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Master Keys To Anatomy: Preliminary Notes

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INTRODUCTION

HUMAN anatomy will never cease to be a live and fascinating study, of the highest practical and philosophic worth. Its rewards, like most things of merit, are not to be had cheaply but only after due expenditure of time and intelligent effort. Familiarity sharpens the recognition that knowledge of no phase of anatomy is complete and that established concepts continue to be modified and enriched by new facts. This perception affects both teaching and research.

In teaching, the unchanged fundamental importance of anatomy in every branch of medicine retains it at the base of the ever expanding medical curriculum, and the devotees of all fields, perpetuating time honored tradition, expect all things of the anatomist in respect to materials and the training of students and specialists for their particular work.

In research, the spearheads of investigation push always further knowledge of the detail and significance of structure and thus continue to open new realms for exploration, inevitably leaving behind more or less encircled problems which require "mopping up" operations of exacting nature.

The scope and content of anatomy, like that of many subjects, have so increased that it is necessary for anatomists to revise and streamline the organization of their subject matter from time to time to keep all the facts integrated in proper perspective and in such manner as to be of greatest usefulness. This account deals with certain efforts in this direction in one laboratory, the foundations, organization, aims and programs of which have been described at length.[1]

It is hoped that the practical importance and timeliness of dealing with the problem here approached will be generally sensed, for it is not enough that things be done, their value must be perceived and applied if they are to contribute to the common weal. Had Leonardo da Vinci, one of the greatest of minds as well as one of the greatest of anatomists, been able to publish the anatomical textbook he had planned in collaboration with della Torre, he would have advanced by centuries the progress of anatomy and physiology, but through misfortune his anatomical manuscripts lay undiscovered until our own day. His potential contributions, therefore, had to be made slowly item by item, by others. We do not look for Leonardos among ourselves, but we should be alert for grains of value in any quarter, which can be applied for the general good.

STATUS OF ANATOMY

The atlas of Vesalius, "De fabrica corporis humani," published at Basel in 1543, has been recognized as "not only the foundation of modern Medicine as a Science, but the first great positive achievement of Science itself in modern times."[2] Anatomy is thus the oldest of medical educational disciplines. For this reason and because of its diversified content and utility, no other subject has acquired so large a literature devoted to its lore and teaching methodology. Swett's comprehensive bibliography[3] and the detailed illustrated surveys of sixty-seven different anatomical departments by the Rockefeller Foundation[4] afford ready acquaintance with this material, the substance of which has been borne in mind in the activity here described.

* Excerpts from an address, "A Decade of Teaching and Research in Anatomy at Howard University," read before the Society for Medical Investigation of Howard University, Washington, D. C., February 10, 1943.

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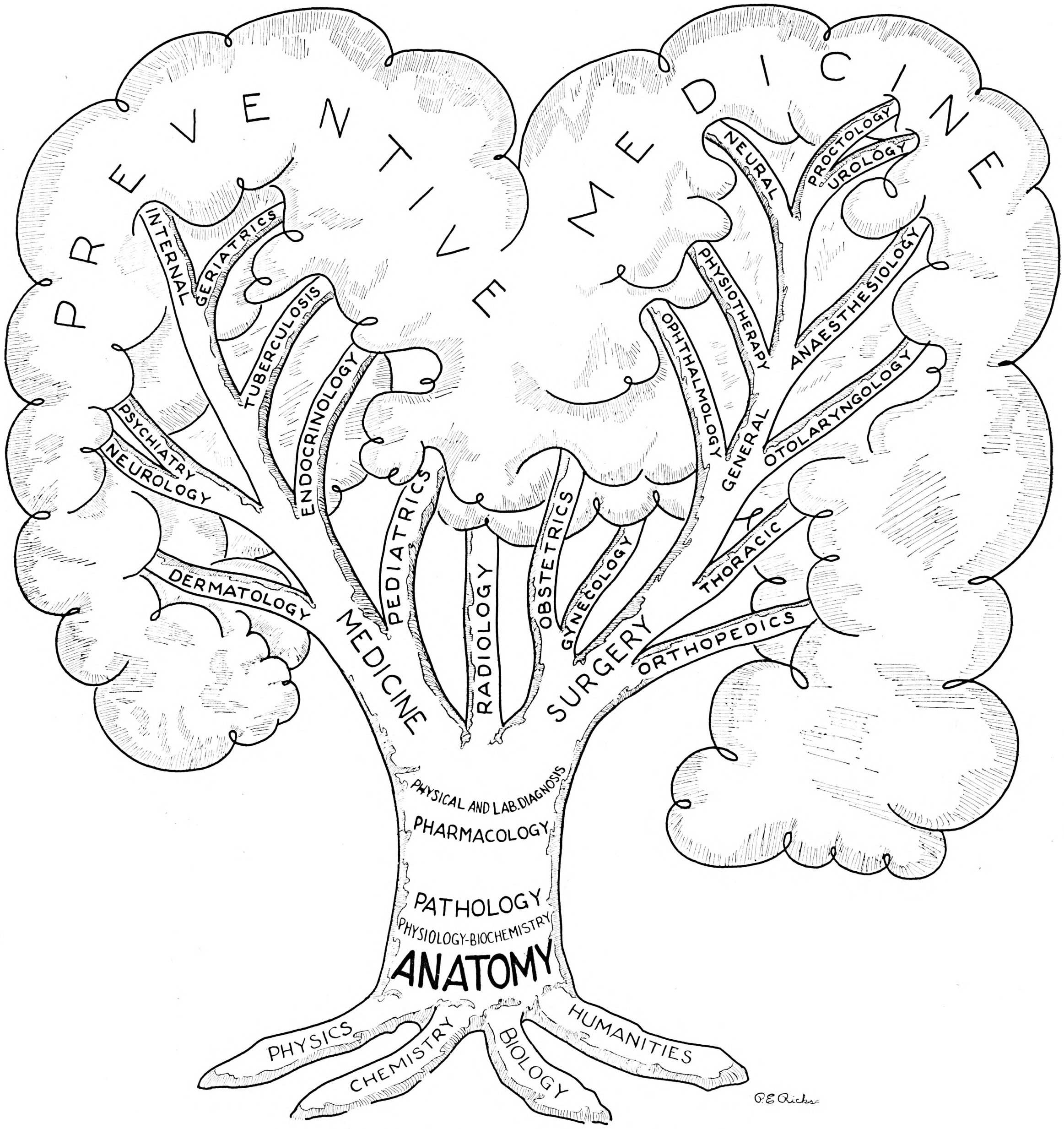


THE MEDICAL CURRICULUM

Figure 1

The position of anatomy in the medical curriculum is apparent in Figure 1, in which the subjects have been arranged in the form of a tree, of which the preparatory humanities and pre-medical subjects form the roots. The basic sciences are represented as the trunk, the broad base of which is formed by anatomy, a primacy unchallenged since Vesalius. Next above are the partners, physiology and biochemistry, which with anatomy comprise a triumvirate which deals in principle and detail with the body's organization and life processes. Pathology, the next foundation study, is devoted to the nature of damage which may be suffered by bodily structure or process. This includes both the intrinsic disorders of degenerative, metabolic, or ageing character and the extrinsic, of traumatic or parasitic origin. Capping the basic training period are physical and laboratory diagnosis and pharmacology, the elementary disciplines dealing with the identification and treatment of ailments.

Then the course branches into its two great clinical limbs, medicine and surgery, and for two years the students climb and leap from branch to branch of these major divisions. Just as the arboreal existence of our early forerunners contributed so much to the development of the primate brain through advances in visual and sensory-motor coordination, so this clinical arboreal period fosters quickened cerebration in the student, by necessitating constant application of all that he is presumed to have learned to successions of cases which constitute unpredictable new problems.

THE ANATOMIST'S CHARGE

The anatomist must endeavor to ensure that the sap of practical utility pass freely from him at the bottom of the trunk to the furthermost twig of the clinical tree. More than this, he should engender an interest in the nature and significance of current anatomical problems and an appreciation of the broader implications of the subject as a phase of human biology, which is after all, the larger province of the physician.

In this school the student acquires his formal training in anatomy through the traditional separate courses in embryology, microscopic anatomy, neuroanatomy and gross anatomy, the latter including, of course, the peripheral and autonomic nervous systems. It is the gross study with which we now deal.

The character of this course is shaped in part by external factors. Recent trends in medical education which need not be treated, have decreased time allotment and increased demands. The work must be done by a limited staff only partly available for this phase. The approved adjustments for the War effort have been made. The cadaver shortage, nationally felt, is acute in the District of Columbia. Experience and the medical aptitude tests show that our students, although recruited by the most rigorous selection possible, require careful orientation and attention to learn how to get the proper yield from their efforts in the techniques of dissecting room study.

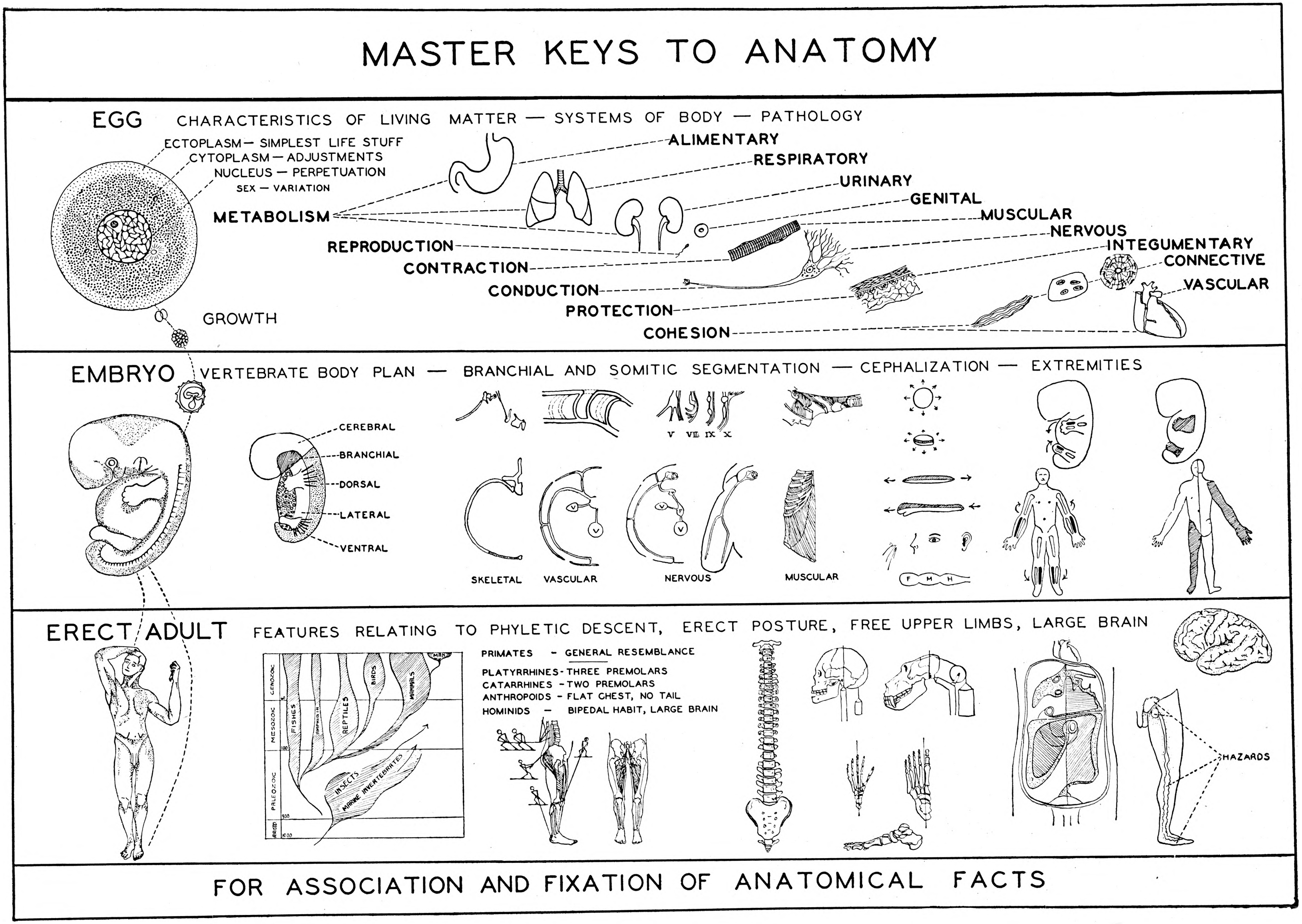
OBJECTIVES OF COURSE

In view of these complexities and the great range of things it might be desirable for a student to know at the end of a course in gross anatomy, our considered aim is the student's mastery of the gross details of the systems of the body and their topographical relations, as gauged by his ability to reproduce these diagrammatically, and give evidence of an understanding of the underlying morphological and functional principles. Any student who at the end of the course can demonstrate such knowledge is with us an "A" man and we believe will know enough to carry him in any company. Because it is position at the finish and not at the start which counts in a race, the grades of the first two quarters have been made advisory so that men who through no immediate personal fault get off to a bad start have opportunity to close gaps once they hit their stride, and, on the other hand, the advantages of working hard at first to relax into subsequent coasting are destroyed. Thus, it is literally possible for a man to fail the first quarter and in the absence of evidence of neglect of his work, earn an "A" for the course.

The presentation of anatomy followed emphasizes five educational tools: (1) the use of certain "master keys" for the inculcation of basic facts and principles; (2) the further elucidation of structural relationship by the allied discipline most suited; (3) the simultaneous coordinated use of skeleton, cadaver and living subject as a regular laboratory habit; (4) roentgenographic demonstration where possible; and (5) the use of mimeographed outlines of different regions and of artistic canons for drill in diagramming structures.

THE MASTER KEYS

Three "least common denominators" which may serve for the association and fixation of all anatomical facts and which every student may readily diagram with his own hand are the human fertilized ovum, the seven week embryo and the erect adult (Fig. 2). We have termed these phases of human development "master keys to anatomy." They not only open into the mysteries of this particular subject, but may help to unify the approach of the entire curriculum to its objective of teaching the physician how best he may restore to and maintain in the living body a state of health. It


MASTER KEYS TO ANATOMY
EGG
CHARACTERISTICS OF LIVING MATTER — SYSTEMS OF BODY — PATHOLOGY
ECTOPLASM — SIMPLEST LIFE STUFF
CYTOPLASM — ADJUSTMENTS
NUCLEUS — PERPETUATION
SEX — VARIATION
METABOLISM
REPRODUCTION
CONTRACTION
CONDUCTION
PROTECTION
COHESION
GROWTH
ALIMENTARY
RESPIRATORY
URINARY
GENITAL
MUSCULAR
NERVOUS
INTEGUMENTARY
CONNECTIVE
VASCULAR
EMBRYO
VERTEBRATE BODY PLAN — BRANCHIAL AND SOMITIC SEGMENTATION — CEPHALIZATION — EXTREMITIES
CEREBRAL
BRANCHIAL
DORSAL
LATERAL
VENTRAL
V VII IX X
SKELETAL
VASCULAR
NERVOUS
MUSCULAR
F M H
ERECT ADULT
FEATURES RELATING TO PHYLETIC DESCENT, ERECT POSTURE, FREE UPPER LIMBS, LARGE BRAIN
CENOZOIC
MESOZOIC
PALEOZOIC
FISHES
REPTILES
BIRDS
MAMMALS
INSECTS
MARINE INVERTEBRATES
PRIMATES - GENERAL RESEMBLANCE
PLATYRRHINES - THREE PREMOLARS
CATARRHINES - TWO PREMOLARS
ANTHROPOIDS - FLAT CHEST, NO TAIL
HOMINIDS - BIPEDAL HABIT, LARGE BRAIN
HAZARDS
FOR ASSOCIATION AND FIXATION OF ANATOMICAL FACTS

is hoped that the full use of these master keys may shortly be presented in the form of a small book. The chart and the following explanatory account may serve to outline their possibilities.

EGG. The fertilized human ovum, or zygote, is a single living cell from which the aggregate of cells constituting the adult body develops. The adult in his differentiated state, exhibits no vital properties not manifest in generalized form in the egg. The egg may, therefore, symbolize for the student of anatomy, the characteristics of living matter, the systems of the body, and pathology.

The zygote, however, as a cell, is itself a highly specialized structure, with nucleus, cytoplasm, organoids, inclusions and cell membrane. Living substance in its simplest form, is represented by that optically empty peripheral layer of the protoplasm of cell, called the ectoplasm.[5] This is known to be composed chiefly of the common elements carbon, hydrogen, nitrogen and oxygen, organized into protein, lipin, and carbohydrate molecules, which are retained in a colloidal state in an aqueous medium.

It has been postulated that in the emergence of life on this planet nucleus and cytoplasm were undifferentiated, and appeared only in the course of evolution.[5] The nearly exclusive occurrence of life in the form of nucleated cells indicates, certainly, the proved adequacy of this structural arrangement. The nucleus may be interpreted as a device for transmitting intact to the next generation the attained properties of an organism, while the cytoplasm cares for environmental adjustments.

The human zygote, though a single cell, represents a fusion of two elements, male and female. Sex, like nucleo-cytoplasmic differentiation, was undoubtedly a later development in the emergence of living matter. Organisms which reproduce sexually have eliminated from competition asexual reproducers. As the effect of sex is the production of new combinations of traits in individuals, the resultant variations in adaptive modification may be recognized as an important factor in evolutionary progress.

Returning now to the zygote as the human body in its earliest, best endowed and simplest stage, its further use as a master key may be described.

The zygote, first of all, exhibits all of the characteristics of living substance. Living matter differs essentially from non-living in that the former is constantly replacing its constituent substance, through a process called metabolism. This involves three elements, absorption, oxidation and excretion. The absorptive phase results in the building of new tissue and is called anabolism. The excretory phase results in the loss of old tissue and is termed katabolism. The life span can be crudely represented by equations of these phases: Anabolism $>$ Katabolism $=$ Growth; Anabolism $=$ Katabolism $=$ Prime; Anabolism $<$ Katabolism $=$ Decline.

Living matter has certain additional properties which facilitate independent existence in the environment, namely, contractility, conductivity, a protecting investment of some kind and elements which make for cohesive force to hold the substance of the organism together.

Finally, living matter has the capacity for reproduction, which is necessary for the survival of species, as all individual organisms from the moment of their origin enter upon a succession of ageing processes which end in the termination of the existence of each individual. Reproduction may be a simple matter of cell division as in cleavage or fission, but in the multicellulae it involves more complex mechanisms.

The zygote metabolizes, manifests contractility and conductivity, has a protective investment in the cell membrane, cohesive mechanisms in the fibrils and elasticity of the cell, and reproduces in the first cleavage. These diagnostic characters of living matter are possessed in varying degree by the twenty-six and a half trillion odd more or less specialized cells of the adult, which are descended from the zygote. Each vital requirement must, then, be met continuously for every cell in the body.

These facts in mind, the directions in which the cells of the higher metazoa have become specialized are readily understood. They are organized into systems of tissues and organs, each one of which is differentiated to care for one of the vital requirements for the organism as a whole. No specialization in any animal cell, tissue or organ occurs which is not directly or indirectly related to one of the vital fundamentals of absorption, respiration, excretion—contractility, conductivity—protection, cohesion—and reproduction. On the chart the nine major systems of the body—alimentary, respiratory, urinary, genital, muscular, nervous, integumentary, connective and vascular—are represented in proper relation to the basic vital function they subserve. The endocrine glands, in this connection, may be grouped with the nervous system.

All pathological states represent interference or aberrance with respect to one or more of the vital functions in the cells of given tissues or organs.

Increase in specialization in cells is generally accompanied with diminution in reproductive and survival capacity. Thus the cells of the cerebral cortex, which are the most highly specialized of the body, have lost regenerative capacity altogether and some will die if denied a fresh blood supply as briefly as thirty seconds, while the more primitive cells of the epidermis have great regenerative powers as shown in the healing of wounds, and may live for many hours after death.

With this orientation the student has recalled to him the significant facts of his premedical general biology. This familiar material is logically expanded in focus to show simply and clearly the number and nature of the bodily systems and the import of derangements in them. Anatomy thus is stripped of any aspect of strangeness or forbidding difficulty which the student may have conceived it to have, and he may enter upon its study with eager confidence upon stepping stones of old acquaintance, which may serve as starting points for other courses as well.

EMBRYO. With the detailed picture of the fertilized human ovum and all that it means clearly in mind, it is possible for each student to carry the ovum in a mental cinema through its development to about the seventh week when the anlagen of all the organ systems will have been established. An excellent means of review and fixing the facts is to draw a series of line diagrams, animated cartoon fashion, carrying the ovum through the stages of zygote, cleavage, morula and blastocyst, then, confining attention to the inner cell mass, through embryonic shield formation, primitive knot, primitive streak, head process, notochord, neural folds, body folds, somite formation, and so on, until the body form is delineated and the organ systems laid down, as in the seven week embryo. Thus are we brought to our second master key, the embryo, which may serve to fix in the student's mind, the vertebrate body plan, and the principle features of branchial and somitic segmentation, cephalization and the extremities.

Vertebrate Body Plan. The flexed head of the embryo clearly demarcates it into head region and body proper. The head obviously consists of a cerebral portion and the underlying well defined branchial arches.

In the body proper, the distinct groove in front of the somites delimits the axial or dorsal region from the remaining ventro-lateral portion, which is itself subdivided into ventral and lateral parts by the distribution of the segmental vessels and nerves.

Branchial and body regions proper are segmented and each branchial and somitic segment consists of skeletal, vascular, nervous, muscular and dermal elements.

The skeletal elements of the branchial arches are, for the first arch, the transient Meckel's cartilage, the sphenomandibular ligament, malleus and incus; for the second, the stapes, styloid process, stylohyoid ligament, and lesser cornua of the hyoid; for the third, the body and greater cornua of the hyoid; for the fourth, the cranial part of the thyroid and the cuneiform cartilages; and for the fifth, the caudal part of the thyroid, the corniculate, arytenoid and cricoid cartilages.

The skeletal element of a typical somitic segment, as in the mid-dorsal region, comprises a unit of the flexible dorsal stiffening rod, represented by the vertebral body, a dorsal neural arch to protect the spinal cord, and a ventral splanchic arch to protect the thoracoabdominal viscera.

The neural arch is fixed to the vertebral body and is formed by stout lateral pedicles upon which rests the gable roof formed by the two laminae. From the junction of laminae above and lamina and pedicle laterally project the spinous and transverse processes, respectively, for muscular attachment. The neural arch is completely formed on all vertebrae except the lower sacral and the coccygeal.

The splanchnic or costal arch is movable upon the vertebral body and in fully developed form is limited to the thoracic region. It is formed by the ribs and costal cartilages, which contact the sternum in front. The latter is an element of the pectoral girdle. Cervical and lumbar ribs adjacent to the thoracic region occasionally occur and a costal element is recognizable in all the cervical, lumbar and sacral vertebrae.

The branchial vascular elements are represented by the aortic arch complex, which may imprint the derivation and adult relationships of the aortic arch, the ligamentum arteriosum, the common, internal and external carotid, and the subclavian arteries.

The patterns of ramification of the somitic vascular and nervous elements are identical. At each segmental level parietal and visceral areas may be supplied by the aorta and spinal cord, respectively. A mid-intercostal vessel and nerve typify the plan of parietal supply. Each gives off a dorsal branch to the dorsal or axial region and continues as a ventro-lateral or ventral division to the remainder of the body wall. In turn the ventral division gives off lateral and ventral branches to those respective regions. By further subdivision, a circle of cutaneous supply is formed around the body, the dorsal branch dividing into medial and lateral limbs; the lateral branch into posterior and anterior; and the ventral into lateral and medial terminal branches.

The viscera are paired and unpaired necessitating paired and unpaired branches for their blood and nerve supply. These are derived, respectively, from the aorta and the prevertebral autonomic plexuses, the nerves accompanying the blood vessels. The blood, it will be noted, passes directly from the aorta, while the sympathetic nerve impulses from the spinal cord are routed through the motor roots of the spinal nerves, the white communicating rami, the sympathetic trunk and various connecting paths to reach the prevertebral plexuses.

The branchial nerves are the mixed cranial nerves: trigeminal (V) to the first arch, facial (VII) to the second, glossopharyngeal (IX) to the third, and vagus (X) to the fourth.

The musculature developed from each branchial and somitic segment is innervated by the nerve of that segment. The developmental origin of the branchial muscles may be identified in this way as follows: from the first arch, the masticatory muscles—masseter, temporalis, external and internal pterygoids, the tensor tympani, tensor veli palatini, mylohyoid and anterior belly of the digastric; from the second arch, the muscles of facial expression, the stapedius, stylohyoid and posterior belly of the diagastric; from the third arch, the pharyngeal constrictors; from the fourth arch, the remainder of the pharyngeal musculature and part of the laryngeal; from the fifth arch, the remaining laryngeal muscles.

The primitive somitic muscles span only one segment, and are represented by the intercostals, intertransversarii, interspinales, rotators and deepest fasciculi of the multifidus. Other skeletal muscles represent modification of this primitive arrangement by fusion of several segments as in the abdominal and more superficial axial muscles; by tangential splitting into two or more layers, as with the intercostals; by longitudinal splitting, as in the case of the infra-hyoid muscles; and by whole or partial degeneration of muscle primordia to form fascias, aponeuroses and ligaments.

The dermal segmental elements form the skin over their respective units and are innervated by the corresponding nerves. The third, fourth and fifth branchial arches are not represented in the skin because of their external obliteration in the cervical sinus.

Cephalization. This term refers to the process of acquiring a head. Many animals like the jellyfish and starfish do not have a head. Representatives of the existing phyla afford evidence of the stages by which animals acquired heads.

Cohesive force will make any mass of free matter tend to assume the shape of a sphere, and this primitive form is found in certain protozoa and other free cells. But since repetition of experience provides the stimulus for adaptive modification, the sphere must be held the poorest shape for the development of structural advancements because none of the infinite points on its surface could be presumed to be favored by chance over others in repeating environmental contacts.

Gravity, however, acts upon all organisms and to its influence must be attributed the development of dorso-ventral asymmetry, the first basic patent in animal evolution, in which the belly or ventral side of the organism is always toward the center of the earth and the back or dorsal side faces the firmament. Disc-shaped organisms, such as the sand-dollar, Echinarachnius parma, represent this stage in evolution, which opened new highways for progress. The ventral surface has naturally become the site of terrestrial adaptations, while the exposed dorsal surface has undergone protective modifications of various sorts. This pattern obtains throughout the metazoa to ourselves. Our ventral skin is thinner and less hairy than our dorsal, and our limbs, jaws, anus and genitalia are all ventrally placed.

With the flattening of the sphere into a disc, the directional possibilities for movement of the organism have been reduced from the infinite points on the surface of a sphere to those on the circumference of a circle. There are too many points on the circumference also, however, to result in any portion acquiring advantage in experience in environmental contact. To carry structural evolution further a new major patent is necessary.

The manner in which Nature provided this may be simulated by squeezing our discoid organism into a rod. The body plan of bilateral symmetry results. Movement is now limited to two directions, fore and aft, and a tubular gut may be run the whole length of the body, opening at each end. The theoretical possibility of movement in two directions must be conceived to have shortly given way to the habit of moving in only one, and with the establishment of the habit of unidirectional movement in a rod-like organism the development of a head becomes inevitable.

The forward end of the body is always the first part to come into contact with new environment and with sources of food, hence it becomes specialized for sensory reception and the intake of food and oxygen. The subsequent history of the head is the story of progressive improvements in the apparatus for these respective purposes.

The most primitive form of sensation is tactile, and since the rostral end of the body acquires more tactile experience than any other, increase in tactile reception elements here would be the first anticipated advancement and this expectation is realized. The mammalian snout possesses highly developed sensitivity and the surface membranes of the tongue and palate have specialized tactile organs in the taste buds, features which are reflected in the relatively large size of the sensory ganglion (Gasserian) of the nerve to the first branchial arch (trigeminal) and the fact that the entire sensory element (chorda tympani) of the nerve to the second branchial arch (facial) has been taken for the sensation of taste.

The utility of tactile sensitivity is definitely limited, however, by the requirement that the organism actually touch the source of sensation. Extension of tactile reception by hairs and antennae cannot be carried very far. Next to develop were sense organs which would apprise an organism of the nature of its environment without actual contact. These organs, the nose, the eye and the ear, collectively termed the distance receptors, arose as agents for the only kinds of distance reception possible in our physical environment, namely sensitivity to minute particles separated from a distant object and brought to the receptor through an intervening fluid or gaseous medium (smell); sensitivity to waves of radiant energy (vision); and sensitivity to vibrations originating in a distant object and transmitted through the intervening medium to the receptor (hearing).

The brain arose as an elaboration of nervous connections incident to the development of the distance receptors, the three primitive subdivisions, forebrain, midbrain and hindbrain, having developed in association with olfactory, visual and auditory-equilibratory sensation, respectively. The neopallium is a master coordinating center of later appearance which has reached its fullest development in man.

The cerebral portion of the head thus has developed in association with the distance receptors. The branchial portion of the head consists of a specialized apparatus for the seizure of food called the jaws. As primitive vertebrates are all marine, oxygen must be acquired by insuck of water. Hence, in fish the jaws are the intake aperture for the functions of both nutrition and respiration. In terrestrial forms the respiratory intake is transferred to the aperture of the olfactory organ.

The head, in short, is the region of the body where are situated the distance receptors, the brain and jaws. Since the primary utility of the sense organs and brain is the detection of new sources of food, which is seized always with the jaws, and since food represents only energy for the organism's continued existence, the head may be described as the lodgement of the organs for the detection and prehension of energy.

Extremities: The final sets of facts which the embryo will help us fix, concern the extremities. We note first that the limbs will be innervated by the nerves of those segments opposite which the limb buds lie when they arise, thus nerves, C5 through T1 will supply the upper extremity through the brachial plexus and nerves L1 through

S3 will supply the lower extremity through the lumbosacral plexus.

Since the limbs develop in entirety from the ventro-lateral region of the body, they can be innervated only by the ventral primary divisions of their nerves. In the embryo both fore and hind limb buds are similarly oriented, and lie flat against the body wall. The flexor muscles will develop on their inner sides, which will retain a thin smooth skin with little hair. The extensor muscles will develop on the outer side, which will acquire a thicker, rougher and more hairy skin. Each nerve of the brachial and lumbosacral plexuses divides into ventral and dorsal divisions which correspond respectively to the ventral and lateral branches of the ventral primary division of the typical segmental nerve. The ventral divisions of the plexus nerves supply the flexor muscles and the dorsal divisions the extensor muscles.

In the primitive position of the limb buds, thumb and great toe are both rostrally directed and therefore comparable elements, which facilitate ready identification of skeletal homologies. Humerus and femur as the only bones of the proximal segments of the respective limbs, correspond. Since radius is on the side of thumb and tibia on the side of great toe, radius and tibia, and ulna and fibula, correspond. Analogy of the remaining components of the pentadactylate hand and foot is obvious.

To attain their functional positions the limbs are turned in opposite directions from their position in the embryo, the upper limb being rotated outward and the lower limb inward. As a result the homologous surfaces of the limbs face in opposite directions, so that the front of the arm corresponds to the back of the leg.

These considerations respecting the limbs form the basis for association of many additional facts concerning their musculature, vascularization and innervation which cannot be treated here.

ERECT ADULT: Man owes his position as the dominant form of earth life to his habitual erect posture. Characters related to this specialization occur in every region of the body. An understanding of them supplementing a grasp of the facts represented by the egg and embryo will constitute a complete basic knowledge of human anatomy.

As evolution is the principal fact of biology, phyletic considerations have been inherent in the use of our two preceding master keys. The study of the orthograde (erect) modifications involves additional facts about our phyletic descent. The figure showing the time of origin and relationships of the major animal groups will serve to remind, in the light of common knowledge, that our bodies are a vast composite of ancient and recent structures, of old patents and new. The forms of our gametes, for example, are ancient (palingenetic) characters. The male is a small and motile element and the female large and passive. This morphology is essentially the same in all forms from ourselves to marine invertebrates, animals whose line of descent diverged from our own over five hundred million years ago. In that tremendous span no further evolution in those particular characters has occurred. By contrast, our orthograde habit is of relatively very recent (caenogenetic) origin and unique to ourselves.

Our living relatives the higher primates hold particular interest not only because of the extensive use in medicine and psychology their kinship has gained them, but for evidence they afford of stages in our own evolution and the nature of our adaptive modifications. The New World monkeys (Platyrrhinae) have the greatest number of primitive features. They are generally recognizable by the presence of a wide distance between the nostrils, three premolar teeth and a prehensile tail. Their deep, narrow chest and four-footed locomotion are general mammalian features, found also in the Old World monkeys (Catarrhini), in which the distance between the nostrils is narrow, the premolar teeth have been reduced to two and the tail has no grasping power. The anthropoid apes like ourselves show the catarrhine features of a narrow distance between the nostrils and two premolars, but the anthropoids have no tail and the habit of brachiation or moving about by swinging by the arms from the branches of trees has broadened the chest from the deep and narrow to shallow and broad form, features found in man also. Man is unique in his bipedal adaptation, generalized hands and large brain size. These few differential features are easy to keep in mind and are of great value when the changes in specific regions are followed from the New World monkeys to man.

The most important anatomical adjustments for the erect posture are associated with the shifting of the weight bearing and locomotor functions from four legs to two and the maintenance of the trunk in a vertical instead of a horizontal position.

The human lower limbs are relatively larger than in quadrupeds. This is clear from the skeleton, femur being much longer and stronger than humerus. The muscles which maintain the trunk erect upon the thigh (glutei), the thigh erect upon the leg (quadriceps), which keep the legs from spreading (adductors), and which lift the heel (triceps surae), all have increased assignments and hence are especially developed in man.

The human foot is distinctive for its arch, which has been developed from an arboreal grasping foot, by adduction of the first metatarsal, lengthening of all the metatarsals, particularly the first, and shortening of the phalanges. The bony prominences and markings of the foot indicate clearly the manner in which the arch is maintained by the conformation of the bones themselves and ligamentous and muscular supports.

The vertebral column manifests weight bearing adaptations in the increase in size of the vertebral bodies from above downward, and the changes in the sacrum. This element has increased greatly in relative breadth, is formed by coalescence of five instead of the typical mammalian three vertebrae and the sacro-iliac articular surface has extended to subtend two and a half instead of the typical mammalian one and a half vertebrae. In the raising of the trunk to the vertical position the pelvis, including the sacrum, has been turned up only part way so that muscular leverage on the lower limb would not be lost. To compensate, the vertebral column has acquired a forward convexity in the lumbar region which is peculiar to man. The human sacrospinalis muscles, which maintain the trunk in its hyperextended position, are exceptionally developed.

Within the trunk cavity gravitational adaptations are found. The heart is settled full upon the diaphragm so that thoracic inferior vena cava has been almost eliminated and the fusion of the mesenteries of the gut to the posterior body wall has proceeded further than in animals with horizontal trunk, thus preventing visceroptosis.

The typical mammalian skull with small braincase and large face, extends in front of the body and must be held onto the vertebral column by a strong neck musculature for the attachment of which bony scaffoldings are often required. The human skull with large braincase and small face is balanced upon the vertebral column permitting a relatively reduced cervical musculature which renders bony reinforcements unnecessary.

The use of only the hind limbs for support and locomotion freed the fore limbs for exercise in the diversified activities which have carried to present proportions the development of the large brain inherited from our arboreal primate ancestors. The relatively greater size of the human neopallium involves all its parts. Cortical representation for sensory-motor impulses of the body proper and for visual and auditory sensation is greater than in any other mammal and parietal and frontal association areas are of unparalleled size.

With the benefits of the erect posture have been acquired certain hazards of which a few may be mentioned. The abdominal wall is so constructed that the normal extended position of the trunk upon the thigh predisposes to inguinal hernia through pressure thrown upon weak areas. This same cause plus the fact that the relatively greater size of the femoral vessels results in a larger femoral canal, predispose to femoral hernia. The passive congestion in our large lower extremities related to such factors as standing for long periods and excessive weight, throw such strain upon the venous walls that where the latter are not adequately strong, varicosities result. The comparable condition around the anal orifice is hemorrhoids. Imperfections in the construction of the foot or abuses of its weight-bearing capacities are likely to cause flat feet. Our erect posture is a new biological patent and a great success, but there are a few "bugs" still in the structural arrangements involved which we may expect to be eliminated in time.

ADJUVANTS

The foregoing synopsis has indicated how our "master keys" may serve as a simple, logical and comprehensive frame of reference for all anatomical facts and as an introductory vehicle for all the other subjects of the medical curriculum. Topical mention may be made of additional procedures found valuable for the lasting inculcation of facts.

First is the consistent emphasis upon approach to the study of the detailed anatomy of a part through the medium of the allied discipline or

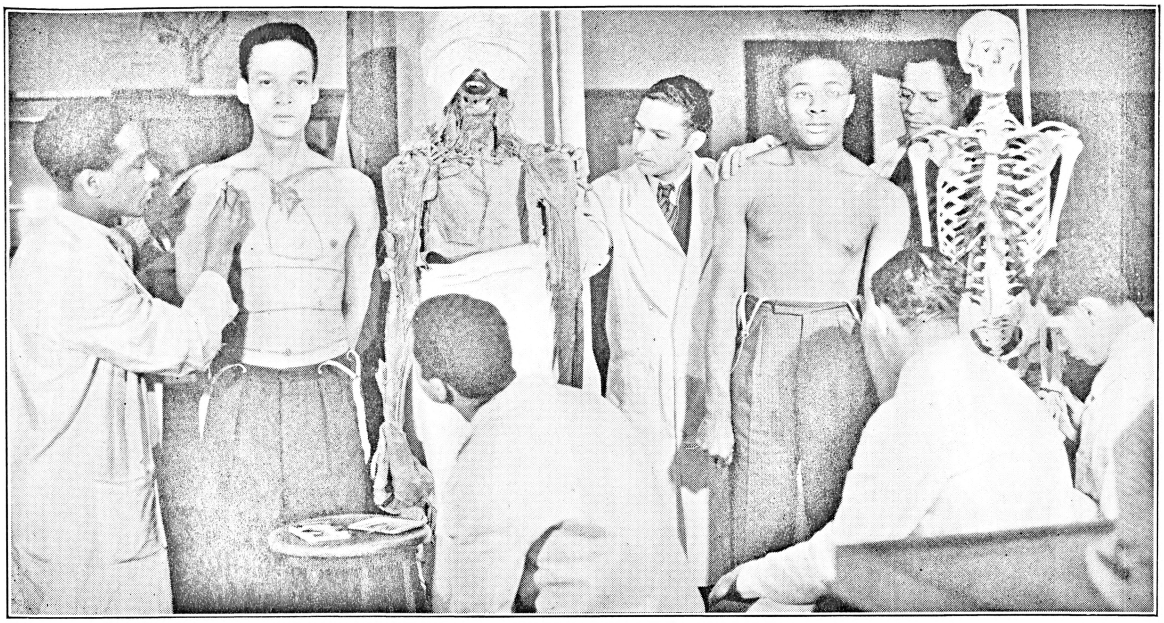


Figure 3

sphere of common knowledge which throws most light upon the nature of that part. Thus the disposition of the peritoneum is best retained through an understanding of the embryological transformations in the abdomen. The structure and maintenance of the arch of the foot is a problem in mechanics and the relative importance of its anatomical features are best fixed through this interpretation. The vascularization of the extremities is a triumph of one-way highway construction in which all traffic moves at regulation speed and there are no tie-ups. The arrangement and ramification of the blood vessels are readily grasped in this light. The components of carpus and tarsus are firmly imprinted through a knowledge of their phylogeny, rather than school-boyish jingles. An understanding of cephalization will give a hold on the cranial nerves which memorization of their topographical order cannot impart. Perception that the functional elements of the vital viscera (e.g. gut, lung, kidney, liver) are different applications of the same basic patent, is essential to adequate understanding of the microscopic detail and gross organization of the several viscera. This patent consists of a cellular wall through which substances are absorbed from or extruded to the exterior or both, and a vascular complex composed of artery, capillary and vein, which collects from or delivers to the tissue fluid around this cellular wall, the substances absorbed or extruded. Extensions of this approach are applicable to all parts and regions.

Another adjuvant used is stress upon the simultaneous and coordinated study of the skeleton, the cadaver and the living subject (Fig. 3). When necessary the cadaver is stood up by the side of the table. By repeated association of the positions of the soft parts as dissected in the cadaver, with the skeleton on one side, and the living subject on the other, the development of the "roentgenoscopic eye," that is, the ability to visualize underlying parts on the patient, is enhanced. The student is encouraged to check his own competence in this direction by regular practice in the surface painting of deep structures on his fellows as illustrated (Fig. 3). Where possible this study is supplemented by roentgenographic demonstrations.

Finally, the use of form sheets bearing mimeographed outlines of the body as a whole or of different parts, on which the students draw-in indicated structures, is extensively employed to develop confidence and accuracy. If a man knows the surface relations of the heart and its valves, he can draw these in on an outline of the bony thorax. If he knows that the flexor carpi radialis arises from the medial epicondyle and inserts on the base of the second metacarpal, he can join these parts on an outline of the skeleton of the arm and in addition show the proportions between belly and tendon of the muscle. If he knows the blood supply of the hand, he can draw in each vessel in correct position on an outline of the hand.

Artistic gift is not necessary for this exercise. Knowledge only is required. Primitive man made pictures long before the written word was invented. The retention of visual impressions which in themselves embody relationships, so important in anatomy, is easier and more permanent than that of concepts derived from words. Those learners who have tested themselves with form sheets know that there is no better way to discover gaps in their own knowledge.

A brief practice in the use of the classical artistic canons for body proportions enables one to make his own form sheets for the whole body or any part. The most widely employed canon represents the body as seven and a half heads high, with the symphysis pubis in the middle of the body. The nipples are two heads from the top and one head apart, and the umbilicus, three heads from the top. Other parts may be readily outlined from these guides.

SUMMARY

In the light of the past and present status of anatomy, the patriarch of medical disciplines, the semantics and further use of three "master keys" for the association and fixation of anatomical fact have been described. These keys have been designed as a coordinating tool for the complex requirements of modern medical education and clinical usage. In addition to their anatomical uses they form a link with the facts of general biology, on the one hand, and with the remaining subjects of the medical curriculum on the other.

These keys are the human fertilized egg, the seven week embryo and the erect adult. With the egg are associated—the characteristics of living matter, the systems of the body and pathology; with the embryo—the vertebrate body plan, and the principal features of branchial and somitic segmentation, of cephalization and of the extremities; and with the erect adult—major facts of our phyletic descent, the anatomical features associated with our erect posture, free upper limbs and large brain, and pathological predispositions related to the erect position.

The supplementary use and significance of other aids to the mastery of anatomy are cited. These are the approach to the study of a specific phase of anatomy through the allied discipline or sphere of common knowledge most suited; the simultaneous coordinated study of skeleton, cadaver and living subject, with roentgenograms when available; and the regular use of form sheets with mimeographed outlines of the body and of the several regions for review by drawing in the details of specific parts.

With the "master keys" and a series of form sheets which one may make for himself, any student or practitioner can give himself a refresher course in anatomy in three evenings.

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