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Imaging the unimaginable: Medical imaging in the realm of photography

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Abstract There is an almost innate urge in human beings to represent reality in a visual form. From rock art in the Paleolithic to images of galaxies, the quotidian and the extraordinary have been visually represented through the ages. Medical and scientific disciplines are no exception. Accurate representation of the human body structures and anatomy based on cadaver dissections was almost not possible up to the Renaissance due to ethical, social, and religious beliefs and objections. The works of Leonardo da Vinci (1452-1519) and others and, later, Andreas Vesalius (1514-1564), who produced *De Humanis Corporis Fabrica,* are considered landmarks in the history of medicine. During the following centuries medical and scientific illustration relied upon the expertise of physician-artists and scientist-artists until a new paradigm appeared in the realm of scientific (medical) illustration: the invention of photography in the 19th century. Two of the medical disciplines most rapidly influenced by photography were dermatology and pathology, both macro- and microscopic. Physicians rapidly started to use photographs as a tool for consultation, documentation, and education, and large collections of images were amassed by individuals and institutions for these purposes. Photographic images are produced by visible light impressing a light-sensitive material such as a silver halide plate, and nowadays a silicon chip. But photons are reflected by nontransparent objects, including the human skin. Developments in science and technology allowed the use of other types of radiation to reveal internal structures in the human body and, most interestingly, noninvasively. Thus today much of the medical diagnosis and treatment is guided by the so-called *medical imaging* with the use of these techniques, that is, medical photography, endoscopy, x-ray radiography, computer-aided tomography, magnetic resonance imaging, ultrasonography, thermography, and nuclear medicine functional imaging techniques as positron emission tomography (PET) and single-photon emission computed tomography (SPECT). Some of these techniques are being applied at the microscopic level to study cell structure and even functional changes in real time. All these advancements in science and technology applied to medicine and other disciplines pose the question as to what extent physicians are trading their capabilities as clinicians. Ethics issues add to the complexity of this new era governed by constant changes in scientific paradigms.

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An image is worth a thousand words.

Introduction

There is an almost innate urge in human beings to represent reality in a visual form. For one thing, visual representation can reach beyond language barriers. Much before writing was developed by early humans, there were pictorial representations of objects, of reality. From rock art in the Paleolithic to images of distant, inaccessible galaxies taken by the Hubbel telescope, the quotidian and the extraordinary have been visually represented through the ages.

Modern humans originated in Africa about 200,000 years ago, before progressively occupying the rest of the planet over the past 100,000 years.[1–3] Abstract art in the form of complex geometric patterns, dating back more than 70,000 years, has been found in the Blombos cave in South Africa near Cape Town. These pictographs may have accompanied the development of spoken language. This discovery suggests that early humans were behaviorally modern 70,000 years ago.[4] Previously, the earliest evidence of abstract art was found mainly in France from the Eurasian Palaeolithic period about 40,000 BCE.

From rock to marble and papyri

Rock paintings and engravings representing animals, human body parts, and symbolic drawings have been found in many parts of the world. Recently archeologists have discovered in Spain what may be the earliest human art manifestations thus far found: a red linear motif in La Pasiega (Cantabria), a hand stencil in Maltravieso (Extremadura), and red-painted speleothems in Ardales (Andalucía). Carbonate crusts overlying paintings have been dated by uranium-thorium (U-Th) to be at least 64.8 thousand years old, predating the arrival of modern humans by some 20,000 years. Using the same dating techniques, rock paintings in 11 caves in Spain, including the sites of Altamira, El Castillo, and Tito Bustillo, have been dated to be as old as 40,800 years. Together with those cave paintings representing seals found in a cave near Málaga (Nerja), dated to be around 43,000 years old, they are attributed to Neanderthals (*Homo neanderthalensis*), challenging the concept that only humans were able to produce artistic manifestations, inferring that Neanderthals and early modern humans were cognitively indistinguishable.[5–7]

The best studied and perhaps most spectacular cave paintings made by early modern humans (*Homo sapiens*) are those found in France and Spain, dating from almost 38,000 BCE (Chauvet-Pont-d'Arc, 37,000 BCE; Lascaux,17,000 BCE; Altamira,15,000 BCE). The Chauvet-Pont-d'Arc Cave in the Ardèche department of southern France, discovered in 1994, contains some of the best preserved figurative cave paintings in the world.[8] These rock paintings depict scenes not only of animals, such as horses, cattle, and mammoths, herbivores that predominate in Paleolithic cave art, but also, most interestingly, other animals such as panthers, bears, hyenas, lions, and rhinoceroses. This indicates that these predators, now extinct, roamed wild in Europe before the last ice age providing a kind of a biogeography notebook. The cave paintings of Chauvet-Pont-d'Arc have been considered as the first artistic manifestation of humankind thus far discovered. It is remarkable that the stencils of hands found in rock painting in Europe, Eastern Asia, and South America were produced by the same technique in a span of over 30,000 years, but paintings of the human body appear very rarely in any of these cave; however, figures of women carved in ivory, bones, or stone, called *Venus figurines,* have been found in many caves, dating from the Upper Paleolithic period (40-35,000 BCE).[9]

Progressively, cave rock art began to appear containing paintings of humans picturing their daily life: hunting, warfare, and social activities. It is amazing how similar these representations of humans are, in different space and time, through the early ages of humankind. In El Pindal cave in Spain, a mammoth is depicted with a figure in its chest, representing the heart. The drawing may have been used to teach young hunters where to aim their arrow or spear.[10,11] This must be one of the first paintings showing inner structures of the body. The Library of Ashurbanipal, the last king of the Assyrians (668-627 BCE), contains many clay tablets with medical information as well as lists of disease diagnoses dating as old as 2000 BCE. In the king's palace, a bass-relief, entitled the Lion Hunt, depicts a lion dragging its hind limbs with an arrow stuck in its spine and a painful looking face. It is perhaps one of the first images relating cause-effect: wound, pain, and physical constraints.

Greek artists admired the human form and portrayed it exquisitely and with exacting proportions, especially in marble sculptures, contributing to medical illustration as topographic anatomy. According to Plato, Hippocrates (460-370 BCE), considered the Father of Medicine, thought that a "complete knowledge of the nature of the body was necessary for medicine"; however, the knowledge of the human body was based on animal dissections and fancied reasoning and illustrations, as dissection of human corpses was not allowed due to taboos and ethical, social, and religious beliefs.

Later, in about 280 BCE, Herophilus (325-255 BCE), together with Erasistratus (c.304 to c.250 BCE), founded a school of anatomy in Alexandria and there performed the first (and last, before the Renaissance) systematic dissections on cadavers and vivisections in living condemned prisoners.[12–14] In addition, Herophilus performed the first autopsies to relate disease with anatomic changes. He wrote 11 volumes on medicine and anatomy. Unfortunately, all of these were lost in the big fire of the Library of Alexandria in 335 AD.[15] It is not known whether Herophilus illustrated his treatises (most probably not); however, bass-relief engravings of medical instruments, including scalpels, forceps, and saws, used in those times of Ptolemaic rule are found in the Kom Omo temple in Egypt. Celsus (c.25 BCE to c.50 CE) and Galen (129 to c. 200/216 CE) accused him of performing vivisections in living humans, and was also called a “butcher” by Tertullian; however, his achievements in anatomy, medicine, and pathology represented a leap forward in the ancient understanding of the body. He has been thus acknowledged by many as the Father of Anatomy.[16]

The question whether the medical and scientific manuscripts in Greco-Roman times were illustrated has been the subject of many discussions and even fanciful analyses. The fact is that no papyrus of the era has been found with illustrations. In addition, the papyrus was not a suitable medium to render quality images; thus, none of the works of the founders of Western science and medicine may have been illustrated. In any case, the images would be present in separate volumes; however, the use of illustrations in education of young physicians in the School of Alexandria by Herophilus and Erasistratus and Galen appeared to be a common practice.[17–19]

Papyrus was progressively replaced by parchment and vellum in the writing of books during the Roman Empire. The great library of Pergamon and then Constantinople after the great fire of the Library of Alexandria started to copy all the works of the classics in literature, philosophy, natural sciences, and medicine. These could be now embellished with painted illustrations rather than the washed ink used in papyri, and they could be bound in the form of books (codices) or kept separate for the study or reading of individual folios.

From codices to the printing press

The earliest surviving illustrated manuscript is an illuminated Byzantine copy of the herbal *De Materia Medica* by Dioscorides (c.40-90 CE) dating form 512 CE. The codex, imprinted on parchment, was presented to Anicia Juliana, daughter of Flavius Anicius Olybrius, who had been Western Roman Emperor in 472 CE. It comprises 491 folios and almost 400 full-page color illustrations. It was bought from Suleyman the Magnificent’s court in 1569 and is housed in Vienna at the Austrian National Library and known as *Codex Vindobonensis Med. Gr. 1.* (from Vindobona, the Latin name for Vienna) or the Vienna Dioscorides. After many years of traveling in Asia Minor and Egypt as botanist, physician, and surgeon of Nero’s army, Dioscorides in about 65 CE compiled his observations and medical experience with almost 700 plant species used with medicinal purposes in *De Materia Medica* (the materials of medicine). This herbal was copied many times during the Middle Ages and the Renaissance with additions from other sources (especially Pliny and Crateuas) and was in continuous use as the Western pharmacopeia for about 1500 years.[20,21]

During the byzantine empire and the Middle Ages, the prohibition of dissecting human cadavers remained. Fortunately, the medieval world gradually gave rise to changes in the way of thinking in all fields of human expression, including arts, music, literature, science, and medicine. One example of this slow evolution is the work of Mondino de Luzzi (cca. 1270-1326 BCE), Italian physician, anatomist, and professor of surgery at the University of Bologna, who wrote his *Anathomia Mundini* in 1316, based on the dissection of cadavers and illustrated with plates by Guido da Vigevano (1280-1349), a student of his. The first printed edition of the *Anatomia* appeared in Padua in 1476, more than 150 years after, shortly after the development of the printing press by Johannes Gutenberg (1398-1468) in 1439.[22–24] After Mondino it is worth mentioning Johannes de Ketham, who produced the monumental *Fasciculus Medicinae,* first published in Venice in 1491, being the first printed book containing anatomic illustrations.[25]

Leonardo da Vinci (1452-1519) was an artist with skills in many other fields of knowledge, including civil engineering, chemistry, geology, geometry, hydrodynamics, mathematics, mechanical engineering, optics, physics, pyrotechnics, and zoology. It is not within the scope of this presentation to discuss his contribution to science in general. Leonardo put together his extraordinary skill as an artist with his deep knowledge of the human body proportions, drawn from observations, and the inner organs and its relationships, gained from the dissection of more than 30 cadavers that he performed in hospitals in Florence, Milan, and Rome. Based on those, he prepared a book on anatomy and physiology, which included more than 200 drawings (of over 750 detailed anatomic drawings that he had produced). His anatomic work was published only in 1680 (161 years after his death) and included as a chapter in his *Trattato della Pittura* (Treatise on painting). His drawings of the skeleton the spine, the heart, the aorta, a fetus in the womb, and many others were magnificent in anatomic detail and esthetics.[26–28] Unfortunately for Leonardo, his anatomic drawings were printed over a century after Vesalius had published his *De Humani Corporis Fabrica* and went almost forgotten until recently.[29,30] The original drawings are housed in The Royal Collection at Windsor Castle, England.

Andreas Vesalius (1514-1564) was a Belgian physician and professor of anatomy and surgery at the University of Padua. He based his anatomic work on dissections of cadavers in front of his students. He believed that knowledge should come from evidence provided by the observational method and systematic experimentation—the scientific method. He identified many anatomic errors in Galen’s book, as this was based on nonhuman dissections, and dared to challenge the dogmas of the Catholic Church, the academic world, and the medical world of his time.[31]

His main scientific work, *De Humani Corporis Fabrica,* contained 670 pages of texts and 186 anatomic plates of the human body, which were accurate and of the highest esthetic quality. It is not known who was (were) the artist(s) collaborating with Vesalius in the illustration of this monumental work. It is only known that at least six plates were drawn by Jan Stephan von Calcar (1499-1546), a student of the Italian master Titian (Tiziano Vecelli; c.1488-1576) and it is thought that the entire set of plates was executed by other students in the Titian studio in Venice. The book, arranged in seven volumes, was published in 1543 in Basel, Switzerland, and dedicated to Charles V, Holy Roman Emperor. The engraved wooden blocks were transported to Basel, as Vesalius wished that the work be published by one of the foremost printers of the time.[11,31,32] The second edition was published in 1555, with improvements and expansions in the text and his physiological experiments and better printing of the illustrations. In 2009 there were at least 113 copies of the second edition of *De Humani Corporis Fabrica* at major universities and libraries in Europe and the United States.[33,34] This book represents a landmark in the history of medicine, anatomy, and pedagogy, and may be considered as the first complete atlas of *medical imaging*.

With the invention of the microscope, the body could be now scrutinized in its intimate components. Robert Hooke (1635-1703), an English natural philosopher, architect, and polymath at Oxford and the Royal Society, published *Micrographia* in 1665, a book lavishly illustrated describing observations made with microscopes and telescopes where he coined the term *cell* to describe the building blocks of cork. This was the first time, by his own account, that a representation of a microscopic image was ever published.[35] Inspired by Hooke, Antonie van Leeuwenhoek (1632-1723), Dutch businessman and scientist, constructed single-lens microscopes and observed for the first time protists, bacteria, red blood cells, human spermatozoa, and many other cells and unicellular organisms. These were illustrated, out of his own hands, in the more than 190 letters he wrote to the Royal Society[36–38]; thus, from the plates of Vesalius to the drawings of Leeuwenhoek, the human body structure and some of its parts commenced to be pictured both macro- and microscopically.

The invention of photography

During the following centuries medical and scientific illustration relied upon the expertise of physician-artists and scientist-artists until a new paradigm appeared in the realm of scientific (medical) illustration: the invention of photography in the 19th century. The invention of the photographic image was made possible by putting together two phenomena: the *camara obscura* and the fact that some chemical substances change color (dark) under exposure to light.

The principle of the *camara obscura* (pinhole image) is that the light reflected from an illuminated object and passing through a pinhole into a darkened area can form an exact image of that object. This may have been known to early humans, but it was first described by the Chinese philosopher Mo Ti about 400 BCE and by Aristotle in 330 BCE. The first graphical description was given by Leonardo da Vinci in 1502 and included in the *Codex Atlanticus*. This was used during the Renaissance as an aid in the drawing and painting of objects and portraits. Later on, and on the other side of the equation, Angelo Sala (1576-1637), an Italian chemist, made the observation in 1614 that "powdered silver-nitrate is blackened by the sun." In 1777 the chemist Carl Wilhelm Scheele (1742-1786) discovered that light would break down the light-sensitive silver chloride into a precipitate of microscopic dark particles of metallic silver; furthermore, silver chloride could be dissolved by ammonia but metallic silver did not. These discoveries set the stage for the invention of photography (see Ref.[39] as a general reference for the history of photography).

It is not in the scope of this paper to make a detailed account of the invention of what we know today as *photography*. Only a few names involved in the key discoveries will be mentioned. Thomas Wedgewood (1771-1805; uncle of Charles Darwin) around 1800 succeeded in producing the first photograms by exposing a silver nitrate–coated paper to light with an interposed object; however, he still could not make the image permanent ("fix") as the white "negative" image also turned dark when the object was retired.

In 1816, Joseph Nicéphore Niépce (1765-1833), using silver chloride–coated paper and employing a *camara obscura* with a lens, captured the images formed in the camera; however, the photographs were negatives, and they were not permanent enough to last but a short time. As Niépce was not happy with the fact that they were negatives, he experimented with light-sensitive organic substances (gaiacum and bitumen). He was the first to make a print of reality, lasting enough to be seen by others. If this is the case, then those were the first photographs.[39] By 1824, he had improved his methods to produce images on a pewter plate coated with bitumen of Judea dissolved in lavender oil. Unfortunately, it would need hours of exposure to produce an image.

In 1829, Louis Jacques Mandé Daguerre (1787-1851) established a collaboration with Niépce, exchanging knowledge derived from research carried out separately on their own; they would share fame and profit. Unfortunately, Niépce died in 1833, leaving Daguerre to continue on his own. By the late 1830s, Daguerre developed what later would be called a daguerreotype: a cooper plate sensitized with silver iodine (which produced a negative image) then developed with mercury vapors and then stabilized with a saturated sodium chloride solution. Mercury would amalgamate with silver to make a whitish precipitate where the plate had been exposed to light, thus making one-of-a-kind, single and unique, positive image. With the help of Francois Arago, an influential scientist and politician, Daguerre presented his invention before the Académie des Sciences in Paris on the 7th of January, 1839. News spread rapidly across the Channel and the same month William Henry Fox-Talbot (1800-1877), an English wealthy scientist and scholar, who had been experimenting with images on silver-coated papers and camera-based imaging since the early 1830s, communicated his developments to the Royal Society. He then invented iodized paper and introduced the negative/positive printing still used in silver-based photography, making possible multiple copying of a single negative. He called his prints *calotypes*—in Greek, beautiful drawings. Later that year Sir John Herschel (1792-1871) communicated with Daguerre and Fox-Talbot about his discovery that sodium hyposulfite would dissolve unexposed silver chloride, thus solving the fixing problem to make images permanent. By the end of 1842, he also had discovered that silver bromide was the most light-sensitive of the halides, devised a method to sensitize glass plates, predicted the possibility of color imaging, and coined the term *photography* to describe the recording of images by light. Although Daguerre and Fox-Talbot are present in the altar as inventors of photography, Niépce and Herschel also deserve a site. Given the amount of knowledge in chemistry, optics, and other scientific disciplines and the dissemination of information necessary for the invention, it is understandable that many people came to similar discoveries at the same time and in different places apart from each other; however, many names did not make it to the annals. Photography immediately revolutionized the way people immortalized reality, impacting all aspects of human activity. Social, commercial, industrial, and, of course, scientific and medical photography applications appeared in almost every civilized corner of the planet.

With the negative and the positive print in hand, photographers and inventors sought, from the earliest times, to reproduce reality in color. The three-color method was first suggested in an 1855 paper on color vision by Scottish physicist James Clerk Maxwell (1831-1879) and used by Thomas Sutton (1819-1875) in 1861 to make the first color photograph as a set of three monochrome "color separations." After the pioneering work of Louis Ducos du Hauron (1837-1920) and Charles Cros (1842-1888) in the 1860s, the brothers Auguste (1862-1954) and Louis Lumière (1862-1948) invented the Autochrome, the first commercially successful color process, which was introduced to the market in 1907.[39] As earlier suggested by Ducos du Hauron, the Eastman Kodak Company of Rochester, NY, developed the Kodachrome, which had three layers of emulsion on a single support, each one recording red, green, and blue, respectively, the three primary colors. Nowadays color films are much more complicated; however, they still use silver bromide, gelatin, and tricolor emulsions. As we will see later, the invention of color photography was welcomed by physicians and scientists as the human body and the natural world could now be reproduced as actually seen.

As photography was developed by scientists it is clear that the applications to science and medicine were immediate. Physicians and scientists rapidly appreciated the merits of photography for its ability to present an objective image of reality, thus avoiding representation by artists who were subject to their interpretation and that of the physicians. Among the pioneers, apparently Fox-Talbot made the first photomicrographs through a solar microscope in 1839 or 1940. Also, Christian Joseph Berres (1796-1844), a professor of anatomy (Vienna), created photomicrographs with a solar microscope already in 1839. At the same time, Joseph Bancroft Reade (1801-1870), an amateur scientist interested in chemistry and botany, met Fox-Talbot and Herschel, after which he made improvements in the developing process and made photographs of specimens through the microscope, including microfossils. These findings were presented to the Royal Society in 1838.[40,41]

Outstanding as a medical doctor, microscopist, and photographer was Alfred François Donné (1801-1878). Among other things, he was the discoverer of *Trichomonas vaginalis,* platelets, and leukemia. Donné, together with León Foucault (who later became famous for demonstrating the Earth's rotation using a pendulum in the Pantheon in Paris), took the first ever photomicrographs in 1838. The images were published by Alfred Donne and León Foucault in 1845 as an atlas, being part of the medical textbook *Cours de Microscopie.* Donné and Foucault took Daguerreotype photographs of specimens through a light microscope. The book features the cellular morphology of various specimens, including liquid materials (pus, blood, urine, mucus from the nose, and milk), cellular debris from various sites of human body (bronchi, gastrointestinal tract, prostate, vagina, and epithelia), spermatozoa, ova, and other materials, including starch and various crystals.[42,43]

Photography was considered a useful tool in psychiatry soon after its invention. Hugh Welch Diamond (1809-1886), considered the father of psychiatric photography, was working in the women's section of the Surrey County Asylum in Twickenham, England, in 1852 and believed that photography could be important in the treatment of patients. Photography could record the facial expressions of people with different mental illnesses, could be used as tools for readmission and identification, and would allow views of patients through an image of what they looked like, which was believed to help in treatment. Diamond published many articles and lectured about the uses of photography, and he was one of the founders of the Photographic Society.[44] The French neurologist, Guillaume-Benjamin Duchenne de Boulogne (1806-1875), starting in 1856 at the Salpêtrière in Paris produced a series of photographs depicting a series of facial expressions produced by electrical stimulation, which he published in *Le Mecanisme de la Physionomie Humaine.*[45] This book was one of the most remarkable of all photographically illustrated books in medical science before 1900.

Among the first medical disciplines influenced by the advent of photography were dermatology and pathology. Dermatology is a visually based specialty that benefits from photography and imaging. Before the invention of photography, illustrations of skin diseases would be sketched or painted. This changed dramatically by the mid-19th century with the introduction of photography even though these were in black and white and had to be hand colored after live observation.

John Balmanno Squire (1836-1908) published *A Manual of the Diseases of the Skin* in 1863 and *Atlas of the Diseases of the Skin* in 1878, both containing black-and-white photographs lavishly hand colored from life.[46,47] Also, Howard Franklin Damon's (1833-1884) *The Structural Lesions of the Skin: Their Pathology and Treatment,* published in 1869, represents an important collection of black-and-white hand-painted dermatologic images.[48] Worth mentioning is the Scottish dermatologist William Herbert Brown's (1878-1959) collection of dermatologic photographs from the early 1900s. His collection of monochrome and hand-tinted clinical photographs and glass-plate negatives is now in the archives of the Royal College of Physicians and Surgeons of Glasgow.

So important had medical photography become by the 1870s that the famous French physician Jean Martin Charcot (1825-1893) believed that photographs would play a significant role in diagnosis and treatment. He established a medical photography department at l'hôpital de la Salpêtrière in Paris in 1878 for which he hired photographer Albert Londe (1858-1917), who worked under Charcot's supervision. In 1893 Londe published the first book on medical photography, *La photographie médicale: Application aux sciences médicales et physiologiques.*[49] Before the end of the 19th century, all major academic and medical institutions in Europe already had a medical photographer or medical photography unit. The first medical photography department in the United States was at Bellevue Hospital (now part of New York University) under the guidance of photographer Oscar G. Mason (1830-1921).

Physicians in the mid and late 1800s used and exchanged photographs for consultation (as we still do nowadays). We could say that this signals the birth of telemedicine, although not in real time as today. The Center for the History of Medicine and Public Health at the New York Academy of Medicine contains many early photographs used by physicians for consultation.

The German pathologist Rudolf Virchow (1821-1902) and the microscope completely changed pathology from the whole organ to a cell-based science. Microscopic pathology had to wait to be finely photographed until techniques for fixation, tissue embedding, sectioning, and staining had been developed and optics and microscopes were improved. Edwin Klebs (1834-1913) introduced paraffin embedding in 1869; formaldehyde solution was introduced in 1893 by Isaac Blum (1833-1903); Franz Böhmer published the use of alum hematoxylin as a nuclear stain and Paul Ehrlich (1854-1915) discovered the aniline dyes. Diseases were now defined by their microscopic characteristics. Thus cells and tissues, in health and disease, were now viewed and photographed.[50]

From the beginning of the 20th century to the present, the increase in new discoveries and technological advances in all areas of science and medicine has been exponential. From the collodion and egg albumin–coated glass plates in the late 1800s to the color slide films developed by Eastman Kodak from 1935 and the development and insertion of digital photography in the late 1990s, technologic changes in the realm of photography have greatly influenced medical practice.[51] In addition, gigantic advances in fluorescence techniques, immunohistochemical staining, molecular methods, microscopy, image processing, and the new world of *medical imaging,* to be commented below, have provided better and more precise diagnostic tools.[52,53]

Dermatology is a very visually based discipline within medicine and, as such, relies heavily on photography and imaging; these are very useful for physicians and investigators. Photographs become an integral part of a patient's record, can aid or be sufficient for diagnosis, and keep track of the effectiveness of treatment. Dermatologists now do not need to remember how their patients' lesions looked like or make it up from a lengthy description and a "photographic memory"; now, everything is on the screen. In addition, medical photographs are useful for the education of patients, for dermatologic publications or presentations, and for teaching medical students and the training of doctors. They may also be important as evidence in medicolegal issues.

The advent of digital photography offers important benefits to dermatologists, and many other specialties using photography in their routine practice. Many clinical departments and medical societies nowadays encourage photographic documentation in medical practice, for health care, education, and research. One great advantage of digital photography is the reduction in costs, time, and archival space; however, photography to be of value for these purposes must be accurate and reflect reality, such to allow recognition and diagnosis on the lesions. All the image data can be archived, together with the corresponding medical record of a patient, in a centralized facility in the hospital, department, or medical office. These images can be accessed in the office or transmitted over the Internet for consultation. This approach and technology is of the greatest interest to specialties dealing with visible pathologies such as dermatology, ophthalmology, and plastic and cosmetic surgery or to microscopic pathology.[54,55] In some of these specialties the *before and after* pictures become important for patients visualize their ailments and results.

In digital photography, light is captured by an electronic sensor, a charge-coupled device (CCD) with millions of cells. At the end of the exposure, the color and intensity signal of each cell is transferred to an internal processor within the camera, subsequently transformed in a viewable image. From the processor the newly formed image is transferred to a temporary storage system (ie, SD memory card), which is then passed to a computer with a storage system large enough to archive thousands or millions of images. Then, suitable software is used for image transfer, editing, storage, and retrieval. This software must be in conjunction with a relational database system that stores patient images and all other relevant information, organized for retrieval.[54,55]

With the available technology today all these procedures are within the reach of any medical facility and office. Many publications provide guidance to physicians who are not familiar with this technology in terms of photographic equipment, storage and software, as well as procedures for accurate, ethical, and effective photography[54–56]; however, this requires initial investment, maintenance, and upgrading costs and a certain training to be effective. Thus, as many as 18% of board-certified US dermatologists in a survey published in 2013 did not use any kind of photography in their daily practice, citing cost and complexity as the major deterrents.[57] All these procedures have been adopted by pathology departments practically since the advent of photography and even more so since digital photography is in the domain of almost everybody.

An area that has greatly benefited from digital photography is telemedicine. In fact, we could argue that telemedicine has become possible because of digital photography, telecommunications, and the Internet.[58] Although distant consultation accompanied with photographs has been used since the 19th century, what characterizes telemedicine is the use of modern technologies to provide clinical health care from a distance in almost real time. Telemedicine aims to provide access to medical services that otherwise would not be available to distant rural communities underserved by specialists. Again, visually based specialties such as dermatology, radiology, and pathology benefited the most at the beginning from telemedicine; however, many other medical specialties and other branches in the health care system, such as cardiology, psychiatry, ophthalmology, pharmacy, and nursing, are included now in the network. The simplest telemedicine setup may be a cell phone using WhatsApp[59] up to, at the high end of the spectrum, telesurgery where operations are performed by robotics even at a distance.[60,61] In some cases, telemedicine is the only means of health care provision in remote areas in developing countries. There have been successful projects in Africa (SAHEL, SATMED) and Latin America, specially Venezuela.[62] In the case of Venezuela, given the current unprecedented humanitarian crisis, including the health system, due to erroneous governmental policies, expansion of the successful telemedicine-based Proyecto Maniapure in combination with the existing but dilapidated infrastructure may constitute a model for the improvement of the health system and provide access to health care to a vast sector of the population.[63,64] The potential benefits of telemedicine in all areas of medical practice and its impacts on health care are beyond imagination and is beginning to be recognized by private insurance companies and federal and state laws. The immediate benefits of cost reduction and better health care appear to be understood.

The digital revolution and beyond

Visible light allows imaging of the human body only from the outside. With the exception of endoscopy, all other techniques for noninvasive or minimally invasive imaging use other types of radiation, as we shall discuss. Endoscopy was the first technique used to look inside a living human body. As early as 1806, physicians attempted to introduce illuminated pipes to explore the gastrointestinal lumen. Two hundred years after, flexible video-endoscopes equipped with digital cameras (CCD) allow not only to see inside the organ and body cavities, but also to perform diagnostic and therapeutic operations.[65,66]

Photographic images are produced by visible light impressing a light-sensitive material such as a silver halide plate, and nowadays a silicon chip. But photons in the visible spectrum are reflected by nontransparent objects, including the human skin. Developments in science and technology allowed the use of other types of radiation to reveal internal structures in the human body and, most interestingly, noninvasively. First were X rays, discovered in 1895 by German physicist Wilhelm Conrad Röntgen (1845-1923) and rapidly incorporated into the diagnostics arsenal in 1896 when John Hall-Edwards (1858-1926) made the first medical radiography. Röntgen himself also discovered that X rays would impress photographic plates and then made the first radiograph of his wife's hand, who upon seeing it exclaimed, "I have seen death." Initially photographic glass plates were used in radiography, then film, invented by Eastman in the 1920s and, nowadays, digital detectors (similar to a camera CCD).[67] But X rays can image the denser structures of the body such as bones and some other organs such as lungs, but not organs with small differences in tissue density. Thus to reveal their structure a selective contrast is used (barium, iodine compounds, or air) given by oral, rectal, vaginal, intra-arterial, or intravenous routes. The invention of fluorography in the 1920s permitted the imaging of the inner structures' functioning in "real time" as the contrast moved through the body mainly in the digestive and genitourinary tracts or blood flow in arteries and veins.[67,68]

The digital revolution brought about the development of numerous noninvasive imaging techniques at an unprecedented pace: computed tomography (CT), dual energy x-ray absorptiometry (DEXA), magnetic resonance imaging (MRI), medical ultrasonography, positron emission tomography (PET), elastography, echocardiography, diffuse optical tomography, electrical impedance tomography, and optical coherence tomography, to name a few. Computer techniques allow to transform these signals in intensity maps, thus creating visual representations of the interior of the human body, statically or dynamically; furthermore, using volume rendering techniques, three-dimensional (3D) representations are produced from CT, MRI, and ultrasound 2D static slices, a valuable resource for the diagnosis and surgical treatment of many pathologies.

Not only the human body can be imaged from the outside and inside, but also its most intimate constituents: cells and molecules. Optical and electron microscopy techniques have also evolved as to allow visual representation of living cells. For example, confocal microscopy (a kind of cell CT), combined with novel fluorescence techniques for the in vivo staining of cell organelles (nuclei, mitochondria, endoplasmic reticulum, etc.), permits the observation of dynamic changes in living cells and its environment. Phenomena such as calcium release from the sarcoplasmic reticulum during muscle contraction, acid secretion by parietal cells, and calcium movements in virus infected cells, imaged in real time, are just a few examples.[69–71] At the clinical level, confocal microscopy is being applied in ophthalmology for the diagnosis of corneal pathologies[72,73] and in dermatology for the diagnosis of skin tumors, specially melanoma, and inflammatory conditions.[74,75] All these advancements in science and technology applied to medicine and other disciplines pose the question what extent physicians are trading their capabilities as clinicians. Ethics issues add to the complexity of this new era governed by constant changes in scientific paradigms.

Conclusions

We (*Homo sapiens*) evolved from our ancestors about 200,000 years ago.[3] It has taken humanity some 50,000 years to know (and picture) many of its bodily secrets. With all these advancements, what is next? It is difficult to predict the future. I shall end quoting Thomas Kuhn (1922-1996) in his marvelous, although controversial, book *The Structure of Scientific Revolutions,* noting that scientific progress develops in two distinct ways, "from the normal science, which is the slow, steady accumulation of knowledge, and from unexpected discoveries that entail paradigm shifts."[76] Paradigmatic changes in science can be traced backward historically, but future ones can only be guessed (*intuition*) by privileged minds. As Albert Szent-Gyorgyi (1893-1986) once said, "Research is to see what everybody else has seen, and to think what nobody else has thought." Those are the ones that change history.

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