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The Scientific Bases of HUMAN ANATOMY

Charles Oxnard

WILEY Blackwell

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For Eleanor
I was a studious student: I married the Medical Librarian
She has been in my work and my life for nearly 60 years
Willingly helping me cross three continents

Contents

Foreword

To readers who think of human anatomy as a petrified science, in which all the facts are established and all the big questions have been answered, Charles Oxnard's new book will come as a surprise. *The Scientific Bases of Human Anatomy* is unlike any other book on the subject. In reading it, you will come to perceive your own body and the bodies of others in a dramatic new light, as the culmination of a story: the narrative of the journey that our bodies have taken to become human.

In other books of human anatomy, the bold outlines of this story are washed away in an inundation of facts. Anatomical pedagogy has traditionally relied on mnemonics and rote memorization to support learning and recall of this flood of detail. Oxnard's approach uncovers the deficiencies of this tradition and overcomes them. His book shows us a way around reliance on memorization and mnemonics by concentrating on how human bodies come into existence. The analytical system

that he uses relies on identifying recurring patterns and tracing these back to the processes that formed them. In Oxnard's words,

> The method that I have developed, over the years is, in contrast to 'the naming of the parts', an holistic integrative approach to human structure. It involves understanding that the structural details of the human body are the end results of a series of biological processes. These produce anatomical pattern due to:
>
> - change from differentiation and growth **over developmental time;**
> - diversification through comparisons of different forms **living at the same time;**
> - adaptation to mechanical and other factors **during functional time;**
> - interaction between body and brain, brain and body, **through mind time**, and
> - innovation in structure resulting from evolution **during deep time.**

Oxnard escorts his readers on a guided exploration of what he identifies as "the principles of body construction from their beginnings" – a tour of the human body factory, in the company of a most engaging guide who reveals and explains how bodies are made and how they work. This exploration is grounded in current ideas drawn from a wide arc of biological sciences, ranging from genomics and neuroscience to the latest findings in comparative anatomy. In the hands of a less skilled and knowledgeable writer, the confluence of all these "developmental, comparative, adaptive, integrative (and) evolutionary" ideas would have left the reader lost in a wilderness of unrelated notions. But Oxnard's mastery of biology and passion for anatomy hold the reader's journey on a steady course, relieved by a few delightful side excursions and enlivened by his unique and accessible narrative style. Profound, strong, sure, sometimes poetic and even beautiful, Oxnard's distinctive voice will remain with his readers long after they have finished this book.

Oxnard is careful to point out that *The Scientific Bases of Human Anatomy* is not a textbook of anatomy. As he emphasizes in Chapter 1, there is nothing here to memorize, and it is not his intention to prepare the reader for a test based on the "naming of the parts." Reading Oxnard will not obviate the need for professionals to acquire this sort of detailed anatomical knowledge, but it will both lighten and illuminate that task. His book conveys lasting images of how bodies come into being and function, which will help students organize those details in ways that make fundamental sense. For teachers of anatomy, the new insights and ways of thinking laid out in the following pages may serve to rekindle the spark of inquiry that drew them to the topic in the first place. For uninitiated readers with no professional interest in anatomy, the book will raise the curtain on a theater of the mind in which they will come to care about the making of bodies. In this book, Oxnard

seeks to lay down new modes of understanding and thinking about the formation of the human body, as both process and product, for students, teachers, researchers, and others. All of his readers will henceforward see the human body in a novel and deeply enlightening way. We are honored and delighted to include his book in the *Advances in Human Biology* series, and to welcome its readers to the New Anatomy.

Kaye Brown and Matt Cartmill

Preface

How it started: I was trained as an old fashioned medical anatomist, a physician who chose to specialize in anatomy; today a species possibly extinct, probably obsolete. Thus, though I just escaped being a student in a medical anatomy course of one thousand hours in two years, I nevertheless took a medical anatomy course of six hundred hours in five terms. I dissected the entire human body and brain and I taught in this mode for six years. I was later involved in teaching a medical anatomy course in two quarters (still with dissection of the entire body), and then a course in one quarter (with dissection of the entire body!). Finally, I was involved in teaching a course that was not entitled anatomy at all, but that contained just enough anatomy to understand physiological systems such as the cardiovascular system, and simple clinical problems. It contained no regional anatomy (though perhaps one third of medical conditions involve complex anatomical regions like

the back of the abdomen) and no human dissection (though a small aliquot of students were permitted to take an elective dissection course in which they dissected a single region of the body of their own choosing). These gradual reductions of anatomical teaching meant that my own teaching became better and better – the smaller the amount of teaching, the higher the quality of teaching!

The researches that I carried out concomitantly with this medical student teaching led me to undertake undergraduate and graduate courses in the scientific bases of human anatomy. For, if one wants to attract graduate and post doctoral students, it is wise, in the American system, to provide graduate level courses in one's own direct discipline. But how does one transmute that kind of medical human anatomy into science-based human anatomy?

The transmutation: This was achieved, without any difficulty, by serendipity. Thus, at a very early stage I had a colleague, a technician in the British university system, who had become so fascinated by anatomical research that he undertook some of it himself. The result: he published a series of papers; these papers could be used to apply for what was called an 'official degree'. As he had no previous degree, it had to be a Bachelor of Anatomical Sciences. Just as he thought it was all settled, he was then informed by the University Senate that he had also to take a written examination in Anatomical Sciences. He was devastated. Extremely bright though he was, he felt that he had had no formal education, and that there was no way he could write the essays for such a requirement.

We conferred. I agreed to give him one-on-one tuition on the scientific bases of human anatomy (which in my book included vertebrates, chordates, and even more) for an entire year. I am most pleased to say that he passed, and went from Junior Technician to, eventually, Senior Lecturer, a transition that was generally almost impossible in the British university system at that time. He was delighted; we remained very close scientific colleagues until the end of his life.

Though this episode did so much for him, it did, perhaps, very much more for me. It meant that I had to look at medical anatomy and reinterpret it through its scientific bases. Of course, at that time, the late fifties, early sixties, of the 20th century, that task could not be fully achieved. The modern genetic, developmental, comparative, functional and evolutionary bases had just not been taken far enough. However, ever since that time, a series of other institutions, students and colleagues, have provided me with the materials, ideas and stimulation, to keep working on that concept.

Chicago, the next step: For me, following Anatomy at the University of Birmingham in the fifties and early sixties, came Anatomy at the University of Chicago in the late sixties and seventies. Although originally a department that taught human anatomy to medical students, it had become transformed under Ronald Singer into a department that included a group of individuals interested in organismal, developmental, functional and evolutionary biologies. I was one of Singer's appointments in that transformation.

My view of human anatomy was further colored by the other evolutionary biologists who were already there: Singer himself, David Wake, James Hopson, Eric

Lombard, Len Radinsky, Lorna Straus, Russ Tuttle, and Leigh Van Valen, together with all the other anatomists in the cell and molecular biology areas. These ideas were further strengthened by discussions with the research student cohort of those days, in alphabetical order: Gene Albrecht, Matt Cartmill, Rebecca German, Walter Greaves, Paul Heltne, Doug Lay, Betty Jean Manaster, Jane Peterson, Jim Shafland, Jack Stern, and Richard Wassersug. These individuals, all interested in human anatomy, all preparing themselves for teaching anatomy to medical students, were, at the same time, interested in the scientific underpinnings of anatomy in organismal, developmental, functional and evolutionary modes. These ideas were further influenced by distinguished colleagues in department outside Anatomy: Stuart and Jean Altmann, Jack Cowan, Al Dahlberg, Richard Klein, Dick Lewontin, Lyn Throckmorton among others. Finally, these ideas were influenced by some of the visitors that we had in that Anatomy Department: Fred Bookstein, George Lauder, La Barbera, Rene Thom, later Neil Shubin (unfortunately after my time, but an influence on me through his book "Our Inner Fish"), and many others who visited Chicago in those days.

Translation to Los Angeles: My translation to the University of Southern California, though initially primarily as graduate dean and Professor of Anatomy, also included appointment as University Professor. These positions allowed continued research and teaching in Biology and Anatomy using the above principles. They involved further work with Gene Albrecht (who had moved there while I was Dean, but also involved a series of other colleagues: Fred Anapol, Bruce Gelvin, Joe Miller, Pete Lestrel, Brad Blood, Sherry Gust, Artyan Hsu, and others. Once again, I continued applying the underlying biological science to my teaching of medical anatomy (though the course was organized and run by Gene Albrecht); all these colleagues contributed.

This was also an especially seminal time for the medical students. They had started to realize that it might be important that they have a research side to their lives. Partly I think this was because of the general interest of extremely bright students; partly, however, it was because they could see that the official, administrative and accounting pressures of the 'new medicine' might need to be leavened by other interests such as research and teaching. Thus, I was approached by a group of some 25 medical students lead by Dan Zinder; they already held undergraduate engineering degrees. They knew my researches included engineering methods. They wanted me to be the director of an 'Engineers in Medicine Group'. Then I was approached by another group of medical students (leaders July Graylow and Hugh Allen) who just wanted to do research in one or other of the laboratories around the medical school; so I became director of a 'Medical Student Research Group'. These students especially participated in the Western Medical Students Research Forum. Finally, perhaps partly as a result of these endeavors, I became the first director (though only for one year as a result of my next move) of the new 'MD/PhD program' in the USC medical school.

Termination (!) in Western Australia: My final move to the University of Western Australia (UWA) has allowed me to continue my way of looking at anatomical

teaching. This was all the more powerful at UWA because, in addition to medical student teaching, we had a full three year program for undergraduates in Human Biology, a strong 4th year Honors research undergraduate program, several Masters programs, as well as standard doctoral studies in aspects of Human Biology (and later also in Forensic Science). But most of all, however, in Anatomy and Human Biology the undergraduate courses already embodied some of these ideas. They were promoted first by David Allbrook and then masterminded by Leonard Freedman. They were further carried forward by many of the academic staff, but especially by Neville Bruce. As a result, I found myself entering a school where the ideas that I had were already in full swing, some, perhaps, well beyond my own thoughts. It was a marriage made in heaven.

These ideas were again yet further stimulated by a series of graduate students, colleagues, and others (but now academics of various ranks) including, but not limited to, Vanessa Hayes, Alanah Buck, Nick Milne, Elizabeth Pollard, Ken Wessen, Robert Kidd, Willem de Winter, Pan Ruliang, Jens Hirschberg, Algis Kuliukas, Dan Franklin, and, most recently, Sara Flood, Warren Mitchell and Sally Stevens (not a student of ours, but a most capable teacher). They all taught in our courses, carried out research in the overall area, and continued to help me after they became academics. One recent student, Sarah Flood (now an Assistant Professor) made especially strong but appropriate criticisms of drafts of this book.

In Retirement: Since then, during 'so-called' retirement, I have been enabled to continue with both my researches and these ideas on teaching the scientific bases of human anatomy. In part this is because the University of Western Australia, through the School of Anatomy, Physiology and Human Biology, and the Forensic Science Centre, continues to permit me to have my research office, space for my graduate students and post-docs, and internal research funds. In part, also, it is because the Australian Research Council and the Medical and Health Infrastructure Fund of Western Australia have continued to provide me with project and infrastructure research funding during the whole of my retirement (my latest ARC and MHRIF grants will not expire until 2015).

In large part, further, it is because, during my retirement, a series of overseas appointments, grants and colleagues have also supported my ideas. These have included, in the last few years, a three year part-time Leverhulme Professorship at University College, London, two Leverhulme Research Grants, a BBSRC Research Grant, and Marie Curie Research and Research Training Funds (all in the UK). These have been achieved through the help of UK colleagues: Paul O'Higgins (first at University College, London, and later at the University of York), Robin Crompton, (University of Liverpool), and Michael Fagan, (University of Hull). Important insights have also been provided by interactions with other faculty, graduate students, and post-docs in York, Hull, Liverpool, Dundee, Zurich and Vienna.

I must also record my indebtedness to a series of technicians and artists who have supported my work on all three continents: they include Bill Pardoe (Birmingham), Joan Hives (Chicago), Erika Oller (Los Angeles), and Martin Thompson, Rebecca

Davies and Sue Hayes (Perth). Their hands are clearly evident in the improvements they made to my initial teaching illustrations.

I am grateful to Matt Cartmill and Kaye Brown, the academic editors of the Foundations of Human Biology book series at Wiley Academic Press in which this volume plays a part. I also owe thanks to the various editorial staff at Wiley. All have been particularly forgiving of the long time this book has been in progress. Matt himself, once a person I taught, has taught me much through his reviews in these final stages.

Finally, four individuals have been with me most of the way.

The first was Tom Spence who died in 1997. He started as a junior technician in Anatomy in Birmingham at the end of WWII, but made the transition, extremely difficult in England at that time, to academic ranks. He eventually retired in 1980 as Senior Lecturer. I had the good fortune to be able to visit him most years in his retirement even though I was then located in the USA. I remember so much our hours of discussion, and the teas (and for me a beer) supplied by his wife Joan, to keep us going. It was, however, his need, while still a technician, for an understanding of the scientific bases of human anatomy, for help to enable him to pass an examination for his Official BSc Degree, that first stimulated many of the ideas underlying this book.

Second, ever since my own entry into Anatomy in 1952, I have been in frequent contact with Peter Lisowski, first at the University of Birmingham, then at Haile Selassie University, Ethiopia, later when he was Head of Anatomy at the University of Hong Kong, and finally at the University of Tasmania, Hobart. Peter and I taught together, examined together and published together. In particular Peter Lisowski was the academic anvil upon which my ideas on the scientific bases of human anatomy were hammered out. Though we were both old-fashioned medical anatomists by training, we both had ideas that were over and beyond the traditional teaching of medical anatomy. He died on 11 January 2007; Eleanor and I were grateful to be with him and Ei Yoke, his wife, only a few days before he slipped away.

The third individual was Len Freedman who spent many years in building up the idea of Human Biology as the science underlying the human condition at the University of Western Australia. I had first met him during Chicago days when he was at the University of Wisconsin. It was in Wisconsin that he was first enabled to elaborate his ideas on Human Biology, but it was on his later appointment at the University of Western Australia (UWA) that, with the total support of his professor at that time, David Allbrook, and of Neville Bruce, and the other academic staff at UWA, that he elaborated this form of Human Biology. Accordingly then, when I arrived at UWA many years later, I found a Human Biology niche already created, almost, as it were, for me. I have been with Len Freedman ever since, including his years in active retirement. He died a true academic's death, reading a book, in 2014 aged 90.

The final individual is, of course, my wife, Eleanor. Since 1954, when I first knew her, she has supported me and my work. Originally a medical librarian (I was a studious student, spent much time in the medical library) she helped in the

bibliographies of my papers and books. Much more so, however, she has helped me through being willing to share our various migrations across the world. Sometimes the moves were initially tough, especially for her; but she fell in with them, made her own way, and remained indispensible to our work and life together. Even now we continue to travel the world yearly for family, collegial and research purposes.

This book has been such a wonderful thing to prepare. The new scientific bases of human anatomy are so much different from those with which I started 63 years ago. They are so unexpectedly exciting. Eleanor and I wish we were at the beginning of it all, and not near the end!

Charles Oxnard,
Claremont, WA, Australia
2015

CHAPTER ONE

A New System of Human Anatomy

1.1 Why a New System?

Another traditional human topographic anatomy book is definitely **not** needed. There are already a very large number of books on human topographic anatomy. They range from huge tomes attempting to lay out most of human anatomy to short summary books presenting the major facts in a pithy way. They form a spectrum from old books that present the anatomy as correctly as possible, including the many variations of normal, to new books that eliminate much information in order to present a simplified picture. They encompass the span from anatomy texts that are based upon anatomy from region to region (e.g. upper limb, thorax) of the

The Scientific Bases of Human Anatomy, First Edition. Charles Oxnard.

body, to expositions that display anatomy in terms of systems (e.g. nervous, gastrointestinal, locomotor). There are picture volumes from anatomy coloring books of the principal features of the body, to major atlases showing, through hundreds of leader lines, every anatomical detail. More specifically, for the health professions, there are books emphasizing the anatomy relevant to exemplar clinical problems, and books of fully detailed clinical anatomy. There are even many ancillary texts showing specific parts of human anatomy (e.g. surface anatomy, imaging anatomy, anatomy for orthopedics, anatomy for nurses, anatomy for artists, and so on).

Almost without exception, however, these books present human topographic anatomy, in each of their different ways, as a road map of the human body to be memorized. As medical curricula have become increasingly crowded the modern anatomical road map has become more and more limited. Today the books (and most of the other sources) used by the medical student show only the motorways and freeways. The larger books have become little more than references for details of the 'lowways' and byways required as references for the medical specialist.

Why then is there a need for a new system of human anatomy?

Because scientific understanding makes human topographic anatomy, like any other science, derivative; it is something that can be handled, and not just an object for memorization.

Because introducing the underlying science can make the anatomy live in the imaginations of students.

Because scientific understanding of anatomy is an important background to many disciplines (such as physical anthropology, human biology, functional anatomy, primate, mammalian and even vertebrate anatomy and evolution) that need not just information but understanding of human anatomy.

Because an introduction to human anatomy via its scientific background is useful for a very large number of disciplines that are human-based but not especially anatomical (e.g. any of a large number of allied medical and health disciplines).

Because, most of all, major advances in several sciences underlying anatomy (such as genetics, developmental biology, molecular biology, growth, behavioral biology, neurobiology and evolutionary biology) now provide exciting new insights into the how and why of the structure of the human body.

As a result, especially of these last, understanding the scientific basis of human anatomy is of particular importance at this time. Of course, there has always been a scientific basis, even if it existed mainly in the minds of investigators, hopefully in the minds of teachers, even, if only rarely, in the minds of medical students. But the recent advances in certain other disciplines have new implications for understanding human anatomy.

1.1.1 What are These Advances?

A new developmental biology is resulting from deeper knowledge of genes and other developmental molecules, and especially through recent developments in

understanding genetics and development from bioinformatics (e.g. in date order: Page and Holmes, 1998; Oxnard, 1983/1984; Hall, 1999; Larson, 2001; Moore, 2001; Twyman, 2001; Carlson, 2004; Shubin, 2008; Carey, 2012). These are all responsible for new understanding of developmental mechanisms and products. When I was a student there was a great gulf fixed between compound eyes in fruit flies and 'simple' eyes in humans. The old embryology had little further to say about this problem; it could show what existed but not how it came to exist. Who would have thought that closely similar genetic mechanisms and molecular processes would be discovered to exist for each; that a single new explanation in development would frame the multiple old anatomies?

A new comparative morphology has resulted from modern views of animal structure. The old comparative anatomy, in my early years, had become bogged down in the anatomy of **the** dogfish, **the** frog, **the** lizard, **the** pigeon, **the** rabbit. It had forgotten that there are many kinds of cartilaginous fishes, amphibians, reptiles, birds and mammals, respectively. This has now been corrected with new burgeonings of comparative morphology that look at diversity and complexity (e.g. again in date order: and starting with an older but very percipient text, Hyman, 1942; Hildebrand, 1974; Hildebrand et al., 1985; Cartmill and Smith, 1987; Stern 1988; Arthur, 1997; Oxnard 2008; Kardong, 2009). As a result, it provides new evidence of an underlying pattern for the anatomy of humans.

A new functional anatomy is resulting from advances in bio-engineering and bio-mathematics. It greatly modifies what could be estimated from the old anatomical inferences about function that were the main evidence presented in my earlier years. Now new concepts are emerging in testing and understanding the adaptations of anatomical structures (e.g. again, some quite a long time ago but developing up to the present: Stern and Oxnard, 1973; Wainright et al., 1976; Currey, 1984; Oxnard et al., 1990; Nigg and Herzog, 1994; Carter, 2001; Carter and Beaupré, 2001; Oxnard, 2008). Who, a few decades ago, would have guessed that the mechanics of fiberglass might illuminate the mechanics of bone?

A new neurobiology is resulting from major advances in studying the nervous system (e.g. Young, 1966; Jerison, 1973; Kandel et al., 2000; Striedter, 2005; Ramachanandran, 2011). Nowadays the brain can be seen both through the underlying molecular mechanisms for its development and through many of the new non-invasive imaging techniques that allow it to be seen during function. Most importantly, for our purposes, these new studies are revealing relationships between the anatomy of the body and the anatomy of the brain, the effects of integrations and communications, that were unguessed only two or three decades ago.

Finally, a new evolutionary biology, is, itself, evolving. It is a new, holistic, subject that integrates ideas from the aforementioned advances in development, comparison, function and integration as they culminate in evolution (e.g. Arthur, 1997; Page and Holmes, 1998; Hall, 1999; Mayr, 2001; Striedter, 2005; Cartmill and Smith, 2009. This, as Mayr has said, "Is Biology".

1.2 For Whom Is This System Useful?

The System of Anatomy in this book will therefore be (as are the other books in this series) of particular use to **students of biological anthropology, human biology,** and **human evolution**. Such students have no particular requirement for individual pieces of anatomical information until they need them for specific reports, term papers, study programs, research projects, grant proposals, dissertations and theses, and even for beginning post-doctoral research. In order, however, to use them in such contexts, these students can benefit from overviews of human structure. Such overviews were previously obtained, like those of an older generation of medical students, by relying upon the old, often hated, feats of memory, or by copying from little understood large anatomical tomes. How much better if they could be garnered through understanding the scientific underpinnings of human anatomy, underpinnings that render human anatomy a living, exciting science?

This book will likewise be of value to all those other students who require an overview of human structure but who also find that memorization alone is too difficult, or too boring, or both. These include:

students in biology who are specializing in **whole organisms**, **development, comparison, function,** and/or **evolution**, and for whom humans are merely a specific exemplar;

students in various health related professions who need a generalized understanding of the anatomy of their patients;

students in human movement sciences for whom a knowledge of specific anatomies is critical but whose understanding will be enhanced by this general approach;

students in bio-engineering and **medical engineering**, especially **biomechanics** (e.g. **orthopedics**) for whom, likewise, special anatomy is critical but who need to realize the science behind what they can divine from the anatomy texts they need to consult;

students in various life sciences who are working in disciplines that use microscopic and chemical methods, such as **micro-anatomy, ultrastructural anatomy, physiology**, **pathology**, **biochemistry**, and/or **molecular biology**, but whose knowledge in various aspects of human micro-structure needs to be seen in the context of human meso- and macro-structure.

This book will not be of much value to **medical students** under current medical educational regimes, where, truly, there is no room for the detail of any subject, and particularly where what little anatomy there is has to be closely related to specific clinical problems. It may, however, be of major value to **premedical students**. In the USA, where medicine has long been a post-baccalaureate degree, these are individuals who take premedical courses in undergraduate degrees as a hopeful preliminary to medical entrance. In the rest of the English speaking medical world, the majority of medical courses are five or six year undergraduate courses that used

to hold a lot, probably far too much, anatomical content. Many medical courses are undergoing major reductions of medical anatomy during the course of conversion to four year graduate medical degrees following upon some other undergraduate degree. For such students, this is often a **premedical degree**.

As a result, even in this arena, there will be large numbers of students, far larger numbers than just those who will eventually enter medical school, who will want **premedical anatomy**. Such premedical anatomy will not be the specific but reduced medical-problem related anatomy of the new medical curricula, but the **science-based human anatomy** of a **general education** or **liberal arts undergraduate degree**.

Finally this book may be of value to those **current students in medical schools**, **current medical school teachers**, and **current medical practitioners** who, while realizing the necessary limitations of the restricted anatomy that they are or were presented with, may, for good intellectual reasons, want an understanding of **how** and **why**, and not just **where**, things are in the human body.

1.2.1 From Dissection to Science

Anatomy traditionally involves the cutting of the body, whether 'real' (i.e. from the cadaver), presented (i.e. in the prosection or model), or 'virtual' (i.e. in the computer). Personal dissection involves cutting and observing, usually from the outside in, from skin to bone. Prosected or modeled 'dissection' involves examining what someone else has cut or made. Computational dissection may also be carried out by moving from the outside in but, interestingly, it can also be done (for example in an@tomedia) in other ways, for example from the inside out, thus gradually clothing the bones, or from the center to the periphery following through the nervous or other system of the body, or through the bodily regions where systems may appear to be conflated, or through the pathways of development and growth, or even through examination of separate islands of related information such as the scattered endocrine glands of the body. Such approaches provide new and improved roadmaps of the body (especially important to the medical student and practitioner). However, without further exposition, they do not easily provide scientific understanding. In fact they often do the opposite, especially through their testing mechanisms, tending to present the learning of human anatomy as a process that I call 'the naming of the parts'. The 'naming of the parts' is often how anatomy is taught and, even more often, how it is learned.

Such approaches primarily seem to involve memorization of large numbers of small details. It is true that such memory can be reinforced through the use of acronyms, eponyms, and mnemonics. It can be especially strengthened by using atlases, diagrams, models, computer programs, and, most of all, examinations that emphasize the reproduction of facts and names. All of this can be useful for individuals who think they do not require understanding but who need the information**. But it is as boring as hell.**

It has well been documented how memorization without understanding (except when memorized at mother's knee) disappears so easily. It is indeed one of the reasons why many practicing professionals, especially some in the non-cutting specialities (remembering that hateful memorizing activity as students) hate anatomy. This reaction in some current medical professionals is partly why anatomy has been all but eliminated from the medical curriculum. Yet other practicing professionals recognize the enjoyment that they had in anatomy and the lifelong friendships they made there. It was the only time in the old medical curriculum where the same small group of students knew, helped, and worked with one-another and a single staff member for a whole year (even a whole two years in my ancient days!). In the new medical curricula this is now largely lost. In fact, no part of medical education today lasts long enough to provide this element of student and staff camaraderie.

My own experiences with science, medical, research and health professions students and practitioners, over more than 50 years, tell me that it can be different. Even today, there are still some medical and health practitioners who are interested in understanding the science underlying anatomy. They understand how anatomy provides them not only with the names of anatomy, but also with the vocabulary of medicine, the grammar and syntax of medicine, the ability to speak, write and understand the language of medicine, and help with unravelling the problems of medicine. They understand how communicating the science in medicine stems as powerfully from anatomy as from any other medical subject. They understand how knowledge of anatomy can be derivative, and how it can allow them to work out the anatomy, if forgotten, when needed. (My own general practitioner has anatomy books, atlases and models on his desk as tools to help him explain to **his** patients what is going on in **their** bodies).

1.3 What is This System?

The method that I have developed, over the years is, in contrast to 'the naming of the parts', an holistic integrative approach to human structure. It involves understanding that the structural details of the human body are the end results of a series of biological processes. These produce anatomical pattern due to:

change from differentiation and growth **over developmental time**
diversification through comparisons of different forms **living at the same time**
adaptation to mechanical and other factors **during functional time**
interaction between body and brain, brain and body, **through mind time**, and
innovation in structure resulting from evolution **during deep time.**

A number of important older texts did attempt to utilize these approaches but they were limited by what was known in those earlier days of the scientific disciplines of development, comparison, adaptation, integration, and evolution. Today, the excitement of totally new concepts in these disciplines cries out to be used to illuminate a new human anatomy.

This new way of approaching the anatomy of the body starts at the opposite end from the traditional. Instead of memorizing the fine detail of the body as dissected, prosected, or demonstrated as a geographical road-map, the principles of body construction are looked at from their main beginnings, whether those beginnings are developmental, comparative, adaptive, integrative, or evolutionary.

All this can be particularly illuminated by the new visualization techniques of the last few years. Thus the **blueprints** and **tool kits** of developmental change can be demonstrated, for example, through imaging of experimental chimeras wherein cells of different ancestry (quail in a chick, male in a female) can be separately defined and followed. The **plans** and **patterns** of comparative differences can be examined using mathematical methods for comparing structures available only to today's scientists. The **adaptations** and **optimizations** of function can be shown, for example, through engineering methods that demonstrate not only the structure, but also that structure when functioning. The **communications** and **controls** of the integrative brain can be illuminated by molecular dissection and three-dimensional non-invasive imaging. The **architectures** and **lifestyles** inherent in evolution can be revealed by combinations of all of the above.

These approaches to human anatomy: **developmental, comparative, functional, integrative** and **evolutionary;** and their internal mechanisms and processes: **blueprints** and **tool kits, plans** and **patterns, optimizations** and **adaptations, communications** and **controls,** and **architectures** and **lifestyles;** are all well known as separate expositions in their own disciplines.

There have been few attempts, however, to bring all of them together to provide the scientific underpinnings of a specifically human macroscopic anatomy. For example, most of the ideas above have been explicated in animal forms. There have been almost no attempts at all to integrate the new knowledge of recent years that, separately exciting in each of these disciplines, can now provide the holistic excitement that gives a truly scientific base to understanding the macroscopic anatomy of the specifically human body.

Yet it must be emphasized that this book **is** an exposition of the science underlying the macroscopic anatomy of the human body, and **not** of the separate disciplines of the developmental, comparative, functional, neural and evolutionary biologies themselves. These latter are the subjects of their own major disciplines, their own curricula, their own books. Yet macroscopic human anatomy is powerfully informed by both the old and new developments in these underlying sciences that are so basic to the understanding of biological structures in general.

1.4 Why, Therefore, This Book?

As a result, the approach that is taken in this book is quite different from that in the usual run of Human Anatomy texts today. Where, for example, the student, the teacher, or even the examiner, may ask, is the information about the triangles of the neck, the posterior abdominal wall, the axilla, and the branches of the maxillary

artery, or even, the maze of arterial anastomoses around the human knee joint? The answer is that **they are not here**. They can already be found, in greater or lesser detail, in any large or small anatomy book. Anatomical information does appear here, of course, but only in the explication of pattern resulting from the various underlying sciences. It is provided, therefore, in a largely new guise.

This book, thus, does not mirror, nor is it meant to, any of the very large number of regional, systematic, dissection-based, clinically-based, or even summary human anatomy texts, whether large or small, exactly because those books do not adopt this special approach. Such books remain, nevertheless, most useful, indeed important, to students because they are sources for more detailed anatomy of specific regions when required.

Yet is it really the case that these new approaches have not been attempted before? In fact, following on Darwin's ideas, even before his time, many individuals tried to use scientific underpinnings as ways of understanding human structure. One of these was Todd and Bowman's Physiological Anatomy of 1845 at a time when it was clearly understood that anatomy and physiology should not be separated. Others were the understandings of vertebrate anatomy by Owen in 1868, and by Wiedersheim in 1882. This last was used to illuminate a specifically human anatomy (Wiedersheim, first edition in 1887). Yet another text that also unashamedly used this approach (so how new is it?) was Sir Arthur Keith's 'Human Embryology and Morphology' (Keith 1902). Of course, there have been enormous changes in physiology, embryology and comparative anatomy since those and other similar books. As a result new books have, over the years, really been needed. But I acknowledge that the idea is not really new – very few ideas are truly new – only the concepts to be integrated are new.

Among other anatomically based texts that do contain elements of the approaches suggested here are a number of books from later in the 20th century. They include, for example, Young's three far-sighted books: 'The Life of Vertebrates' (1950), 'The Life of Mammals' (1966) and 'An Introduction to the Study of Man' (1971). Likewise, but in a different vein, yet also employing elements of the approach implied here, is Hildebrand's wonderful 'Analysis of Vertebrate Structure' (1974). These, and others not cited, are excellent books, and still, in my opinion, very useful to students. But of course they were originally written many years ago and as a result do not include the mass of new developmental, comparative, functional, integrative and evolutionary information that has been elucidated in recent years. More recent are modern textbooks of vertebrate anatomy (e.g. Kardong, 2009). Most importantly, however, unlike the earlier essays by Wiedersheim and Keith, these books are not aimed at human anatomy, other than including humans as a minor example of another mammal, another tetrapod, another vertebrate, and so on. To be very fair, they were not aimed at understanding humans, specifically, in the first place.

An approach like that adopted here also exists in a number of excellent 'evo-devo' books published very recently. These, naturally, do include the new information. Indeed, these books, and the primary literature on which they are based, have been most important in deriving some of the underlying concepts for this book. They

are excellent references for students wanting to take the combined developmental and evolutionary concepts further. They include, among many, for example, Hall's 'Evolutionary and Developmental Biology' (1999) and Twyman's 'Developmental Biology' (2001). Though these books include the evolutionary/developmental information underlying human anatomy, they, too, are primarily aimed at explicating the evolutionary and developmental anatomy of many other forms: primates, mammals, tetrapods, vertebrates, even invertebrates, and so on. They are excellent books. Their thrust, however, is not human anatomy specifically. The human anatomy is secondary, and, when it is included at all, is abbreviated, appropriately in context it must be said, as just another animal in the broader picture.

Yet another set of useful books include, among others, primary embryology texts. Larson's 'Human Embryology' (1993 and later editions), and Carlson's 'Human Embryology and Developmental Biology' (2004), figure among these. They are excellent texts, and they **are** aimed at the human situation. They are, however, specifically human embryology texts. They do provide many important and fascinating linking materials from other species to humans, but they remain treatises separate from human anatomy *per se*.

The final set of books that use elements of the approach adopted here are genuinely human anatomy books. They include Cartmill, Hylander and Shafland's 'Human Structure' (1987), and Stern's 'Essentials of Gross Anatomy' (1988) among a number of others. The former of these two books (Cartmill, et al.) provides much explanatory information from developmental, functional and evolutionary biology. However, though it gives short useful introductions to these matters, because it was written some time ago, it does not include some of the more recent linking material from other disciplines. Further, its organization is still largely based on the traditional anatomical regions. Its primary aim is to fully cover the anatomy of the human body at an appropriate level, with the result that the developmental, functional and evolutionary information is integrated into the human anatomy in only a secondary manner.

The second of these two books (Stern) is an even more standard human anatomy text for medical students. Yet it, too, integrates considerable information about developmental, comparative and functional aspects of human anatomy. For example, in one place, Stern gives an excellent description of the changes in limb form during limb evolution, common in vertebrate anatomy texts, unusual in human anatomy texts. In a different vein, however, he gives a mnemonic for remembering aspects of knee anatomy: "The professors who taught me my anatomy … " he says were " … [the late] Ronald Singer and Charles Oxnard. Their initials – RSCO – remind me that if I could peer through my femur down onto the top of the tibial plateau of my **R**ight **S**ide, I would see the letters **C** and **O** formed by the medial and lateral menisci, respectively … " Stern notes that "The value of this mnemonic to persons not trained by Singer and Oxnard is unclear".

I am proud to have figured in Jack's description and regret that Ron Singer is no longer with us. As with Jack's codicil, however, I cannot believe that his mnemonic is a good scientific reason for understanding the shapes of the menisci! The functional

explanations related to load bearing and movement of the femur on the tibia during knee function are so much better! The general arrangement of Stern's book is, again, and appropriately so, quite classical. The conceptual parts are more in the form of useful and important *obiter dicta* in a mainly human macroscopic anatomical text.

Finally, I draw your attention to a beautiful book by Shubin, also from Chicago. This book: "Your Inner Fish" is truly a journey into the 3.5 billion year history of the human body. It should be read by all who might find the present book useful. Again, however, it does not replicate this book. Its emphasis is truly on vignettes on "the long long journey" to human anatomy, rather than on the final effects on human anatomy itself. It is, nevertheless a wonderful introduction to the story being told here.

Let me emphasise that I am not criticizing any of these texts as being inadequate, quite the reverse. I owe much to them and to many others not cited. In fact, all these other books would be most valuable when used alongside the current text. I am, however, trying to emphasize differences from the approach adopted here.

1.5 What is My Hope for My Readers?

One hope is that this book will introduce the student to the use of the scientific underpinnings of human anatomy as the major rationale for understanding it.

A second is that the student will realize that the book makes no attempt to cover everything in anatomy in an equal manner. It certainly does not try to capture the whole of human anatomy. As an example, the book goes into considerable detail about the combined developmental and comparative underpinnings of human variation in the proximal parts of both limbs, but it does not address the equivalent distal limb parts in anywhere near so much detail. Likewise, other regions of the body are covered in this patchwork manner.

Why?

One reason is the intention to introduce students to principles in some parts, and to add to their learning by leaving it to them to work out the extensions of the principles in other parts. In other words, I want the students to build on the partial story that I am providing.

A second reason, however, is because the principles have not yet been equally and fully worked out in all areas. I myself have not yet worked in all areas. For example, much more is known about the head than about the trunk, much more about muscles, joints and bones, than about tendons, ligaments and fascial sheets. As a result, some of the concepts that I suggest here may well turn out to be wrong! And other concepts, apparently equivocal or even unlikely, may well turn out to have been right. In other words, I want the students to see that I don't know the full story, that possibly at this time no-one does, and that, therefore, there are more questions to be asked.