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Evolution of Illustrations in Anatomy: A Study from the Classical Period in Europe to Modern Times

Sanjib Kumar Ghosh*

Department of Anatomy, Employees' State Insurance, Post Graduate Institute of Medical Sciences and Research (ESI-PGIMSR), Employees' State Insurance Corporation Medical College, Joka, Kolkata, West Bengal, India

Illustrations constitute an essential element of learning anatomy in modern times. However it required a significant evolutionary process spread over centuries, for illustrations to achieve the present status in the subject of anatomy. This review article attempts to outline the evolutionary process by highlighting on the works of esteemed anatomists in a chronological manner. Available literature suggests that illustrations were not used in anatomy during the classical period when the subject was dominated by the descriptive text of Galen. Guido da Vigevano was first to use illustrations in anatomy during the Late Middle Ages and this concept developed further during the Renaissance period when Andreas Vesalius pioneered in illustrations becoming an indispensable tool in conveying anatomical details. Toward later stages of the Renaissance period, Fabricius ab Aquapendente endeavored to restrict dramatization of anatomical illustrations which was a prevalent trend in early Renaissance. During the 18th century, anatomical artwork was characterized by the individual styles of prominent anatomists leading to suppression of anatomical details. In the 19th century, Henry Gray used illustrations in his anatomical masterpiece that focused on depicting anatomical structures and were free from any artistic style. From early part of the 20th century medical images and photographs started to complement traditional handmade anatomical illustrations. Computer technology and advanced software systems played a key role in the evolution of anatomical illustrations during the late 20th century resulting in new generation 3D image datasets that are being used in the 21st century in innovative formats for teaching and learning anatomy. Anat Sci Educ 8: 175–188. © 2014 American Association of Anatomists.

Key words: anatomical illustrations; history of medical illustrations; review, Vigevano; Vesalius; Fabricius; Gray; computer technology; software systems; 3D interactive models

INTRODUCTION

Illustrations form an integral part of modern day anatomical texts and empowered with technological advancements the illustrations that are being used today for visual representation of anatomical details are truly of highest standards. However the earliest anatomical texts were purely descriptive and were not illustrated (Joutsivuo, 1997; Olry, 1997). Later on the acceptance of human dissection as a scientific method to advance understanding of anatomical structure led to the development of anatomical illustration (Calkins et al., 1999). Over the years pictorial representation of anatomy has evolved considerably with the artistic expression varying across all the ages (Tsafrir and Ohry, 2001). This review article highlights the works of esteemed anatomists in a chronological pattern in an attempt to outline the sequential manner of the process of evolution of anatomical illustrations. This article covers a considerably long time span starting from ancient Greece in 4th century BC, looking into the anatomical developments during the Roman Empire in the Late Middle Ages, emphasizing on the revolutionary changes during the Renaissance period in Italy (which ultimately spread into most parts of Europe) and eventually focusing on the legendary work of Henry Gray in the 19th century. It also traces the evolutionary process into the 20th century which

*Correspondence to: Dr. Sanjib Kumar Ghosh, Department of Anatomy, ESI-PGIMSR & ESIC Medical College, Joka, Kolkata-700104, West Bengal, India. E-mail: drsanjib79@gmail.com

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witnessed the emergence of medical images and photographs as two new entities that complemented the handmade anatomical illustrations. It highlights on the advent of computer technology and advanced digital methods during the later part of the 20th century that enabled anatomical illustration to evolve beyond traditional two dimensional (2D) images to innovative three dimensional (3D) image datasets (Corl et al., 1999; Trelease, 2002). Finally this review reflects on the prominence of anatomical illustrations in the 21st century when advanced software programs have ensured fast production without compromising on quality of the illustration (Wang, 2008) and rise of Internet has considerably increased the outreach of illustrations to anatomists worldwide (Trelease, 2002).

CLASSICAL PERIOD (700 BC TO 600 AD)

The study of anatomy in the form that we are familiar with could be traced back to the Greeks in 4th century BC, when Aristotle based on his work with animal dissection, introduced the concept of comparative anatomy (Blits, 1999). Later on Herophilus of Chalcedon and Erasistratus of Ceos performed human cadaveric dissections and documented anatomical details that were more close to the actual structures of the human body (Singer, 1957). The available literature throws very little light on the use of illustrations during this early period of human anatomy.

Galen of Pergamum (129–216/217 AD) was undoubtedly the most important medical scholar of the classical period and his concepts in the field of anatomy dominated western medicine until the 16th century (Maksimović, 2000; Marx, 2013). By this time dissection in humans had become a controversial and restricted practice, limited by religious and popular beliefs (Di Ieva et al., 2007). Hence the anatomical descriptions of Galen was mostly based on insights gained through animal dissection and study of wounds in gladiators (Singer, 1957). The anatomical writings of Galen relied solely on textual descriptions (Joutsivuo, 1997) and a literature search does suggest that illustrations were not used in anatomy in those days.

LATE MIDDLE AGES (1300 TO 1450 AD)

It was not until the Late Middle Ages that considerable advances could be achieved in the field of anatomical science. During AD 1300–1500, many universities and centers of learning excellence were established across Europe, particularly in Italy leading to the development of a positive academic environment. King Frederick II, the holy Roman emperor took significant measures that gave the much needed boost to medical education as such (Rengachary et al., 2009). During this period, Mondino de Liuzzi (1275–1326) carried out the first officially sanctioned systematic human dissection since Herophilus and Erasistratus, that is, after a hiatus of over 1700 years (Rengachary et al., 2009). Based on his observations of the dissected corpses, De Liuzzi wrote his landmark text *Anathomia Mondini*, which provided significant insights into understanding human anatomy (Crivellato and Ribatti, 2006). De Liuzzi's text was completed in 1316 and was used for teaching anatomy for more than 200 years (Choulant, 1920). The popularity of the book can be assessed by the fact that after the advent of printing technology it was printed and published again in 1478 (Olry, 1997). However there has been no mention about the use of illustrations in this important piece of work in the literature. In other words, De Liuzzi's text was mostly descriptive in nature, similar to that of Galen. This could be the reason why De Liuzzi's work was mostly unsuccessful in compelling scholars to break free from Galen's dominating influence which lasted until the 16th century (Olry, 1997). Nevertheless his efforts led to the revival of human dissection as a scientific method to advance the understanding of anatomical structures which eventually proved to be instrumental in the development of anatomical illustrations (Calkins et al., 1999).

De Liuzzi's student, Guido da Vigevano (1280–1349) was the first to introduce the concept of using illustrations in anatomy (Rengachary et al., 2009). He was the pioneer in using pictures to illustrate his anatomical descriptions, developing for the first time a close relationship between anatomical studies and artistic drawings (Di Ieva et al., 2007). Vigevano's manuscript *Anathomia* which was published in 1345, displayed six drawings showing for the first time neuroanatomical structures and techniques (Olry, 1997) (Fig. 1). These drawings showed the trephination of the head by means of a scalpel and hammer to expose the brain and the meninges (Di Ieva et al., 2007). There are written accounts of this procedure in the ancient Greek and Roman world by Hippocrates and Galen, respectively (Missios, 2007). Vigevano's drawings depicted structures like the meninges, cerebrum, spinal cord, ventricles and cortical convolutions (although vague) (Di Ieva et al., 2007). The drawings in Vigevano's manuscript marked the beginning of a new trend which became increasingly popular during the following centuries (Olry, 1997). Anatomical illustrations during the Late Middle Ages were mostly unrealistic and rudimentary which could be attributed to the lack of precise anatomical knowledge (Gurunluoglu et al., 2013). During this period illustrations used to be handmade drawings, however with the onset of Renaissance and the invention of book printing in the second half of 15th century, wood cut illustrations were prepared which made multiplication of the figures easier while reproducing anatomical texts (Gurunluoglu et al., 2013).

RENAISSANCE PERIOD (1400 TO 1600 AD)

Leonardo da Vinci (1452–1519) enlightened the subject of anatomy with his exceptional powers of observation, his knowledge of perspective and his amazing skills in drawing that enabled him to record his findings with unparallel accuracy and clarity (Bührer, 1974; Dunn, 1997). His anatomical illustrations were based on his observations from dissections of 30 cadavers (both of men and women of all ages) performed between 1489 and 1513 (MacCurdy, 2009). His sketches were as realistic and accurate as possible and were incredibly detailed (Perloff, 2013). Some of his legendary artwork in anatomy includes the depiction of reproductive organs of both men and women, the illustration of coitus, sketches of muscles of superior extremity, representations of hand, drawings of human skeleton to name a few (Mathé, 1984; Dunn, 1997). He was the first to observe and comment on the fetal membranes—chorion and amnion. His drawing of fetus in the womb is noteworthy and was not bettered for more than two centuries (Dunn, 1997). A characteristic feature of Da Vinci's anatomical illustrations, particularly those

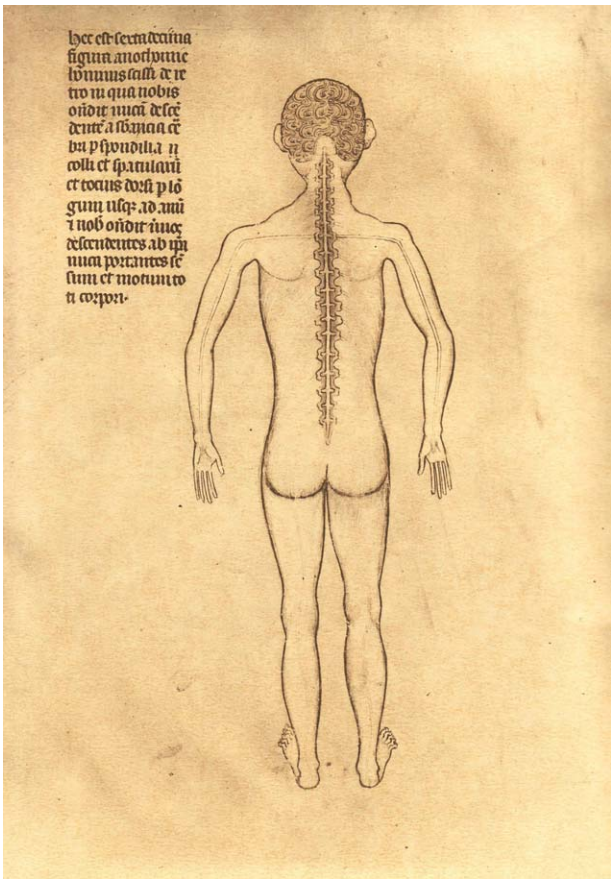

Figure 1.

One of the plates prepared by Guido da Vigevano to display the neuroanatomical structures (1345). The plate shows the spinal cord and the origin of the spinal nerves (only 18 in number), bilaterally passing through the vertebral foramina. Reproduced with permission from Di Ieva et al., 2007. The neuroanatomical plates of Guido da Vigevano. Neurosurg Focus 23:E15.

of the limbs, was the demonstration of each part from different viewpoints (as if the part is rotating) thus enabling the viewer to acquire a full comprehension of the anatomy of the concerned region (Jose, 2001). This was probably the best possible way to illustrate anatomical details in a three dimensional manner in those days. His anatomical drawings several hundred in number, were not widely known until some 380 years after his death when these paintings were first published in facsimile (Mathé, 1984), hence it may be opined that his artwork had limited influence on contemporary anatomists. However the influence of his drawings could be observed in the illustrations used by prominent anatomists during the 18th century (Thornton and Want, 1974).

Michelangelo Buonarroti (1475–1564) was the younger contemporary of Leonardo da Vinci. Michelangelo had a vision of architecture that was rooted in the understanding of the human body and his theory of anatomy was articulated in the study and design of architecture (Summers, 1981). He had a lifelong interest in anatomy that began in his early teens, when he joined the court of Lorenzo de' Medici and started to participate in public dissections (Condivi, 1976). His early anatomical interests were revived later in life when after having established himself as a painter, sculptor, and architect, he possibly aspired to become a published author and scholar (Eknoyan, 2000). His anatomical illustrations represent a brilliant intersection between art and anatomy, which is so very characteristic of the Renaissance period (Schultz, 1982). Michelangelo's profound interest in anatomy is reflected in his painting of the *Last Judgement* (1536–1541), in which he prominently displayed Saint Bartholomew to the left of Jesus, holding a flayed skin in his left hand and the flaying knife in his right (Eknoyan, 2000) (Fig. 2). Later on Michelangelo came across Paduan anatomist and physician Realdo Colombo (1516–1559), who diagnosed and started treating him for nephrolithiasis in 1549 (Steinberg, 1982). Meanwhile Spanish anatomist Juan de Valverde de Amusco (1525–1587), who was a pupil of Colombo, published an illustrated text in anatomy *Historia de la Composicion de Cuerpo Humano* in 1556, and the illustrations were prepared by Spanish artist, Gaspar Becerra (1520–1570), who himself had trained in the studio of Michelangelo (Guerra, 1967). In one of the illustrations from Amusco's book, Becerra had displayed a muscular man, shown as a flayed body holding its skin in one hand and a blade in the other. The similarity of this illustration with that of Michelangelo's portrait of Bartholomew in *Last Judgement* emphasizes Michelangelo's influence on contemporary artists (Szladits, 1957) (Fig. 2). Michelangelo had intended to collaborate with Colombo and prepare the illustrations of a medical anatomy text being written by Colombo, but whether he actually was able to is not known. He was particularly interested in the depiction of anatomy of kidney which is evident in some of his masterpieces prepared toward the end of his career and this could have a link with his own kidney related ailments, which ultimately resulted in his demise (Eknoyan, 2000).

Andreas Vesalius (1514–1564) was born in Brussels, however he graduated as Doctor of Medicine from Padua, Italy in 1537 (Benini and Bonar, 1996). For the next six years, he served as a teacher of human anatomy in Padua and during this period Vesalius engaged in significant academic activities and published his masterpiece in anatomy, *De Humani Corporis Fabrica* in 1543 (Vesalius, 1543; Hildebrand, 1996). The book contained anatomic illustrations of incomparable artistic quality prepared by Stefan van Calcar (1499–1546), who himself was a pupil of one of the most versatile Italian painters of Renaissance period, Tiziano Vecellio (1490–1576), also known as Titian (Benini and Bonar, 1996). The woodcut illustrations used in *De Humani Corporis Fabrica* exhibits specifically northern European influence (as Vesalius and Calcar, who was German by birth, were both northerners working in Italy) alongside the humanist grandeur of the figures, which is characteristic of ancient Graeco-Roman sculpture (Kemp, 2010). In other words, the illustrations used in Vesalius' work were an exquisite fusion of Italianate and Gothic art. These illustrations similar to others from the Renaissance period were a seamless combination of artistic precision, refinement and anatomical synthesis which resulted in images of great polish far removed from the flesh and blood reality of dissection (Riva et al., 2010) (Fig. 3). The overwhelming presence of artistic flavors in these anatomical illustrations could possibly be due to the fact that anatomy and human dissection became popular social phenomena as well as scholarly pursuits during the early Renaissance, which also involved the world of fine arts. Artists involved in preparing anatomical illustrations considered this as the best medium to communicate their discoveries of the natural world in objective form (Cavalcanti et al., 2009). Vesalius'

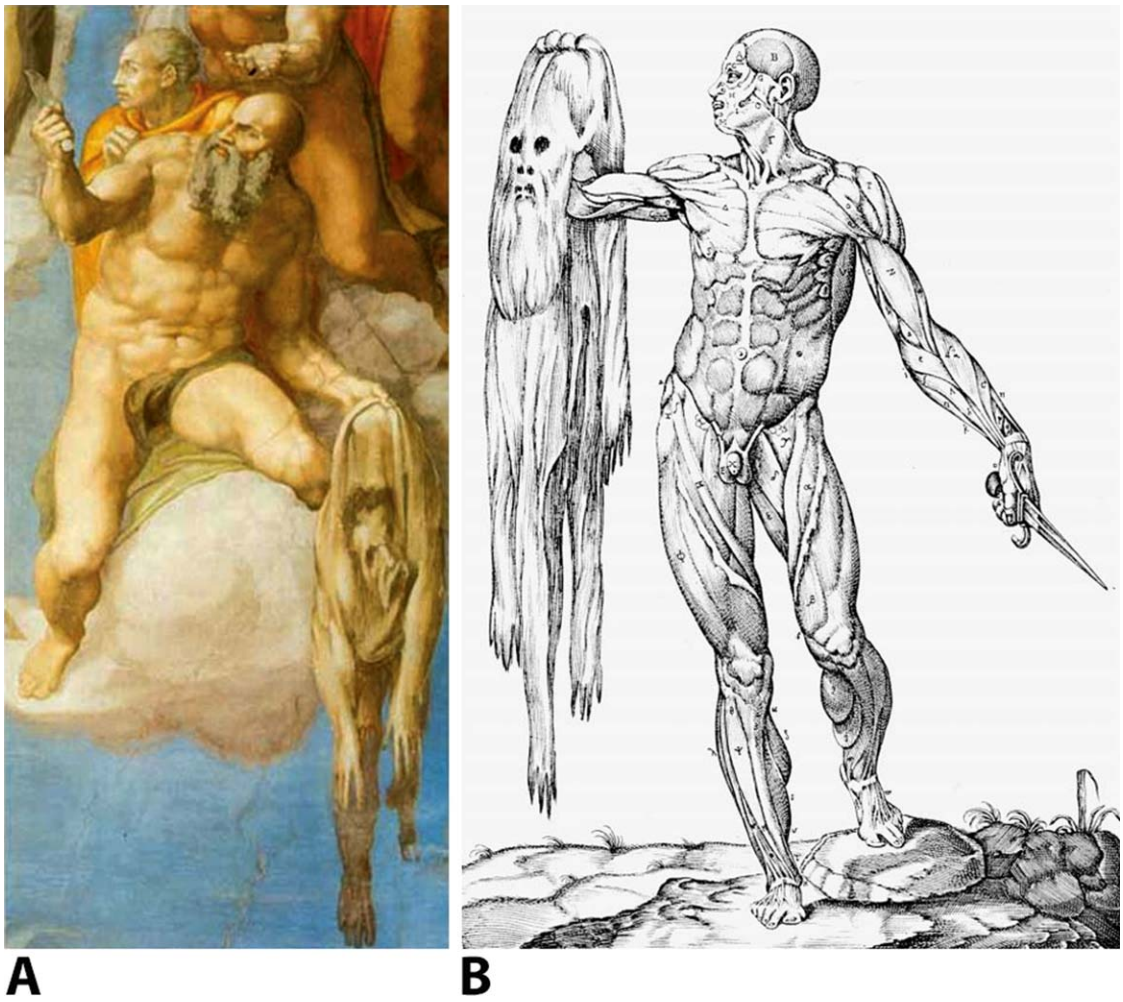

Figure 2.

Influence of Michelangelo on his contemporary artists. (**A**) Saint Bartholomew holding a flayed skin in his left hand and the flaying knife in his right from *Last Judgement (1536–1541)* by Michelangelo. Reproduced with permission from Kemp, 2010. Style and non-style in anatomical illustration: From Renaissance Humanism to Henry Gray. J Anat 216:192–208, © John Wiley and Sons; (**B**) Figure of the flayed muscle man holding his skin and flaying knife by Gaspar Becerra in *Historia de la Composicion del Cuerpo Humano* by Juan Valverde de Amusco. Reproduced with permission from Eknoyan, 2000. Michelangelo: Art, anatomy, and the kidney. Kidney Int 57:1190–1201, © Nature Publishing Group.

philosophy of teaching was his conviction that truthful knowledge of anatomy can only be gained through dissection of human corpses and not by following authoritative texts (Joutsivuo, 1997). Accordingly the illustrations used in his text were complimented with great details gained through cumulative observations from human cadaveric dissections. His efforts catalyzed the shift in the use of illustrations in anatomy from serving a visual record to compensate for limited access to cadavers in teaching to becoming an indispensable tool to accurately convey detailed anatomical structure trough medium of printing (Russel, 2013). His work contributed to free the study of human anatomy from mythic speculations of authoritative texts (particularly that of Galen), which had encrusted it for close to 1500 years. Vesalius' exploits significantly assisted human anatomy to become an empirical science (Lasky, 1990; Benini and Bonar, 1996; Toledo-Pereyra, 2008).

Charles Estienne (1504–1564) was an early exponent of the science of anatomy in France and a contemporary of Vesalius. In fact both of them were influenced by the same teacher, Jacque Dubois Sylvius, who was a follower of Galenic tradition. More than any of his contemporaries, Estienne ventured to doubt the age long tradition of blindly following Galen in his own work, followed this path courageously but ultimately compromised with the Galenic thoughts (Rath, 1964). This discordance—courage on one hand and fear on the other—epitomized Estienne's anatomical work (Rath, 1964). In 1545, Estienne's *Tres libri de dissectione partium corporis humani* was published in Paris. The illustrations used in his work like most of the anatomical artwork of the Renaissance period depicted "active limbs" combined with "ragged muscles, naked bones and dissected bowels" (Estienne, 1545). However the salient feature of the illustrations in Estienne's text was the apparent contrast between the anatomical content (at times limited to a smallish insert) in the woodcuts and the elaborate figures posturing in fancy settings within which the anatomical details were highlighted (Kemp, 2010). Such illustrative

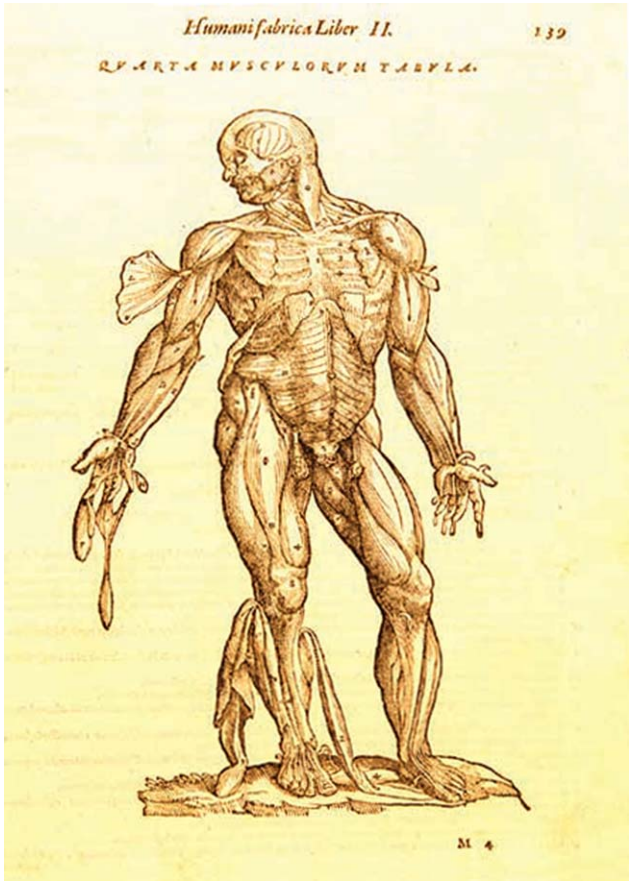

Figure 3.

Anatomical illustration from Andreas Vesalius' *De Humani Corporis Fabrica* drawn by Stefan van Calcar. Reproduced with permission from Porzionato et al., 2012. The anatomical school of Padua. Anat Rec 295:902–916, © John Wiley and Sons Publisher.

representations were completely different from his views in which Estienne had elaborated that visual images were more powerful than words in bringing the anatomical structures before our eyes (Estienne, 1546). His illustrations—whether men shown in heroic poses in grand settings or anatomical details displayed in women in bedrooms—correspond to the grandeur of human life as created by God (Estienne, 1590), which could be attributed to the fact that his family had strong traditional values and his own life was dominated by religious opinions (Rath, 1964).

Hieronymus Fabricius ab Acquapendente (1533–1619), noted anatomist and surgeon, held the chair of anatomy in the University of Padua, Italy for 50 years (Riva et al., 2010). He was an institution by himself as his teachings had a comprehensive influence on his students, among who were eminent anatomists Julius Casserius (1552–1616), Adrianus Spigelius (1578–1625), William Harvey (1578–1657), and many others from all over Europe. Fabricius was greatly influenced by Aristotle's philosophy (dominated by the concept of comparative anatomy) which is reflected in his published works (Cunningham, 1997). Fabricius took the initiative to prepare an atlas of both human and animal anatomy and by 1600 he had amassed more than 300 paintings that together made the *Tabulae Pictae*, a masterpiece on anatomical illustrations (Riva, 2004). In contrast to the artwork used by Vesalius, illustrations in *Tabulae Pictae* were represented in their natural size and more significantly in their natural colors (Riva et al., 2006) (Fig. 4). Most of the illustrations in *Tabulae* were prepared by unknown artists (Premuda, 1957; Kemp, 2004), and although unlabeled these drawings are of very high quality and represent the most important anatomical work of 16th–17th century (Sterzi, 1909). Among the many anatomical observations made in the drawings of *Tabulae*, those depicting the foramen of Monro, Sylvian fissure, arachnoid layer, bulbourethral glands needs special mention (Riva, 2004; Riva et al., 2006; Collice et al., 2008). Fabricius provided a crucial turning point in the evolution of anatomical illustration. His focus was strictly on scientific illustrations developed in the context of previous anatomists' work and theories, which was a clear deviation from the early Renaissance anatomists who were more artistic than scientific with their images (Smith, 2006). Paintings used by Fabricius were simple representations of anatomical

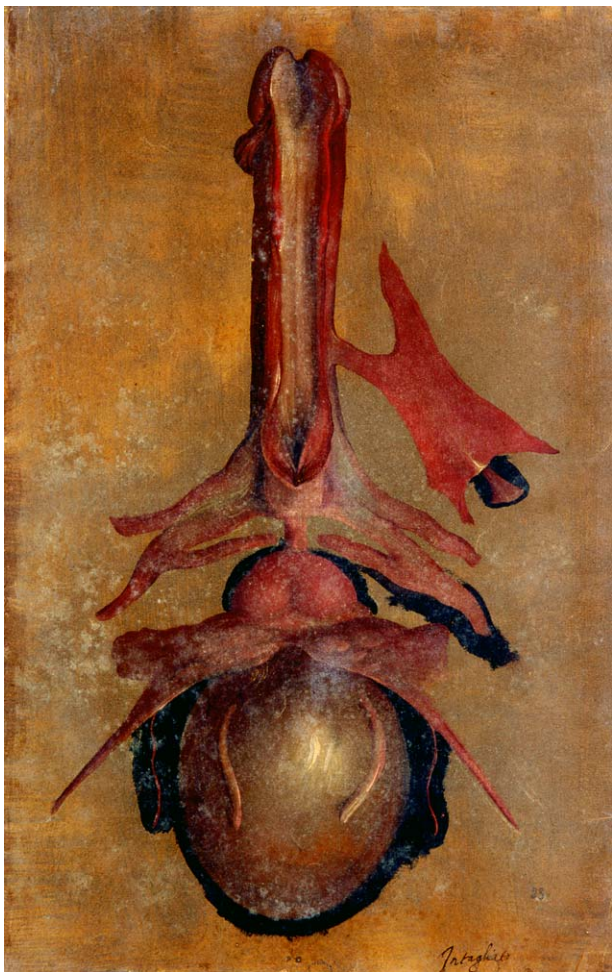

Figure 4.

An illustration showing the male genital apparatus from *Tabulae Pictae* by Fabricius ab Acquapendente. Rari 117.23 (De Anatomia) signature St. Mark's. Reproduced with permission from Marciana Library, Venice, Italy.

preparations, which are admired till date for their realism and scientific outlook (Kemp, 2004; Murakami et al., 2007).

Although the illustrations used by Fabricius in his work were highly admired by his students and contemporaries who had free access to these paintings (Riva, 2004), the *Tabulae* disappeared after Fabricius's death and was only rediscovered in 1909, when Giuseppe Sterzi traced them to the Marciana, the State Library of Venice (Riva et al., 2000). However the influence of Fabricius's work could be observed in the copper engraved figures prepared by his most illustrious pupil Casserius, which were ultimately published along with the works of Spigelius, another famous student of Fabricius (Riva, 2004; Murakami et al., 2007). Although Casserius deviated from Fabricius's principle by dramatizing his anatomical figures set against ornate landscapes as if alive (which was more in accordance with Vesalius's anatomical illustrations) many anatomical details seen in the *Tabulae* were also present in Casserius's work (Riva et al., 2010). Perhaps the greatest influence of Fabricius's style of anatomical illustrations was on Johann Wesling or Veslingius (1598–1649), who was a contemporary of Fabricius and similar to him was also associated with the University of Padua (Porzionato et al., 2012). In his anatomical treatise *Syntagma Anatomicum*, Veslingius used simple diagrammatic figures to describe the anatomy of a region exactly as it is seen at dissection (Roberts and Tomlinson, 1992). Such was the popularity of Veslingius's figures that they often served as models for illustrating anatomy textbooks later published in Northern Europe (Choulant, 1920). The influence of Fabricius is clearly underlined by the fact that Veslingius praised Fabricius in the preface of *Syntagma* (Riva et al., 2010). Hence it may be suggested that Fabricius and Veslingius were pioneers in changing the trend of dramatization of anatomical figures (prevalent from the time of Vesalius) by avoiding the use of theatrical attitudes and ornate landscapes in their illustrations thus making them more realistic and appropriate for medicine and surgery (Riva et al., 2010).

SEVENTEENTH AND EIGHTEENTH CENTURIES

Govert Bidloo (1649–1713) was a Dutch physician and anatomist, who was trained as a surgeon in early part of his academic career and later on became a professor of anatomy in universities of Hague and Leiden. Toward the end of the 17th century, he performed dissections on the corpses of executed criminals to teach and study anatomy (Ijpma and van Gulik, 2013). Based on his findings, he published a magnificent anatomical atlas in 1685, entitled *Anatomia Humani Corporis* (Bidloo, 1685). The atlas had 105 illustrations which were prepared by the talented Dutch painter Gerard De Lairesse (1640–1711), a pupil of the great Dutch painter Rembrandt (1606–1669), in collaboration with Bidloo (Ijpma and van Gulik, 2013). However working with such an esteemed painter in preparing the anatomical drawings led to some degree of disparity. The master-hand of Lairesse prevailed almost alone in an artistic confrontation with the dissected body parts (Bell, 1794). The most glaring example of this disparity is observed in a painting showing the dissection of abdomen in which Lairesse beautifully illustrated a fly in full detail. In fact plates used alongside Bidloo's text required the knowledge an anatomist and expertise of a painter to interpret in a coherent manner what is actually displayed in them (Kemp, 2010). Such a conflict between the anatomical perspectives and the artistic detail in the illustrations of *Anatomia* led to considerable disorder and confusion among contemporary anatomists (Bell, 1794).

Bernhard Siegfried Albinus (1697–1770) was a German born Dutch anatomist, who served as a professor of anatomy and surgery in the University of Leiden (Jensen, 1978). Albinus is best known for his monumental *Tabulae sceleti et musculorum corporis humani*, which was published in Leiden in 1747 (Albinus, 1747). Albinus prepared the anatomical illustrations of his work along with Jan Wandelaar (1690–1759), an eminent artist of his time (Rudakewich, 1998). In an attempt to increase the scientific accuracy of anatomical paintings, Albinus and Wandelaar devised a new technique of placing nets with square webbing at specified intervals between the artist and the anatomical specimen and copying the images using the grid patterns (Huisman, 1992). Albinus was obsessed with his concept of "homo perfectus", which is very much evident in the illustrations used in his text. He was always in pursuit of an idealistic and invariable norm in anatomy, thus rejecting the naturalistic alternative (Hildebrand, 2005). The structural details of anatomical specimens have been so much compromised in favor of perfection in Albinus' illustrations that everything appears like ivory cut figures or anatomized statues (Kemp, 2010). Such an approach, which attempts to unite both science and arts was later termed as "attic perfection" in anatomy by Samuel Thomas Soemmerring (1755–1830), who himself strove to emulate Albinus in his own illustrations (Hildebrand, 2005). Moreover some of the illustrations used by Albinus were widely criticized for their whimsical backgrounds (for example in a painting a human skeleton is illustrated with a rhinoceros in the background) which were added by Wandelaar (Ferguson, 1989) (Fig. 5). Anatomical illustrations in Albinus' work are a study in contrast with the naturalistic styles followed by Govard Bidloo (1649–1713), Albrecht Von Haller (1708–1777) and William Hunter (1718–1783) (Audette, 1979).

William Hunter (1718–1783) was a Scottish anatomist and physician. He was a leading teacher of anatomy and an outstanding obstetrician of his day. He was elected a Fellow of the Royal Society in 1767 and was appointed professor of anatomy to the Royal Academy in the following year (Philipp, 1985–1987). His greatest work was *Anatomia uteri humani gravidi*, where the anatomy of the human gravid uterus was displayed in figures (Hunter, 1774). The illustrations for Hunter's text were prepared by Jan van Rymsdyk (1730–1790), the famous medical artist of the 18th century (Thornton, 1982). Hunter was notably influenced by the drawings of Leonardo da Vinci and could be attributed with the rediscovery of the legacy of da Vinci in his anatomical illustrations (Thornton and Want, 1974). Hunter ensured that the anatomical drawings used in his work were clear, precise and schematic illustrations of anatomical dissection and above all as naturalistic as possible (Philipp, 1985–1987; McCulloch et al., 2002). He was of the view that anatomical illustration should be a simple portrait in which structures should be represented exactly as they are seen (Hunter, 1774). He emphasized on careful scrutiny of all that is being observed in a specimen in an uncompromising manner and ensured that these observations be included in the final representation (Kemp, 2010). In one instance he had insisted his illustrator to show the reflection of the window of his dissection room on the shiny membrane over the head of the fetus

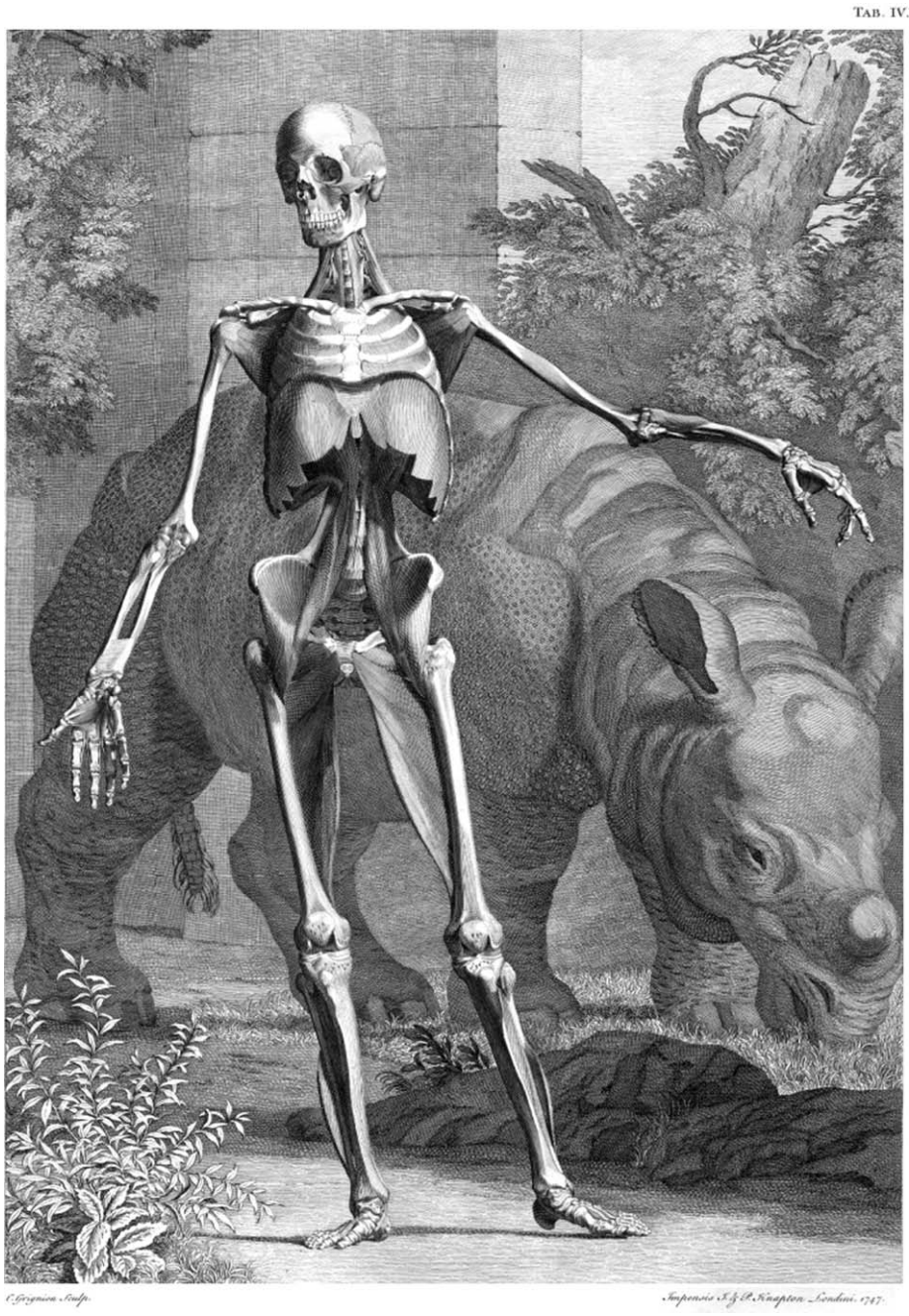

Figure 5.

An illustration from *Tabulae sceleti et musculorum corporis humani* by Bernhard Siegfried Albinus, drawn by Jan Wandelaar. The illustration shows a human skeleton standing with a Rhinoceros in the background. Reproduced with permission from Kemp, 2010. Style and non-style in anatomical illustration: From Renaissance Humanism to Henry Gray. J Anat 216:192–208, © John Wiley and Sons.

(Hunter, 1774). Hunter's style of anatomical illustration was termed as "grand naturalism" by his contemporaries and such a method in reality worked against the actual representation of the anatomical details (Kemp, 2010).

Felix Vicq d'Azyr (1748–1794) was a French anatomist and social reformer, who made significant contributions in the field of neuroanatomy (Tubbs et al., 2011). In 1786, Vicq d'Azyr published a monumental piece of work describing the anatomy of the human brain (Parent, 2007). The book contained original descriptions illustrated by means of nature-sized sections of the human brain (mostly in the axial plane) colored by means of aquatint (van Gijn, 2009). The human brain figures used in his work were exceptional in terms of quality and exactitude and as an anatomist Vicq d'Azyr was one of the first to illustrate coronal sections of the brain in his work (Parent, 2007).

Paolo Mascagni (1755–1815) was an Italian physician, known for his study of anatomy, in particular for the first complete description of the lymphatic system in *Vasorum lymphaticum* (Mascagni, 1787). Mascagni aimed to create a masterpiece of anatomical illustrations, *Anatomia Universa*, which ultimately was an incompletely realized project. He commissioned Antonio Serantoni (1780–1837), a renowned artist of that time, to produce elaborate sets of anatomical drawings in huge folios, having three plates for one complete figure (Mascagni, 1823–32). In Mascagni's view, such an exercise would incorporate a deep understanding of the component parts of the human body in the viewer's mind (Kemp, 2010). Mascagni's style of anatomical illustrations was more close to the idealistic approach of Albinus and was considerably distant from the naturalistic approach of Hunter (Choulant, 1920).

John Bell (1763–1820) was a Scottish anatomist and surgeon, who served as a professor of surgery in Edinburgh. He was among the first to emphasize the relevance of anatomy in surgical practice and is referred to as the "father of surgical anatomy" (Kaufman, 2005). He himself taught anatomy while practicing as a surgeon and prepared notes on anatomy and surgical anatomy, which were later published as *Anatomy of the Human Body* (Bell and Bell, 1794−1804). The illustrations used by Bell in his text were prepared by himself unlike most of his predecessors, who had relied on eminent artists to prepare illustrations for their work (Bell, 1794). This was clearly an indication of a new horizon in the domain of anatomical illustrations. Bell took the liberty in demonstrating anatomical details in his own particular way in most of his drawings thereby signaling the directness of representation to the viewer. His drawings never pretended to be anything other than handmade rendering and there were no attempts to make the figures act as if they are alive (Kemp, 2010). Such lack of style in illustrations by John Bell actually evolved as a new recognizable style in anatomy. Bell's illustrations were devoid of the grand naturalism of Hunter and the lavish grandeur of Mascagni and reflected sort of "pliable naturalism", a trend which became popular among future anatomists (Kemp, 2010). His legacy was carried forward by his brother Sir Charles Bell (1774–1842), who similar to his brother illustrated his own anatomical texts (Kazi and Rhys-Evans, 2004). At a very young age, under the guidance of his brother, Sir Charles published his own work *A system of dissection explaining the anatomy of the human body*, which contained excellent illustrations (Jay, 1999). Later on in his career, he even assisted John Bell in preparing the illustrations *Anatomy of the Human Body*, where Sir Charles prepared the drawings of nerves, the sensory organs and the viscera (Bell and Bell, 1794−1804). Sir Charles was gifted with incredible artistic skills and he saw anatomy and art as closely related subjects, and was of the view that making illustrations would actually discipline a surgeon's hand and the study of anatomy would discipline the artist's eye (Chikwe, 1994; Berkowitz, 2011). Sir Charles' depiction of the facial muscles in different emotional expressions of humans (Bell, 1806) and his significant contributions in the field of neuroanatomy has established him as a legend in anatomical sciences (Ellis, 1996).

NINETEENTH CENTURY

At the beginning of the 19th century, anatomical illustrations were enriched by the works of some of the outstanding French anatomists. Jules Germain Cloquet (1790–1883), the famed anatomist and surgeon, is remembered for his detailed anatomical descriptions of hernial disorders that have been useful in developing innovative surgical techniques (Loukas et al., 2007). He was blessed with artistic talents and in his best known work, *Anatomie de l'homme*, most of the illustrations were drawn by him. Cloquet attracted many pupils with his innovative teaching style and implementation of anatomical preparations, drawings, and sketches on the black board with chalk (Loukas et al., 2007). Jean-Baptiste Marc Bourgery (1797–1849) was a physician and anatomist, known for his masterpiece on human anatomy, *Traite complet de l'anatomie*. The atlas contained 2,108 pages of folio-sized text and 726 hand colored lithographs. The illustrations were prepared by the famed artist Nicolas Henri Jacob (1782–1871) (Hildebrand, 1985). Ludwik Maurycy Hirschfeld (1814–1876) was a Polish anatomist and scientist, who moved to Paris in 1834 (Reymond et al., 2008). He worked under the guidance of Bourgery and discovered his passion for anatomy. His skills as a dissector enabled him to prepare anatomical specimens for illustration (Reymond et al., 2008). His most well known work in anatomy, the *Neurologie*, was immensely popular among anatomists of that period. The artwork for this atlas was prepared by the French artist Francois Leveille (1769–1829) (Hildebrand, 1985). The anatomical atlases prepared by Bourgery and Jacob and by Hirschfeld and Leveille are among the best works in medical iconography. By virtue of the excellent illustrative plates and precise descriptive text, they set a new standard in anatomical illustration (Hildebrand, 1985).

Illustrations in anatomy evolved further during the 19th century as evident in the work of Henry Gray (1827–1861), who was an English anatomist and surgeon. He was a student of the Royal College of Surgeons and in 1852 was elected a Fellow of the Royal Society. He was a painstaking and methodical worker, who advanced his anatomical knowledge by the slow but invaluable method of making dissections for himself (Poynter, 1958). His legendary work, *Anatomy: Descriptive and Surgical* was first published in 1858 and had 363 illustrations (Gray, 1858), which were prepared by Gray's friend Henry Vandyke Carter (1831–1897), who himself was a demonstrator of anatomy at St.George's Hospital and later became Professor of Anatomy in Grant Medical College in Bombay, India (Hiatt and Hiatt, 1995). The masterpiece work of Henry Gray is still published under the title *Gray's Anatomy* and is widely appreciated and regarded by many as the "Bible of anatomy" (Hiatt and Hiatt, 1995). The success of Henry Gray's *Anatomy* at least to some extent could be attributed to the excellence of its illustrations (Roberts, 2000). There were no attempts to place figures in graceful poses or against unrealistic/whimsical backgrounds. The use of imposing, enlarged views of the human body was consciously avoided and even a complete skeleton was not depicted anywhere in the book (Kemp, 2010). Carter's illustrations were aimed at scientific description of the anatomical parts (Gray, 1858) and the real strength of these wood engravings was the diagrammatic clarity which was considerably atypical with respect to that period. The images in contemporary anatomy books were characteristically proxy labeled, whereby the reader had to look for the key, which was usually situated in a footnote. Carter's illustrations by contrast unified name and structure thus enabling the reader's eye to assimilate both at a glance (Richardson, 2008). Gray's vision was to provide visual

descriptions in anatomy that would be useful for the aspiring surgeon and clinician and Carters' wood engravings which were deliberately restrained in their visual means, ensured that the focus remained on the anatomical details (Roberts, 2000; Pearce, 2009). The illustrations used in Gray's *Anatomy* were also characterized by the use of sections (sectional anatomy) which although were depicted in a limited and rudimentary manner (Kemp, 2010) but was a considerable effort in terms of advancement of a concept which was introduced by anatomists like Vicq d'Azyr and his contemporaries in the 18th century (Parent, 2007).

The concept of sectional anatomy was later perfected by German anatomist Christian Wilhelm Braune (1831–1892), who pioneered the use of frozen cadavers for anatomical investigations. Braune developed a technique of preparing illustrations of sectional anatomy by drawing the sections directly on a transparent paper placed over a thin layer of ice laid down on the surface of the section concerned (Braune, 1872). Such representation of human anatomical sections was greatly appreciated by contemporary anatomists.

MODERN TIMES (1900 AD TO PRESENT DAY)

By the end of 19th century illustrations became an integral part of the teaching process in anatomy. However preparation of anatomical illustrations was yet to develop as an independent profession. With the beginning of 20th century, opportunities started to grow permitted by social and cultural changes as well as technological advances (Tsafrir and Ohry, 2001). Such favorable circumstances paved the way for the emergence of professional anatomical illustrators, who made significant contributions to the subject in the last century. Max Brödel (1870–1941), a young artist from Leipzig, Germany, was invited to the Johns Hopkins School of Medicine in Baltimore, United States, in 1894 and he started working here with the famous gynecologist, Howard A. Kelley (Schultheiss and Jonas, 1999). Although Brödel did not have any formal medical training, he quickly acquired knowledge of anatomy, pathology, physiology, and surgery and became a well-known medical illustrator (Patel et al., 2011). He introduced new innovative art media, such as his carbon dust and stipple board technique to reproduce human tissue in a vivid manner (Schultheiss et al., 2000). He skillfully incorporated tissue realism with cross-sectional anatomy to accentuate concepts while maintaining topographical accuracy (Patel et al., 2011). He developed an instructive and didactic pattern of medical illustration and is considered by many as the father of modern medical illustration. His reputation spread quickly and in 1911, Brödel was appointed the director of the Department of Art as Applied to Medicine at Johns Hopkins School of Medicine, the first academic department of its kind in the world (Schultheiss et al., 2000). This was a phenomenal event in the history of anatomical illustrations (medical illustration as such) and for the next few decades generations of medical illustrators were trained in this department under the guidance of Max Brödel, who passed on his exceptional skills and knowledge in the field to his students (Patel et al., 2011). Brödel founded the profession of medical illustrator and changed the outlook of anatomical illustrations at the beginning of the 20th century. The Department of Art as Applied to Medicine recently completed 100 years of its foundation and continues to train future medical illustrators, maintaining the highest standards while embracing new medical, scientific, and communication technologies (Patel et al., 2011).

Frank H. Netter (1906–1991) was an American surgeon and celebrated medical illustrator. He grew up wanting to be an artist and continued doing freelance art during his medical training. In the initial part of his career, Netter started doing medical art to supplement his income as a medical practitioner. But very soon he embraced medical illustration as a full time profession and started working for pharmaceutical companies (Duguid, 1989). Netter's illustrations always began with meticulous research into the forms of the human body, a philosophy that steered his broad and deep medical understanding. He was of the view that no matter how beautifully it is prepared, a medical illustration would be of little value if it does not clarify a medical point. His greatest success was charting a middle course between artistic clarity and instructional complexity (Dominiczak, 2013). His illustrations were immensely popular among contemporaries and this led to the first comprehensive collection of Netter's work, *The CIBA collection of Medical Illustrations* being published as a single volume in 1948 (Hansen, 2006). Such was the success of the collection that over the next few decades, it was expanded into a 13 volume series comprising of over 4,000 medical illustrations prepared by Netter during his illustrious career. In 1989, Netter's *Atlas of Human Anatomy* was published, which was assembled from his previous illustrations (Netter, 1989). The atlas rapidly became the most widely used atlas of anatomy in American medical schools and is currently published in 16 languages (Hansen, 2006). The illustrations from Netter's atlas are routinely used by modern day illustrators as references to create two dimensional as well as three dimensional (3D) anatomical artworks with the help of software advances. Netter's sublime lifelike artwork enable fast production of computer assisted 3D volume-rendered images that are being used as templates or backgrounds for preparing high quality anatomical illustrations (Corl et al., 1999) (Fig. 6).

Till the end of 19th century, anatomical illustrations solely relied on handmade sketches/diagrams. During the 20th century use of illustrations in anatomy considerably increased and it was revolutionized by the emergence of two new entities; medical images and photographs. Medical imaging began in 1895 with Wilhelm Conrad Roentgen's discovery of the X-rays (Bradley, 2008). The use of X-ray films in teaching anatomy was an important landmark and it particularly helped in understanding of surface anatomy. In the early part of the 20th century, two dimensional plane X-ray films were available depicting the anatomy of the chest and bones of the human body. From 1920s contrast X-ray images were available in the form of barium swallow and barium enema, which provided anatomical details of different parts of the gastrointestinal tract (Bradley, 2008). X-ray tomography (analog tomography) was introduced in the 1940s, allowing visualization of tissue slices without the over or underlying tissues being seen (Hendee, 1989). In the 1950s X-rays formed the basis of contrast enhanced angiographic images which helped to understand the anatomical distribution of the arteries in the human body particularly that of the coronary and carotid arteries (Bradley, 2008). During the 1960s ultrasound technology came into prominence and its clinical applications were explored. Over this period, sonography was recognized as the primary imaging technology in the field of obstetrics and was used to obtain images of the developing fetus during pregnancy. Echocardiography was

acknowledged as an important tool which provided an overview regarding the anatomy of the cardiac chambers (Hendee, 1989). A major breakthrough was achieved in the 1970s with the advent of computed tomography (CT) followed by magnetic resonance imaging (MRI) (Geva, 2006; Bradley, 2008). The entry of computers into the world of medical imaging in the early 1970s contributed to further development of these two new technologies. CT was a major advance as it allowed multiple tomographic images (slices) of the desired tissue to be acquired. Initially CT scanners were slow in acquiring images but with the advent of spiral CT in the mid 1980s, images of an entire anatomical region could be obtained in seconds (Bradley, 2008). In fact CT imaging is used in present day to virtually dissect a human body in multiple planes. After its introduction MRI was used to obtain cross-sectional images involving the soft tissues in the human body (Geva, 2006). Initially these images had low spatial resolution; however, the introduction of super conducting magnets (initially at 1.5 Tesla and now at 3 Tesla) over the 1980s and 1990s has led to the production of high resolution images with increased clarity (Bradley, 2008). The introduction of CT and MRI together with advanced computer technologies proved to be a watershed event in the evolution of anatomical illustrations. Prior to these technological innovations, learning and understanding anatomy was limited by the traditional two dimensional images. Both CT as well as MRI provided anatomists with a large volume of cross-sectional image datasets which could be transformed into 3D images of anatomical structures by volumetric reconstruction (Corl et al., 2000). Compilation of these image datasets became essential as it had the potential to develop into an invaluable collection for anatomical education and research. Under these circumstances, the US National Library of Medicine undertook the "The Visible Human Project" in 1989 with the long-term goal of creating a digital image dataset of complete human male and female cadavers in MRI, CT and anatomical modes that would provide a link between visual knowledge and symbolic knowledge formats such as names of body parts (Ackermann, 1999). This project involved acquisition of transverse CT, MR, and cryosection images of representative male cadavers (sectioned at 1 mm interval) and female cadavers (sectioned at 1/3rd of a mm interval) and the first prototype digital image dataset of a complete adult human (one male and one female) was created in 1995 (Zhang et al., 2006). Over the years, the Visible Human database has revolutionized anatomical education by providing computer simulation of the live human body (Spitzer and Whitlock, 1998) thereby shifting the focus from traditional dissection-based cadaveric anatomy to virtual reality (VR) techniques for anatomy learning (Temkin et al., 2006). Inspired by its success, similar projects have been undertaken by other countries worldwide (Park et al., 2006; Zhang et al., 2006). In recent times both CT and MRI are being used in combination with positron emission tomography (PET) to develop new generations of intrinsically digital images depicting the 3D structural details of the living anatomy (Lester and Olds, 2001)

Photography had a delayed role in anatomical illustrations (Kemp, 1997), however its introduction and subsequent advances have actually changed the face of visual representation in anatomy. Toward the end of 19th century the potential of photography in medicine and anatomy began to be fully explored owing to the revival of stereoscopic photography, which was first introduced in the 1850s (Wade, 2012).

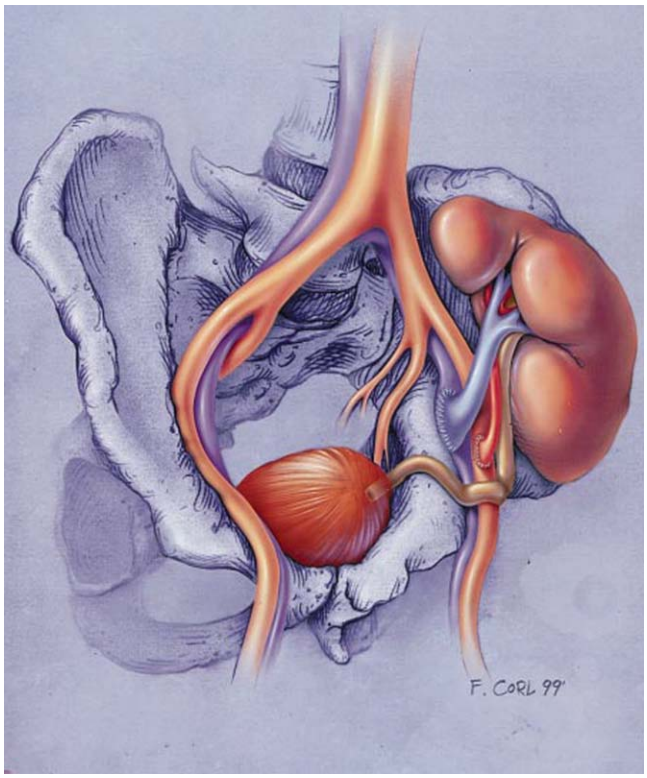

Figure 6.

A computer-rendered modern day anatomical illustration showing the position of kidney after transplantation into pelvic region. This figure shows use of combination of computer software to create electronic image that looks like traditionally rendered illustration. Reproduced with permission from Corl and Fishman, 1999. Medical illustration gallery. J Biocommun 26:10–13.

Among several innovative applications of stereo-photography in anatomy during this period, the ones which particularly stand out include the works of Arthur Thomson (he was the first professor in Human Anatomy at Oxford); *A Handbook of Anatomy for Art Students* (Thomson, 1896) and *The Anatomy of Human Eye, as Illustrated by Enlarged Stereoscopic Photographs* (Thomson, 1912). Another notable work illustrated by stereoscopic photographs was *The Edinburgh Stereoscopic Atlas of Anatomy* (Waterson, 1905). Color photography based on the autochrome process was commercially introduced as early as in 1907 and within the first two decades of the 20th century roll-film cameras were made available, which were crucial to medical photography (Ollerenshaw, 2000). These developments encouraged a group of photographers working in medicine at the Yale University in US, to come together and form the Biological Photographic Association (BPA) in 1931 (Gibson, 1979), which later became the BioCommunication Association (BCA). This was a seminal event in the history of medical photography as it became a specialized field and over the years the association evolved as a medium for exchange of technical information and recognition of professional excellence. For the greater part of the 20th century silver-grain photographic methods were used as the principal standard method to capture macroscopic and microscopic images in anatomy (Trelease, 2002). However a major technological advancement

was achieved in the early 1980s with the introduction of digital photography (Schaaf et al., 2009). One of the many advantages of digital photography is the possibility of reviewing the picture immediately after it has been captured to judge technical aspects such as sharpness, illumination, color and positioning of the anatomical structure (Galdino et al., 2001). Digital technology also allows successive or serial shots thus enabling the professional to capture anatomical details with remarkable perfection (Schaaf et al., 2009). In present day, all photographs used as anatomical illustrations are digital in nature or become so in the course of publication, because publishing technology has become universally digital (Wang, 2008). Availability of powerful data storage tools and software allows these digital photographs to be integrated into digital files that facilitate convenient retrieval of the data (Kommeri et al., 2011). Pixel-based graphics have become the mainstay of modern day digital photography and virtually all medical images in present day are pixel based (Wang, 2008). The key aspect of pixel-based images is that in order to achieve maximum clarity, the spatial resolution has to be accurate. In other words, these images are resolution dependent and cannot be infinitely enlarged or shrunk without compromising on quality. Based on advanced digital photographic methods, anatomical illustrations have evolved beyond handling primarily static 2D images to innovative 3D and 4D data arrays related to living anatomy as for example the endoscopic images providing a close view of internal cavities and compartments such as airway, gut, peritoneal cavity, and joints (Trelease, 2002).

The last decade of 20th century and the beginning of 21st century have witnessed the influence of advanced software programs on all forms of anatomical illustrations. The introduction of Picture Archiving and Communication System (PACS) has revolutionized the world of medical imaging. PACS allows acquiring, archiving, transmitting and displaying digital radiological images in the Digital Imaging and Communications in Medicine (DICOM) format (Bick and Lenzen, 1999). In other words PACS ensures a smooth and organized filmless data flow in the field of medical imaging (Strickland, 1999) thus allowing high performance Web-based image distribution, whereby user using Web browsers can access, view and manipulate these images (Zhang et al., 2003). The Adobe Photoshop (Adobe Systems Corp., San Jose, CA) software system is being extensively used by professionals in editing pixel-based digital photographs after they have been captured. This software enables re-sizing of the image (in accordance with its pixel resolution), grey-scale manipulation, image noise reduction, correction of lens distortion, introduction of on-image indicators and annotation as per requirement (Wang, 2008). Photoshop editing enhances the quality of photographic illustrations and makes them informative and easily interpretable. The advent of Adobe Illustrator (Adobe Systems Corp, San Jose, CA) software allows professional illustrators to prepare computer generated anatomical artwork with greater flexibility and speed while ensuring anatomic accuracy (Corl et al., 1999; Wang, 2008). Thus it may be opined that the application of advanced software technology has actually changed the style and presentation of anatomical illustrations in the 21st century. The last two decades of the 20th century saw the rise of Internet (a global digital network) and the trend is continuing in the 21st century. From academic perspective, Internet has become a popular medium for sharing data, information, and knowledge (Trelease, 2002). Recent technological advances enable Web-based dissemination of anatomical illustrations thereby enhancing its outreach to the anatomists worldwide (Trelease, 2002). Appropriate selection of the Web-based dataset of anatomical images, followed by processing and presentation enable institutions as well as students to build their own 3D interactive virtual human anatomy models that can be used as a powerful learning tool in the present day (Petersson et al., 2009), when the focus is on using virtual reality (VR) techniques for teaching anatomy (Trelease and Rosset, 2008; Tam, 2010). Web-based anatomical illustrations are also being utilized to build online anatomy atlases, which are regarded by students and physicians as a useful aid for learning and reviewing anatomical details (Jastrow and Vollrath, 2002). Hence convenient accessibility has enhanced the potential of anatomical illustrations to play a pivotal role in the learning process of anatomy in modern times.

CONCLUSION

In the present day the text and illustrations in anatomy complement each other to provide the optimum pedagogical effect thereby enhancing the understanding and overall learning process. However it required a significant evolutionary process for anatomical illustrations, spread over centuries to achieve the present status in the field of anatomy. During the classical period and the Middle Ages, the subject of anatomy was dominated by the descriptive text of Galen, which was devoid of any illustration. In the Late Middle Ages, Mondino de Liuzzi endeavored to revive human dissection as the principle method for advancement of anatomical knowledge. De Liuzzi's efforts encouraged his student Vigevano to use illustrations for the first time in anatomy, a concept which was further developed by the anatomists from the Renaissance period. A striking feature of the anatomical illustrations during the Renaissance period was that they were usually prepared by renowned artists/painters belonging to that period. Either these artists were themselves expert in the field of anatomy or they were commissioned by the anatomists to prepare the illustrations for their texts. Such a practice resulted in the dominance of artistic features over anatomical details which are quite apparent in the anatomical illustrations from this period. Vesalius established the importance of using illustrations alongside texts in anatomy which enabled anatomists to come out of the influence of descriptive texts prevalent among scholars since the ancient period. However illustrations used by Vesalius were very much dramatic in outlook, with full figures of human in grand poses or full skeleton appearing as if they are alive. Toward the later stages of Renaissance, Fabricius and Veslingius came out with anatomical drawings that were close to their real forms, and this proved to be a turning point in the evolution of anatomical illustrations. Similar to other anatomists of this period, Fabricius also had taken help of artists in preparing his drawings. However the very fact that he sought assistance of lesser known artists resulted in plates that were free from the overindulgence of artistic flavors. The practice of anatomists seeking assistance from renowned artists/painters in preparing illustrations for their texts, which was prevalent in the Renaissance period, continued into the 17th and 18th centuries. However the common pattern of grand human figures (prominent feature in the anatomical illustrations from Renaissance period) was now replaced by the individual styles, characteristic of the anatomists of the 18th century. Albinus' obsession for perfection or the naturalistic style of

Hunter or the ambitious desire of Mascagni to produce magnum size illustrations, every instance eventually led to the suppression of the anatomical details. Hence the conflict between the artistic expression and the anatomical representation, which has its roots in the Renaissance period, had a considerable influence on the anatomical illustrations till the end of 18th century. The later part of the 18th century and the beginning of the 19th century witnessed the emergence of a new trend in anatomical illustrations, when anatomists like John Bell, Sir Charles Bell and Cloquet, who were gifted with exceptional artistic skills, started preparing their own illustrations. Their efforts significantly contributed toward an improved outlook of anatomical artwork in terms of representation of anatomical knowledge. However in accordance with the long lasting tradition, anatomists continued to collaborate with professional artists even during the 19th century. An interesting modification of this tradition is observed in Gray's anatomical masterpiece, when Carter (who himself was an eminent anatomist) was entrusted with preparing the anatomical illustrations and he was successful in negating any tendency to turn the illustrations into pieces of art. Finally the emergence of professional anatomical illustrators in the 20th century marked the beginning of a new age of cooperation between art and anatomy resulting in illustrations enriched with artistic beauty and scientific accuracy. In keeping pace with the changing times, like many scientific disciplines, anatomical illustrations also had to embrace the technological advances, which played a pivotal role in its evolution in the 20th and 21st centuries. The entry of computers and subsequent advances in the software technology during the later part of the 20th century led to computer-assisted digitally-enhanced images which have become the face of anatomical illustrations in the modern times after the prevalence of handmade, woodcut, and wood-engraved artwork for centuries. At the onset of 21st century, revolution in the world of communication has resulted in rapid dissemination of anatomical informatics including images among the scientific community. Novel avenues are being explored by anatomists worldwide to utilize new generation anatomical illustrations in innovative formats for teaching as well as learning anatomy.

NOTES ON CONTRIBUTOR

SANJIB KUMAR GHOSH, M.D., is an assistant professor in the Department of Anatomy at the ESI-PGIMSR and ESIC Medical College, Joka, Kolkata, India. He teaches anatomy, histology, and embryology to first-year medical students.

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