Introduction: A View of the Past

EXERCISE PHYSIOLOGY: ROOTS AND HISTORICAL PERSPECTIVES

Acknowledging all of the pioneers who created the field of exercise physiology is a difficult task in the span of an introduction to a textbook in this area. Indeed, it would be a herculean task to faithfully chronicle the rich history of exercise physiology from its origins in ancient Asia to the present. For this brief overview, we present a chronological historical tour regarding topics often not adequately developed in exercise physiology courses or their traditional textbooks. Along the way, we delve into events and people that have profoundly influenced the emerging field of exercise physiology—specifically the creation of science-based curriculum in colleges and universities at the turn of the 19th century, and the influential scientists who helped to create these early programs. It was the dogged insistence of the latter on innovation and experimental rigor that propelled desperate fields in medicine and the biological sciences to make rapid strides in creating new knowledge about how humans functioned during various modes and intensities of physical activity and the impact on humans of heat, cold, depth/pressure, altitude, and microgravity environmental stressors.

Our discussion begins with an acknowledgment of the ancient but tremendously influential Indian, Arabic, and prominent Greek physicians; we highlight some milestones (and ingenious experiments), including the many contributions from Sweden, Denmark, Norway, and Finland that fostered the study of sport and exercise as a respectable field of scientific inquiry. A treasure-trove of information about the early beginnings of exercise physiology in America was uncovered in the archives of Amherst College, Massachusetts, in an anatomy and physiology textbook (incorporating a student study guide) written by the first American father-and-son writing team. The father, Edward Hitchcock, was President of Amherst College; the son, Edward Hitchcock, Jr., an Amherst graduate and Harvard-trained physician, made detailed anthropometric and strength measurements of almost every student enrolled at Amherst College for almost three decades from 1861 to 1889. In 1891, much of what forms current college curricula in exercise physiology, including evaluation of body composition by anthropometry and muscular strength by dynamic measurements, began in the first physical education scientific laboratory at Harvard's University's prestigious Lawrence Scientific School (founded in 1847, and in 1906, absorbed into Harvard College and Graduate School of Arts and Letters). Even before the fortuitous creation of this science-oriented laboratory, another less formal but still tremendously influential factor affected the development of exercise physiology: the publication during the 19th century of American textbooks on anatomy and physiology, physiology, physiology and hygiene, and anthropometry. The availability of physiology texts allowed teachers and research scientists with an interest in physiology to offer formal coursework in these topics as they related to exercise and human movement. More than 45 textbooks published between 1801 and 1899 contained information about the muscular, circulatory, respiratory, nervous, and digestive systems—including the influence of exercise and its effects—and eventually shaped the content area of exercise physiology during the next century.

thePoint **Appendix A, available online at http://thepoint.lww.com/mkk8e, provides several bibliographies of influential publications pertaining to anatomy and physiology, anthropometry, exercise and training, and exercise physiology.**

Professor Roberta Park, distinguished UC Berkeley physical education, exercise science, and sport historian, chronicles the early contributions of many physicians and science-oriented physical educators who steadfastly believed that physical education (and medicine) should be grounded on a sound scientific foundation fueled by cutting-edge research.[53,54,56,58,60,61]

Well-documented historical chronologies and other con tributions[8,9,55,57,59]provide context and foster appreciation for the scholars and educators who paved the way for the new generation of researchers; the early innovators developed new techniques and methodologies in the fields of health, fitness, sports performance, and physical activity that became essential components of the early exercise physiology core curriculum. Appendix A (online) lists additional influential texts from 1900 to 1947 dealing with exercise, training, and exercise physiology.[a]

IN THE BEGINNING: ORIGINS OF EXERCISE PHYSIOLOGY FROM ANCIENT GREECE TO AMERICA IN THE EARLY 1800S

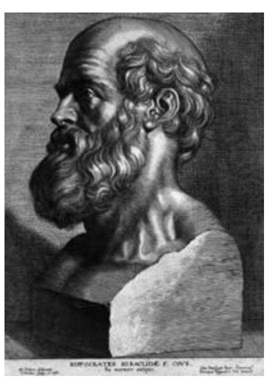
Exercise physiology arose primarily in the civilizations of early Greece and Asia Minor, although the topics of exercise, sports, games, and health concerned even earlier civilizations. These included the Minoan and Mycenaean cultures; the great

[a]Buskirk[13] provides a bibliography of books and review articles on exercise, fitness, and exercise physiology from 1920 to 1979. Berryman[7] lists many textbooks and essays from the time of Hippocrates through the Civil War period in the United States.

McArdle WD, Katch FI, Katch VL. "Introduction: A View from the Past." In *Exercise Physiology: Nutrition, Energy, and Human Performance*, 8th ed. Baltimore, MD: Wolters Kluwer, 2015.

biblical realms of David and Solomon; and the territories of Assyria, Babylonia, Media, and Persia, including the empires of Alexander the Great. Early references to sports, games, and health practices (personal hygiene, exercise, and training) were recorded by the ancient civilizations of Syria, Egypt, Macedonia, Arabia, Mesopotamia and Persia, India, and China. Tipton chronicles the doctrines and teachings of Sushruta, an Indian physician, teacher of aspiring medical students, and surgeon who practiced in the 5th century BC. Sushruta is remembered as the first plastic surgeon,[66] and as a scholar who produced the ancient treatise *Sushruta Samhita* 150 years before Hippocrates lived. Sushruta's compendium from 600 BC is housed in the Oxford University library, and a 1911 English translation in three volumes can be read online at **http://archive.org/stream/englishtranslati00susruoft#page/n3/mode/2up**. He detailed 800 medical procedures, described 120 blunt and sharp surgical instruments, and penned detailed accounts of hundreds of medical conditions relating to various disease states and organ deficiencies (**www.faqs.org/health/topics/50/Sushruta.html**), including the influence of different modes of exercise on human health and disease.[74] Tipton notes that Sushruta considered obesity a disease, and posited that a sedentary lifestyle contributed to obesity. The greatest influence on Western Civilization, however, came from the Greek physicians of antiquity—Herodicus (5th century BC), Hippocrates (460–377 BC), and Claudius Galenus or Galen (AD 131–201[b]).

Herodicus, a physician and athlete, strongly advocated proper diet in physical training. His early writings and devoted followers influenced the famous physician Hippocrates, considered to be the "father" of modern medicine, who first wrote about preventative medicine. Hippocrates is credited with producing 87 treatises on medicine—several on health and hygiene—during the influential Golden Age of Greece.[7,47] He espoused a profound understanding of human suffering, emphasizing a doctor's place at the patient's bedside. Today, physicians take either the classical or modern Hippocratic Oath (**www.nlm.nih.gov/hmd/greek/greek_oath.html**) based on Hippocrates' "Corpus Hippocratum."


Hippocrates

Five centuries after Hippocrates, during the early decline of the Roman Empire, Galen emerged as perhaps the most well-known and influential physician that ever lived. The son of a wealthy architect, Galen was born in the city of Pergamos[c] and educated by scholars of the time. He began studying medicine at approximately age 16. During the next 50 years, he implemented and enhanced current thinking about health and scientific hygiene, an area that some might consider "applied" exercise physiology. Throughout his life, Galen taught and practiced the "laws of health": breathe fresh air, eat proper foods, drink the right beverages, exercise, get adequate sleep, have a daily bowel movement, and control one's emotions.[7] A prolific writer, Galen produced at least 80 sophisticated treatises (and perhaps 500 essays) on numerous topics, many of which addressed human anatomy and physiology, nutrition, growth and development, the beneficial effects of exercise, the deleterious consequences of sedentary living, and a variety of diseases and their treatment including obesity. Sushruta's notions about obesity were undoubtedly influenced by Galen, who introduced the concept of *polisarkia* (now known as morbid obesity).[71] Galen proposed treatments commonly in use today—diet, exercise, and medications. One of the first "bench physiologists," Galen conducted original experiments in physiology, comparative anatomy, and medicine, and performed dissections of humans, goats, pigs, cows, horses, and elephants. As physician to the gladiators of Pergamos, Galen treated torn tendons and muscles ripped apart in combat with various surgical procedures he invented, including the procedure depicted in **FIGURE I.1**, a 1544 woodcut of shoulder surgery. Galen also formulated rehabilitation therapies and exercise regimens, including treatment for a dislocated shoulder. He followed the Hippocratic school of medicine that believed in logical science grounded in experimentation and observation.

Galen wrote detailed descriptions about the forms, kinds, and varieties of "swift" and vigorous exercises, including their proper quantity and duration. The following definition of exercise is from the first complete English translation by Green[27] of Hygiene (*De Sanitate Tuenda*, pp. 53–54; see **TABLE I.1**), Galen's insightful and detailed treatise on healthful living:

> To me it does not seem that all movement is exercise, but only when it is vigorous.... The criterion of vigorousness is change of respiration; those movements that do not alter the respiration are not called exercise. But if anyone is compelled by any movement to breathe more or less or faster, that movement becomes exercise from him. This therefore is what is commonly called exercise or gymnastics, from the gymnasium or public-place to which the inhabitants of a city come to anoint and rub themselves, to wrestle, throw the discus, or engage in some other sport.... The uses of exercise, I think are twofold, one for the evacuation of the excrements, the other for the production of good condition of the firm parts of the body.

During the early Greek period, the Hippocratic school of physicians devised ingenious methods to treat common maladies; these methods included procedures to reduce pain from

[b]According to Green, the dates for Galen's birth are estimates based on a notation Galen made when at age 38 he served as personal physician to the Roman emperors Marcus Aurelius and Lucius Verus.[27] Siegel's bibliography contains an excellent source for references to Galen.[62]
[c]An important city on the Mediterranean coast of Asia Minor, Pergamos influenced trade and commerce. From CE 152 to 156, Galen studied in Pergamos, renowned at the time for its library of 50,000 books (approximately one-fourth as many as in Alexandria, the greatest city for learning and education) and its famous medical center in the Temple of Asclepios (http://whc.unesco.org/en/list/491).

FIGURE I.1 • Woodcut by Renaissance artist Franceso Salviati (1510–1563) based on Galen's *De Fascius* from the first century BC. The woodcut showing shoulder surgery provides a direct link with Hippocratic surgical practice that continued through the Byzantine period.

dislocated lower lumbar vertebrae. The illustration from the 11th-century *Commentairies of Apollonius of Chitiron* on the Periarthron of Hippocrates (**Fig. I.2**) provided details about early Greek surgical "sports medicine" interventions to treat athletes and even the common citizen.

Most of the credit for modern-day medicine has been attributed to the early Greek physicians, but other influential physicians contributed to knowledge about physiology, particularly the pulmonary circulation. West, in an insightful review of the contribution of Arab physician Ibn al-Nafis (1213–1288),[75] points out that Ibn al-Nafis challenged the long-standing beliefs of Galen about how blood moved from the right to left sides of the heart, and also predicted the existence of capillaries 400 years before Malpighi's discovery of the pulmonary capillaries. The timeline in **Figure I.3** shows the period of the Islamic Golden Age of Medicine. During this interval, interspaced between the Galenic era in 200 AD to the late 1400s and early 1500s, many physicians, including Persian physician Ibn Sina (Avicenna [ca. 980–1037]: www.muslimphilosophy.com/sina/) contributed their knowledge to 200 books, including the influential *Shifa* (*The Book of Healing*) and *Al Qanun fi Tibb* (*The Canon of Medicine*) about bodily functions.[75]

The era of more "modern-day" exercise physiology includes the periods of Renaissance, Enlightenment, and Scientific Discovery in Europe. It was then that Galen's ideas affected the writings of the early physiologists, anatomists, doctors, and teachers of hygiene and health.[52,62,63] Significant contributions during this time period included those of da Vinci (1452–1519), Michael Servetus (1511–1564; discovered that blood passed through the pulmonary circulation without moving directly from the right to left ventricle), Realdus Columbus (1516–1559; student of Vesalius who developed concepts concerning pulmonary circulation and that the heart has two ventricles,

TABLE I.1 Table of Contents for Books 1 and 2[a] of Galen's *De Sanitate Tuenda (Hygiene)*

Chapter	Title
Book 1 The Art of Preserving Health	
I	Introduction
II	The Nature and Sources of Growth and of Disease
III	Production and Elimination of Excrements
IV	Objectives and Hypothesis of Hygiene
V	Conditions and Constitutions
VI	Good Constitution: A Mean Between Extremes
VII	Hygiene of the Newborn
VIII	The Use and Value of Exercise
IX	Hygiene of Breast-Feeding
X	Hygiene of Bathing and Massage
XI	Hygiene of Beverages and Fresh Air
XII	Hygiene of the Second Seven Years
XIII	Causes and Prevention of Excrementary Retardation
XIV	Evacuation of Retained Excrements
XV	Summary of Book 1
Book 2 Exercise and Massage	
I	Standards of Hygiene Under Individual Conditions
II	Purposes, Time, and Methods of Exercise and Massage
III	Techniques and Varieties of Massage
IV	Theories of Theon and Hippocrates
V	Definitions of Various Terms
VI	Further Definitions About Massage
VII	Amount of Massage and Exercise
VIII	Forms, Kinds, and Varieties of Exercise
IX	Varieties of Vigorous Exercise
X	Varieties of Swift Exercises
XI	Effects, Exercises, Functions, and Movements
XII	Determination of Diet, Exercise, and Regime

[a]Book III. Apotherapy, Bathing, and Fatigue. Book IV. Forms and Treatment of Fatigue. Book V. Diagnosis, Treatment, and Prevention of Various Diseases. Book VI. Prophylaxis of Pathological Conditions.

FIGURE I.2 • Ancient treatment for low-back pain, as illustrated in the Commentaires of Apollonius of Chitiron.

not three as postulated by the Galenic School), Andreas Vesalius (1514–1564), Santorio (1514–1564), and William Harvey (1578–1657). The contributions of da Vinci, Vesalius, Santorio, and Harvey are detailed later in this introduction.

Iin Venice in 1539, Italian physician Hieronymus Mercurialis (1530–1606) published *De Arte Gymnastica Apud Ancientes* (The Art of Gymnastics Among the Ancients). This text, heavily influenced by Galen and other early Greek and Latin authors, profoundly affected subsequent writings about physical training and exercise (then called gymnastics) and health (hygiene), not only in Europe (influencing the Swedish and Danish gymnastic systems), but also in early America (the 19th-century gymnastic–hygiene movement). **Figure I.4**, redrawn from *De Arte Gymnastica*, acknowledges the early Greek influence of one of Galen's famous essays, "Exercise with the Small Ball," and his technical regimen of specific strengthening exercises (discus throwing and rope climbing).

RENAISSANCE PERIOD TO NINETEENTH CENTURY

New ideas formulated during the Renaissance exploded almost every concept inherited from antiquity. Johannes Gutenberg's (ca. 1400–1468 AD) printing press (the first to incorporate replaceable, movable type) allowed for the dissemination to the masses of both classic and newly acquired knowledge (**www.ideafinder.com/history/inventors/gutenberg.htm**). Hundreds of new text materials were created for the arts, history, geography, and the emerging sciences. New educational opportunities for the wealthy and privileged sprang up in universities and colleges throughout Europe (Angiers, Bologna, Cambridge, Cologne, Heidelberg, Lisbon, Montpellier, Naples, Oxford, Orleans, Padua, Paris, Pisa, Prague, Salamanca, Siena, Toulouse, Uppsala, Valencia). Art broke with past forms, emphasizing spatial perspective and realistic depictions of the human body (see Fig. I.4).

Although the supernatural still influenced discussions of physical phenomena, prior ideas grounded in religious dogma

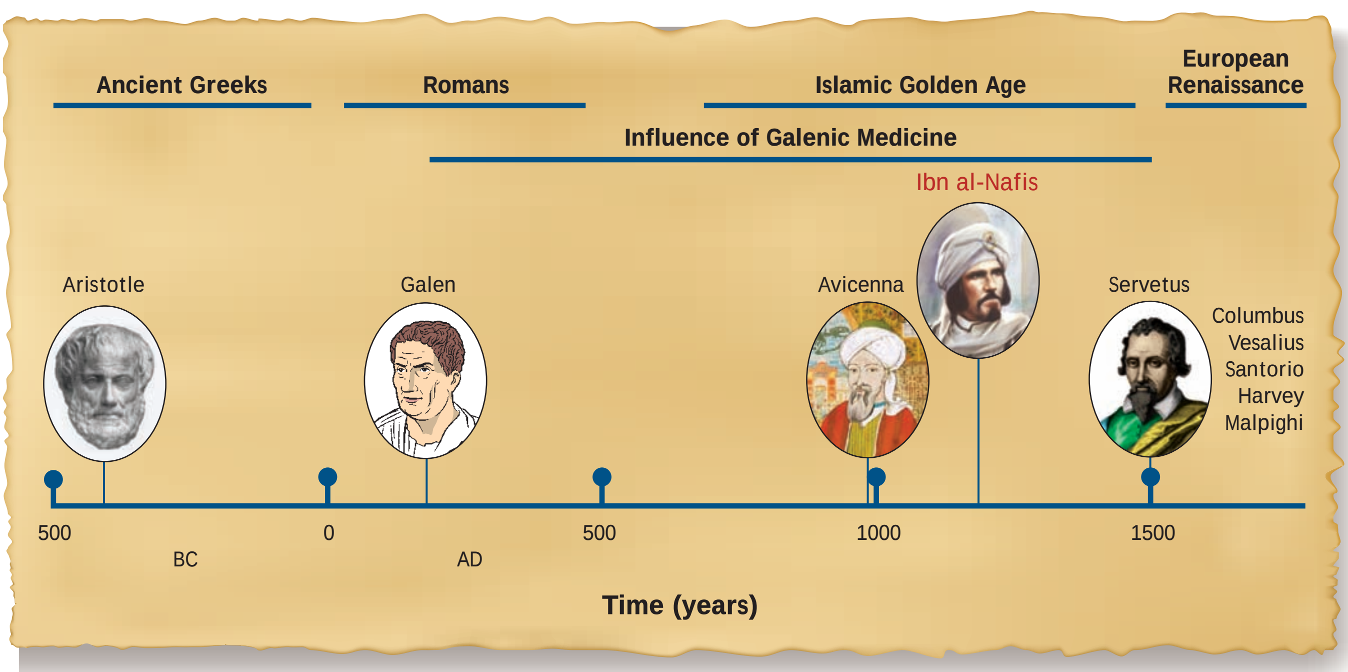


FIGURE I.3 • Timeline of the influence of Galenic medicine and the Islamic Golden Age.

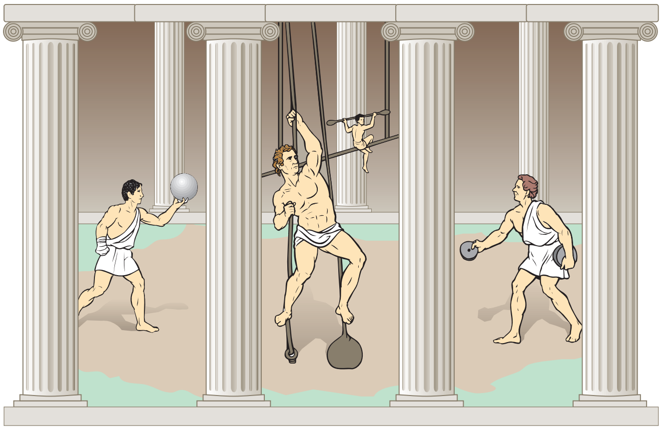


FIGURE I.4 • The early Greek influence of Galen's famous essay *Exercise with the Small Ball* and specific strengthening exercises (throwing the discus and rope climbing) appeared in Mercurialis's *De Arte Gumnastica*, a treatise about the many uses of exercise for preventative and therapeutic medical and health benefits. Mercurialis favored discus throwing to aid patients suffering from arthritis and to improve the strength of the trunk and arm muscles. He advocated rope climbing because it did not pose health problems, and he was a firm believer in walking (a mild pace was good for stimulating conversation, and a faster pace would stimulate appetite and help with digestion). He also believed that climbing mountains was good for those with leg problems, long jumping was desirable (but not for pregnant women), but tumbling and handsprings were not recommended because they would produce adverse effects from the intestines pushing against the diaphragm! The *three panels* above represent the exercises as they might have been performed during the time of Galen.

now expanded to scientific experimentation as a source of knowledge. For example, medicine had to confront the new diseases spread by commerce with distant lands. Plagues and epidemics decimated at least 25 million people throughout Europe in just 3 years (1348–1351; **www.pegasplanet.com/articles/EuropeanBlackPlaque.htm**). New towns and expanding populations in confined cities led to environmental pollution and pestilence, forcing authorities to cope with the problems of community sanitation and care for the sick and dying. Science had not yet uncovered the link between diseases and their insect and rat hosts.

As populations expanded throughout Europe and elsewhere, medical care became more important for all levels of society. Unfortunately, medical knowledge failed to keep pace with need. For roughly 12 centuries, with the exception of the Islamic physicians, few advances were made from those in Greek and Roman medicine. The writings of the early physicians had either been lost or preserved only in the Arab world. Thanks to the reverence given to classical authors, Hippocrates and Galen still dominated medical education until the end of the 15th century. Renaissance discoveries greatly modified these theories. New anatomists went beyond simplistic notions of four humors (fire, earth, water, air) and their qualities of hot, dry, cold, and wet as they discovered the complexities of circulatory, respiratory, and excretory mechanisms.[7,11]

Once rediscovered, these new ideas caused turmoil. The Vatican banned human dissections, yet a number of "progressive" medical schools continued to engage in such practices, usually sanctioning one or two cadavers a year or with official permission to perform an "anatomy" (the old name for a dissection) every 3 years. Performing autopsies helped physicians solve legal questions about a person's death, or determine cause of a disease. In the mid-1200s at the University of Bologna, every medical student had to attend one dissection each year, with 20 students assigned to a male cadaver and 30 students to a female cadaver. In 1442, the Rector of the University of Bologna required that cadavers used for an "anatomy" come from an area located at least 30 miles outside the city limits. The first sanctioned anatomical dissection in Paris, performed in public, took place in 1483.[45]

In Rembrandt's first major 1632 portrait commission, *The Anatomy Lesson of Dr. Nicholas Tulp* (**Fig. I.5**), medical students listen intensely (but without "hands-on" experience) to the renowned Dr. Tulp as he dissects the arm of a recently executed criminal. The pioneering efforts of Vesalius and Harvey made anatomic study a central focus of medical education, yet conflicted with the Catholic church's strictures against violation of the individual rights of the dead because of the doctrine concerning the eventual resurrection of each person's body. In fact, the Catholic church considered anatomic dissections a disfiguring violation of bodily integrity, despite the common practice of dismembering criminals as punishment. Nevertheless, the art of the period reflected close collaboration between artists and medical school physicians to portray anatomic dissections, essential for medical education, and to satisfy a public thirst for new information in the emerging fields of physiology and medicine.

FIGURE I.5 • Rembrandt's 1632 *The Anatomy Lesson of Dr. Nicholas Tulp. (The Yorck Project: 10,000 Meisterwerke der Malerei.)*

In 1316, Mondino de Luzzio (ca. 1275–1326; http://lacytite.com/whatisit/anathomia/), a professor of anatomy at Bologna, published *Anathomia*, the first book of human anatomy. He based his teaching on human cadavers, not Greek and Latin authorities or studies of animals. The 1513 edition of *Anathomia* presented the same drawing of the heart with three ventricles as was in the original edition, a tribute to de Luzzio's accuracy in translation of the original inaccuracies! Certainly by the turn of the 15th century, anatomic dissections for postmortems were common in the medical schools of France and Italy; they paved the way for the Renaissance anatomists whose careful observations accelerated understanding of human form and function.

Professor Laura Bassi (Image courtesy National Library of Medicine)

Early on, two women from the University of Bologna achieved distinction in the field of anatomy. Laura Caterina Bassi (1711–1778; www.sciencemuseum.org.uk/broughttolife/people/laurabassi.aspx), the first woman to earn a doctor of philosophy degree and the university's first female professor, specialized in experimental physics and basic sciences but had to conduct her experiments at home.

Soon after, female scholars were allowed to teach in university classrooms. At the time, Bassi gave her yearly public lectures on topics related to physics (including electricity and hydraulics, correction distortion in telescopes, hydrometry, and relation between a flame and "stable air"). Anna Morandi Manzolini (1717–1774; www.timeshighereducation.co.uk/story.asp?storycode=415248), also a professor and chair of the Department of Anatomy at the University of Bologna, was an expert at creating wax models of internal organs and became the anatomy department's chief model maker.


Professor Anna Manzolini (Erich Lessing/Art Resource, NY)

She produced an ear model that students took apart and reassembled to gain a better understanding of the ear's internal structures. Her wax and wood models of the abdomen and uterus were used didactically in the medical school for several hundred years. The wax self-portrait in the Museum of Human Anatomy at the University of Bologna (http://pacs.unica.it/cere/mono02_en.htm) shows Manzolini performing an anatomical dissection, clad in the traditional white lab coat, but also dressed in silks with diamonds and pearl jewelry—the manner expected of a woman of her high social and economic status.

Progress in understanding human anatomic form paved the way for specialists in physical culture and hygiene to design specific exercises to improve overall body strength, and the ever increasing popularity of training regimens to prepare for rowing, boxing, wrestling, competitive walking, and track and field activities and competitions. These specialist instructors were the early link to today's personal trainers.

Notable Achievements by European Scientists

An explosion of new knowledge in the physical and biologic sciences helped prepare the way for future discoveries about human physiology during rest and exercise.

Leonardo da Vinci (1452–1519)

Da Vinci dissected cadavers at the hospital of Santa Maria Nuova in Florence (www.lifeinthefastlane.com/2009/04/leonardo-da-vinci-first-anatomist/) and made detailed anatomic drawings.


Leonardo Da Vinci self-portrait (c. 1512–1513)

Da Vinci's achievements in anatomy include:

1. Deduced the hierarchical structure of the nervous system, with the brain as a command center.
2. Deduced that the eye's retina, not the lens as previously believed, was sensitive to light. He dissected the fragile eye structures by inventing new dissection methods that included sectioning the eye after its proteins had been fixed by heating in egg whites.
3. Observed the lesions of atherosclerosis and their possible role in obstructing coronary arteries.
4. Identified the heart as a muscle "pump," and that the arterial pulse corresponded to ventricular contraction.
5. Developed a system to explain muscular movements by using an arrangement of wires. For example, he determined the mechanics of biceps brachii muscle and arm action. He explained elbow flexion and hand supination through the twisting action on the ulna. His detailed drawings with written explanations showed the full arm and its motions, including scapular function.
6. Deduced the equal contribution from the mother and father to the inherited characteristics of the fetus.

Accurate as his numerous and detailed sketches were (Fig. I.6), they still preserved Galenic ideas. Although he never saw the pores in the septum of the heart, he included them, believing they existed because Galen had "seen" them. Da Vinci first drew accurately the heart's inner structures and constructed models of valvular function that showed how the blood flowed in only one direction. This observation contradicted Galen's notion about the ebb and flow of blood between the heart's chambers. Da Vinci could not explain the role of

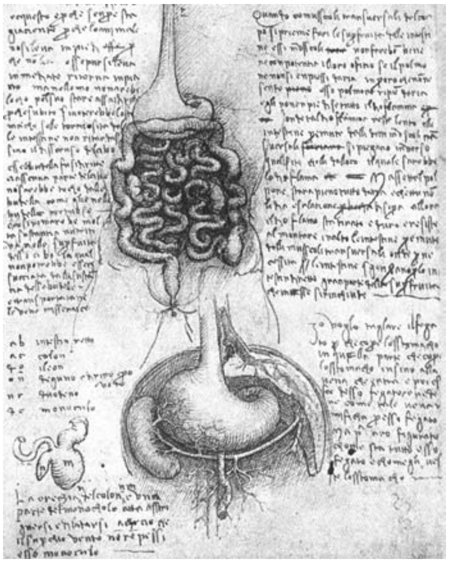


FIGURE I.6 • Anatomical sketch of stomach, intestines, kidney, and pancreas by Da Vinci.

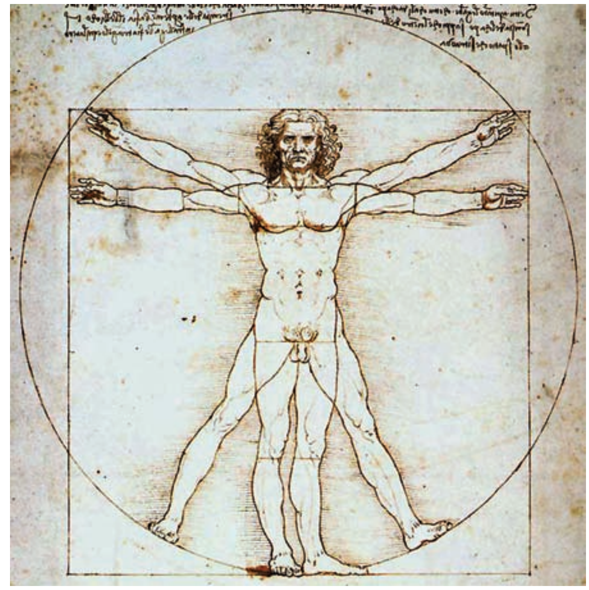


FIGURE I.7 • Da Vinci's *Vitruvian Man*.

the veins and arteries in blood flow to and from the heart. It would take another half-century for Harvey to discover that veins return blood to the heart, and only the arteries conduct blood from the heart to the periphery. Because many of Da Vinci's drawings were lost for nearly two centuries, they did not impact later anatomic research.

Da Vinci's work built on and led to discoveries by two fellow artists. Leon Battista Alberti (1404–1472; **www.kirjasto.sci.fi/alberti.htm**), an architect who perfected three-dimensional perspectives, which influenced Da Vinci's concepts of internal relationships. Da Vinci's drawings (while not published during his lifetime) no doubt inspired the incomparable Flemish anatomist Andreas Vesalius (1514–1564; **www.evolution.berkeley.edu/evolibrary/article/history_02**). These three exemplary Renaissance anatomists—Da Vinci, Alberti, and Vesalius—empowered physiologists to understand the systems of the body with technical accuracy, not theoretical or religious bias.

Albrecht Dürer (1471–1528)

Dürer, a German contemporary of Da Vinci (**www.albrecht-durer.org**), extended the Italian's concern for ideal dimensions as depicted in Da Vinci's famous "1513 Vitruvian Man" (**Fig I.7**) by illustrating age-related differences in body segment ratios formulated by 1st century BCE Roman architect Marcus Vitruvius Pollio (*De architectura libri decem* [*Ten books on architecture*]). Dürer created a canon of proportion, considering total height as unity. For example, in his schema, the length of the foot was one-sixth of this total, the head one-seventh, and the hand one-tenth. Relying on his artistic and printmaking skills rather than objective comparison, Dürer made the ratio of height between men and women as 17 to 18 (soon thereafter proved incorrect). Nonetheless, Dürer's work inspired Behnke in the 1950s to quantify body proportions relative to height into reference standards to evaluate body composition in men and women (see Chapter 28).

Michelangelo Buonarroti (1475–1564)

Michelangelo, like Da Vinci, was a superb anatomist (**www.ncbi.nlm.nih.gov/pmc/articles/PMC1279184/**). In his accurate drawings, body segments appear in proper proportion. His famous sculpture "David" clearly shows the veins, tendons, and muscles enclosing a realistic skeleton. His frescos on the ceiling of the Sistine Chapel (**mv.vatican.va/3_EN/pages/CSN/CSN_Main.html**) often exaggerate musculature; nevertheless they still convey a scientist's vision of the human body's proportions.

Michelangelo's "David"

Andreas Vesalius (1514–1564)

Belgian anatomist and physician Vesalius learned Galenic medicine in Paris, but after making careful human dissections, he rejected the Greek's ideas about bodily functions. At the start of his career, Vesalius authored books on anatomy, originally relying on Arabic texts, but then incorporating observations from his own dissections in addition to a self-portrait from *Fabrica* published at age 29 showing the anatomic details of an upper and lower right arm.

Portrait of Vesalius from his *De Humani Corporis Fabrica* (c. 1543) (Courtesy National Library of Medicine.)

His research culminated in the exquisitely illustrated text first published in Basel, Switzerland, in 1543, *De Humani Corporis Fabrica* (On the Fabric of the Human Body) (**Fig. I.8**).

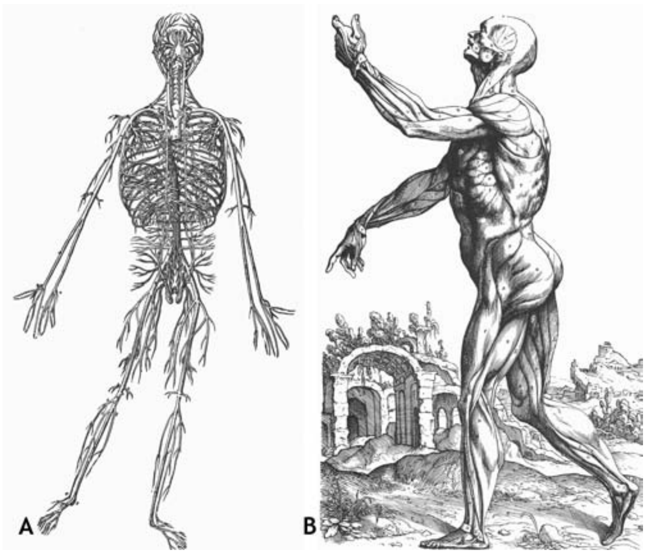


FIGURE I.8 • Vesalius's anatomic drawings. **(A)** Major nerves. **(B)** Muscular system in action. Note the graveyard crypts. (Courtesy National Library of Medicine.)

Many consider Vesalius's drawings and accompanying 200 woodcuts the best anatomical renderings ever made, ushering in the age of modern medicine (**www.metmuseum.org/TOAH/HD/anat/ho_53.682.htm#**). The same year, he published *Epitome*, a popular version of *De Fabrica* without Latin text (**www.ncbi.nlm.nih.gov/pmc/articles/PMC1520217/**).

Some physicians and clergymen became outraged, fearful that the new science was overturning Galen's time-honored speculations. Vesalius's treatise accurately rendered bones, muscles, nerves, internal organs, blood vessels (including veins for blood-letting, a popular technique to rid the body of diseases and toxins; **medicalantiques.com/medical/Scarifications_and_Bleeder_Medical_Antiques.htm**), and the brain, but he differed from Galenic tradition by ignoring what he could not see. His masterful detailed depiction of the muscular and skeletal architecture of the human body pared away one muscle layer at a time to reveal the hidden structures underneath.

Some of Vesalius's drawings contain curious inaccuracies. For example, he drew the inferior vena cava as a continuous vessel; inserted an extra muscle to move the eyeball; and added an extra neck muscle present only in apes. Despite these minor discrepancies, Vesalius clearly attempted to connect form with function. He showed that a muscle contracted when a longitudinal slice was made along the muscle's belly, but a transverse cut prevented contraction. Vesalius was one of the first to verify that nerves controlled muscles and stimulated movement. His two beautifully illustrated texts profoundly influenced medical education. Their intricate details about human structures demolished traditional theories about human anatomy and emboldened later researchers to explore circulation and metabolism unburdened by past misconceptions. The illuminating and detailed artwork of Vesalius hastened the subsequent important discoveries in physiology and the beginning of modern science.

Santorio Santorio (1561–1636)

Santorio's scale. (Courtesy National Library of Medicine.)

A friend of Galileo and professor of medicine at Padua, Italy, Santorio invented innovative tools for his research (**www.istrianet.org/istria/illustri/santorio/index.htm**). He recorded changes in daily body temperature with the first air thermometer, crafted in 1612 as a temperature-measuring device. Accuracy was poor because scientists had not yet discovered the effects of differential air pressures on temperature. Santorio also measured pulse rate with Galileo's pulsilogium (pulsiometer; **http://galileo.rice.edu/sci/instruments/pendulum.html**). Ever inventive, Santorio, a pioneer physician in the science of physical measurement, introduced quantitative experimentation into biological science in a treatise published in late 1602 or early 1603 (*Methodus vitandorum errorum omnium qui in arte medica contingent* [Methods to avoid errors in medical practice]). Santorio studied digestion and changes in metabolism by constructing a wooden frame that supported a chair, bed, and worktable. Suspended from the ceiling with scales, the frame recorded changes in body weight.

For 30 continuous years, Santorio slept, ate, worked, and made love in the weighing contraption to record how much his weight changed as he ate, fasted, or excreted. He coined the term "insensible perspiration" to account for differences in body weight because he believed that weight was gained or lost through the pores during respiration. Often depriving himself of food and drink, Santorio determined that the daily change in body mass approached 1.25 kg. Santorio's book of medical aphorisms, *De Medicina Statica Aphorismi* (1614), drew worldwide attention. Although this scientifically trained Italian instrument inventor did not explain the role of nutrition in weight gain or loss, Santorio nevertheless inspired later 18th-century researchers in metabolism by quantifying metabolic effects.

William Harvey (1578–1657)

William Harvey

William Harvey discovered that blood circulates continuously in one direction and, as Vesalius had done, overthrew 2000 years of medical dogma. Animal vivisection disproved the ancient supposition that blood moved from the right to left side of the heart through pores in the septum—pores that even Da Vinci and Vesalius had erroneously acknowledged. Harvey announced his discovery during a 3-day dissection–lecture on

April 16, 1616, at the oldest medical institution in England—the Royal College of Physicians in London. Twelve years later, he published the details of his experiments in a 72-page monograph, *Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus* (*An Anatomical Treatise on the Movement of the Heart and Blood in Animals*; **www.bartleby.com/38/3/**). Harvey was aware of the uniqueness of his contributions, and he penned these prescient thoughts in the introduction to his scientific masterpiece:

> At length, yielding to the requests of my friends, that all might be made participators in my labors, and partly moved by the envy of others, who, receiving my views with uncandid minds and understanding them indifferently, have essayed to traduce me publicly, I have moved to commit these things to the press, in order that all may be enabled to form an opinion both of me and my labours. This step I take all the more willingly, seeing that Hieronymus Fabricius of Aquapendente, although he has accurately and learnedly delineated almost every one of the several parts of animals in a special work, has left the heart alone untouched. Finally, if any use or benefit to this department of the republic of letters should accrue from my labours, it will, perhaps, be allowed that I have not lived idly.… So will it, perchance, be found with reference to the heart at this time; or others, at least, starting hence, with the way pointed out to them, advancing under the guidance of a happier genius, may make occasion to proceed more fortunately, and to inquire more accurately.

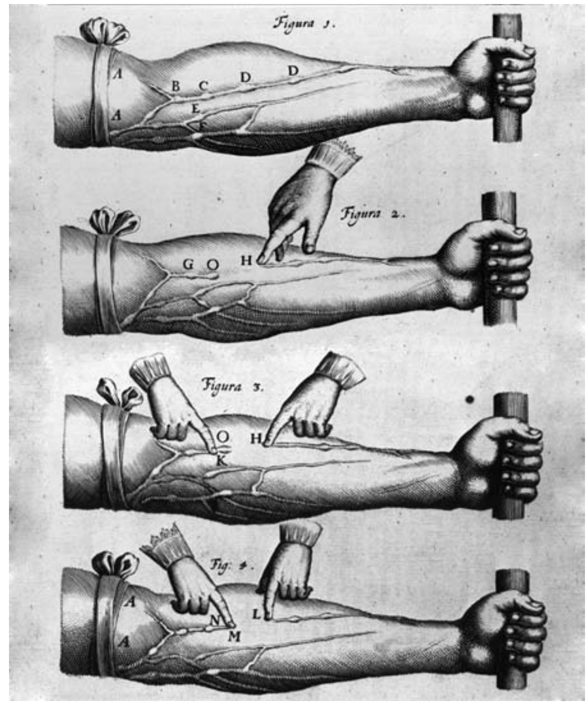


FIGURE I.9 • Harvey's famous illustration demonstrating the one-way flow of the circulation. (Courtesy National Library of Medicine.)

By combining the new technique of experimentation on living creatures with mathematical logic, Harvey deduced that contrary to conventional wisdom, blood flowed in only one direction—from the heart to the arteries and from the veins back to the heart. It then traversed to the lungs before completing a circuit and reentering the heart. Harvey publicly demonstrated the one-way flow of blood by placing a tourniquet around a man's upper arm that constricted arterial blood flow to the forearm and stopped the pulse (**Fig. I.9**). By loosening the tourniquet, Harvey allowed some blood into the veins. Applying pressure to specific veins forced blood from a peripheral segment where there was little pressure into the previously empty veins. Thus, Harvey proved that the heart pumped blood through a closed, unidirectional (circular) system, from arteries to veins and back to the heart. As he put it:

> It is proved by the structure of the heart that the blood is continuously transferred through the lungs into the aorta as by two clacks of a water bellows to raise water. It is proved by a ligature that there is a passage of blood from the arteries to the veins. It is therefore demonstrated that the continuous movement of the blood in a circle is brought about by the beat of the heart.[24]

Harvey's experiments with sheep proved mathematically that the mass of blood passing through the sheep's heart in a fixed time was greater than the body could produce—a conclusion identical to that concerning the human heart. Harvey reasoned that if a self-contained constant mass of blood exists, then the large circulation volumes would require a one-way, closed circulatory system. Harvey did not explain why the blood circulated, only that it did. However, he correctly postulated that circulation might distribute heat and nourishment throughout the body. Despite the validity of Harvey's observations, distinguished scientists publically and soundly criticized them. Jean Riolan (1577–1657), an ardent Galenist who chaired the anatomy and botany departments at the University of Paris in the 1640s, maintained that if anatomic findings differed from Galen's, then the body in question must be abnormal and the results faulty. Nevertheless, Harvey's epic discovery governed subsequent research on circulation and demolished 1500 years of rigid dogma.

Giovanni Alfonso Borelli (1608–1679)

Giovanni Alfonso Borelli

Borelli, a protégé of Galileo and Benedetto Castelli (1578–1643) and a mathematician at the University of Pisa in Italy, used mathematical models to explain how muscles enabled animals to walk, fish to swim, and birds to fly. His ideas explaining how air entered and exited the lungs, though equally important, were less well known. Borelli's accomplished student, Marcello Malpighi (1628–1694; **www.nndb.com/people/033/000095745/**), described blood flowing through microscopic structures (capillaries) around the lung's terminal air sacs (alveoli). Borelli observed that lungs filled with air because chest volume increased as the diaphragm moved downward. He concluded that air passed through the alveoli and into the blood, a sharp contrast to Galen's notion that air in the lungs cooled the heart, and an advance on Harvey's general observation concerning unidirectional blood flow.

Robert Boyle (1627–1691)

Working at Gresham College in London with his student Robert Hooke (1635–1703; www.ucmp.berkeley.edu/history/hooke.html), Boyle devised experiments with a vacuum pump and bell jar to show that combustion and respiration required air. Boyle partially evacuated air from the jar containing a lit candle. The flame soon died. When he removed air from a jar containing a rodent or bird, it became unconscious; recirculating air back into the jar often revived the animal. Compressing the air produced the same results: animals and flames survived longer (www.woodrow.org/teachers/ci/1992/boyle.html).

Portrait of Robert Boyle by Johann Kerseboom, 1689

Boyle removed the diaphragm and ribs from a living dog and forced air into its lungs with a bellows. The experiment did not prove that air was essential for life, yet demonstrated that air pressure and volumes alternately contracted and expanded the lungs. He repeated the experiment, this time pricking the lungs so air could escape. Boyle kept the animal alive by forcing air into its lungs, proving that chest movement maintained airflow and disproving the earlier assertion that the lungs effected circulation.

Scientific societies and journals broadcasted these pioneering and insightful discoveries. Boyle belonged to the Royal Society of London (www.royalsociety.org/about-us/history/), chartered in 1662 by King Charles II. Four years later in France, Louis XIV sponsored the Académie Royale des Sciences (the French Academy of Sciences was established to preserve French scientific research) so its staff could conduct and sponsor a variety of studies in physics, chemistry, medicine, agronomy, nutrition and metabolism, and exploratory expeditions to distant lands. Both societies established journals to disseminate information to scientists and an increasingly educated lay public fascinated by the quick pace of new discoveries.

Stephen Hales (1677–1761)

A renowned English plant physiologist and Fellow of the Royal Society (http://galileo.rice.edu/Catalog/NewFiles/hales.html), Hales amassed facts from his experiments with animals about blood pressure, the heart's capacity, and velocity of blood flow in *Vegetable Statics: Or, an Account of Some Statical Experiments on the Sap in Vegetables* (1727).

Stephen Hales (Courtesy National Library of Medicine)

In this venerable text, Hales tells how water absorbed air when phosphorus and melted brimstone (sulfur) burned in a closed glass vessel (FIG. I.10) that shows the transfer of "air" released from substances burned in a closed vessel. Hales measured the volume of air either released or absorbed, and he demonstrated that air was a constituent of many common substances. His experiments proved that chemical changes occurred in solids and liquids during calcination (oxidation during combustion). Hales developed an idea suggested by Newton in 1713 that provided the first experimental evidence that the nervous system played a role in muscular contraction.

James Lind (1716–1794)

Trained in Edinburgh, Lind entered the British Navy as a Surgeon's Mate in 1739 (www.sportsci.org). During an extended trip in the English Channel in 1747 on the 50-gun, 960-ton H.M.S. *Salisbury* (www.ncbi.nlm.nih.gov/pmc/articles/PMC539665/), Lind carried out a decisive experiment (the first planned, controlled clinical trial) that changed the course of naval medicine. He knew that scurvy often killed two thirds of a ship's crew. Their diet included 1 lb 4 oz of cheese biscuits daily, 2 lb of salt beef twice weekly, 2 oz of dried fish and butter thrice weekly, 8 oz of peas 4 days per week, and 1 gallon of beer daily. Deprived of vitamin C, sailors fell prey to scurvy ("the great sea plague"). By adding fresh fruit to their diet, Lind fortified their immune systems so that British sailors no

James Lind

FIGURE I.10 • Hale's closed glass vessel experiment.

longer perished on extended voyages. From Lind's *Treatise on the Scurvy* (1753) comes the following poignant excerpt[38]:

> On the 20th of May, 1747, I selected 12 patients in the scurvy, on board the Salisbury at sea. Their cases were as similar as I could have them. They all in general had putrid gums, the spots and lassitude, with weakness of their knees.... The consequence was, that the most sudden and visible good effects were perceived from the use of oranges and lemons; one of those who had taken them, being at the end of 6 days fit for duty. The spots were not indeed at that time quite off his body, nor his gums sound; but without any other medicine than a gargle for his mouth he became quite healthy before we came into Plymouth which was on the 16th of June. The other was the best recovered in his condition; and being now pretty well, was appointed nurse to the rest of the sick.... Next to oranges, I thought the cyder had the best effects. It was indeed not very sound. However, those who had taken it, were in a fairer way of recovery than the others at the end of the fortnight, which was the length of time all these different courses were continued, except the oranges. The putrification of their gums, but especially their lassitude and weakness, were somewhat abated, and their appetite increased by it.

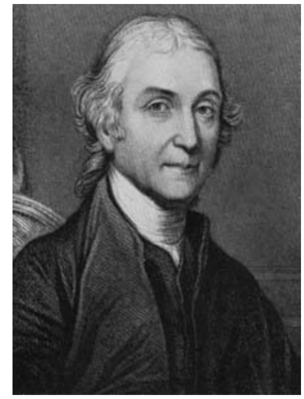
Lind published two books[72]: *An Essay on Preserving the Health of Seamen in the Royal Navy* (1757) and *Essay on Diseases Incidental to Europeans in Hot Climates* (1768). Easily available, his books were translated into German, French, and Dutch. Lind's landmark emphasis on the crucial importance of dietary supplements antedates modern practices. His treatment regimen defeated scurvy, but 50 years had to pass with many more lives lost before the British Admiralty required fresh citrus fruit on all ships (**www.jameslindlibrary.org/illustrating/articles/james-lind-and-scurvy-1747-to-1795**).

Joseph Black (1728–1799)

Joseph Black (Courtesy National Library of Medicine)

After graduating from the medical school in Edinburgh, Black became a professor of chemistry at Glasgow (**www.chem.gla.ac.uk/~alanc/dept/black.htm**). His *Experiments Upon Magnesia Alba, Quicklime, and Some Other Alcaline Substances* (1756) determined that air contained carbon dioxide gas. He observed that carbonate (lime) lost half its weight after burning. Black reasoned that removing air from lime treated with acids produced a new substance he named "fixed air," or carbon dioxide ($CaCO_3 = CaO + CO_2$). Black's discovery that gas existed either freely or combined with other substances encouraged later, more refined experiments on the chemical composition of gases.

Joseph Priestley (1733–1804)



Joseph Priestly

Although Priestley discovered oxygen by heating red oxide of mercury in a closed vessel, he stubbornly clung to the phlogiston theory that had misled other scientists (**www.spartacus.schoolnet.co.uk/PRpriestley.htm**). Dismissing Lavoisier's (1743–1794) proof that respiration produced carbon dioxide and water, Priestley continued to believe in an immaterial constituent (phlogiston) that supposedly escaped from substances upon burning. He lectured at the Royal Society about oxygen in 1772 and published *Observations on Different Kinds of Air* in 1773. Elated by his discovery, Priestley failed to grasp two facts that later research confirmed: (1) the body requires oxygen and (2) cellular respiration produces the end product carbon dioxide. **Figure I.11** depicts Priestly's London laboratory.

Karl Wilhelm Scheele (1742–1786)

Carl Wilhelm Scheele (Artist J. Falander, Edgar Fahs Smith Collection, University of Pennsylvania Library)

In one of history's great coincidences, Scheele, a Swedish pharmacist, discovered oxygen independently of Priestley (**www.britannica.com/EBchecked/topic/527125/Carl-Wilhelm-Scheele**). Scheele noted that heating mercuric oxide released "fire-air" (oxygen); burning other substances in fire-air produced violent reactions. When different mixtures contacted air inside a sealed container, the air volume decreased by 25% and could not support combustion. Scheele named the gas that extinguished fire "foul air." In a memorable experiment, he added two bees to a glass jar immersed in lime water containing fire-air (**Fig. I.12**). After a few days, the bees remained alive, but the level of lime water had risen in the bottle and become cloudy. Scheele concluded that fixed air replaced the fire-air to sustain the bees. At the end of 8 days, the bees died despite ample honey within the container. Scheele blamed their demise on phlogiston, which he felt was hostile to life. What Scheele

McArdle WD, Katch FI, Katch VL. "Introduction: A View from the Past." In *Exercise Physiology: Nutrition, Energy, and Human Performance*, 8th ed. Baltimore, MD: Wolters Kluwer, 2015.

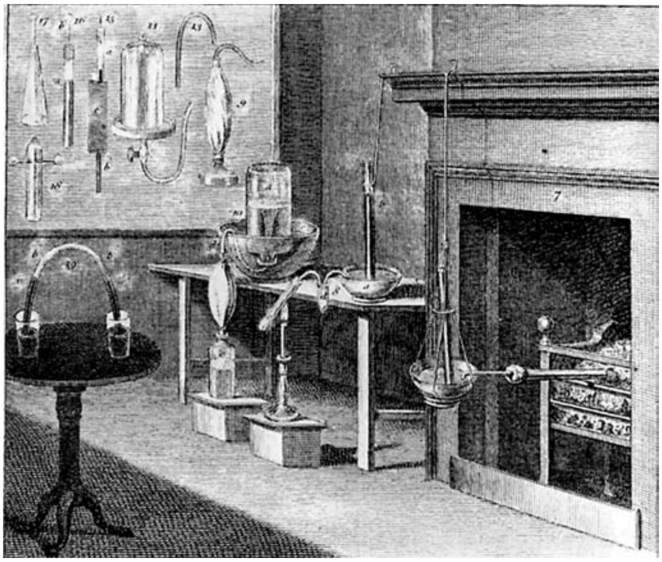


FIGURE I.11 • Priestley's London laboratory. (Edgar Fahs Smith Collection, University of Pennsylvania Library.)

called foul-air (phlogisticated air in Priestley's day) was later identified as nitrogen.

Just like Priestley, Scheele refused to accept Lavoisier's explanations concerning respiration. Although Scheele adhered to the phlogiston theory, he discovered, in addition to oxygen, chlorine, manganese, silicon, glycerol, silicon tetrafluoride, hydrofluoric acid, and copper arsenite (named Scheele's green in his honor). Scheele also experimented with silver salts and how light influenced them (which became the basis of modern photography). He was the first and only student of pharmacy elected in 1775 into the prestigious Royal Swedish Academy of Sciences (founded by naturalist Carl Linnaeus [1707–1778] in 1739; www.kva.se/en/).

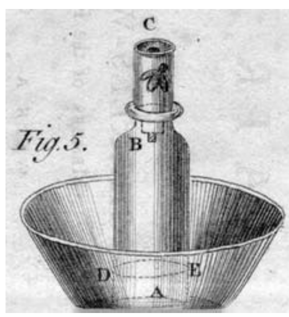


FIGURE I.12 • Scheele's instrument. (Edgar Fahs Smith Collection, University of Pennsylvania Library.)

Henry Cavendish (1731–1810)

Cavendish and his contemporaries Black and Priestley began to identify the constituents of carbohydrates, lipids, and proteins (www.nndb.com/people/030/000083778/). *On Factitious Air* (1766) describes a highly flammable substance, later identified as hydrogen, that was liberated when acids combined with metals. *Experiments in Air* (1784) showed that "inflammable air" (hydrogen) combined with "deflogisticated air" (oxygen) produced water. Cavendish performed meticulous calculations using a sensitive torsion balance to measure the value of the gravitational constant G that allowed him to compute the mass of the Earth (5.976×10^{24} kg). His work eventually played an important role in the development of the space sciences, especially modern rocketry and space exploration (see Chapter 27).

Antoine Laurent Lavoisier (1743–1794)

Antoine Laurent Lavoisier (Courtesy National Library of Medicine)

Lavoisier ushered in modern concepts of metabolism, nutrition, and exercise physiology (www.sportsci.org; http://cti.itc.virginia.edu/~meg3c/classes/tcc313/200Rprojs/lavoisier2/home.html#history). His discoveries in respiration chemistry and human nutrition were as essential to these fields as Harvey's discoveries were to circulatory physiology and medicine. Lavoisier paved the way for studies of energy balance by recognizing for the first time that the elements carbon, hydrogen, nitrogen, and oxygen involved in metabolism neither appeared suddenly nor disappeared mysteriously. He supplied basic truths: only oxygen participates in animal respiration, and the "caloric" liberated during respiration is itself the source of the combustion. In the early 1770s, Lavoisier was the first person to conduct experiments on human respiration with his colleague, chemist Armand Séguin (1767–1835). They studied the influence of muscular work on metabolism. A contemporary painting shows the seated Séguin as he depresses a pedal while a copper mask captures the expired air (Fig. I.13). A physician takes Séguin's pulse to determine the separate effects of exercise and food consumption. (For several hours before the experiment, Séguin had abstained from food.) Resting energy metabolism without food in a cold environment increased by 10%; it increased 50% due solely to food, 200% with exercise, and 300% by combining food intake with exercise. According to Lusk,[44] Lavoisier told of his experiments in a letter written to a friend dated November 19, 1790, as follows:

> The quantity of oxygen absorbed by a resting man at a temperature of 26°C is 1200 pouces de France (1 cubic pouce = 0.0198 L) hourly. (2) The quantity of oxygen required at a temperature of 12°C rises to 1400 pouces. (3) During the digestion of food the quantity of oxygen amounts to from 1800 to 1900 pouces. (4) During exercise 4000 pouces and over may be the quantity of oxygen absorbed.

These discoveries, fundamental to modern concepts of energy balance, could not protect Lavoisier from the intolerance of his revolutionary countrymen. The Jacobean tribunal beheaded him in 1794. Yet once more, thoughtless resistance to innovative science temporarily delayed the triumph of truth.

FIGURE I.13 • **(A)** Lavoisier supervises the first "true" exercise physiology experiment (heart rate and oxygen consumption measured as the seated subject at the right breathes through a copper pipe while pressing a foot pedal to increase external work). Sketched by Madame Lavoisier (sitting at the left taking notes). **(B)** The equipment of Lavoisier's laboratory from the mid-1700s can be viewed at Musee des Arts et Metiers in Paris, France, at 160 rue Reaumur. (Image © Frank Katch.)

Lazzaro Spallanzani (1729–1799)

Lazzaro Spallanzani (Courtesy National Library of Medicine)

An accomplished Italian physiologist, Spallanzani debunked spontaneous generation as he studied fertilization and contraception in animals (**www.whonamedit.com/doctor.cfm/2234.html**). In a famous study of digestion, he refined regurgitation experiments similar to those of French entomologist and scientist René-Antoine Fercault de Réaumur (1683–1757; **http://esapubs.org/bulletin/current/history_list/history21.pdf**). Réaumur's *Digestion in Birds* (1752) told how he recovered partially digested food from the gizzard of a kite. Spallanzani swallowed a sponge tied to the end of a string and then regurgitated it. He found that the sponge had absorbed a substance that dissolved bread and various animal tissues, thus indirectly observing how gastric juices function. His experiments with animals showed that the tissues of the heart, stomach, and liver consume oxygen and liberate carbon dioxide, even in creatures without lungs.

Spallanzani's idea that respiration and combustion took place within the tissues was novel and appeared posthumously in 1804. A century later, this phenomenon would be called *internal respiration*.[2]

Nineteenth Century Metabolism and Physiology

The untimely death of Lavoisier did not terminate fruitful research in nutrition and medicine. During the next half-century, scientists discovered the chemical composition of carbohydrates, lipids, and proteins and further clarified what we now term the energy balance equation.[14]

Claude Louis Berthollet (1748–1822)

Claude Louis Berthollet (in white lab coat)

A French chemist and contemporary of Lavoisier, Berthollet identified the "volatile substances" associated with animal tissues. One of these "substances," nitrogen, was produced when ammonia gas burned in oxygen. Berthollet showed that normal tissues did not contain ammonia. He believed that hydrogen united with nitrogen during fermentation to produce ammonia. In 1865, Berthollet took exception to Lavoisier's ideas concerning the amount of heat liberated when the body oxidized an equal weight of carbohydrate or fat. According to Berthollet, "the quantity of heat liberated in the incomplete oxidation of a substance equaled the difference between the total caloric value of the substance and that of the products formed." This established the foundation for the concept of metabolic efficiency—heat production above the actual heat required to produce work.

Joseph Louis Proust (1755–1826)

Joseph Louis Proust (Courtesy National Library of Medicine)

Proust proved that a pure substance isolated in the laboratory or found in nature would always contain the same elements in the same proportions. Known as the "Law of Definite Proportions," Proust's ideas about the chemical constancy of substances provided an important milestone for future nutritional explorers, helping them analyze the major nutrients and calculate energy metabolism as measured by oxygen consumption.

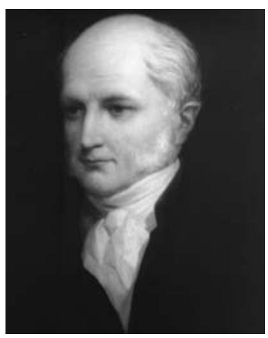
Louis-Joseph Gay-Lussac (1778–1850)

In 1810, Gay-Lussac, a pupil of Berthollet, analyzed the chemical composition of 20 animal and vegetable substances (**www.nndb.com/people/885/000100585/**). He placed the vegetable substances into one of three categories depending on their proportion of hydrogen to oxygen atoms. One class of compounds he called saccharine, later identified as carbohydrate, was accepted by William Prout (1785–1850) in his classification of the three basic macronutrients.

Louis-Joseph Gay-Lussac

William Prout (1785–1850)

Following up the studies of Lavoisier and Séguin on muscular activity and respiration, Prout, an Englishman, measured the carbon dioxide exhaled by men exercising to self-imposed fatigue (*Annals of Philosophy* 1813;2:328). Moderate exercise such as natural walking raised carbon dioxide production to an eventual plateau. This observation heralded the modern concept of steady-rate gas exchange kinetics in exercise. Prout could not determine the exact amount of carbon dioxide respired because no instrumentation existed to measure respiration rate, yet he nevertheless observed that carbon dioxide concentration in expired air decreased dramatically during fatiguing exercise (**www.jn.nutrition.org/content/107/1/15.full.pdf**).



William Prout (© Royal College of Physicians of London)

François Magendie (1783–1855)

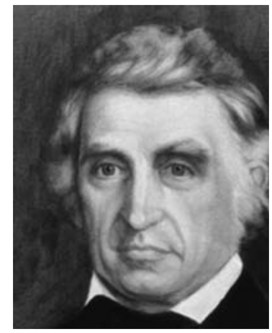
In 1821, Magendie founded the first journal for the study of experimental physiology (*Journal de Physiologie Expérimentale*), a field he literally created. The next year, he showed that anterior spinal nerve roots control motor activities and posterior roots control sensory functions.

François Magendie (Courtesy National Library of Medicine)

Magendie's accomplishments were not limited to neural physiology. Unlike others who claimed that the tissues derived their nitrogen from the air, Magendie argued that the food they consumed provided the nitrogen. To prove his point, he studied animals subsisting on nitrogen-free diets (**www.ncbi.nlm.nih.gov/pmc/articles/PMC1692468/pdf/medlibhistj00006-0055.pdf**).

William Beaumont (1785–1853)

One of the most fortuitous experiments in medicine began on June 6, 1822, at Fort Mackinac in upstate Michigan (**www.sportsci.org; www.james.com/beaumont/dr_life.htm**). As fort surgeon, Beaumont tended the accidental shotgun wound that perforated the abdominal wall and stomach of a young French Canadian, Samata St. Martin, a voyageur for the American Fur Company.



William Beaumont (Courtesy National Library of Medicine)

The wound healed after 10 months but continued to provide new insights concerning digestion. Part of the wound formed a small natural "valve" that led directly into the stomach. Beaumont turned St. Martin on his left side, depressing the valve, and then inserted a tube the size of a large quill 5 or 6 inches into the stomach. He began two kinds of experiments on the digestive processes from 1825 to 1833. First, he observed the fluids discharged by the stomach when different foods were eaten (*in vivo*); second, he extracted samples of the stomach's content and put them into glass tubes to determine the time required for "external" digestion (*in vitro*).

Beaumont revolutionized concepts about digestion. For centuries, the stomach was thought to produce heat that somehow "cooked" foods. Alternatively, the stomach was portrayed as a mill, a fermenting vat, or a stew pan.[d]

Beaumont published the first results of his experiments on St. Martin in the *Philadelphia Medical Recorder* in January 1825 and full details in his "Experiments and Observations on the Gastric Juice and the Physiology of Digestion" (1833).[24] Beaumont ends his treatise with a list of 51 inferences based on his 238 separate experiments. Although working away from the centers of medicine, Beaumont used findings culled from the writings of influential European scientists. Even with their information, he still obeyed the scientific method, basing all his inferences on direct experimentation. Beaumont concluded:

> Pure gastric juice, when taken directly out of the stomach of a healthy adult, unmixed with any other fluid, save a portion of the mucus of the stomach with which it is most commonly, and

[d]Jean Baptise van Helmont (1577–1644), a Flemish doctor, is credited as first to prescribe an alkaline cure for indigestion.[27] Observing the innards of birds, he reasoned that acid in the digestive tract could not alone decompose meats and that other substances ("ferments," now known as digestive enzymes) must break down food.

McArdle WD, Katch FI, Katch VL. "Introduction: A View from the Past." In *Exercise Physiology: Nutrition, Energy, and Human Performance*, 8th ed. Baltimore, MD: Wolters Kluwer, 2015.

> perhaps always combined, is a clear, transparent fluid; inodorous; a little saltish; and very perceptibly acid. Its taste, when applied to the tongue, is similar to thin mucilaginous water, slightly acidulated with muriatic acid. It is readily diffusible in water, wine or spirits; slightly effervesces with alkalis; and is an effectual solvent of the materia alimentaria. It possess the property of coagulating albumen, in an eminent degree; is powerfully antiseptic, checking the putrefaction of meat; and effectually restorative of healthy action, when applied to old, fetid sores, and foul, ulcerating surfaces.

Beaumont's accomplishment is even more remarkable because the United States, unlike England, France, and Germany, provided no research facilities for experimental medicine. Little was known about the physiology of digestion. Yet Beaumont, a "backwoods physiologist,"[14] inspired future studies of gastric emptying, intestinal absorption, electrolyte balance, rehydration, and nutritional supplementation with "sports drinks."

Michel Eugene Chevreul (1786–1889)


Michel Eugene Chevreul (Courtesy National Library of Medicine)

During his long life, Chevreul carried on a 200-year family tradition of studying chemistry and biology. His *Chemical Investigations of Fat* (1823) described different fatty acids (**www.lipidlibrary.aocs.org/history/Chevreul/index.htm**). In addition, he separated cholesterol from biliary fats, coined the term *margarine*, and was first to show that lard consisted of two main fats (a solid he called *stearine* and the other a liquid called *elaine*). Chevreul also demonstrated that sugar from a diabetic's urine resembled cane sugar.

Jean Baptiste Boussingault (1802–1884)


Jean Baptiste Boussingault (Courtesy National Library of Medicine)

Boussingault's studies of animal nutrition paralleled later studies of human nutrition (see, for example, **jn.nutrition.org/content/84/1/1.full.pd**). He calculated the effect of calcium, iron, and other nutrient intake (particularly nitrogen) on energy balance. His pioneering work among Columbians formed the basis for his recommendations that they receive iodine to counteract goiter. Boussingault also turned his attention to plants. He showed that the carbon within a plant came from atmospheric carbon dioxide. He also determined that a plant derived most of its nitrogen from the nitrates in the soil, not from the atmosphere, as previously believed.

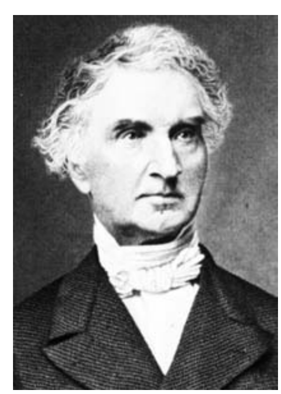
Gerardus Johannis Mulder (1802–1880)


Gerardus Johannis Mulder (© Science Museum/Science & Society Picture Library)

A professor of chemistry at Utrecht University, Netherlands, Mulder analyzed albuminous substances he named "proteine." He postulated a general protein radical identical in chemical composition to plant albumen, casein, animal fibrin, and albumen. This protein would contain substances other than nitrogen available only from plants. Because animals consume plants, substances from the plant kingdom, later called amino acids, served to build their tissues. Unfortunately, an influential German chemist, Justus von Liebig (1803–1873) attacked Mulder's theories about protein so vigorously that they fell out of favor.

Despite the academic controversy, Mulder strongly advocated society's role in promoting quality nutrition. He asked, "Is there a more important question for discussion than the nutrition of the human race?" Mulder urged people to observe the "golden mean" by eating neither too little nor too much food. He established minimum standards for his nation's food supply that he believed should be compatible with optimum health. In 1847, he gave these specific recommendations: laborers should consume 100 g of protein daily; those doing routine work about 60 g. He prescribed 500 g of carbohydrate as starch and included "some" fat without specifying an amount (**www.encyclopedia.com/topic/Gerardus_Johannes_Mulder.aspx**).

Justus von Liebig (1803–1873)


Justus von Liebig (Courtesy National Library of Medicine)

Embroiled in professional controversies, Liebig nevertheless established a large, modern chemistry laboratory that attracted numerous students (**www.sportsci.org**) (**Fig. I.14**). He developed unique equipment to analyze inorganic and organic substances. Liebig restudied protein compounds (alkaloids discovered by Mulder) and concluded that muscular exertion (by horses or humans) required mainly proteins, not just carbohydrates and fats. Liebig's

FIGURE I.14 • Hundreds of chemists trained at Liebig's Geisen laboratory, many achieving international reputations for pioneering discoveries in chemistry. (Photo courtesy of Magnus Mueller, Liebig Museum, Giessen, Germany.)

influential *Animal Chemistry* (1842) communicated his ideas about energy metabolism.

Liebig dominated chemistry; his theoretical pronouncements about the relation of dietary protein to muscular activity were usually accepted without critique by other scientists until the 1850s. Despite his pronouncements, Liebig never carried out a physiologic experiment or performed nitrogen balance studies on animals or humans. Liebig, ever so arrogant, demeaned physiologists, believing them incapable of commenting on his theoretic calculations unless they themselves achieved his level of expertise.

By midcentury, physiologist Adolf Fick (1829–1901) and chemist Johannes Wislicenus (1835–1903) challenged Liebig's dogma concerning protein's role in exercise. Their simple experiment measured changes in urinary nitrogen during a mountain climb. The protein that broke down could not have supplied all the energy for the hike (**www.sportsci.org**). The result discredited Liebig's principle assertion regarding the importance of protein metabolism in supplying energy for vigorous exercise.

Although erroneous, Liebig's notions about protein as a primary exercise fuel worked their way into popular writings. By the turn of the 20th century, an idea that survives today seemed unassailable: athletic prowess requires a large protein intake. He lent his name to two commercial products; *Liebig's Infant Food*, advertised as a replacement for breast milk, and *Liebig's Fleisch Extract* (meat extract) that supposedly conferred special benefits to the body. Liebig argued that consuming his extract and meat would help the body perform extra "work" to convert plant material into useful substances. Even today, fitness magazines tout protein supplements for peak performance with little except anecdotal confirmation. Whatever the merit of Liebig's claims, debate continues, building on the metabolic studies of W. O. Atwater (1844–1907), F. G. Benedict (1870–1957), and R. H. Chittenden (1856–1943) in the United States and M. Rubner (1854–1932) in Germany.[14]

Henri Victor Regnault (1810–1878)

With his colleague Jules Reiset, Henri Regnault, a professor of chemistry and physics at the University of Paris, used closed-circuit spirometry to determine the respiratory quotient (RQ; carbon dioxide ÷ oxygen) in dogs, insects, silkworms, earthworms, and frogs (1849). Animals were placed in a sealed, 45-L bell jar surrounded by a water jacket (**Fig. I.15**). A potash solution filtered the carbon dioxide gas produced during respiration. Water rising in a glass receptacle forced oxygen into the bell jar to replace the quantity consumed during energy metabolism. A thermometer recorded temperature, and a manometer measured variations in chamber pressure. For dogs, fowl, and rabbits deprived of food, the RQ was lower than when the same animals consumed meat. Regnault and Reiset reasoned that starving animals subsist on their own tissues. Foods never were completely destroyed during metabolism because urea and uric acid were recovered in the urine.

Regnault established relationships between different body sizes and metabolic rates. These ratios preceded the law of surface area and allometric scaling procedures now applied in kinesiology and the exercise sciences.

Claude Bernard (1813–1878)

Claude Bernard

Bernard, typically acclaimed as the greatest physiologist of all time, succeeded Magendie as professor of medicine at the Collège de France (**www.sportsci.org; www.claude-bernard.co.uk/page2.htm**) (**Fig. I.16**). Bernard interned in medicine and surgery before serving as laboratory assistant (préparateur) to Magendie in 1839. Three years later, he followed Magendie to the Hôtel-Dieu (hospital) in Paris. For the next 35 years, Bernard discovered fundamental properties concerning physiology. He participated in the explosion of scientific knowledge in the midcentury. Bernard indicated his

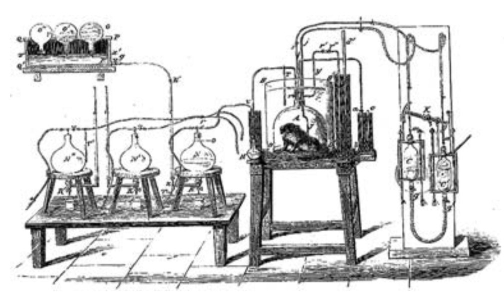


FIGURE I.15 • Regnault's closed-circuit spirometry experiment. (Courtesy Max Planck Institute for the History of Science, Berlin/Virtual Lab.; **http:mpiwg-berlin.mpg/technology/data?id=tec205**.)

FIGURE I.16 • The Lesson of Claude Bernard, or Session at the Vivisection Laboratory, L'hermitte, Leon Augustine, Academie de Medicine, Paris, France, 1889. Students observing Bernard (white apron, no hat) perform a dissection as part of their medical training.

single-minded devotion to research by producing a doctorate thesis on gastric juice and its role in nutrition (*Du sac gastrique et de son rôle dans la nutrition*; 1843). Ten years later, he received the Doctorate in Natural Sciences for his study titled *Recherches sur une nouvelle fonction du foie, consideré comme organe producteur de matière sucrée chez l'homme et les ani-maux* (Research on a new function of the liver as a producer of sugar in man and animals). Before this seminal research, scientists assumed that only plants could synthesize sugar, and that sugar within animals must derive from ingested plant matter. Bernard disproved this notion by documenting the presence of sugar in the hepatic vein of a dog whose diet lacked carbohydrate.

Bernard's experiments that profoundly impacted medicine include:

1. Discovery of the role of the pancreatic secretion in the digestion of lipids (1848)
2. Discovery of a new function of the liver—the "internal secretion" of glucose into the blood (1848)
3. Induction of diabetes by puncture of the floor of the fourth ventricle (1849)
4. Discovery of the elevation of local skin temperature upon section of the cervical sympathetic nerve (1851)
5. Production of sugar by washed excised liver (1855) and the isolation of glycogen (1857)
6. Demonstration that curare specifically blocks motor nerve endings (1856)
7. Demonstration that carbon monoxide blocks the respiration of erythrocytes (1857)

Bernard's work also influenced other sciences.[24] His discoveries in chemical physiology spawned physiological chemistry and biochemistry, which in turn spawned molecular biology a century later. His contributions to regulatory physiology helped the next generation of scientists understand how metabolism and nutrition affected exercise. Bernard's influential *Introduction à l'étude de la médecine expérimentale* (*The Introduction to the Study of Experimental Medicine*, 1865) illustrates the self-control that enabled him to succeed despite external disturbances related to politics. Bernard urged researchers to vigorously observe, hypothesize, and then test their hypothesis. In the last third of the book, Bernard shares his strategies for verifying results. His disciplined approach remains valid, and exercise physiologists and their students would profit from reading this book (**www.ncbi.nlm.nih.gov/pmc/articles/PMC195131/**).

Edward Smith (1819–1874)

Edward Smith (Courtesy National Library of Medicine)

Edward Smith, physician, public health advocate, and social reformer, promoted better living conditions for Britain's lower class, including prisoners (**www.sportsci.org**). He believed prisoners were maltreated because they received no additional food while toiling on the exhausting "punitive treadmill." Smith had observed prisoners climbing up a treadwheel, whose steps resembled the side paddle wheels of a Victorian steamship. Prisoners climbed for 15 min, after which they were allowed a 15-min rest, for a total of 4 hr of work three times a week. To overcome resistance from a sail on the prison roof attached to the treadwheel, each man traveled the equivalent of 1.43 miles up a steep hill.

Curious about this strenuous exercise, Smith conducted studies on himself. He constructed a closed-circuit apparatus (facemask with inspiratory and expiratory valves; **Fig. I.17**) to measure carbon dioxide production while climbing at Brixton prison.[24] He expired 19.6 more grams of carbon while climbing for 15 min and resting for 15 min than he expired while resting. Smith estimated that if he climbed and rested for 7.5 hr, his daily total carbon output would increase 66%. Smith analyzed the urine of four prisoners over a 3-wk period to show that urea output was related to the nitrogen content of the ingested foods, while carbon dioxide related more closely to exercise intensity.

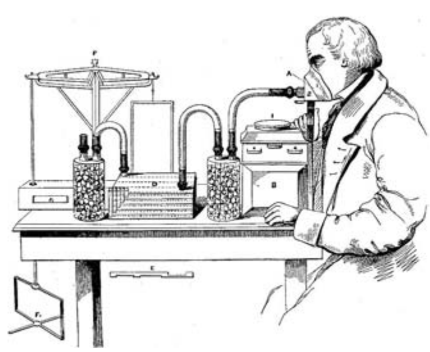


FIGURE I.17 • Edward Smith's apparatus. (Courtesy Max Planck Institute for the History of Science, Berlin/Virtual Lab; **http://mpiwg-berlin.mpg/technology/data?id=tec2626**.)

Smith inspired two German researchers to validate the prevailing idea that protein alone powered muscular contraction. Adolf Eugen Fick (1829–1901), a physiologist at the University of Zurich, and Johannes Wislicenus (1835–1903), a professor of chemistry at Zurich, questioned whether oxidation of protein or oxidation of carbohydrates and fats supplied energy for muscular work. In 1864, they climbed Mt. Faulhorn in the Swiss Alps. Prior to the climb, they eliminated protein from their diet, reasoning that nonprotein nutrients would have to supply them energy. They collected their urine before and immediately after the ascent and the following morning. They calculated the external energy equivalent of the 1956-m climb by multiplying body mass by the vertical distance. This external energy requirement exceeded protein catabolism reflected by nitrogen in the urine. Therefore, they concluded that the energy from protein breakdown hardly contributed to the exercise energy requirement. Again, these findings posed a serious challenge and decisive blow to Liebig's claim that protein served as the primary source of muscular power.

Health and Hygiene Influences in the United States

By the early 1800s in the United States, ideas about health and hygiene were strongly promoted by European science-oriented physicians and experimental anatomists and physiologists.[25,26] Prior to 1800, only 39 first edition American-authored medical books had been published, a few medical schools had been started in the 13 colonies (College of Philadelphia, 1765; Harvard Medical School 1782), seven medical societies existed (the New Jersey State Medical Society being the first in 1766[7,10]), and only one medical journal was available (*Medical Repository*, published in 1797; **www.beckerexhibits.wustl.edu/rare/collections/periodicals.html**). Outside of the United States, 176 medical journals were being published, but by 1850 the number in the United States had increased to 117.[70]

Medical journal publications in the United States had increased tremendously during the first half of the 19th century, concurrent with a steady growth in the number of scientific contributions, yet European influences still affected the thinking and practice of U.S. medicine.[49] This influence was particularly apparent in the "information explosion" that reached the public through books, magazines, newspapers, and traveling "health salesmen" who peddled an endless array of tonics, elixirs, and other products for purposes of optimizing health and curing disease. The "hot topics" of the early 19th century (also true today) included nutrition and dieting (slimming), general information concerning exercise, how to best develop overall fitness, training (or gymnastic) exercises for recreation and sport preparation, and all matters relating to personal health and hygiene.[27]By the middle of the 19th century, fledgling medical schools in the United States began to graduate their own students, many of whom assumed positions of leadership in the academic world and allied medical sciences. Interestingly, physicians had the opportunity either to teach in medical school and conduct research (and write textbooks) or become associated with departments of physical education and hygiene. There, they would oversee programs of physical training for students and athletes.[46]

Within this framework, we begin our discussion of the early physiology and exercise physiology pioneers with Austin Flint, Jr., MD, a respected physician, physiologist, and successful textbook author. His writings provided reliable information for those wishing to place their beliefs about exercise on a scientific footing.

thePoint **Appendix A, available online at http://thepoint.lww.com/mkk8e, provides several bibliographies of influential publications pertaining to anatomy and physiology, anthropometry, exercise and training, and exercise physiology, including those of Dr. Austin Flint.**

Austin Flint, Jr., MD: American Physician-Physiologist

Austin Flint, Jr., MD (1836–1915), was one of the first influential American pioneer physician-scientists whose writings contributed significantly to the burgeoning literature in physiology. Flint served as a professor of physiology and physiological anatomy in the Bellevue Hospital Medical College of New York, and chaired the Department of Physiology and Microbiology from 1861 to 1897. In 1866, he published a series of five classic textbooks, the first titled *The Physiology of Man; Designed to Represent the Existing State of Physiological Science as Applied to the Functions of the Human Body. Vol. 1; Introduction; The Blood; Circulation; Respiration*. Eleven years later, Flint published *The Principles and Practice of Medicine*, a synthesis of his first five textbooks, which consisted of 987 pages of meticulously organized sections with supporting documentation. The text included 4 lithograph plates and 313 woodcuts of detailed anatomic illustrations of the body's major systems, along with important principles of physiology. In addition, there were illustrations of equipment used to record physiologic phenomena, such as Etienne-Jules Marey's (1830–1904) early cardiograph for registering the wave form and frequency of the pulse and a refinement of one of Marey's instruments, the sphygmograph, for making pulse measurements (**www.themitralvalve.org/mitralvalve/jean-baptiste-auguste-chauveau**)—the forerunner of modern cardiovascular instrumentation (**Fig. I.18**).

Austin Flint, Jr. (Courtesy National Library of Medicine)

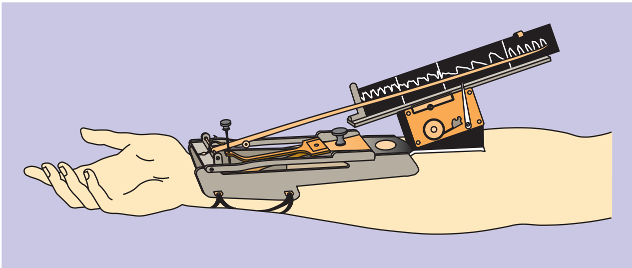


FIGURE I.18 • Marey's advanced sphygmograph, including portions of four original tracings of the pulse under different conditions. It was not until the next century in 1928 that Ernst P. Boas (1891–1955) and colleague Ernst F. Goldschmidt (cited in the 1932 Boas and Goldschmidt text *The Heart Rate*) reported on their human experiments with the first electronic cardiotachometer. (Goldschmidt had invented the pulse resonator for recording pulse rate in 1927.)

Dr. Flint, one of six generations of physicians spanning the years 1733 to 1955, was well trained in the scientific method. In 1858, he received the American Medical Association's prize for basic research on the heart, and his medical school thesis titled "The Phenomena of Capillary Circulation," was published in 1878 in the *American Journal of the Medical Sciences*. A characteristic of Flint's textbooks was his admiration for the work of other scholars. These included noted French physician Claude Bernard (1813–1878); the celebrated observations of Dr. William Beaumont; and William Harvey's momentous discoveries.

Dr. Flint was a careful writer. This was a refreshing approach, particularly because so many "authorities" in physical training, exercise, and hygiene in the United States and abroad were uninformed and unscientific about exercise and its possible role in health care. In his 1877 textbook, Flint wrote about many topics related to exercise. The following sample passages are quoted from Flint's 1877 book to present the flavor of the emerging science of exercise physiology in the late 19th century:

> It has been observed that the position of the body has a very marked influence upon the rapidity of the pulse. Experiments of a very interesting character have been made by Dr. Guy and others, with a view to determine the difference in the pulse in different postures. In the male, there is a difference of about ten beats between standing and sitting, and fifteen beats between standing and the recumbent posture. In the female, the variations with position are not so great. The average given by Dr. Guy is, for the male standing, 81; sitting, 71; lying, 66;-for the female: standing, 91; sitting, 84; lying, 80. This is given as the average of a large number of observations.
>
> *Influence of age and sex*. In both the male and female, observers have constantly found a great difference in the rapidity of the heart's action at different periods of life.
>
> *Influence of exercise, etc*. It is a fact generally admitted that muscular exertion increases the frequency of the pulsations of the heart; and the experiments just cited show that the difference in rapidity, which is by some attributed to change in posture (some positions, it is fancied, offering fewer obstacles to the current of blood than others), is mainly due to muscular exertion. Everyone knows, indeed, that the action of the heart is much more rapid after violent exertion, such as running, lifting, etc.
>
> Nearly all observers are agreed that there is a considerable increase in the exhalation of carbonic acid during and immediately following muscular exercise. In insects, Mr. Newport has found that a greater quantity is sometimes exhaled in an hour of violent agitation than in twenty-four hours of repose. In a drone, the exhalation in twenty-four hours was 0.30 of a cubic inch, and during violent muscular exertion the exhalation in one hour was 0.34. Lavoisier recognized the great influence of muscular activity upon the respiratory changes. In treating of the consumption of oxygen, we have quoted his observations on the relative quantities of air vitiated in repose and activity.

Through his textbooks, Austin Flint, Jr., influenced the first medically trained and scientifically oriented professor of physical education, Edward Hitchcock, Jr., MD. Hitchcock quoted Flint about the muscular system in his syllabus of Health Lectures, required reading for all students enrolled at Amherst College between 1861 and 1905.

The Amherst College Connection

Two physicians, father and son, pioneered the American sports science movement. Edward Hitchcock, DD, LLD (1793–1864), a professor of chemistry and natural history at Amherst College, also served as president of the college from 1845–1854. He convinced the college president in 1861 to allow his son Edward [(1828–1911); Amherst undergraduate (1849); Harvard medical degree (1853)] to assume the duties of his anatomy course. Subsequently, Edward Hitchcock, Jr., was officially appointed on August 15, 1861, as Professor of Hygiene and Physical Education with full academic rank in the Department of Physical Culture at an annual salary of $1000, a position he held almost continuously until 1911. This was the second such appointment in physical education to an American college in the United States.[e]

[e]Edward Hitchcock, Jr., is often accorded the distinction of being the first professor of physical education in the United States, whereas, in fact, John D. Hooker was first appointed to this position at Amherst College in 1860. Because of poor health, Hooker resigned in 1861, and Hitchcock was appointed in his place. The original idea of a Department of Physical Education with a professorship had been proposed in 1854 by William Agustus Stearns, DD, the fourth president of Amherst College, who considered physical education instruction essential for the health of the students and useful to prepare them physically, spiritually, and intellectually. Other institutions were slow to adopt this innovative concept; the next department of physical education in America was not created until 1879. In 1860, the Barrett Gymnasium at Amherst College was completed and served as the training facility where all students were required to perform systematic exercises for 30 min, 4 days a week. The gymnasium included a laboratory with scientific instruments (e.g., spirometer, strength and anthropometric equipment) and also a piano to provide rhythm during the exercises. Hitchcock reported to the Trustees that in his first year, he recorded the students' "vital statistics—including age, weight, height, size of chest and forearm, capacity of lungs, and some measure of muscular strength."

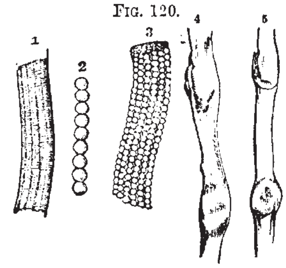
CHAPTER SECOND.

THE MOVING POWERS OF THE SYSTEM.—MYOLOGY, OR THE HISTORY OF THE MUSCLES.

DEFINITIONS AND DESCRIPTIONS.

228. **Microscopic Structure of Muscle.**—The Muscles, known as flesh or lean meat, compose a large part of the extremities, and the covering of the trunk. To the naked eye they appear to be fibrous, and, with the assistance of the microscope, these fibers are found to be bundles—called Fasciculi—of still smaller fibers, called Ultimate Fibers. These seem to be polygonal in form, and with an average diameter of $\frac{1}{400}$th of an inch in man, though in some of the lower animals their size is much less.

FIG. 120.



View of the stages of development of Muscular Fiber. 1, A Muscular Fiber of Animal life enclosed in its Sheath or Myolemma. 2, An Ultimate Fibril of the same. 3, A more highly magnified View of Fig. 1, showing the true nature of the Longitudinal Striæ, as well as the mode of formation of the Transverse Striæ. The Myolemma is here so thin as to permit the Ultimate Fibrils to be seen through it. 4, A Muscular Fibre of Organic life with two of its Nuclei; taken from the Urinary Bladder, and magnified 600 Diameters. 5, A Muscular Fibre of Organic life from the Stomach, magnified the same.

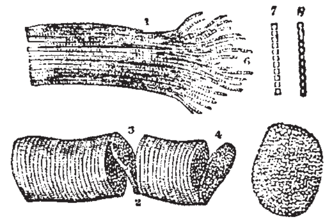
229. **Fibrils.**—The ultimate fibers are still further divisible into what are termed Fibrils. These have an average diameter of about $\frac{1}{10000}$th

228. What is lean meat? How does muscle appear to the naked eye? What are the three microscopic elements? Describe each. 229. What is the diameter of the Fibrils?

A

108 HITCHCOCK'S ANATOMY

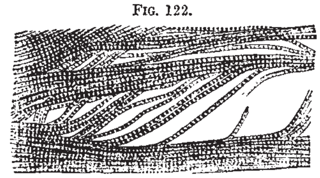
FIG. 121.



A View of the Fragments of Striped elementary Fibers, showing a cleavage in opposite directions—magnified 300 Diameters. 1, The Longitudinal Cleavage. 2, The Transverse Cleavage, the Longitudinal Lines being scarcely visible. 3, Incomplete Fracture, following the opposite surfaces of a Disc which stretches across the Interval and retains the two Fragments in connexion. The Edge and Surface of this Disc are seen to be minutely granular, the Granules corresponding in size to the thickness of the Disc and to the distance between the faint Longitudinal Lines. 4, Another Disc nearly detached. 5, A detached Disc more highly magnified, showing the Sarcous Elements. 6, Fibrillæ separated by violence from each other at the broken end of the Fiber. 7, 8, The two appearances commonly presented by the separated single Fibrillæ; more highly magnified, at 7 the spaces are rectangular, at 8 the borders are scalloped and the spaces bead-like.

of an inch, and number about 650 in each ultimate fiber. They are unprotected by any covering, while both the fasiculus and ultimate fiber are everywhere protected by a delicate sheath called the Sarcolemma.

FIG. 122.



Fibrils of Human Muscle.

230. **Organic, or Unstriped, and Animal, or Striped Fibers.**—All the muscles of the body are divided into two classes, according to their function. Those necessary for carrying on the vital functions, such as breathing and digestion, are called Organic, and those under the control of the will Animal Fibers. In addition to their use as a means of distinction, they may be known by their appearance under the micro-

What is the Sarcolemma? On what element of muscle is this wanting? 230. Give the two functional classes of the muscles.

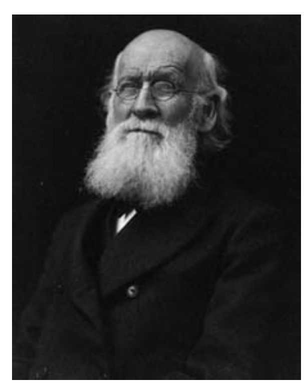
B

FIGURE I.19 • Examples from the Hitchcocks' text on structure and function of muscles. (Reproduced from Hitchcock E, Hitchcock E Jr. Elementary anatomy and physiology for colleges, academies, and other schools. New York: Ivison, Phinney & Co., 1860:132, 137. Materials courtesy of Amherst College Archives and permission of the Trustees of Amherst College, 1995.)

The Hitchcocks geared their textbook to college physical education (Hitchcock E., Hitchcock E., Jr. *Elementary Anatomy and Physiology for Colleges, Academies, and Other Schools*. New York: Ivison, Phinney & Co., 1860; Edward Hitchcock, Sr., had previously published a textbook on hygiene in 1831). The Hitchcock and Hitchcock anatomy and physiology book predated Flint's anatomy and physiology text by 6 years. Topics covered were listed in numerical order by subject, and considerable attention was devoted to the physiology of species other than humans. The text included questions at the bottom of each page concerning the topics under consideration, making the textbook a "study guide" or "workbook," not an uncommon pedagogic feature (Cutter, 1848; see the bibliographies in Appendix A online). **FIGURE I.19** shows sample pages on muscle structure and function from the Hitchcock and Hitchcock text.

Dr. Edward Hitchcock (1793–1864)

From 1865 to approximately 1905, Hitchcocks' syllabus of Health Lectures (a 38-page pamphlet titled *The Subjects and Statement of Facts Upon Personal Health Used for the Lectures Given to the Freshman Classes of Amherst College*) was part of the required curriculum. The topics included hygiene and physical education, with brief quotations about the topic, including a citation for the quote. In addition to quoting Austin Flint, Jr., regarding care of the muscles, "The condition of the muscular system is an almost



Dr. Edward Hitchcock, Jr., MD (1828–1911) unfailing evidence of the general state of the body," other quotations peppered each section of the pamphlet, some from well-known physiologists such as Englishman Thomas Henry Huxley (1825–1895: **www.lexicorps.com/Huxley.htm**) and Harvard's Henry Pickering Bowditch (1840–1911; cofounder of the American Physiological Society in 1887 and American editor of the *Journal of Physiology*; **www.nasonline.org/publications/biographical-memoirs/memoir-pdfs/bowditch-henry-p.pdf**). For example, with regard to physical education and hygiene, Huxley posited "The successful men in life are those who have stored up such physical health in youth that they can in an emergency work sixteen hours in a day without suffering from it." Concerning food and digestion, Bowditch stated: "A scientific or physiological diet for an adult, per day, is two pounds of bread, and three-quarters of a pound of lean meat," and in regard to tobacco use, "Tobacco is nearly as dangerous and deadly as alcohol, and a man with tobacco heart is as badly off as a drunkard." Other quotations were used for such tissues as skin. Dr. Dudley A. Sargent (1849–1924; pioneer Harvard physical educator; **http://hul.harvard.edu/huarc/summersch/physed.html**) told readers, "Wear dark clothes in winter and light in summer. Have three changes of underclothing—heavy flannels for winter, light flannels for spring and fall, lisle thread, silk or open cotton for summer."

Anthropometric Assessment of Body Build

During the years 1861 to 1888, Dr. Hitchcock, Jr., obtained 6 measures of segmental height, 23 girths, 6 breadths, 8 lengths, 8 measures of muscular strength, lung capacity, and pilosity (amount of hair on the body) from almost every student who attended Amherst College. From 1882 to 1888, according to Hitchcock, his standardization for measurement was improved based on the suggestions of Dr. W. T. Brigham of Boston and Dr. Dudley A. Sargent (Yale medical degree, 1878; assistant professor of physical training and director of Harvard's Hemenway Gymnasium).

In 1889, Dr. Hitchcock and his colleague in the Department of Physical Education and Hygiene, Hiram H. Seelye, MD (also served as college physician from 1884–1896), published a 37-page anthropometric manual that included five tables of anthropometric statistics of students from 1861 to 1891. This resource compendium provided detailed descriptions for taking measurements that also included eye testing and an examination of the lungs and heart before testing subjects for muscular strength. In the last section of the manual, Dr. Seelye wrote detailed instructions for using the various pieces of gymnasium apparatus for "enlarging and strengthening the neck, to remedy round or stooping shoulders, to increase the size of the chest and the capacity of the lungs, to strengthen and enlarge the arm, abdominal muscles, and weak back, and to enlarge and strengthen the thighs, calves, legs and ankles." The Hitchcock and Seelye manual, the first of its kind devoted to an analysis of anthropometric and strength data based on detailed measurements, influenced other departments of physical education in the United States (e.g., Yale, Harvard, Wellesley, Mt. Holyoke) to include anthropometric measurements as part of the physical education and hygiene curriculum.[f]

One reason for the early interest in anthropometric measurement was to demonstrate that engaging in daily, vigorous exercise produced desirable bodily results, particularly for muscular development. Although none of the early physical education scientists used statistics to evaluate the outcomes of exercise programs, it is instructive to apply modern methods of anthropometric analysis to the original data of Hitchcock on entering students at Amherst College in 1882 and on their graduation in 1886. **Figure I.20** shows how the average student changed in anthropometric dimensions throughout 4 years of college in relation to Behnke's reference standards presented in Chapter 28. Note the dramatic increase in biceps girth and decreases in the nonmuscular abdomen and hip regions. Although data for a nonexercising "control" group of students were not available, these changes coincided with daily resistance training prescribed in the Hitchcock and Seelye *Anthropometric Manual*. This training used Indian club or barbell swinging exercises (**Fig. I.21**) and other strengthening modalities (horizontal bar, rope and ring exercises, parallel bar exercises, dipping machine, inclined presses with weights, pulley weights, and rowing machine workouts). The Hitchcock data presentation, a first of its kind initially reported in the *Anthropometric Manual* in March 1892, used "bodily stature" as the basis of comparison "from measurements of 1322

[f]Probably unknown to Hitchcock was the 1628 manuscript of the Flemish fencing instructor at the French Royal Court, Gerard Thibault, who studied optimal body proportions and success in fencing.[65] This early text, *L'Académie de l'Espée*, appeared at a time when important discoveries were being made by European scientists, particularly anatomists and physiologists, whose contributions played such an important role in laboratory experimentation and scientific inquiry. Had Hitchcock known about this early attempt to link anthropometric assessment with success in sport, the acceptance of anthropometry in the college curriculum might have been easier. Nevertheless, just 67 years after Hitchcock began taking anthropometric measurements at Amherst, and 37 years following the creation of Harvard's physical education scientific laboratory in 1891, anthropometric measurements were made of athletes at the 1928 Amsterdam Olympic Games. One of the athletes measured in Amsterdam, Ernst Jokl from South Africa, became a physician and then a professor of physical education at the University of Kentucky. Jokl was a charter member and founder of the American College of Sports Medicine. Thus, Hitchcock's visionary ideas about the importance of anthropometry finally caught on, and such assessment techniques are now used routinely in exercise physiology to assess physique status and the dynamics between physiology and performance. The more modern application of anthropometry is now known as *kinanthropometry*. This term, first defined at the International Congress of Physical Activity Sciences in conjunction with the 1976 Montreal Olympic Games,[64] was refined in 1980[65] as follows: "Kinanthropometry is the application of measurement to the study of human size, shape, proportion, composition, maturation, and gross function. Its purpose is to help us to understand human movement in the context of growth, exercise, performance, and nutrition. We see its essentially human-enobling purpose being achieved through applications in medicine, education, and government."

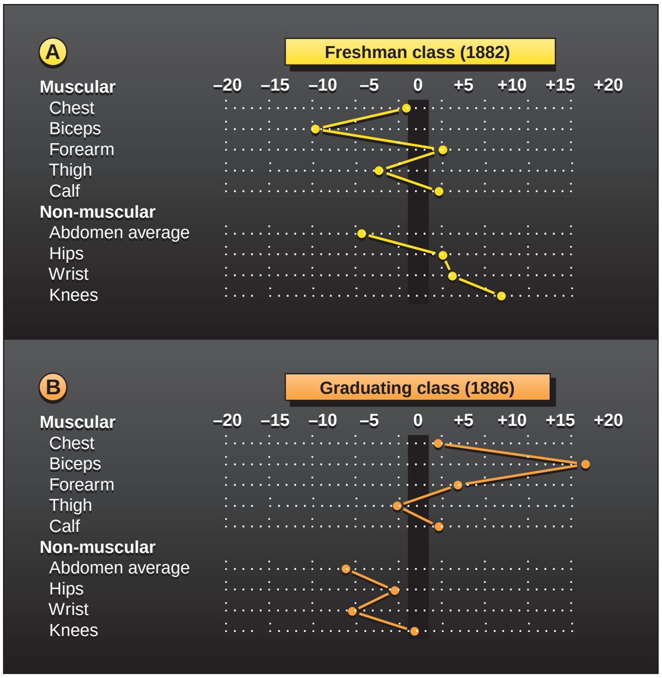


FIGURE 1.20 • Changes in selected girth measurements of Amherst College men over 4 years of college using Behnke's reference man standards (presented in Chapter 28). **(A)** The average body mass of the freshman class in 1882 was 59.1 kg (stature, 171.0 cm). **(B)** Four years later, average body mass increased 5.5 kg (11.3 lb) and stature increased by 7.4 cm (2.9 in).

FIGURE I.21 • Dr. Edward Hitchcock, Jr. (second from right, with beard), observing the students perform barbell exercises in the Pratt Gymnasium of Amherst College. (Photo courtesy of Amherst College Archives and by permission of the Trustees of Amherst College, 1995.)

students between 17 and 26 years of age. The strength tests are derived from 20,761 items." The Hitchcock anthropometric and strength studies were acknowledged in the first formal American textbook on anthropometry, published in 1896 by Jay W. Seaver, MD (1855–1915), physician and lecturer on personal hygiene at Yale University. **Table I.2** presents a sample

TABLE I.2 Average and Best Anthropometric and Strength Records of Amherst College from 1861 to 1900 Inclusive

	Average		Maximal			
Items[a]	Metric	English	Metric	English	Held By	Date of Record
Weight	61.2	134.9	113.7	250.6	K.R. Otis '03	Oct. 2, '99
Height	1725	67.9	1947	76.6	B. Matthews '99	Oct. 28, '95
Girth, head	572	22.5	630	24.8	W.H. Lewis '92	Feb '92
Girth, neck	349	13.7	420	16.5	D.R. Knight '01	Feb. '91
Girth, chest, repose	880	34.6	1140	44.9	K.R. Otis '03	Oct. 2, '99
Girth, belly	724	28.5	1017	40.1	G.H. Coleman '99	May '97
Girth, hips	893	35.1	1165	45.9	K.R. Otis '03	Oct. 2, '99
Girth, right thigh	517	20.3	745	29.3	K.R. Otis '03	Oct. 2, '99
Girth, right knee	361	14.2	460	18.1	K.R. Otis '03	Oct. 2, '99
Girth, right calf	359	14.1	452	17.8	K.R. Otis '03	Oct. 2, '99
Girth, upper-right arm	257	10.1	396	15.6	K.R. Otis '03	Oct. 2, '99
Girth, right forearm	267	10.5	327	12.8	K.R. Otis '03	Oct. 2, '99
Girth, right wrist	166	6.5	191	7.5	H.B. Haskell '94	April '92
Strength, chest, dip	6	–	45	–	H.W. Lane '95	March '95
Strength, chest, pull up	9	–	65	–	H.W. Seelye '79	Oct. '75
Strength, right forearm	41	90	86	189.6	A.J. Wyman '98	April '96
Strength, left forearm	38	84	73	160.9	A.J. Wyman '98	April '96

From Hitchcock E, et al. An anthropometric manual, 4th ed. Amherst, MA: Carpenter and Morehouse, 1900.
[a]Weight in kg or lb; height in. cm or in. girths in mm or in. strength in kg or lb.

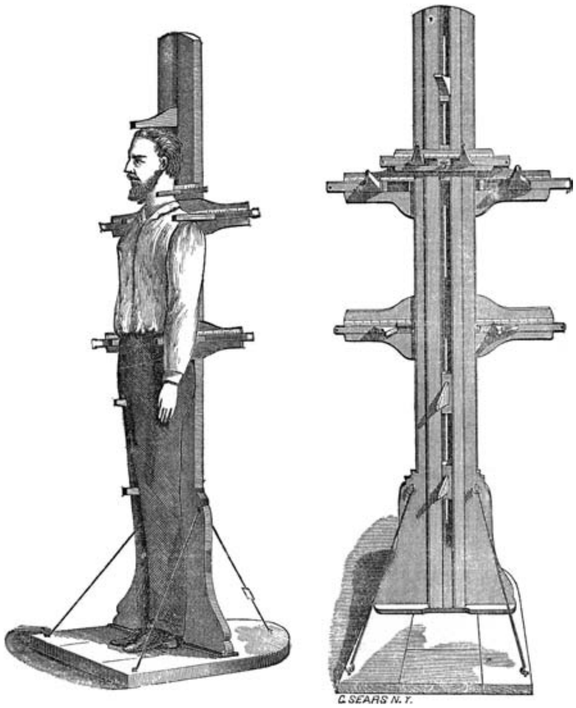


FIGURE I.22 • The andrometer, first used by the United States Sanitary Commission at numerous military installations along the Atlantic seaboard during the early 1860s, sized soldiers for clothing.

of the average and "best" anthropometric values at Amherst College from 1861 to 1900.

While Hitchcock was performing pioneering anthropometric studies at the college level, the military was making the first detailed anthropometric, spirometric, and muscular strength measurements on Civil War soldiers in the early 1860s, published in 1869 by Gould (see the bibliographies in Appendix A online). The specially trained military anthropometrists used a unique device, the *andrometer* (**Fig I.22**), to secure the physical dimensions to the nearest 1/10th of an inch of soldiers for purposes of fitting uniforms. The andrometer was originally devised in 1855 by a tailor in Edinburgh, Scotland, commissioned by the British government to determine the proper size for British soldiers' clothing. This device was set by special gauges to adjust "sliders" for measurement of total height; breadth of the neck, shoulders, and pelvis; and the length of the legs and height to the knees and crotch. Each examiner received 2 days of practice to perfect measurement technique before assignment to different military installations (e.g., Fort McHenry in Baltimore, Naval Rendezvous in New York City, Marine Barracks at the Brooklyn Navy Yard, and bases in South Carolina, Washington, D.C., Detroit, and New Orleans). Data were compiled on the actual and relative proportions of 15,781 men ("Whites, Blacks, Indians") between the ages of 16 and 45 years. These early investigations about muscular strength and body dimensions served as prototypical studies whose measurement techniques led the way to many later studies conducted in the military about muscular strength and human performance per se. Most laboratories in exercise physiology today include assessment procedures to evaluate aspects of muscular strength and body composition.[63,76]

Figure I.23A shows two views of the instrument used to evaluate muscular strength in the military studies; Figure I.23B shows the early spirometers used to evaluate pulmonary dimensions. The strength device predates the various strength-measuring instruments shown in **Figure I.24** used by Hitchcock (Amherst), Sargent (Harvard), and Seaver (Yale), as well as anthropometric measuring instruments used in their batteries of physical measurements. The *inset* shows the price list of some of the equipment from the 1889 and 1890 Hitchcock manuals on anthropometry. Note the progression in complexity of the early spirometers and strength devices used in the 1860 military studies (Fig. I.23), and the more "modern" equipment of the 1889–1905 period displayed in Figure I.24. **Figure I.25** includes three photographs (circa 1897–1901) of the strength-testing equipment (Kellogg's Universal Dynamometer) acquired by Dr. Hitchcock in 1897 to assess the strength of arms *(A)*; anterior trunk and forearm supinators *(B)*; and leg extensors, flexors, and adductors *(C)*.[g]

The First Exercise Physiology Laboratory and Degree Program in the United States

The first formal exercise physiology laboratory in the United States was established in 1891 at Harvard University and housed in a newly created Department of Anatomy, Physiology, and Physical Training at the Lawrence Scientific School.[25,44] Several instructors in the initial undergraduate BS degree program in Anatomy, Physiology, and Physical Training started at the same time were Harvard-trained

[g]According to Hitchcock and Selye's *Anthropometric Manual*, the device consisted "of a lever acting by means of a piston and cylinder on a column of mercury in a closed glass tube. Water keeps the oil in the cylinder from contact with the mercury and various attachments enable the different groups of muscles to be brought to bear on the lever. By means of this apparatus, the strength of most of the large muscles may be tested fairly objectively" (p. 25). In the photographs, note the attachment of the tube to each device. Interestingly, Hitchcock determined an individual's total strength as a composite of body weight multiplied by dip and pull tests, strength of the back, legs, and average of the forearms, and the lung strength. Hitchcock stated, "The *total strength* is purely an arbitrary, and relative, rather than an actual test of strength as its name would indicate. And while confessedly imperfect, it seems decidedly desirable that there should be some method of comparison which does not depend entirely on lifting a dead weight against gravity, or steel springs."

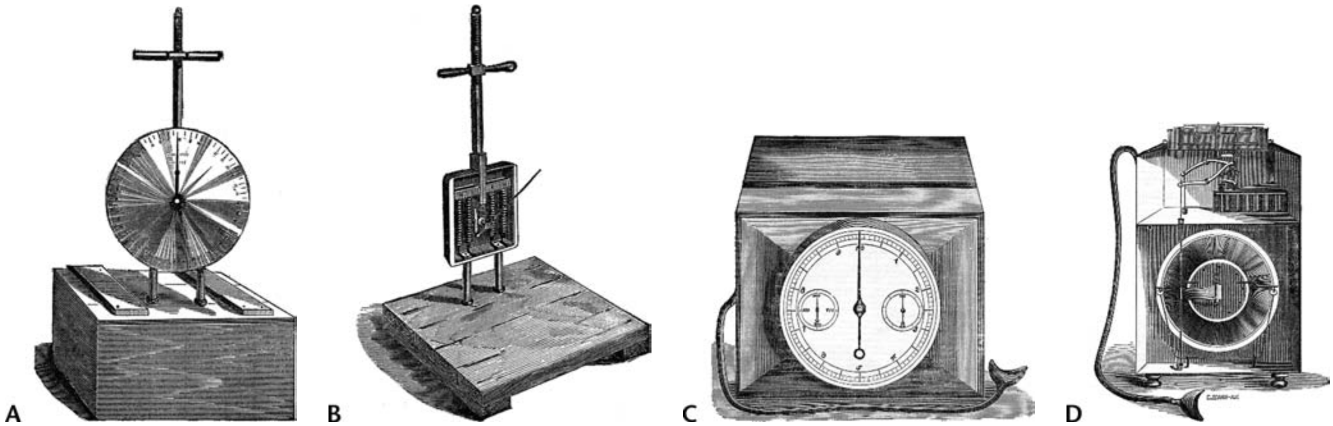


FIGURE I.23 • **(A** and **B)** Instrument used to evaluate muscular strength in the military studies of Gould in 1869. The illustration on the *left* shows the general look of the device, while the *right side* shows the internal arrangement without face-plate. Gould described the procedure for measuring muscular strength as follows: "The man stands upon the movable lid of the wooden packing box, to which the apparatus is firmly attached, and grasps with both hands the rounded extremities of a wooden bar, of convenient shape and adjustable in height. The handle is conveniently shaped for firm and easy grasp, its height well suited for application and the full muscular power, and the mechanism such as to afford results which are to all appearance very trustworthy." This was not the first dynamometer; Gould cites Regnier (no date given), who published a description of a dynamometer to measure the strength of Parisians; and Péron, who carried a dynamometer on an expedition to Australia. Other researchers in Europe had also used dynamometers to compare the muscular strength of men of different races. Figure 22.2C (in Chapter 22) shows the modern back-leg lift dynamometer still used for assessing muscular strength as part of physical fitness test procedures. **(C** and **D)** Spirometers (or dry gas meters), manufactured by the American Meter Company of Philadelphia, were used to measure vital capacity. According to Gould, the spirometers needed to be rugged "… to undergo the rough usage inseparable from transportation by army trains or on military railroads, which are in danger of being handled roughly at some unguarded moment by rude men …". The spirometers were graduated in cubic centimeters and were "furnished with a mouth-piece of convenient form, connected with the instrument by flexible tubing."

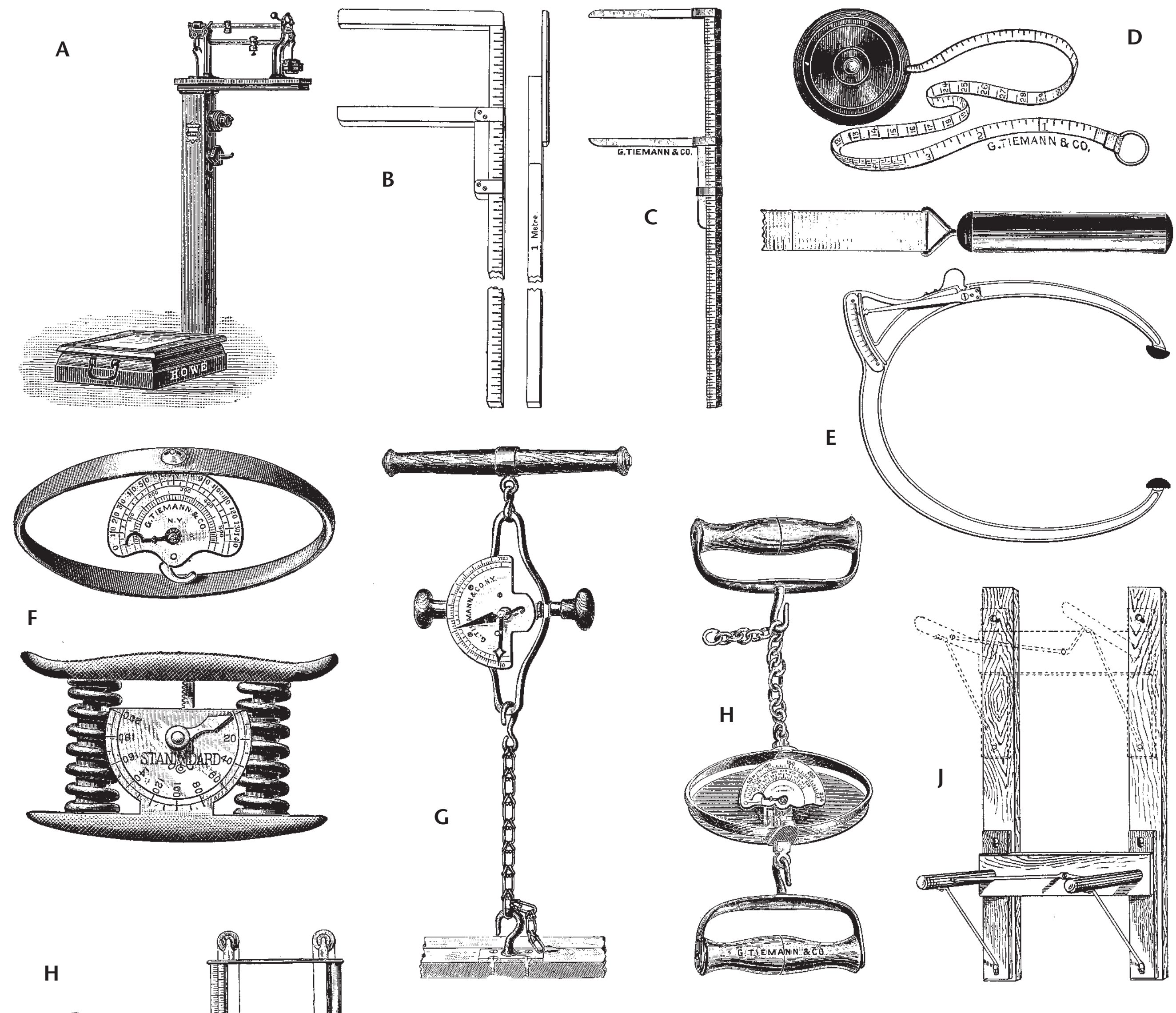
physicians; others—including Henry Pickering Bowditch, renowned professor of physiology who discovered the all-or-none principle of cardiac contraction and treppe, the staircase phenomenon of muscular contraction, and William T. Porter, also a distinguished physiologist in the Harvard Medical School—were respected for their rigorous scientific and laboratory training.

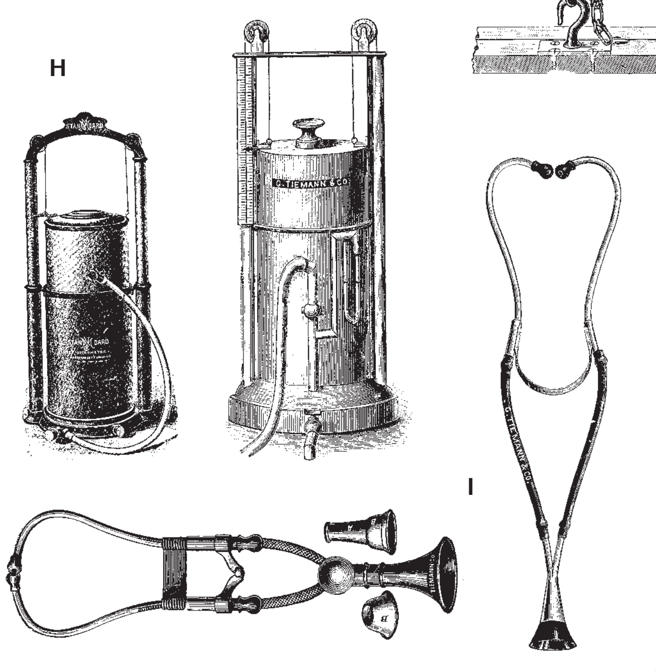
George Wells Fitz, MD: A Major Influence

An important influence in creating the new departmental major and recruiting top scientists as faculty in the Harvard program was George Wells Fitz, MD (1860–1934). Fitz vociferously supported a strong, science-based curriculum in preparing the new breed of physical educators. The archival records show that the newly formed major was grounded in the basic sciences, including formal coursework in exercise physiology, zoology, morphology (animal and human), anthropometry, applied anatomy and animal

George Wells Fitz, MD

FIGURE I.24 • Anthropometric instruments used by Hitchcock, Seaver, and Sargent. Sargent, also an entrepreneur, constructed and sold specialized strength equipment used in his studies. **(A)** Metric graduated scale. **(B)** Height meter. **(C)** Sliding anthropometer. **(D)** Cloth tape measure, with an instrument made by the Narragansett Machine Co. at the suggestion of Dr. Gulick (head of the Department of Physical Training of the YMCA Training School, Springfield, MA) in 1887. The modern version of this tape, now sold as the "Gulick tape," was "for attachment to the end of a tape to indicate the proper tension, so that the pressure may be always alike." **(E)** Calipers for taking body depths. **(F)** Several types of hand dynamometers, including push holder and pull holder instruments. **(G)** Back and leg dynamometer, also used to measure the strength of the pectoral and "retractor" muscles of the shoulders. **(H)** Vital capacity spirometer and Hutchinson's wet spirometer. **(I)** Two stethoscopes. The soft rubber bell was used to "secure perfect coaptation to the surface of the chest." The Albion Stethoscope was preferred because it could be conveniently carried in the pocket. **(J)** Parallel bars for testing arm extensors during push-ups and testing of flexors in pull-ups. In special situations, physiology laboratories used Marey's cardiograph to record pulse, but the preferred instrument was a pneumatic kymograph (or sphygmograph; see Fig. 2). The *inset table* shows a price comparison for the testing equipment from the 1889 and 1890 Hitchcock manuals. Note the yearly variation in prices. (Inset courtesy of Amherst College Archives, reproduced by permission of the Trustees of Amherst College, 1995.)





Anthropometric Apparatus

The essential apparatus for securing these statistics and measurements are:

	1889	1890
Fairbanks' scales,	$18.00	$18.00
Measure for heights,	9.00	8.00
Measure for breadths,	4.00	3.00
Measure for depths,	3.50	4.00
Wall Parallel for Dip and Pull Up,	–	7.50
Back and Leg Dynamometer,	30.00	50.00
Hand Dynamometer,	15.00	10.00
Lung Dynamometer,	15.00	18.00
Lung Spirometer,	17.00	12.00
Tapes,	1.00	.25
ALSO		
A Record book,	$8.00	$8.00
A Stethoscope,	1.25	3.00
Set of colored worsteds,	1.25	2.50
Cards for Eye Tests,	1.00	1.50
Two Pairs of Spectacles,	3.00	3.00
Tuning Fork,	.35	.50

These may be obtained of the Narragansett Machine Co., Providence, R.I., or A.G. Spalding, Nassau St., New York City.

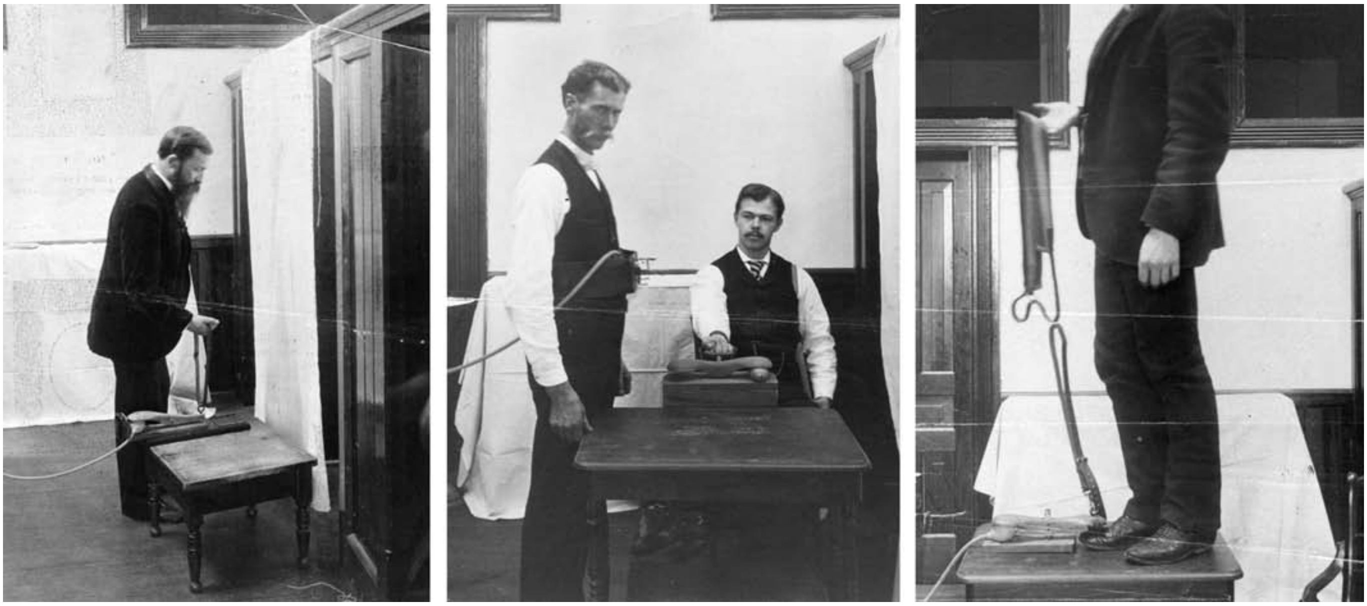


FIGURE I.25 • Kellogg's Universal Dynamometer acquired by Dr. Hitchcock to test the muscular strength of Amherst College students. From 1897 to 1900, strength measurements were taken on 328 freshmen, 111 sophomores, and 88 seniors, including retests of 58 individuals. Arm strength was measured bilaterally for the forearms and for the latissimus dorsi, deltoid, pectoral, and shoulder "retractor" muscles. Trunk measurements included the anterior trunk, and anterior and posterior neck. The leg measurements included the leg extensors and flexors and thigh adductors. (**Left**) "Arm pull." (**Center**) Anterior trunk (standing) and forearm supinators (sitting). (**Right**) Legs. (Photos courtesy of Amherst College Archives and by permission of the trustees of Amherst College, 1995.)

mechanics, medical chemistry, comparative anatomy, remedial exercises, physics, gymnastics and athletics, history of physical education, and English. Physical education students took general anatomy and physiology courses in the medical school; after 4 years of study, graduates could enroll as second-year medical students and graduate in 3 years with an MD degree. Dr. Fitz taught the *physiology of exercise* course; thus, we believe he was one of the first medically trained persons to formally teach such a course. It included experimental investigation and original work and thesis, including 6 hr a week of laboratory study. The course prerequisites included general physiology at the medical school or its equivalent. The purpose of the course was to introduce the student to the fundamentals of physical education and provide training in experimental methods related to exercise physiology. Fitz also taught a more general course titled Elementary Physiology of the Hygiene of Common Life, Personal Hygiene, Emergencies. The course included one lecture and one laboratory section a week for a year (or three times a week for one-half year). The official course description stated:

> This is a general introductory course intended to give the knowledge of human anatomy, physiology and hygiene which should be possessed by every student; it is suitable also for those not intending to study medicine or physical training.

Fitz also taught a course titled Remedial Exercises. The Correction of Abnormal Conditions and Positions. Course content included observations of deformities such as spinal curvature (and the corrective effects of specialized exercises) and the "selection and application of proper exercises, and in the diagnosis of cases when exercise is unsuitable." Several of Fitz's scientific publications dealt with spinal deformities; one study, published in the *Journal of Experimental Medicine* 1896;1(4) ("A Study of Types of Respiratory Movements") dealt with the mechanics of breathing. In addition to the remedial exercise course, students took a required course, *Applied Anatomy and Animal Mechanics. Action of Muscles in Different Exercises*. This thrice-weekly course, taught by Dr. Dudley Sargeant, was the forerunner of modern biomechanics courses. Its prerequisite was general anatomy at the medical school or its equivalent. Sargeant designed numerous exercise machines with pulleys and weights (**www.ihpra.org/imagesa/sargentex.jpg**), many of which he sold to individuals and schools, but not without the disdain of the university administration, which probably led to his unplanned separation from Harvard a few years after the last students graduated.

By the year 1900, nine men had graduated with bachelor of science degrees from the Department of Anatomy, Physiology, and Physical Training. The aim of the major was to prepare students to become directors of gymnasia or instructors in physical training, to provide students with the necessary knowledge about the science of exercise, and to offer suitable training for entrance to the medical school. The stated purpose of the new exercise physiology research laboratory was as follows:

> A large and well-equipped laboratory has been organized for the experimental study of the physiology of exercise. The object of this work is to exemplify the hygiene of the muscles, the conditions under which they act, the relation of their action to the body as a whole affecting blood supply and general hygienic conditions, and the effects of various exercises upon muscular growth and general health.

With the activities of the department in full operation, its outspoken and critical director was not afraid to speak his mind about academic topics. For example, Dr. Fitz reviewed a new physiology text (*American Text-Book of Physiology*, edited by William H. Howell, PhD, MD) in the March 1897 issue of the *American Physical Education Review* (Vol. II, No. 1, p. 56). The review praised Dr. Howell's collection of contributions from outstanding physiologists (such as Bowditch, Lee, Lusk, and Sewall), and attacked an 1888 French book by Lagrange that some writers consider the first important text in exercise physiology.[h] The following is Fitz's review:

> No one who is interested in the deeper problems of the physiology of exercise can afford to be without this book [referring to Howell's Physiology text], and it is to be hoped it may be used as a text-book in the normal schools of physical training. These schools have been forced to depend largely on Lagrange's "physiology of exercise" for the discussion of specific problems, or at least for the basis of such discussions. The only value Lagrange has, to my mind, is that he seldom gives any hint of the truth, and the student is forced to work out his own problems. This does very well in well-taught classes, but, Alas! for those schools and readers who take his statements as final in matters physiological. We have a conspicuous example of the disastrous consequences in Treve's contribution of the "Cyclopaedia of Hygiene on Physical Education," in which he quotes freely from Lagrange and rivals him in the absurdity of his conclusions.
>
> The time has surely come for a thoroughly scientific investigation of the physiological problems involved in physical exercise and the promulgation of the exact and absolute. It is not too much to hope that the use of the American Text-Book of Physiology by training schools and teachers, may aid to bring about this much needed consummation.

For unknown reasons, but coinciding with Fitz's untimely departure from Harvard in 1899,[i] the department changed its curricular emphasis (the term *physical training* was dropped from the department title), thus terminating at least temporarily this unique experiment in higher education.

One of the legacies of the Fitz-directed "Harvard experience" between 1891 and 1899 was the training it provided to the cadre of young scholars, who began their careers with a strong scientific basis in exercise and training and its relationship to health. Unfortunately, it would take another quarter century before the next generation of science-oriented physical educators (led not by physical educators but by such world-class physiologists as Nobel laureate A. V. Hill and 1963 ACSM Honor Award recipient David Bruce Dill) would once again exert a strong influence on the physical education curriculum.

Other individuals also contributed to the scientific explosion of new knowledge in exercise physiology. Russian-born research scientist Peter V. Karpovich (1896–1975; **www.la84foundation.org/SportsLibrary/IGH/IGH0804/IGH0804c.pdf**) directed the Physiological Research Laboratory at Springfield College in western Massachusettes for 40 years. His distinguished career included 150 published articles, book chapters, and monographs dealing with fitness and exercise (salient examples include the biomechanics of swimming, artificial respiration, caloric expenditure of physical activities, weightlifting and flexibility, warmup, and footwear studies). His influential textbook, *Physiology of Muscular Activity* (Philadelphia: W.B. Saunders, 3rd ed., 1948), first coauthored with Edward C. Schneider (1874–1954) in 1948 and then published under sole authorship in 1953, was translated into five languages and eight editions. It served to educate thousands of physical education students (including the authors of this textbook) on exercise physiology.

Karpovich also served as Chief of the Laboratory of Physical Fitness, School of Army Aviation Medicine, Army Air Force, Randolph Field, Texas from 1942 to 1945, and worked with the United States Army Quartermaster Research and Development Command in Natick, Massachusetts, on projects concerning soldiers' clothing and footwear (**www.qmfound.com/quartermaster_research_development_command.htm**). In 1966, he and son George received a patent for a rotary electrogoniometer to measure the degree of forearm rotation during arm movements—with subsequent publications using the apparatus applied to different limbs in humans and animals.

In May 1954, Karpovich and his wife Dr. Josephine L. Rathbone (1899–1989) (**Fig. I.26**), became founding members

FIGURE I.26 • (Left) Peter V. Karpovich. Center. Wife Josephine Rathbone. **(Right)** Former graduate assistant Charles M. Tipton, 1964. (Photo courtesy of C. M. Tipton.)

[h]We disagree with Berryman's[6] assessment of the relative historical importance of the translation of the original Lagrange text. We give our reasons for this disagreement in a subsequent section, "First Textbook in Exercise Physiology: The Debate Continues."

[i]The reasons for Fitz's early departure from Harvard have been discussed in detail in Park's scholarly presentation of this topic.[50] His leaving was certainly unfortunate for the next generation of students of exercise physiology. In his 1909 textbook *Principles of Physiology and Hygiene* (New York: Henry Holt and Co.), the title page listed the following about Fitz's affiliation: Sometime Assistant Professor Physiology and Hygiene and Medical Visitor, Harvard University.

fyi First Course in the Physiology of Exercise or in Exercise Physiology

Note: ACSM Honor Award winner Dr. Charles Tipton has been concerned about who taught the first college-/university-level course in exercise physiology, and when and where it was offered. Here are his written thoughts on the matter after spending time researching the question in the archives of both Harvard University and Springfield College. Tipton has previously written an historical perspective of our field (Tipton, CM. "Historical Perspective: Origin to Recognition." ACSM's Advanced Exercise Physiology. Baltimore: Lippincott Williams & Wilkins, 2006: 11–38.)

The first textbook devoted to exercise and physiology was written in Latin during 1553 by Spanish physician Cristóbal Méndez (1500–1561), entitled *Book of Bodily Exercise*.[1] In North America, the first time that the words "physiology of exercise" appeared in print was during 1855 in an article by physician William H. Byford (1817–1890). Byford lamented that physicians were indifferent to the health benefits of exercise while encouraging them to become better informed and to initiate research on the subject.[2] Although such physicians as Edward Hitchcock, Jr. (1828–1911), of Amherst College and Dudley A. Sargent (1849–1924) of Harvard University likely included physiology of exercise topics in their physical education courses, it was not until 1892–1893 or 1893–1894 that courses listed as the Physiology of Exercise were officially listed in an institutional Catalogue. In the 1892–1893 Catalogue of Harvard University, the Department of Anatomy, Physiology and Physical Training offered a formal course in Experimental Physiology, in which the Physiology of Exercise was listed as an integral component with physician George Wells Fitz (1896–1934) as the instructor.[3] During the 1893–1894 school year, senior students majoring in physical education at the International Young Men's Christian Association Training School in Springfield, Massachusetts, were enrolled in a Physiology of Exercise course with physician Luther Halsey Gulick, Jr. (1865–1928), responsible for the course.[4] However, there was no catalogue information concerning the semester when the course was taught. Although there is no official record of the assigned text for the Harvard students, it is known that at Springfield College, the required text for the Gulick course was the 1889 text of Fernand LaGrange translated from the French edition, titled, *The Physiology of Bodily Exercise*.[5]

Sources:

1. Méndez C. *The Book of Bodily Exercise (1553)*. Copyright Elizabeth Light. Baltimore: Waverly Press, 1960.
2. Byford WH. *On the Physiology of Exercise. AM J Med Sci* 1855;30:32.
3. *The Harvard University Catalogue, 1892–1893*. Cambridge, MA: Harvard University, 1892: 246–249.
4. *Ninth Catalogue of the International Young Men's Christian Association Training School*. Springfield, MA, 1893–1894.
5. LaGrange F. *Physiology of Bodily Exercise*. New York: D. Appleton, 1889.

of the American Federation of Sports Medicine (now the American College of Sports Medicine [ACSM; www.acsm.org]). Karpovich served as the fifth president of the ACSM (1961–1962). He trained a cadre of outstanding graduate students in exercise physiology who established their own productive laboratory research programs and service to the profession (e.g., Charles M. Tipton, ACSM President, 1974–1975; Howard Knuttgren, ACSM President, 1973–1974; Loring (Larry) Rowell, see "Interview with Dr. Loring B. Rowell").

Exercise Studies in Research Journals

Another notable event in the growth of exercise physiology occurred in 1898: the appearance of three articles dealing with physical activity in the first volume of the *American Journal of Physiology*.[j] This was followed in 1921 with the publication of the prestigious journal *Physiological Reviews* (physrev.physiology.org).

thePoint **Appendix A, available online at http://thepoint.lww.com/mkk8e, provides several bibliographies of influential publications pertaining to anatomy and physiology, anthropometry, exercise and training, and exercise physiology, and includes a list of the articles in this journal (and two from the *Annual Review of Physiology*), from the first review of the mechanisms of muscular contraction by A. V. Hill (www.sportsci.org) in 1922, to pioneer researcher in exercise physiology, physical medicine, and rehabilitation Professor Francis Hellebrandt's classic review of exercise in 1940 (www.secfac.wisc.edu/senate/2002/1007/1656(mem_res).pdf).**

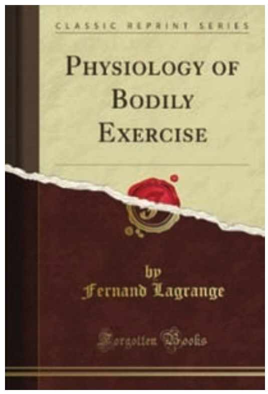
The German applied physiology publication *Internationale Zeitschrift fur angewandte Physiologie einschliesslich Arbeitsphysiologie* [1929–1973; now the *European Journal of Applied Physiology* (www.springerlink.com/content/1439-6319)], a significant journal for research in exercise physiology, published hundreds of research articles in numerous disciplines related to exercise physiology. The *Journal of Applied Physiology* (www.jap.physiology.org) first published in 1948. Its first volume contained the now-classic paper on ratio expressions of physiologic data with reference to body size and function by British child-growth and development researcher-pediatrician James M. Tanner, MD (1920-2010; *A History of the Study of Human Growth*, 1981), a must-read for exercise

[j] The originator of the *American Journal of Physiology* was physiologist William T. Porter of the St. Louis College of Medicine and Harvard Medical School, who remained editor until 1914.[12] Porter's research focused on cardiac physiology. The three articles in volume 1 concerned spontaneous physical activity in rodents and the influence of diet (C. C. Stewart, Department of Physiology, Clark University), neural control of muscular movement in dogs (R. H. Cunningham, College of Physicians and Surgeons, Columbia University), and perception of muscular fatigue and physical activity (J. C. Welch, Hull Physiological Laboratory, University of Chicago). As pointed out by Buskirk,[12] the next four volumes of the *American Journal of Physiology* (1898–1901) contained six additional articles about exercise physiology from experimental research laboratories at Harvard Medical School, the Massachusetts Institute of Technology, the University of Michigan, and the Johns Hopkins University.

physiologists. The journal *Medicine and Science in Sports* (now *Medicine and Science in Sports and Exercise* [**www.journals.lww.com/acsm-msse/pages/default.aspx**]).first published in 1969 with a goal of integrating the medical and physiologic aspects of the emerging fields of sports medicine and exercise science.

The First Textbook in Exercise Physiology: The Debate Continues

What was the first textbook in exercise physiology? Several recent exercise physiology texts give the distinction of being "first" to the English translation of Fernand Lagrange's book, *The Physiology of Bodily Exercise*, originally published in French in 1888.[6,73,76]



To deserve such historical recognition, we believe the work needs to meet the following three criteria:

1. Provide sound scientific rationale for major concepts
2. Provide summary information (based on experimentation) about important prior research in a particular topic area (e.g., contain scientific references to research in the area)
3. Provide sufficient "factual" information about a topic area to give it academic legitimacy

After reading the Lagrange book in its entirety, we came to the same conclusion as did George Wells Fitz in the early 1900s in a review of the text (see above). Specifically, it was a popular book about health and exercise with a "scientific" title. In our opinion, the book is *not* a legitimate "scientific" textbook of exercise physiology based on any reasonable criteria of the time. Despite Lagrange's assertion that the focus of his book assessed physiology applied to exercise and not hygiene and exercise, it is informed by a 19th-century hygienic perspective, not science. We believe Fitz would accept our evaluation.

Much information was available to Lagrange from existing European and American physiology textbooks about the digestive, muscular, circulatory, and respiratory systems, including some limited information on physical training, hormones, basic nutrition, chemistry, and the biology of muscular contraction. Admittedly, this information was relatively scarce, but well-trained physiologists Austin Flint (profiled earlier), William H. Howell (1848–1896; first professor of physiology in the Johns Hopkins Medical School), John C. Dalton (1825–1889; first professor of physiology in America), and William B. Carpenter (1813–1885; textbook writer and experimentalist) had already produced high-quality textbooks that contained relatively detailed information about physiology in general, with some reference to muscular exercise.[49] We now understand why Fitz was so troubled by the Lagrange book. By comparison, the two-volume text by Howell, titled *An American Text-Book of Physiology*, was impressive; this edited volume contained articles from acknowledged American physiologists at the forefront of physiologic research. The Howell textbook represented a high-level physiology text even by today's standards. In his quest to provide the best possible science to teach his physical education and medical students, Fitz could not tolerate a book that did not live up to his expectations of excellence. In fact, the Lagrange book contained fewer than 20 reference citations, and most of these were ascribed to French research reports or were based on observations of friends performing exercise. This plethora of anecdotal reports must have given Fitz "fits."

Lagrange, an accomplished writer, wrote extensively on exercise. Despite the titles of several of his books,[k] Lagrange was not a scientist but probably a practicing "physical culturist." Bibliographic information about Lagrange is limited in the French and American archival records of the period—a further indication of his relative obscurity as a scholar of distinction. As far as we know, there have been no citations to his work in any physiology text or scientific article. For these reasons, we contend the Lagrange book does not qualify as the first exercise physiology textbook.[l]

Other Early Exercise Physiology Research Laboratories

The Nutrition Laboratory at the Carnegie Institute in Washington, D.C. (**www.carnegiescience.edu/legacy/findingaids/CIW-Administration-Records.html**), was created in 1904 to study nutrition and energy metabolism. The first research laboratories established in physical education in the United States to study exercise physiology were at George Williams

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[k] The following books (including translations, editions, and pages) were published by Lagrange beginning in 1888: *Physiologie des Exercices du Corps*. Paris: Alcan, 1888, 372 pp. (6th ed., 1892); *L'Hygiene de l'Exercice Chez les Enfants et les Jeunes Gens*. Paris: Alcan, 1890, 312 pp. (4th ed., 1893; 6th ed., 1896; 7th ed, 1901; 8th ed., 1905); *Physiology of Bodily Exercise*. New York: D. Appleton, 1890, 395 pp.; *De l'Exercice Chez les Adultes*. Paris: Alcan, 1891, 367 pp. (2nd ed., 1892, 367 pp.; 4th ed., 1900, 367 pp.; Italian translation, *Fisiologia degli Esercizj del Corpo*. Milano: Dumolard, 1889; Hungarian translation, 1913); *La Medication par l'Exercice*. Paris: Alcan, 1894, 500 pp.

[l] Possible pre-1900 candidates for "first" exercise physiology textbook listed in Table 1 also include Combe's 1843 text *The Principles of Physiology Applied to the Preservation of Health, and to the Improvement of Physical and Mental Education (*read online at **https://archive.org/stream/principlesofphys1835comb#page/n5/mode/2up**); Hitchcock and Hitchcock's *Elementary Anatomy and Physiology for Colleges, Academies, and Other Schools* (1860; read online at **https://archive.org/stream/0264002.nlm.nih.gov/0264002#page/n5/mode/2up**); George Kolb's 1887 German monograph, translated into English in 1893 as *Physiology of Sport*; and the 1898 Martin text, *The Human Body. An Account of Its Structure and Activities and the Conditions of Its Healthy Working*.

McArdle WD, Katch FI, Katch VL. "Introduction: A View from the Past." In *Exercise Physiology: Nutrition, Energy, and Human Performance*, 8th ed. Baltimore, MD: Wolters Kluwer, 2015.

College (1923), the University of Illinois (1925), and Springfield College (1927). However, the real impact of laboratory research in exercise physiology (along with many other research specialties) occurred in 1927 with the creation of the 800-square foot Harvard Fatigue Laboratory in the basement of Morgan Hall of Harvard University's Business School.[36] During the next two decades, the outstanding work of this laboratory established the legitimacy of exercise physiology on its own merits as an important area of research and study.

Another exercise physiology laboratory started before World War II, the Laboratory of Physiological Hygiene, was created at the University of California, Berkeley in 1934. The syllabus for the Physiological Hygiene course (taught by professor Frank Lewis Kleeberger (1904–1993), the course was the precursor of contemporary exercise physiology courses) contained 12 laboratory experiments.[51] Several years later, Dr. Franklin M. Henry (1904–1993) assumed responsibility for the laboratory. Dr. Henry began publishing the results of different experiments in various physiology-oriented journals including the *Journal of Applied Physiology, Annals of Internal Medicine*, *Aviation Medicine*, *War Medicine*, and *Science*. Henry's first research project, published in 1938 as a faculty member in the Department of Physical Education, concerned the validity and reliability of the pulse–ratio test of cardiac efficiency;[29,30,31] a later paper dealt with predicting aviators' bends. Henry applied his training in experimental psychology to exercise physiology topics, including individual differences in the kinetics of the fast and slow components of the oxygen uptake and recovery curves during light- and moderate-cycle ergometer exercise; muscular strength; cardiorespiratory responses during steady-rate exercise; assessment of heavy-work fatigue; determinants of endurance performance; and neural control factors related to human motor performance (**Fig. I.27**).

Henry also is remembered for his experiments regarding specificity-generality of motor tasks and the "Memory-Drum Theory" of neuromotor reaction and physical performance (*J Mot Behav* 1986;18:77). Henry's seminal paper on "Physical Education as an Academic Discipline" (**www.sph.umd.edu/KNES/IKE/Body/Papers/KNES/Henry-1978.pdf**), paved the way for departments of physical education to change their emphasis to the science of physical activity that included in-depth study of exercise physiology, biomechanics, exercise biochemistry, motor control, and ergonomics. Henry's 1950 lab manual, *The Physiological Basis of Muscular Exercise*, was used by undergraduate and graduate students in the physiology of exercise course at UC Berkeley (*Res Q Exerc Sport* 1994;65:295).

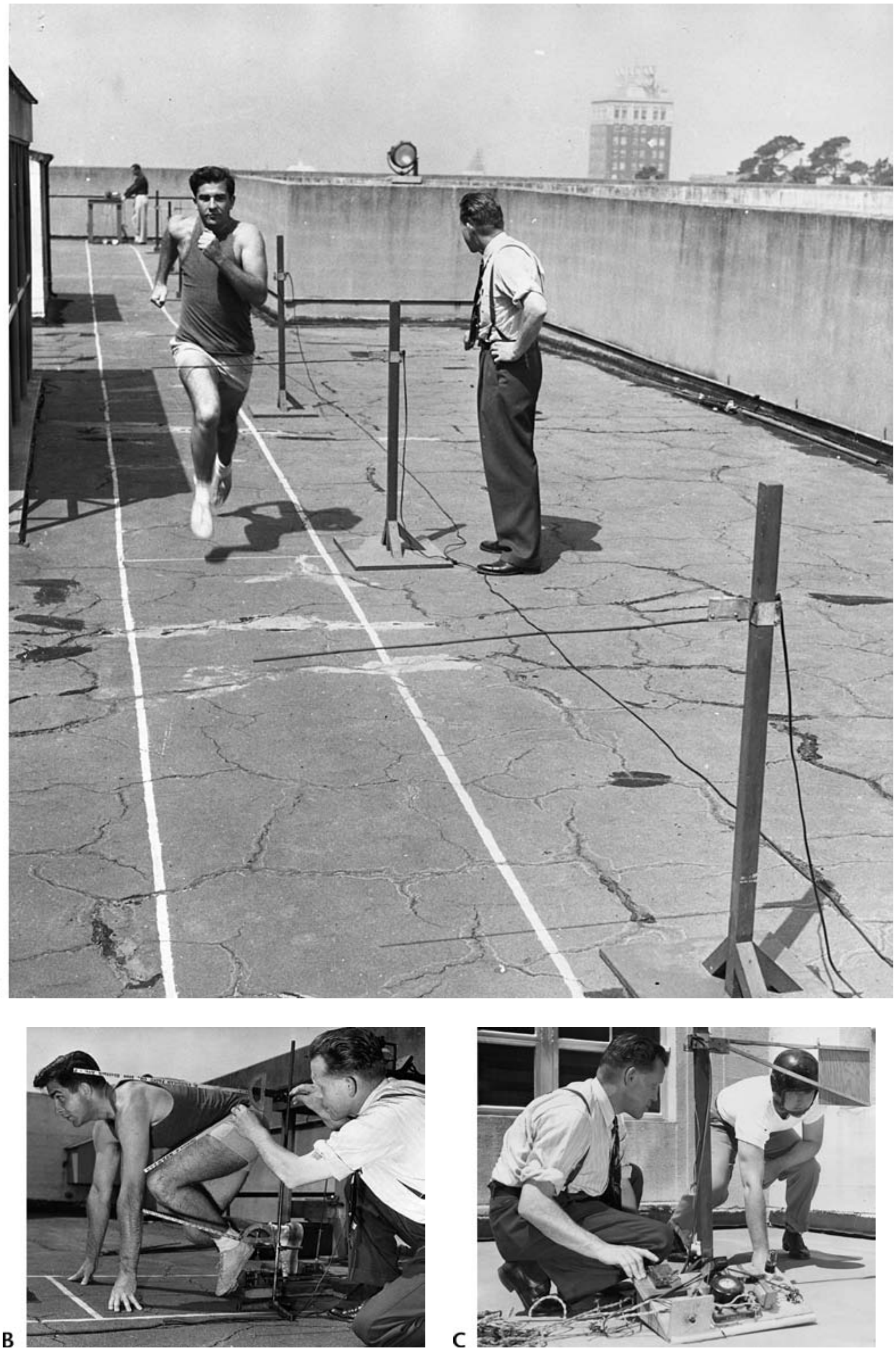
Contributions of the Harvard Fatigue Laboratory (1927–1946)

Many of the great scientists of the 20th century with an interest in exercise were associated with the Harvard Fatigue Laboratory. This research facility was established by Lawrence J. Henderson, MD (1878–1942), renowned chemist and professor of biochemistry at the Harvard Medical School. The first and only scientific director of the Fatigue Laboratory was David Bruce Dill (1891–1986; **www.libraries.ucsd.edu/speccoll/testing/html/mss0517a.html**), a Stanford PhD in physical chemistry. Dill changed his academic interest as a biochemist to an experimental physiologist while at the Fatigue Laboratory. He remained an influential driving force behind the laboratory's numerous scientific accomplishments.[20] His early academic association with Boston physician Arlen Vernon Bock (a student of famous high-altitude physiologist Sir Joseph Barcroft [1872–1947] at the Cambridge Physiological Laboratory at Cambridge, England[5] [**www.pdn.cam.ac.uk/doc/phys/**; **http://www.encyclopedia.com/doc/1G2-2830900266.html**], and Dill's closest friend for 59 years) and contact with 1922 Nobel laureate Archibald Vivian (A. V.) Hill (for his discovery related to heat production in muscles) provided Dill with the confidence to successfully coordinate the research efforts of dozens of scholars from 15 different countries. A. V. Hill convinced Bock to write a third edition of Bainbridge's text *Physiology of Muscular Activity*. Bock, in turn, invited Dill to coauthor the book republished in 1931.[19]

David Bruce Dill

Over a 20-year period, at least 352 research papers, numerous monographs,[37] and a book[20] were published in areas of basic and applied exercise physiology, including methodologic refinements concerned with blood chemistry analysis and simplified methods for analyzing the fractional concentrations of expired air.[18] Research at the Fatigue Laboratory before its demise[21] included many aspects of short-term responses and chronic physiologic adaptations to exercise under environmental stresses produced by exposure to altitude, heat, and cold (**Fig. I.28**).

Like the first exercise physiology laboratory established at Harvard's Lawrence Scientific School in 1892,[50] the Harvard Fatigue Laboratory demanded excellence in research and scholarship. Many of the scientists who had contact with the Fatigue Laboratory profoundly affected a new generation of exercise physiologists in the United States and abroad. Noteworthy were Ancel Keys (1904–2004), who established the Laboratory of Physiology and Physical Education (later renamed the Laboratory of Physiological Hygiene; **www.cehd.umn.edu/kin/research/lphes/history.html**) at the University of Minnesota, and Henry L. Taylor (1912–1983). Keys and Taylor were mentors to exercise physiologist Elsworth R. Buskirk (1925–2010), formerly at the National Institutes of Health and later the Noll Laboratory at Pennsylvania State University; Robert E. Johnson at the Human Environmental Unit at the University of Illinois; Sid Robinson (1902–1982; the first to receive a PhD from the Harvard Fatigue Laboratory) at Indiana University; Robert C. Darling (1908–1998) at the Department of Rehabilitation Medicine at Columbia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B C

FIGURE I.27 • (A) Professor Franklin Henry supervising 50-yard sprints (at 5-yd intervals) on the roof of Harmon Gymnasium. Henry's study[31] was prompted by A. V. Hill's 1927 observations concerning the "viscosity" factor of muscular contraction that at first helped to explain the large decline in metabolic efficiency at fast rates of movement and that the oxygen requirement of running increased with the cube of speed. Henry verified that metabolic efficiency was not correlated with a muscle viscosity factor. **(B)** Henry making limb and trunk anthropometric measurements on a sprinter during continuous studies of the force-time characteristics of the sprint start[32] to further evaluate A. V. Hill's theoretical equation for the velocity of sprint running. **(C)** Henry recording the timing of the initial movements of blocking performance in football players.[48]

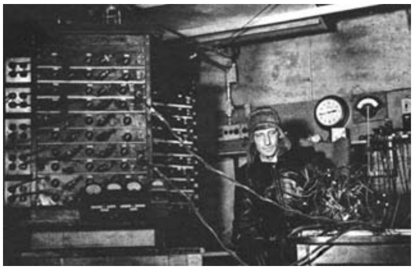


FIGURE I.28 • In 1944, researcher Donald Griffin tests the equipment he designed to assess heat distribution in gloves at –40°F. (From Folk, GE. The Harvard Fatigue Laboratory; contributions to World War II. *Adv Physiol Educ* 2010;34:119.) (**www.advan.physiology.org/content/34/3/119.full.pdf+html**)

University; Harwood S. Belding (1909–1973), who started the Environmental Physiology Laboratory at the University of Pittsburgh; C. Frank Consolazio (1924–1985) of the U.S. Army Medical Research and Nutrition Laboratory at Denver; Lucien Brouha (1899–1968), who headed the Fitness Research Unit at the University of Montreal and then went to the Dupont Chemical Company in Delaware; and Steven M. Horvath (1911–2007), who established the Institute of Environmental Stress at the University of California, Santa Barbara, where he worked with visiting scientists and mentored graduate students in the Departments of Biology and Ergonomics and Physical Education. After the Fatigue Laboratory was unfortunately forced to close in 1946, Dill continued as the deputy director of the U.S. Army Chemical Corps Medical Laboratory in Maryland from 1948 to 1961. Thereafter, he worked with Sid Robinson at Indiana University's physiology department. He then started the Desert Research Institute (www.dri.edu), where he studied the physiologic responses of men and animals to hot environments, a topic that culminated in a book on the subject.[22]

The group of scholars associated with the Harvard Fatigue Laboratory mentored the next generation of students who continue to make significant contributions to the field of exercise physiology. The monograph by Horvath and Horvath[36] and the chronology by Dill[21] are the best direct sources of historical information about the Harvard Fatigue Laboratory; recent studies have chronicled its research contributions.[23,67]

Exercise physiology continued to expand after the closing of the Fatigue Laboratory. Subsequent efforts probed the full range of physiologic functions. The depth and breadth of these early investigations, summarized in **Table I.3**, provides much of the current knowledge base for establishing exercise physiology as an academic field of study.

TABLE I.3 Areas of Investigation at the Harvard Fatigue Laboratory that Helped to Establish Exercise Physiology as an Academic Discipline

1.	Specificity of the exercise prescription.
2.	Genetic components of an exercise response.
3.	Selectivity of the adaptive responses by diseased populations.
4.	Differentiation between central and peripheral adaptations.
5.	The existence of cellular thresholds.
6.	Actions of transmitters and the regulation of receptors.
7.	Feed-forward and feedback mechanisms that influence cardiorespiratory and metabolic control.
8.	Matching mechanisms between oxygen delivery and oxygen demand.
9.	The substrate utilization profile with and without dietary manipulations.
10.	Adaptive responses of cellular and molecular units.
11.	Mechanisms responsible for signal transduction.
12.	The behavior of lactate in cells.
13.	The plasticity of muscle fiber types.
14.	Motor functions of the spinal cord.
15.	The ability of hormonally deficient animals to respond to conditions of acute exercise and chronic disease.
16.	The hypoxemia of severe exercise.

From Tipton CM. Personal communication to F. Katch, June 12, 1995. From a presentation made to the American Physiological Society Meetings, 1995.

Research Methodology Textbook Focusing on Physiologic Research

In 1949, the Research Section of the Research Council of the Research Section of the American Association for Health, Physical Education, and Recreation (AAHPER; an outgrowth of the American Association for the Advancement of Physical Education created in 1885) sponsored publication of the first textbook devoted to research methodology in physical education.[1] Thomas Cureton, PhD (1901–1992; 1969 ACSM Honor Award), a pioneer researcher in physical fitness evaluation and director of the exercise physiology research laboratory, established at the University of Illinois in 1944, appointed Dr. Henry (UC Berkeley) to chair the committee to write the chapter on physiologic research methods. The other committee members were respected scientists in their own right and included the following: Anna Espenshade (1905–1973; PhD in psychology from UC Berkeley, specialist in motor development and motor performance during growth[58]); Pauline Hodgson (UC Berkeley PhD in physiology who did postdoctoral work at the Harvard Fatigue Laboratory); Peter V. Karpovich (originator of the Physiological Research Laboratory at Springfield College); Arthur H. Steinhaus, PhD (director of the research laboratory at George Williams College, one of the 11 founders of the American College of Sports Medicine and a research physiologist who authored an important review article [*Physiological Reviews*, 1933] about chronic effects of exercise); and distinguished Berkeley physiologist Hardin Jones, PhD (Donner Research Laboratory of Medical Physics at UC Berkeley).

The book chapter by this distinguished committee stands as a hallmark of research methodology in exercise physiology.

The 99 references, many of them key articles in this then-embryonic field, covered such exercise-related topics as the "heart and circulation, blood, urine and kidney function, work, lung ventilation, respiratory metabolism and energy exchange, and alveolar air."

Another masterful compendium of research methodologies published 14 years later, *Physiological Measurements of Metabolic Functions in Man*, by C. F. Consolazio and colleagues, provided complete details about specific measurements in exercise physiology.[18] Several sections in this book contained material previously published from the Harvard Fatigue Laboratory one year before its closing in 1946[35] and from another book dealing with metabolic methods published in 1951.[17]

THE NORDIC CONNECTION (DENMARK, SWEDEN, NORWAY, AND FINLAND)

Denmark and Sweden significantly impacted the history of physical education as an academic subject field. In 1800, Denmark was the first European country to include physical training (military-style gymnastics) as a requirement in the public school curriculum. Since that time, Danish and Swedish scientists have made outstanding contributions to research in both traditional physiology and exercise physiology.

Danish Influence

In 1909, the University of Copenhagen endowed the equivalent of a Chair in Anatomy, Physiology, and Theory of Gymnastics.[47] The first docent was Johannes Lindhard, MD (1870–1947). He later teamed with August Krogh (1874–1949; www.sportsci.org), Nobel Prize recipient specializing in physiological chemistry and research instrument design and construction, to conduct many of the now classic experiments in exercise physiology (www.nobelprize.org/nobel_prizes/medicine/laureates/1920/krogh-bio.html). For example, Krogh and Lindhard investigated gas exchange in the lungs, pioneered studies of the relative contribution of fat and carbohydrate oxidation during exercise, measured the redistribution of blood flow during different exercise intensities, and measured cardiorespiratory dynamics in exercise (including cardiac output using nitrous oxide gas, a method described by a German researcher in 1770).

Professors August Krogh and Johannes Lindhard in the early 1930s

By 1910, Krogh and his wife Marie (a physician) had proven through a series of ingenious, decisive experiments[40–43] that diffusion was how pulmonary gas exchange occurred—not by secretion of oxygen from lung tissue into the blood during exercise and exposure to altitude, as postulated by Scottish physiologist Sir John Scott Haldane 1860–1936) and Englishman James Priestley.[28] By 1919, Krogh had published reports of a series of experiments (with three appearing in the *Journal of Physiology*, 1919) concerning the mechanism of oxygen diffusion and transport in skeletal muscles. The details of these early experiments are included in Krogh's 1936 textbook,[40] but he also was prolific in many other areas of science.[39–42] In 1920, Krogh received the Nobel Prize in Physiology or Medicine for discovering the mechanism of capillary control of blood flow in resting and exercising muscle (in frogs). To honor his prolific achievements (which included 300 scientific articles), the Institute for Physiologic Research in Copenhagen was named for him. We highly recommend the book by Schmidt-Nielsen that chronicles the incomparable contributions of August and Marie Krogh to science and exercise physiology.[68]

Marie and August Krogh

Three other Danish researcher-physiologists—Erling Asmussen (1907–1991; ACSM Citation Award, 1976 and ACSM Honor Award, 1979), Erik Hohwü-Christensen (1904–1996; ACSM Honor Award, 1981), and Marius Nielsen (1903–2000)—conducted pioneering studies in exercise physiology. These "three musketeers," as Krogh referred to them, published numerous research papers from the 1930s to the 1970s. Asmussen, initially an assistant in Lindhard's laboratory, became a productive researcher specializing in muscle fiber architecture and mechanics. He also published papers with Nielsen and Christensen as coauthors on many applied topics including muscular strength and performance, ventilatory and cardiovascular response to changes in posture and exercise intensity, maximum working capacity during arm and leg exercise, changes in oxidative response of muscle during exercise, comparisons of positive and negative work, hormonal and core temperature response during different intensities of exercise, and respiratory function in response to decreases in oxygen partial pressure. As evident in his classic review article of muscular exercise that cites many of his own studies (plus 75 references from other Scandinavian researchers)[2], Asmussen's grasp of the importance of the study of biologic functions during exercise is as relevant today as it was more than 45 years ago when the article was published. He clearly defines exercise physiology within the context of biologic science:

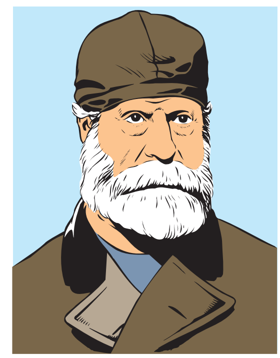
The "three musketeers," Drs. Erling Asmussen (left), Erik Hohwü-Christensen (center), and Marius Nielsen (right) (1988 photo).

> The physiology of muscular exercise can be considered a purely descriptive science: it measures the extent to which the human organism can adapt itself to the stresses and strains of the environment and thus provides useful knowledge for athletes, trainers, industrial human engineers, clinicians, and workers in rehabilitation on the working capacity of humans and its limitations. But the physiology of muscular exercise is also part of the general biological science, physiology, which attempts to explain how the living

organism functions, by means of the chemical and physical laws that govern the inanimate world. Its important role in physiology lies in the fact that muscular exercise more than most other conditions, taxes the functions to their uttermost. Respiration, circulation, and heat regulation are only idling in the resting state. By following them through stages of increasing work intensities, a far better understanding of the resting condition is also achieved. Although the physiology of muscular exercise must be studied primarily in healthy subjects, the accumulated knowledge of how the organism responds to the stresses of exercise adds immensely to the understanding of how the organism adapts itself to disease or attempts to eliminate its effects by mobilizing its regulatory mechanisms.

Christensen became Lindhard's student in Copenhagen in 1925. Together with Krogh and Lindhard, Christensen published an important review article in 1936 that described physiologic dynamics during maximal exercise.[15] In his 1931 thesis, Christensen reported on studies of cardiac output with a modified Grollman acetylene method; body temperature and blood sugar concentration during heavy cycling exercise; comparisons of arm and leg exercise; and the effects of training. Together with Ové Hansen, he used oxygen consumption and the respiratory quotient to describe how diet, state of training, and exercise intensity and duration affected carbohydrate and fat use. Interestingly, the concept of "carbohydrate loading" was first discovered in 1939! Other notable studies included core temperature and blood glucose regulation during light-to-heavy fatiguing exercise at various ambient temperatures. A study by Christensen and Nielsen in 1942 used finger plethysmography to study regional blood flow (including skin temperature) during brief periods of constant-load cycle ergometer exercise.[15] Experiments published in 1936 by physician Olé Bang, inspired by his mentor Ejar Lundsgaard, described the fate of blood lactate during exercise of different intensities and durations.[4] The experiments of Christensen, Asmussen, Nielsen, and Hansen were conducted at the Laboratory for the Theory of Gymnastics at the University of Copenhagen. Today, the August Krogh Institute (**www1.bio.ku.dk/english/**) carries on the tradition of basic and applied research in exercise physiology. Since 1973, Swedish-trained scientist Bengt Saltin (1935-) (**Fig. I.29**) (the only Nordic researcher besides Erling Asmussen to receive the ACSM Citation Award [1980] and ACSM Honor Award [1990]; former student of Per-Olof Åstrand, discussed in the next section; see "Interview with Bengt Saltin," Section 4) has been a professor and continues his significant scientific studies as professor and director of the Copenhagen Muscle Research Centre at the University of Copenhagen in Denmark (**www.cmrc.dk/people.htm**).

Swedish Influence


Hjalmar Ling

Modern exercise physiology in Sweden can be traced to Per Henrik Ling (1776–1839) who in 1813 became the first director of Stockholm's Royal Central Institute of Gymnastics.[3] Ling, a specialist in fencing, developed a system of "medical gymnastics." This system, which became part of the school curriculum of Sweden in 1820, was based on his studies of anatomy and physiology.

Ling's son Hjalmar also had a strong interest in medical gymnastics and physiology and anatomy, in part owing to his attendance at lectures by French physiologist Claude Bernard in Paris in 1854. Hjalmar Ling published a book on the kinesiology of body movements in 1866. As a result of the Lings' philosophy and influence, the physical educators who graduated from the Stockholm Central Institute were well schooled in the basic biologic sciences, in addition to being highly proficient in sports and games. Currently, the College of Physical Education (Gymnastik-Och Idrottshögskolan; **www.gih.se/In-English/**) and Department of Physiology in the Karolinska Institute Medical School in Stockholm continue to sponsor studies in exercise physiology and related disciplines (**http://ki.se/?l=en**).


A


B

FIGURE I.29 • **(A)** Bengt Saltin taking muscle biopsy of gastrocnemius muscle. (Photo courtesy of Dr. David Costill.) **(B)** Saltin (hand on hip) during an experiment at the August Krogh Institute, Copenhagen. (Photo courtesy Per-Olof Åstrand.)

Per-Olof Åstrand, MD, PhD (1922–), is the most famous graduate of the College of Physical Education (1946); in 1952, he presented his thesis to the Karolinska Institute Medical School. Åstrand taught in the Department of Physiology in the College of Physical Education from 1946 to 1977. When the College of Physical Education became a department of the Karolinska Institute, Åstrand served as professor and department head from 1977 to 1987 (**Fig. I.30**). Christensen was Åstrand's mentor and supervised his doctoral dissertation, which included data on the physical working capacity of both sexes aged 4 to 33 years. This important study—along with collaborative studies with his wife Irma Ryhming—established a line of research that propelled Åstrand to the forefront of experimental exercise physiology for which he

FIGURE I.30 • P-O. Åstrand, Department of Physiology. Karolinska Institute, Stockholm. **(A)** Measuring maximal performance of Johnny Nilsson, Olympic Gold Medal speed skater, 1964. **(B)** Maximal oxygen consumption measured during cycle ergometer exercise, 1958. **(C)** Laboratory experiment, 1955. **(D)** Invited lecture, 1992 International Conference on Physical Activity, Fitness and Health, Toronto.

[m] Personal communication to F. Katch, June 13, 1995, from Dr. Åstrand regarding his professional background. Recipient of five honorary doctorate degrees (Université de Grenoble [1968], University of Jyväskylä [1971], Institut Superieur d'Éducation Physique, Université Libre de Bruxelles [1987], Loughborough University of Technology [1991], and Aristoteles University of Thessaloniki [1992]). Åstrand is an honorary Fellow of nine international societies, a Fellow of the American Association for the Advancement of Science (for "outstanding career contributions to understanding of the physiology of muscular work and applications of this understanding"), and has received many awards and prizes for his outstanding scientific achievements, including the ACSM Honor Award in 1973. Åstrand served on a committee for awarding the Nobel Prize in physiology or medicine from 1977 to 1988 and is coauthor with Kaare Rodahl of *Textbook of Work Physiology* (3rd edition, 1986; translated in Chinese, French, Italian, Japanese, Korean, Portuguese, and Spanish). His English publications number about 200 (including book chapters, proceedings, a history of Scandinavian scientists in exercise physiology,[3] and monographs), and he has given invited lectures in approximately 50 countries and 150 different cities outside of Sweden. His classic 1974 pamphlet *Health and Fitness* has an estimated distribution of 15 to 20 million copies (about 3 million copies in Sweden)—unfortunately, all without personal royalty!

McArdle WD, Katch FI, Katch VL. "Introduction: A View from the Past." In *Exercise Physiology: Nutrition, Energy, and Human Performance*, 8th ed. Baltimore, MD: Wolters Kluwer, 2015.

achieved worldwide fame.[m] Four papers published by Åstrand in 1960, with Christensen as one of the authors, stimulated further studies on the physiologic responses to intermittent exercise. Åstrand has mentored an impressive group of exercise physiologists, including such "superstars" as Bengt Saltin and Björn T. Ekblom.

Further evidence of their phenomenal international influence is seen in the number of times each is cited annually in the scientific literature: an average of 15,000 to 20,000 times *annually* from 1996 through April 2001.

thePoint **Appendix A, available online at http://thepoint.lww.com/mkk8e, provides several bibliographies of influential publications pertaining to anatomy and physiology, anthropometry, exercise and training, and exercise physiology, including a sampling of contributions to the exercise physiology literature by Åstrand and Saltin in books, book chapters, monographs, and research articles.**

Two Swedish scientists at the Karolinska Institute, Drs. Jonas Bergström and Erik Hultman, performed important experiments with the needle biopsy procedure that have provided a new vista from which to study exercise physiology. With this procedure, it became relatively easy to conduct invasive studies of muscle under various exercise conditions, training, and nutritional status. Collaborative work with other Scandinavian researchers (Saltin and Hultman from Sweden and Lars Hermanson from Norway) and leading researchers in the United States (e.g., Phillip Gollnick [1935–1991; Washington State University] and David Costill [1936-] [John and Janice Fisher Professor Emeritus of Exercise Science, Ball State University]) contributed a unique new dimension to the study of the physiology of muscular exercise.

Drs. Jonas Bergström (left) and Eric Hultman, Karolinska Institute, mid-1960s

Norwegian and Finnish Influence

The new generation of exercise physiologists trained in the late 1940s analyzed respiratory gases by means of a highly accurate sampling apparatus that measured relatively small quantities of carbon dioxide and oxygen in expired air. The method of analysis (and also the analyzer) was developed in 1947 by Norwegian scientist Per Scholander (1905–1980). A diagram of Scholander's micrometer gas analyzer[69] is presented in Chapter 8, Figure 8.7, along with its larger counterpart, the Haldane analyzer.

Another prominent Norwegian researcher was Lars A. Hermansen (1933–1984; ACSM Citation Award, 1985) from the Institute of Work Physiology, who died prematurely. Nevertheless, his many contributions include a classic 1969 article, "Anaerobic Energy Release," that appeared in the first volume of *Medicine and Science in Sports*.[33] Other papers included work with exercise physiologist K. Lange Andersen.[34]

Lars A. Hermansen (1933–1984), Institute of Work Physiology, Oslo

In Finland, Martti Karvonen, MD, PhD (ACSM Honor Award, 1991; 1918–2009;), from the Physiology Department of the Institute of Occupational Health in Helsinki, is best known for a method to predict optimal exercise training heart rate, the so-called "Karvonen formula." He also conducted studies dealing with exercise performance and the role of exercise in longevity. In 1952, Lauri Pikhala, a physiologist, suggested that obesity was the consequence and not the cause of physical "unfitness." Ilkka Vuori, starting in the early 1970s, reported on hormone responses to exercise. Paavo Komi, Professor Emeritus from the Department of Biology of Physical Activity at the University of Jyväskylä, has been Finland's most prolific researcher, with numerous experiments published in the combined areas of exercise physiology and sport biomechanics. **Table I.4** lists the Nordic researchers who have received the prestigious ACSM Honor Award or ACSM Citation Award.

OTHER CONTRIBUTORS TO THE KNOWLEDGE BASE IN EXERCISE PHYSIOLOGY

In addition to the distinguished American and Nordic applied scientists profiled earlier, there have been many other "giants" in the field of physiology and experimental science[n] who have made monumental contributions that indirectly added to the knowledge base in exercise physiology. The list includes:

[n]There are many excellent sources of information about the history of science and medicine, including the following: Bettman O. *A Pictorial History of Medicine*. Springfield, IL: Charles C Thomas, 1956; Clendening L. *Source Book of Medical History*. New York: Dover Publications/Henry Schuman, 1960; Coleman W. *Biology in the Nineteenth Century*. New York: Cambridge University Press, 1977; Franklin K. *A Short History of Physiology*, 2nd ed. London: Staples Press, 1949; Fye WB, *The Development of American Physiology. Scientific Medicine in the Nineteenth Century*. Baltimore: Johns Hopkins University Press, 1987; Guthrie D. A *History of Medicine*. London: T. Nelson & Sons, 1945; Haskins T. *Science and Enlightenment*. New York: Cambridge University Press, 1985; Holmes FL. *Lavoisier and the Chemistry of Life*. Madison: University of Wisconsin Press, 1985; Knight B. *Discovering the Human Body*. London: Bloomsbury Books; Lesch JE. *Science and Medicine in France. The Emergence of Experimental Physiology, 1790–1855*. Cambridge, MA: Harvard University Press, 1984; Vertinsky PA. *The Eternally Wounded Woman: Women, Exercise, and Doctors in the Late Nineteenth Century*. Urbana: University of Illinois Press; Walker K. *The Story of Medicine*. London: Arrow Books, 1954.

TABLE 1.4 Nordic Researchers[a] Awarded the ACSM Honor Award and ACSM Citation Award

ACSM Honor Award	ACSM Citation Award
Per-Olof Åstrand, 1973	Erling Asmussen, 1976
Erling Asmussen, 1979	Bengt Saltin, 1980
Erik Hohwü-Christensen, 1981	Lars A. Hermansen, 1985
Bengt Saltin, 1990	C. Gunnar Blomqvist, 1987
Martti J. Karvonen, 1991	

[a]Born and educated in a Nordic country.

Sir Joseph Barcroft (1872–1947). High-altitude research physiologist who pioneered fundamental work concerning the functions of hemoglobin, later confirmed by Nobel laureate August Krogh. Barcroft also performed experiments to determine how cold affected the central nervous system. For up to 1 hr, he would lie without clothing on a couch in subfreezing temperatures and record his subjective reactions.

Marie Krogh collects data at Barcraft's high altitude experimental station to assess oxygen tension of gases

Christian Bohr (1855–1911). Professor of physiology in the medical school at the University of Copenhagen who mentored August Krogh, and father of nuclear physicist and Nobel laureate Niels Bohr. Bohr studied with Carl Ludwig in Leipzig in 1881 and 1883, publishing papers on the solubility of gases in various fluids, including oxygen absorption in distilled water and in solutions containing hemoglobin. Krogh's careful experiments using advanced instruments (microtonometer) disproved Bohr's secretion theory that both oxygen and carbon dioxide were secreted across the lung epithelium in opposite directions based on the time required for equalization of gas tension in blood and air.

Christian Bohr

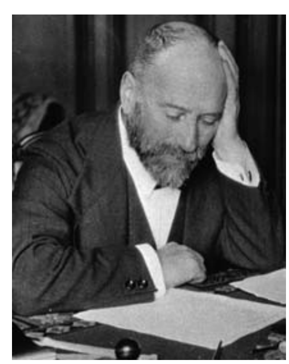
John Scott Haldane (1860–1936; **www.faqs.org/health/bios/55/John-Scott-Haldane.html***).* Conducted research in mine safety, investigating principally the action of dangerous gases (carbon monoxide), the use of rescue equipment, and the incidence of pulmonary disease. He devised a decompression apparatus for the safe ascent of deep-sea divers. The British Royal Navy and the United States Navy adopted tables based on this work. In 1905, he discovered that carbon dioxide acted on the brain's respiratory center to regulate breathing. In 1911, he and several other physiologists organized an expedition to Pikes Peak, Colorado, to study the effects of low oxygen pressures at high altitudes. Haldane also showed that the reaction of oxyhemoglobin with ferricyanide rapidly and quantitatively released oxygen and formed methemoglobin. The amount of liberated oxygen could be accurately calculated from the increased gas pressure in the closed reaction system at constant temperature and volume. Haldane devised a microtechnique to fractionate a sample of a mixed gas into its component gases (see Chapter 8). Haldane founded the *Journal of Hygiene*.

Haldane investigating carbon monoxide gas in an English coal mine at the turn of the 20th century

Otto Meyerhof (1884–1951; **www.nobelprize.org/nobel_prizes/medicine/laureates/1922/meyerhof-bio.html***).* Meyerhof's experiments on the energy changes during cellular respiration led to discoveries on lactic acid related to muscular activity, research that led to the Nobel Prize (with A.V. Hill in 1923). In 1925, Meyerhof extracted from muscle the enzymes that convert glycogen to lactic acid. Subsequent research confirmed work done by Gustav Embden in 1933; together they discovered the pathway that converts glucose to lactic acid (the Embden-Meyerhof pathway).

Otto Meyerhof (Courtesy National Library of Medicine)

Nathan Zuntz (1847–1920). Devised the first portable metabolic apparatus to assess respiratory exchange in animals and humans at different altitudes; proved that carbohydrates were precursors for lipid synthesis. He maintained that dietary lipids and carbohydrates should not be consumed equally for proper nutrition. He produced 430 articles concerning blood and blood gases, circulation, mechanics and chemistry of respiration, general metabolism and metabolism of specific foods, energy metabolism and heat production, and digestion.



Nathan Zuntz (Courtesy National Library of Medicine)

McArdle WD, Katch FI, Katch VL. "Introduction: A View from the Past." In *Exercise Physiology: Nutrition, Energy, and Human Performance*, 8th ed. Baltimore, MD: Wolters Kluwer, 2015.

Zuntz tests his portable, closed-circuit spirometer, carried on his back. This device made it possible for the first time to measure O_2 consumed and CO_2 produced during ambulation. (Courtesy Max Planck Institute for the History of Science, Berlin/Virtual Lab; http://mpiwg-berlin.mpg/technology/data?id=tec1715.)

Carl von Voit (1831–1908; **www.bookrags.com/biography/karl-von-voit-wsd/**) and his student *Max Rubner (1854–1932)*. Discovered the isodynamic law and the calorific heat values of proteins, lipids, and carbohydrates; Rubner's surface area law states that resting heat production is proportional to body surface area and that consuming food increases heat production. Voit disproved Liebig's assertion that protein was a primary energy fuel by showing that protein breakdown does not increase in proportion to exercise duration or intensity.

Carl von Voit (Courtesy National Library of Medicine)

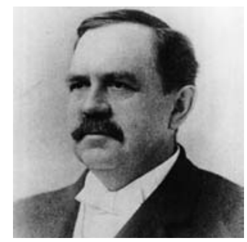
Max Joseph von Pettenkofer (1818–1901). Perfected the respiration calorimeter (**Fig. I.31**) to study human and animal metabolism; discovered creatinine, an amino acid in urine. The top chamber of the figure below shows the entire calorimeter. The cut-away image shows a human experiment where fresh air was pumped into the sealed chamber and vented air sampled for carbon dioxide.

Max Joseph von Pettenkofer

Eduard F. W. Pflüger (1829–1910). First demonstrated that minute changes in the partial pressure of blood gases affect the rate of oxygen release across capillary membranes, thus proving that blood flow alone does not govern how tissues receive oxygen.

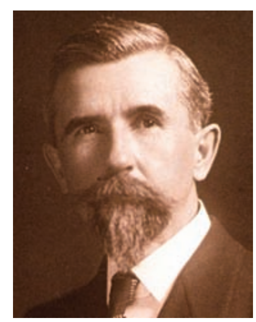
Edward F. W. Pflüger (Courtesy National Library of Medicine)

Wilbur Olin Atwater (1844–1907; **www.sportsci.org**). Published data about the chemical composition of 2600 American foods currently used in databases of food composition. Also performed human calorimetric experiments and confirmed that the law of conservation of energy governs transformation of matter in the human body.



Wilbur Olin Atwater (Courtesy National Library of Medicine)

Russel Henry Chittenden (1856–1943; **www.sportsci.org**). Refocused attention on the minimal protein requirement of humans while resting or exercising; concluded that no debilitation occurred if protein intake equaled 1.0 $g \cdot kg$ body $mass^{-1}$ in either normal or athletic young men. Chittenden received the first PhD in physiological chemistry given by an American university. Some scholars[12] regard Chittenden as the father of biochemistry in the United States. He believed that physiological chemistry would provide basic tools for researchers to study important aspects of physiology and provided the impetus for incorporating biochemical analyses in exercise physiology.



Russel Henry Chittenden (Courtesy National Library of Medicine)

Frederick Gowland Hopkins (1861–1947; **www.sportsci.org**). Nobel Prize in 1929 for isolating and identifying the structure of the amino acid tryptophan. Hopkins collaborated with W. M. Fletcher (mentor to A. V. Hill) to study muscle chemistry. Their classic 1907 paper in experimental physiology used new methods to isolate lactic acid in muscle. Fletcher

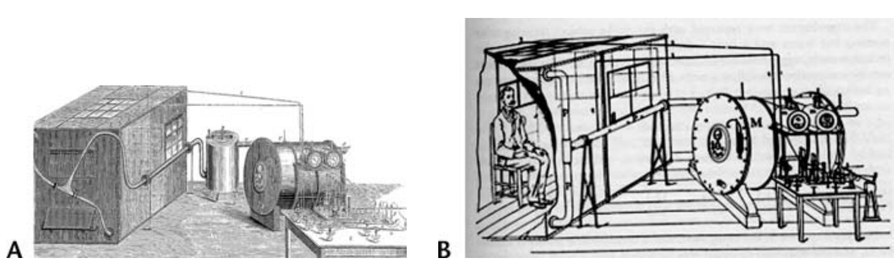
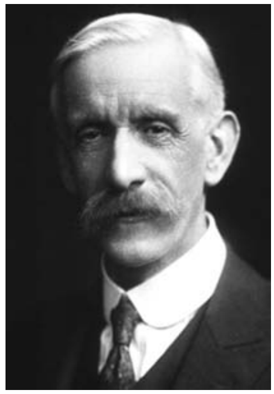


FIGURE I.31 • Human respiration calorimeter. (Courtesy Max Planck Institute for the History of Science, Berlin/Virtual Lab; **http://mpiwg-berlin.mpg/technology/data?id=tec209**.)

and Hopkins's chemical methods reduced the muscle's enzyme activity prior to analysis to isolate the reactions. They found that a muscle contracting under low oxygen conditions produced lactate at the expense of glycogen. Conversely, oxygen in muscle suppressed lactate formation. The researchers deduced that lactate forms from a nonoxidative (anaerobic) process during contraction; during recovery in a noncontracted state, an oxidative (aerobic) process removes lactate with oxygen present.



Frederick Gowland Hopkins (Courtesy National Library of Medicine)

Francis Gano Benedict (1870–1957; **www.sportsci.org***)*. Conducted exhaustive studies of energy metabolism in newborn infants, growing children and adolescents, starving persons, athletes, and vegetarians. Devised "metabolic standard tables" based on sex, age, height, and weight to compare energy metabolism in normals and patients. His last monograph, *Vital Energetics, A Study in Comparative Basal Metabolism* (Carnegie Institution Monograph no. 503, 1938), refers to many of his approximately 400 publications.

Francis Gano Benedict (Courtesy National Library of Medicine)

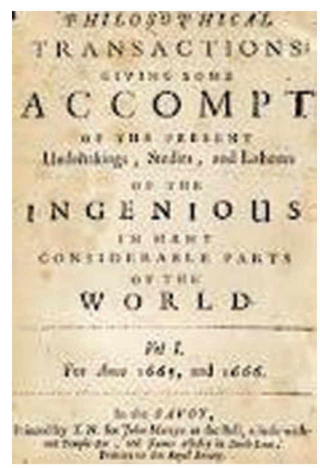
THE ROYAL SOCIETY OF LONDON

Arguably the oldest scientific society, founded in 1660 in England, the Royal Society of London began as a group of 12 physicians and philosophers who studied nature and the physical universe (the genesis of the natural sciences such as physics and astronomy) to advance discourse concerning the discoveries of new knowledge. The founders included Christopher Wren (1632–1723; astronomer, English architect who rebuilt 51 churches in London after the devastating fire of London in 1666) and Robert Boyle (1627–1691). Weekly meetings viewed experiments and discussed scientific topics of interest developed in England including continental Europe, most notably scientific advances in France. In 1662, King Charles II granted the organization its official charter, known formally in 1663 as The Royal Society of London for Improving Natural Knowledge or simply the Royal Society (**http://royalsociety.org/about-us/history/**) (**Fig. I.32**).

The society soon began publication of its journals (*The Philosophical Transactions*) the world's first devoted to science, published in March 1665, that included peer review,

FIGURE I.32 • The Royal Society's motto "Nullius in verba" translates as "Take nobody's word for it," which expressed the members' desire to overcome the domination of aristocratic authority, and foster the appreciation of facts determined by experiment, not dogma, ritual, and personal opinion.

and currently deals with thematic issues. The *Proceedings of the Royal Society* includes *Series A* that publishes research related to mathematical, physical, and engineering sciences, and *Series B* that publishes research related to biology. Fellowship in the Society consists of the most eminent engineers, scientists, and technologists from the United Kingdom and British Commonwealth. Each year the Society elects 44 new Fellows, including 8 Foreign Members and up to 1 Honorary Member from about 700 proposed candidates. In 2012, there were 1450 Fellows and Foreign Members. The elite Society membership beginning in 1901 includes 80 Nobel Laureates. Within the domain relevant to exercise science, the Members include seven scientists we chronicle in this text, all winning the Nobel Prize in the category Physiology or Medicine (August Krogh, 1920; Otto Meyerhof, 1922; A.V. Hill, 1922; Frederick Hopkins, 1929; Hans Krebs, 1953; and James Watson and Maurice Wilkins, 1962).


PHILOSOPHICAL
TRANSACTIONS:
GIVING SOME
ACCOMPT
OF THE PRESENT
Undertakings, Studies, and Labours
OF THE
INGENIOUS
IN MANY
CONSIDERABLE PARTS
OF THE
WORLD.
Vol I.
For Anno 1665, and 1666.

CONTRIBUTIONS OF WOMEN TO SCIENCE AT THE DAWN OF THE 20TH CENTURY

The triumphs and accomplishments during the evolution of exercise physiology reveal a glaring absence of credit to the contributions of women from the 1850s and continuing for the next 100 years. Many reasons explain this occurrence—but it was not from women's lack of interest in pursuing a career in the sciences. Rather, females who wished to stand with male colleagues found the going difficult. Opposition included hostility, ridicule, and professional discrimination, typically in chemistry, physics, and medicine, but also in related fields such as botany, biology, and mathematics. A few women did break through the almost exclusively male-dominated fields to make significant contributions despite such considerable hurdles. The leadership at the "top" of the scientific culture (college presidents, academic deans, curriculum and personnel committees, governing bodies, heads of departments, and review boards for grants and journals) subtly and directly repressed women's attempts to even enter some fields, let alone achieve parity with male scientists. Subtle discrimination included assignment to underequipped, understaffed, and substandard laboratory facilities; having to teach courses without proper university recognition; disallowing membership on graduate thesis or dissertation committees; and having a male colleague's name appear first (or only) on research publications, regardless of his involvement. Male "supervisors" typically presented the results of joint work at conferences and seminars when the woman clearly worked as the lead scientist. Direct suppression included outright refusal to hire women to teach at the university or college level. For those who were hired, many could not directly supervise graduate student research projects. Women also routinely experienced shameful inequity in salary received or were paid no salary as "assistants."

The Nobel Prize in the sciences, the most prestigious award for discoveries in physics, chemistry, and physiology or medicine, has honored 300 men but only 10 women since the award originated in 1901. The Karolinska Institute in Stockholm (**http://ki.se/ki/jsp/polopoly.jsp?d=130&l=en**) selects the Nobel laureates in physiology or medicine, and the Swedish Academy of Sciences awards the prizes in chemistry and physics. Considerable controversy has emerged over the years about the role of "infighting and politics" in the selection process. The difference in the gender-specific pool of outstanding scientists cannot adequately explain the disparity between male and female Nobel winners. Reading about the lives and times of the 10 female winners, including others who by all accounts probably deserved the honor, gives a better appreciation for the inequity. Each of the 10 female laureates and the other 3 world-class scientists listed here overcame huge "nonscientific" issues before achieving their eventual scientific triumphs.

1. Gerty Radnitz Cori (1896–1954); Biological chemistry
2. Marie Sklodowska Curie (1867–1934); Chemistry, physics
3. Irene Joliot-Curie (1897–1956); Chemistry
4. Barbara McClintock (1902–1992); Cytogenetics
5. Maria Goeppert Mayer (1906–1972); Physics
6. Rita Levi-Montalcini (1909–2012); Developmental neurology and physiology
7. Dorothy Crowfoot Hodgkin (1910–1994); x-ray crystallography and chemistry
8. Gertrude B. Elion (1918–1999); Chemistry
9. Rosalyn Sussman Yalow (1921–2011); Medicine
10. Christiane Nüsslein-Volhard (1942–); Developmental biology
11. Lise Meitner (1878–1968); Physics
12. Rosalind Franklin (1920–1958); Chemistry
13. Wu-Chien-Shiung Wu (1912–1997); Theoretical physics

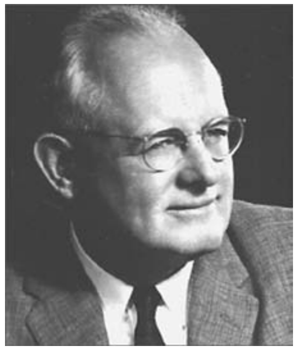
thePoint **Appendix B, "Scientific Contributions of 13 Outstanding Female Scientists," available online at http://thepoint.lww.com/mkk8e, provides details about the lives and times of the women listed above.**

We hope the legacy of the exercise physiology pioneers discussed in this chapter inspires students to strive for excellence in their particular specialty. Successful scientists often must surmount many obstacles along the way to achieve success and recognition. They all shared common traits—an unyielding passion for science and uncompromising quest to explore new ground where others had not ventured. As you progress in your own careers, we hope that you too will experience the pure joy of discovering new truths in exercise physiology. Perhaps the achievements of women scientists from outside our field will serve as a gentle reminder to support the next generation of scientists from their accomplishments and passion for their field.

Summary

This introductory section on the historical development of exercise physiology illustrates that interest in exercise and health had its roots with the ancients. During the 2000 years that followed, the field we now call *exercise physiology* evolved from a symbiotic (albeit, sometimes rocky) relationship between the classically trained physicians, the academically based anatomists and physiologists, and a small cadre of physical educators who struggled to achieve their identity and academic credibility through research and experimentation in the basic and applied sciences. The physiologists used exercise to study the dynamics of human physiology, and the early physical educators often adapted the methodology and knowledge of physiology to study human responses to exercise.

Beginning in the mid-1850s in the United States, a small but slowly growing effort to raise standards for the scientific training of physical education and hygiene specialists primarily targeted teaching at the college and university level. The creation of the first exercise physiology laboratory at Harvard University in 1891 contributed to an already burgeoning knowledge explosion in basic physiology, primarily in Britain and throughout Europe. Originally, medically trained physiologists made the significant scientific advances in most of the subspecialties now included in the exercise physiology course curriculum. They studied oxygen metabolism, muscle structure and function, gas transport and exchange, mechanisms of circulatory dynamics, digestion, and neural control of voluntary and involuntary muscular activity.



Thomas K. Cureton

The field of exercise physiology also owes a debt of gratitude to the pioneers of the physical fitness movement in the United States, spearheaded by Thomas K. Cureton (1901–1993). Cureton was one of the charter members of the American College of Sports Medicine (ACSM; 1969 recipient of the prestigious ACSM Honor Award) and a professor of physical education at the University of Illinois at Champaign. Cureton trained four generations of Master's and PhD degree students beginning in 1941 after an initial teaching period at Springfield College in Massachusetts that began in 1929.

Many of the graduates who were mentored by individuals such as T. K. Cureton assumed leadership positions as professors with teaching and research responsibilities in exercise physiology at numerous colleges and universities in the United States and throughout the world.

Although we have focused on the contributions of selected early American scientists and physical educators and their counterparts from the Nordic countries to the development of modern-day exercise physiology, we would be neglectful not to acknowledge the numerous contributions from many scholars in other countries. The group of foreign contributors, many still active researchers, includes but certainly is not limited to the following individuals: Roy Shephard, School of Physical and Health Education, University of Toronto (ACSM Citation Award, 1991; ACSM Honor Award, 2001; **http://g-se.com/es/usuario/perfil/roy-j-shephard**); Claude Bouchard, Pennington Biomedical Research "Center, Baton Rouge, LA (ACSM Citation Award, 1992; ACSM Honor Award, 2002; John W. Barton, Sr. Endowed Chair in Genetics and Nutrition); Oded Bar-Or (1937–2005), McMaster University, Hamilton, Ontario, Canada (ACSM Citation Award, 1997; ACSM President's Lecture); Rodolfo Margaria (1901–1983) and P. Cerretelli (1932–2008), Institute of Human Physiology, Medical School of the University of Milan; M. Ikai, School of Education, University of Japan; Wildor Holloman (1925–), Director of the Institute for Circulation, Research and Sports Medicine and L. Brauer and H. W. Knipping (1895-1984), Institute of Medicine, University of Cologne, Germany (in 1929, they described the "vita maxima," now called the maximal oxygen consumption); L. G. C. E. Pugh (1909–1994), Medical Research Council Laboratories, London; Z. I. Barbashova, Sechenov Institute of Evolutionary Physiology, Leningrad, USSR; Sir Cedric Stanton Hicks (1892–1976), Human Physiology Department, University of Adelaide, Australia; Otto Gustaf Edholm (1862–1950), National Institute for Medical Research, London; John Valentine George Andrew Durnin, Department of Physiology, Glasgow University, Scotland; Lucien Brohua (1899–1968), Higher Institute of Physical Education, Faculty of Medicine of the State University of Liège, Belgium, and Harvard Fatigue Laboratory; Reginald Passmore (1910–1999), Department of Physiology, University of Edinburgh, Scotland; Ernst F. Jokl (1907–1997) [ACSM founder and charter member], Witwatersrand Technical College, Johannesburg, South Africa, and later the University of Kentucky; and C. H. Wyndham and N. B. Strydom, University of the Witwatersrand, South Africa. There were also many early German scientific contributions to exercise physiology and sports medicine.[35]

CONCLUDING COMMENT

One theme unites the history of exercise physiology: the value of mentoring by those visionaries who spent an extraordinary amount of their careers "infecting" students with love for hard science. These demanding but inspiring relationships developed researchers who, in turn, nurtured the next generation of productive scholars. This applies not only to the current group of exercise physiologists, but also to scholars of previous generations. Siegel[71] cites Payne,[62] who in 1896 wrote the following about Harvey's 1616 discovery of the mechanism of the circulation, acknowledging the discoveries of the past:

> No kind of knowledge has ever sprung into being without an antecedent, but is inseparably connected with what was known before.… We are led back to Aristotle and Galen as the real predecessors of Harvey in his work concerning the heart. It was the labors of the great school of Greek anatomists … that the problem though unsolved, was put in such a shape that the genius of Harvey was enabled to solve it.… The moral is, I think, that the influence of the past on the present is even more potent than we commonly suppose. In common and trivial things, we may ignore this connection; in what is of enduring worth we cannot.

We end our overview of the history of exercise physiology with a passage from *A Treatise on Physiology and Hygiene* (New York: Harper & Brothers 1868), a textbook written 146 years ago by John Call Dalton (1825–1889), MD, the first American-born professor of physiology at the College of Physicians and Surgeons in New York City. It shows how current themes in exercise physiology share a common bond with what was known and advocated at that time (the benefits of moderate physical activity, walking as an excellent exercise, the appropriate exercise intensity, the specificity of training, the importance of mental well-being). Even the "new" thoughts and ideas of Dalton penned in 1869 had their roots in antiquity—reinforcing to us the importance of maintaining a healthy respect for the importance of exercise in our daily lives.

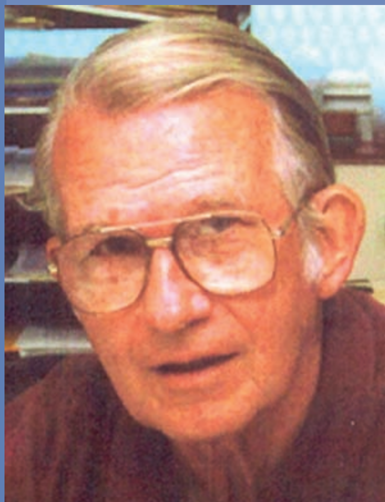
> The natural force of the muscular system requires to be maintained by constant and regular exercise. If all of the muscles, or those of any particular part, be allowed to remain for a long time unused they diminish in size, grow softer, and finally become

McArdle WD, Katch FI, Katch VL. "Introduction: A View from the Past." In *Exercise Physiology: Nutrition, Energy, and Human Performance*, 8th ed. Baltimore, MD: Wolters Kluwer, 2015.

sluggish and debilitated. By use and exercise, on the contrary, they maintain their vigor, continue plump and firm to the touch, and retain all the characters of their healthy organization. It is very important, therefore, that the muscles should be trained and exercised by sufficient daily use. Too much confinement by sedentary occupation, in study, or by simple indulgence in indolent habits, will certainly impair the strength of the body and injuriously affect the health. Every one who is in a healthy condition should provide for the free use of the muscles by at least two hours' exercise each day; and this exercise can not be neglected with impunity, any more than the due provision of clothing and food.… The muscular exercise of the body, in order to produce its proper effect, should be regular and moderate in degree. It will not do for any person to remain inactive during the greater part of the week, and then take an excessive amount of exercise on a single day.… It is only a uniform and healthy action of the parts that stimulates the muscles and provides for their nourishment and growth.… Walking is therefore one of the most useful kinds of exercise.… Running and leaping, being more violent should be used more sparingly.… The exact quantity of exercise to be taken is not precisely the same for different persons, but should be measured by its effect. It is always beneficial when it has fully employed the muscular powers without producing any sense of excessive fatigue or exhaustion.… In all cases, the exercise that is taken should be regular and uniform in degree, and should be repeated as nearly as possible for the same time every day.

As a student of exercise physiology, you are about to embark on an exciting journey into the world of human physiologic response and adaptation to physical activity. We hope our tour of the beginnings of exercise physiology inspires you in your studies to begin your own journey to new discoveries.

thePoint **References are available online at http://thepoint.lww.com/mkk8e.**



INTERVIEW WITH

Dr. Charles M. Tipton

Education: BA (Springfield College, Springfield, MA); MA, PhD in Physiology, with minors in Biochemistry and Anatomy (University of Illinois, Champaign).

Current Affiliation: Professor Emeritus of Physiology and Orthopaedic Surgery at the College of Medicine at the University of Arizona.

Honors, Awards, and ACSM Honor Award Statement of Contributions: See Appendix C, available online at http://thepoint.lww.com/mkk8e

Research Focus: The physiologic effects of short- and long-term exercise and their responsible mechanisms.

Memorable Publication: Tipton CM, et al. The influence of exercise, intensity, age, and medication on resting systolic blood pressure of SHR populations. *J Appl Physiol* 1983;55:1305.

What first inspired you to enter the exercise science field? What made you decide to pursue your degree and/or line of research?

➤ My experiences in athletics and as a Physical Fitness Instructor in an infantry division convinced me that I should secure an education on the G.I. Bill of Rights to be able to teach health and physical education while coaching in a rural high school. Once I realized that I did not enjoy my chosen career, I returned to the University of Illinois for more education in health education. To support a growing family, I secured a summer and part-time position as a 4-H Club Fitness Specialist who conducted fitness tests and clinics throughout the state of Illinois. When it became apparent that I had to have more physiology and biochemistry to explain what I was testing and advocating, I knew I had to be a physiologist with expertise in exercise physiology. So I transferred to the Physiology Department, and the rest is history.

What influences did your undergraduate education have on your final career choice?

➤ Very little. Although I had the late Peter V. Karpovich as my exercise physiology instructor at Springfield College, he did not stimulate, motivate, or encourage me to consider becoming one. My mindset was to teach and coach in a rural high school, and everything in the undergraduate curriculum or experience was to help me achieve that goal.

Who were the most influential people in your career, and why?

➤ The drive to learn and acquire more education was imprinted by my father, who had to leave school in the eighth grade to help support his family. Early in graduate school at the University of Illinois, I became interested in the physiological and biochemical foundations of physical fitness by the interesting and evangelical lectures of Dr. Thomas K. Cureton in the Physical Education Department and Director of the Physical Fitness Laboratory. However, my interest in physiological research and its scientific foundations was stimulated, developed, and perfected by Darl M. Hall, who was an intelligent critical and caring research scientist in the Illinois Extension Service who had the responsibility of testing the fitness levels of 4-H Club members. Our discussions made me realize that functional explanations require in-depth scientific knowledge and encouraged me to transfer into the physiology department to secure such information. Once in physiology, I became exposed to the impressive intelligence and outstanding scholarship of Robert E. Johnson and to his example of the scientific attributes necessary to become a productive exercise physiologist. Inherent with this profile of recognition is the fact that without the love and support of my wife, Betty, and our four daughters, my transition to physiology and the survival of a poverty state would have never occurred.

What has been the most interesting/enjoyable aspect of your involvement in science? What was the least interesting/enjoyable aspect

➤ To me, the most interesting and stimulating aspect of exercise physiology was the planning, testing, and evaluation of a research hypotheses. The least enjoyable were the administrative aspects of supervising a laboratory and the constant search for funding of research ideas.

What are your most meaningful contributions to the field of exercise science, and why are they so important?

➤ There are two. The first requires the understanding that exercise science evolved from the discipline of physical education and includes exercise physiology. When I entered the profession in the 1950s, I lacked intellectual rigor and scientific knowledge. Consequently, my graduate years were spent securing an undergraduate education. Thus, my most meaningful and satisfying contribution to the field was the planning and implementation of a rigorous, science-based Ph.D. graduate program in exercise physiology at the University of Iowa, which served as a model for other departments of physical education to follow. It was important to me because it attracted many outstanding individuals to the University of Iowa who became dear friends and helped pave the way for exercise science to become an academic entity. As for influencing the most individuals, I would have to list our research pertaining to the Iowa Wrestling Studies and the search for a minimum wrestling weight. According to Caspersen,[1] our research findings and recommendations provided the foundation for the National Federation of State High School Association to require a certified minimal wrestling weight (7% fat) that involved 270,000 high school students.

What advice would you give to students who express an interest in pursuing a career in exercise science research?

➤ Research requires more than intellectual curiosity and infectious enthusiasm. It is an exciting occupation that demands hard work, while requiring an individual to be disciplined, dedicated, and honest. A future researcher must acquire an education that enables him/her to be well prepared in mathematics, the biological and physical sciences, and the ability to communicate by written and verbal means. Lastly, seek a mentor whose research interests you and one who is concerned about you as a future researcher and not as a contributor to their vitae.

What interests have you pursued outside of your professional career?

➤ Becoming a civil war "buff," enjoying the pleasures of dancing and listening to Dixieland jazz, exercising regularly, participating in road races, reading nonfiction, learning about poetry, being a member of a book club, watching televised sports, cheering for the Washington Redskins football team, and observing our grandchildren as they grow up.

Where do you see the exercise science field (particularly your area of greatest interest) heading in the next 20 years?

➤ It is my speculation that because of the genomic and molecular biology revolution, and the obesity and diabetes epidemics, the next 20 years will observe exercise physiologists addressing system diseases with molecular and genetic solutions. These solutions will be complex because the effects of acute and chronic exercise are a product of both genomic genetics and epigenetics. Consequently, future investigators must be thoroughly educated in these three sciences and the exercise response in normal and diseased populations.

You have the opportunity to give a "last lecture." Describe its primary focus.

➤ It would be titled "Exercise Physiology in the Last Frontier," and would pertain to what is known and unknown about exercising in a microgravity environment.

[1]Casperson, C. Dr. Charles M. Tipton selected as the 2012 recipient of the Clark W. Hetherington Award. *National Academy of Kinesiology Newsletter*. 34:15–17, 2012.