can be positively identified but also describe the morphological changes that occur in that bone throughout its development. However, it has not always been possible to illustrate a specific stage of development due to the limited availability of material. The illustrations in this section are half-tone drawings of actual bone specimens, many of which are of known age and sex and again only the right side of the body is depicted.

The final section within each chapter is headed '**Practical notes**'. It was thought that some readers may want to use this text as a field or laboratory manual and so a summary of a morphological timetable of events from the commencement of ossification to final epiphyseal fusion (or the attainment of final adult form) is presented. The practical notes include guidelines on the sideing of remains and how to orientate them to achieve correct identification of the skeletal element. In addition, there is a small section that offers suggestions on which other bones have a

similar morphology that may cause some confusion and thus result in misidentification.

Finally, some tables of metric information are included that may prove useful in the determination of age at death. This includes only observations on individuals of *documented* age in order to remove the inherent errors of the circular argument that ensues when age is subsequently predicted on the basis of the accuracy of another method (see Chapter 2). Naturally, this dramatically reduces the number of studies that could be included but it may serve to highlight where further research could be pursued. Because so much information is available on the long bones from undocumented archaeological sources, a summary of these studies is included in Appendix 3.

By far the most comprehensive account of fetal bones is that published by Fazekas and Kósa (English translation of 1978) referring to a group of 136 fetuses ranging from 12–40 weeks gestation. However, the sample was essentially of undocumented age at death and age was assigned on the basis of its well-documented relationship with body length (Streeter, 1920; Scammon and Calkins, 1929; Schultz, 1929a). There is, however, no other detailed text on fetal osteology and given the fact that all fetal material must by necessity be of uncertain age (see Chapter 2) its inclusion was considered justified.

As each bone of the skeleton is considered from its earliest formation to its adult morphology, it is obvious that each would display its own idiosyncrasies and resist being forced into a standard chapter format. As a result, whilst an attempt has been made to adhere to an organized structure, each chapter is by necessity slightly different in terms of its layout. For example, in Chapter 5 (Head, Neck and Dentition) there is a general introduction to the early development of the skull as a whole to prevent needless repetition of material that is common to a structure composed of so many conjoined elements. Also, there is no section on secondary centres, as these do not occur in the skull. Similarly in Chapter 6, as the vertebral column is a midline structure, there is obviously no section on side identification and instead this is replaced by a section on identification of position within a series.

The main thrust of the book lies with the osseous development of the skeleton, but to leave out dental development in a book of this nature would be a serious omission. However, there are many excellent texts which discuss in detail the development and identification of the teeth and this section (in Chapter 5) has therefore been reduced to a general introduction and review of the subject, thereby directing readers to other reference sources.

In addition to the principal elements of the skeleton, other structures such as the larynx and costal cartilages have been included. Being composed of hyaline cartilage, these structures maintain the potential to ossify and may do so at an age when the remainder of the skeleton is still in its late developmental phase. For this reason it is important that the structures can be identified, as they may be encountered in the excavation or retrieval of immature remains. Whilst such ossifications have always tended to be considered entirely within the domain of the elderly, the inaccuracy of this assumption is highlighted. In fact, awareness of their existence can lead to an increase in successful retrieval rates.

No apology is made for the length of the **bibliography**; in fact, it is hoped that this may prove to be one of the values of this text. The quantity of literature differs for each bone and so by necessity some areas are more heavily referenced than others. Many of the most basic descriptions of bones were written many years ago and for this reason again no apology is made for the fact that the bibliography spans over 300 years. Wise (1995) accused many authors of ignoring the contributors of the past, stating that 'we may have stood on the shoulders of giants but we did

not cite them'. He attributes this to authors becoming victims of technology, relying like a crutch on the use of information retrieval systems that tend not to extend to more than 10 years ago. Many of the older texts may also express views and descriptions that would not now be considered ethically acceptable. Titles of these papers have obviously been given as they stand and where appropriate the text has been quoted *verbatim* in the hope that accusations of political incorrectness may not be directed at this text. O'Rahilly (1996) raised the criticism that rather than seek out the original reference, many authors substitute reviews of the subject or even cite student textbooks where, in all fairness, original research is rarely published. In addition, he further accused authors of repeating information from one text to another without due recourse to the original work, which can of course lead to the perpetuation of errors. Where possible this text has attempted to avoid these pitfalls by extensive literature searches but it is inevitable that vital references, perhaps in another language, may have been omitted and errors may indeed have been unwittingly perpetuated. It is hoped that readers may identify these and make them known to the authors of this text so that due rectification can be made.

Skeletal Development and Ageing

*The childhood shows the man
As morning shows the day*

(John Milton, *Paradise Regained*)

This chapter outlines the basic principles on which the estimation of age from the juvenile skeleton is based. It also attempts to identify the major areas of study from which information on the development of the skeleton is drawn.

Growth

Growth is a general term applied to the progressive incremental changes in size and morphology that occur throughout the development of the individual. In general, overall growth is positively correlated with age, but the relationship is not a simple one. It consists of two components, increase in size and increase in maturity, and while these two elements are closely integrated, they do not necessarily advance in synchrony. As a result, individuals reach developmental milestones, or biological ages, along the maturity continuum at different chronological ages. For example, two boys, both aged 8 years, may differ considerably in height or similarly, two girls, aged 13, may both be at sexually and skeletally different stages of maturity. Generally speaking, growth in size is a regular process, although there are distinct increases in rate, possibly between 6 and 8 years in mid-childhood and at the adolescent growth spurt. However, the only consistent characteristic of growth is its variability.

There are variations in growth rate between different tissues and organs of the body in all individuals. The brain and head attain their adult size early in childhood, while the lymphoid system reaches its peak in late childhood. The reproductive system displays yet another rate and develops later in the adolescent period (Tanner, 1978). Growth also varies between the sexes, between individuals of the same population and between populations themselves. These differences are due to both genetic and environmental influences, the varying admixture of the two elements being the basis of the old 'nature versus nurture' argument. In

spite of much research, the causal picture still remains unclear. On the one hand, it is almost impossible to study the effects of a single factor alone and on the other, the effects of a factor on an individual may vary, depending at which stage of development it acts. Thus the causes responsible for differences in any particular person are complex and difficult to isolate.

Rates of increase in size and increase in maturity differ between the sexes and this becomes evident before birth (Choi and Trotter, 1970; Pedersen, 1982). There are also differences in the timing of ossification of bones and mineralization of teeth (Garn *et al.*, 1966a; Mayhall, 1992). Postnatally, skeletal maturation is more advanced in girls than boys (Pyle and Hoerr, 1955; Brodeur *et al.*, 1981) but bone mineral density is significantly less in girls than boys, the latter having a higher mineral density and larger long bones (Maresh, 1970; Specker *et al.*, 1987; Miller *et al.*, 1991). At adolescence, differential hormone secretion increases sexual dimorphism. The growth spurt occurs later in boys than in girls and therefore has its greatest influence at a different critical phase of growth. It establishes more growth beforehand and results in a greater adult size, predominantly because muscle mass increases rapidly during this period, which affects overall skeletal robusticity (Tanner, 1978). As in childhood, bone mineral density and the rate of accumulation of peak bone mass varies between the sexes during puberty (Gordon *et al.*, 1991).

Genetic differences are the basis for differences between population groups and it is self-evident that the adults of different ethnic groups have overall size differences; witness a group of Japanese and a group of Dutch tourists. A comprehensive survey of variation in the growth of children world-wide can be found in Eveleth and Tanner (1990). The difference that the environment may make on this intrinsic genetic factor is complex and one interesting approach to its eluci-