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Historical Overview

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INTRODUCTION

To know where you are and where you are going means knowing where you come from. Therefore this thesis starts with a historical overview explaining the thoughts of our predecessors that led to the eventual development of CASAM. In Dissection the works of the founding fathers of modern anatomy and surgery such as “The first known anatomist”, “the father of modern Surgery”, and “the restorer of anatomy” are described giving an historic overview of human dissection. Averaging describes how scientists such as Leonardo Da Vinci have long tried to capture the shapes of anatomy and reduce them to average and ideal proportions. Warping illustrates “how thinking outside the box” leads to exceptional theories; A Scottish biologist reduced the differences in shapes of related species (such as ape and man) to simple mathematical functions. In essence this was the basis for the application of algorithms in the description of variations in anatomy and species.

DISSECTION

Although the interest in human anatomy has been of all times, the opportunity for human cadaver dissection has been controversial till date. Without the monumental works of past visionary anatomists, human dissection as we know it today would not be possible. Also, current concepts of surgery, embalming techniques and dissection legislation have been greatly influenced by them.

Ancient Greece

The Greek Physician (335-280 BC) Herophilos[1,2] is to be considered as the first anatomist[3]. Born in Chalcedon Herophilos attended the medical faculty located at Cos, founded by Hippocrates himself. Having finished his education Herophilos moved to Alexandria where he and his companion Eristratus started the school of Aleksandria. Both had been given permission from Ptolemy the First to perform vivisections ("vivus" means alive and "section" means cutting) on convicted criminals[4]. They often performed such vivisections publicly as to better demonstrate the actual effects of their dissections and it is said that both vivisected at least 600 prisoners[1]. The vivisections were not without controversy as people such as Celcus[5] and Tertullian were publicly opposed to them.

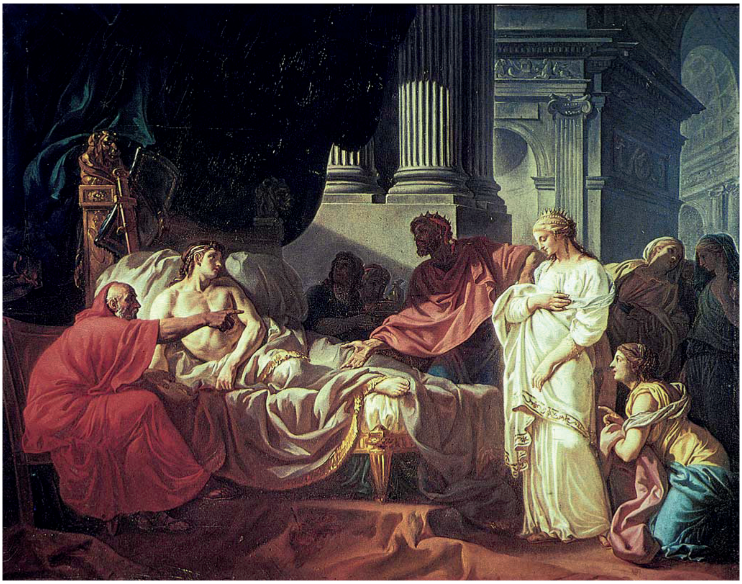

Figure 1. Erasistratus discovers the cause of the illness of Antiochus. Jacques_Louis Davis (1774)

Ancient Rome

In ancient Roman times the dissection of human specimen had been banned from 150 BC[7] as interference with the dead body was considered to be impious and offending to the gods. The act of crucifixion for instance was the most horrible form of punishment as the victim`s remains were left to rot and could not be buried.

Aelius Galenus (AD 129 – c. 200/c. 216), also known as Galen, was a physician and surgeon in the Roman Empire who advocated anatomy dissection on animals as a substitute to human dissection. He mostly dissected primates and especially the Barbary macaque as he considered their anatomy to be closest related to that of humans. His most valuable anatomic work was on the difference between venous blood (dark) and arterial blood (bright red), an observation he made during vivisections of primates and pigs[8]. His work however was not flawless. He for instance, deduced from his dissections that venous blood was made in the liver, distributed by veins and arterial blood was created in the heart being distributed through arteries. Galen also did multiple experiments in which he ligated nerves to support his theory that muscles are controlled via cranial and peripheral nerves[9].

Galen`s anatomical work, although based on animal dissection and Greek anatomy books greatly influenced Islamic surgery[10,11] and was uncontested and considered as human anatomy even in the Western World until the 1500`s AD.

Islamic World

Abu al-Qasim Khalaf ibn al-Abbas Al-Zahrawi (936–1013), is not only considered the greatest medieval surgeon of the Islamic World but has also been described as "the father of modern surgery"[12]. Among many medical and surgical

Figure 2. Abū al-Qāsim Khalaf ibn al-'Abbās az-Zahrāwī
Source: Wikipedia[15]

books his greatest work is the Kitab al-Tasrif, a thirty-volume encyclopedia full of medical practices[13]. In it he describes the equivalent of the “Kocher`s method” for treating a dislocated shoulder, or ligating the temporal artery for migraines and the stripping of varicose veins in such detail that even today, it reads as a modern surgical treatise. He also stated that “He who devotes himself to surgery must be versed in the science of anatomy”[14].

However it is still debated if al-Zahrawi performed any human dissections. Although he and his scholars regularly reference human dissection al-Zahrawi was also considered a devoted Muslim for whom the study of the human body would imply breaking the Sharia (Islamic law).

Medieval times

In contrast to the complete cultural, scientific and economic decline during the Dark Ages, human dissection revived. During the thirteenth century it even became an obligatory subject of the medical universities. Mondino de Liuzzi, (1270-1326), also known as “the restorer of anatomy”[16], reintroduced human cadaver dissection and made it an integral part of the medical curriculum. He was also the first to describe that “when studying the muscles of the limbs, a sun-dried body could be used as an alternative to the dissection of a rapidly decaying cadaver”[17]. Despite the human dissections, ancient views on anatomy as postulated by Galen would not be contested until the renaissance.

Renaissance

Until the works of the Belgian anatomist Andries van Wesel (1545-1564), better known as Andreas Vesalius, the works of the old Greeks were recited and the ancient anatomical work had not been verified for ages. Vesalius however began to again carry out his own dissections and urged students to perform dissections themselves[18]. Having the opportunity for human dissection Vesalius began to refute old Roman and Galen`s claims on anatomical subjects such as the purpose of arteries and veins. Vesalius` most important contributions to anatomy are his books “De Corporis Fabrica”(on the fabric of the human body) and “De humani corporis fabrica librorum epitome”(the students abbreviated version) both of which are based on human dissection. The books focus on the visual drawings instead of actual text and highlight the importance of human dissections in understanding the three dimensional complexity of anatomy[19.] Also, Vesalius made a point of doing his own dissections and was known for inviting students and publishers of his books to join the anatomy classes.

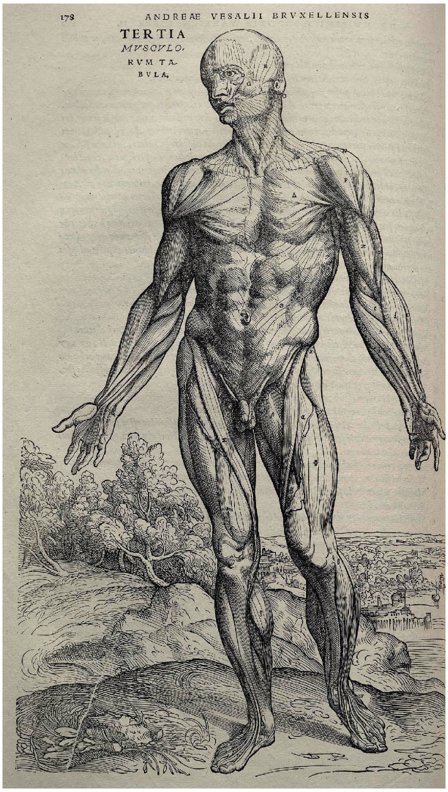

Figure 3. Andreas Vesalius, Illustration from De Corporis Fabrica[19], showing the muscular anatomy of man.

Vesalius` work however was also subject to much controversy as human dissection was forbidden by the Catholic Church. Also, Vesalius admitted the cadavers he used were gathered at graveyards and places of execution which stirred public emotions even more. Eventually Vesalius had to resign from his academic post and took a position as the imperial physician to Emperor Charles V. Vesalius` work however was not futile and his re-emphasis on human dissection slowly made anatomy again a central part in medical training and research.

Enlightenment

During the "age of enlightenment" (18th century) the thirst for knowledge and scientific progress further overcame centuries of ethical concerns regarding human anatomy research. The Scottish anatomist Alexander Monro "Primus" founded the Edinburgh Medical School[20] in which he openly participated in (and stimulated) dissection of the human body. His work on the human anatomy of bones, nerves and lacteal sac and duct is still being sold[21] and future generations of the Monro family (Alexander his son, "Secundus" and grandson, "Tertius") have all taught at the Edinburgh Medical School, making it one of the oldest (and best)[22] medical schools in the English speaking world[23].

19th Century

At the start of the 19the century the Napoleonic Wars (1803-1815) led to an increased demand in medical and anatomical research. As a result of an increased demand for human specimen used for dissections, the disinterment of bodies at graveyards became more common and stirred public opinion so much that guards were placed at graveyards[24]. During this time William Burke and William Hare had killed 16 people, selling the bodies to anatomist Robert Knox[25]. Also the "London Burkers" a group of so called "resurrection-men"[26] tried to sell the body of a young Italian boy to a London surgeon[27]. The public outrage of these incidents eventually led to Great-Britain's 1832 Anatomy Act, legislating the donation of human cadavers to universities and medical schools. To this date the amended act is in use in Scotland and it has been the basis of Britain's Human Tissue Act of 2004 and similar acts in European countries and the U.S.[28].

Current times

Controversies surrounding anatomy and human dissection are also of modern times. Artist Damien Hirst stirred public opinion when he showcased his 'For the love of God", a human skull plated with 8601 diamonds[29] and Gunther von Hagen made international headlines when he performed the first televised public autopsy in 2002[30]. Millions of people of people visited the "body world" exhibition[31], showcasing human specimen plastinated using a technique created by dr. Von Hagen himself[32]. The exhibition was controversial by nature; it showcased human remains as pieces of art but also made anatomy accessible to the public. Interestingly, since the specimen were plastinated they legally weren't human cadavers anymore and could be classified as "objects of art" or "items in anatomical collections"[33].

If history teaches us anything it is that the general public opinion sets the boundaries for human dissection in anatomy research and anatomy teaching. The privilege anatomists currently have is most certainly fought hard over by our predecessors and not as ordinarily as most people think. The active preservation of the opportunity for human dissection should be of interest to any anatomist or surgeon and the impact of public opinion should not be underestimated.

Currently there are also new shifts in mapping 3d anatomy such as CT and MRI (see Warping). These techniques are evolving at a huge pace and become more accurate every day. And although some regard these new techniques as a replacement, they are currently best considered as good additions to conventional human dissection.

AVERAGING

The ambition of society to define and average the proportions and shapes of the human body has been long-standing and initially mostly driven by (divined) art. In ancient Egypt for instance the proportions of the body were recorded in "fists", meaning the length measured across the knuckles. The average length of an Egyptian was 18 fists[34,35]. In modern day drawing the head has been chosen as the basic unit of measurement and to establish the correct proportions of the rest of the body[36]. The head is measured from the top down to the most distal edge of the chin. Ideally the body then is 7.5 heads long with the hips being exactly halfway. Interestingly when gods or heroic figures were drawn they were typically 8 heads long with the extra length coming from longer legs and torso[37] (figure 4).

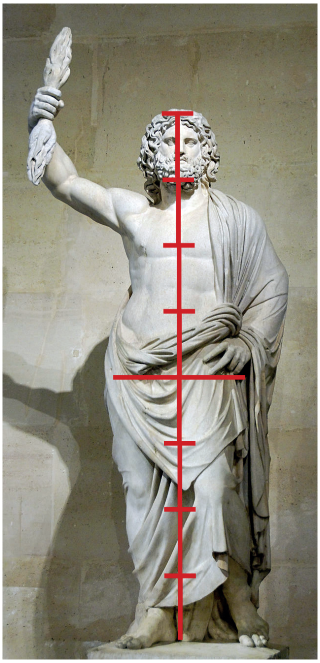

Figure 4. Jupiter of Smyrna (currentday Izmir, Turkey) currently exhibited in the Louvre paris. Exactly eight heads tall.

Famously, Leonardo da Vinci also tried to capture the proportions of our body in the "Vitruvian man" drawing[38] (figure 5). In this drawing and accompanying letters he correlated the ideal proportions of a human body to the basic laws of geometry as described by Vitruvius. In more recent studies on ideal features Pallett et al[40] found an amusing correlation that would forever change the meaning to the phrase "you are so average". In four experiments they set out to find the ideal facial proportions that would be able to theoretically "optimise" any given face. After having found the "golden facial ratios" they realised that these matched the proportions of an average face.

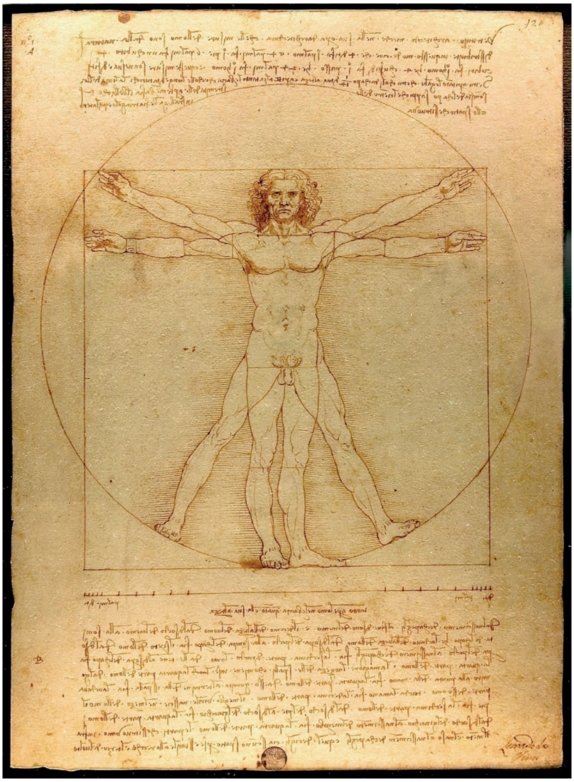

Figure 5.Vitruvian man C. 1492, pendrawing by Leonardo da Vinci. Photographed by Luc Viatour[39]

All methods of defining the human body so far had in common that they use an easy to identify measuring unit to describe the length of the entire body or certain parts of that body. In other words, the measurements are all relative (for instance to the fist or to the head).

To define a specific body part easily identifiable landmarks are used that define its borders. Although the exact definitions have changed over time the general principle is still being used not only in art but also in science and product designs[37,38] such as tables and clothes.

WARPING

One of the founding fathers of what we currently call Bio-Mathematics was the Scottish biologist and mathematician Sir D`Arcy Wentworth Thompson[41,42]. Besides holding the record for having a professorial chair for the period of 64 years at the university of St. Andrews (and Dundee), Thompson`s main work was the 1917 book "On Growth and Form" [43], in which he explains the mathematical patterns and physical laws by which plants and animals are evolutionary formed. Using multiple examples he explains how biological forms are related to purely mechanical phenomena, for example he observed that phyllotaxis (the way leaves are organised on a stem) is based on the Fibonacci sequence (figure 6). He also stated that Darwinism is inadequate to explain the origin of new species and he regarded the phenomenon of "natural selection" to be secondary to the biological form[44].

Figure 6. Phyllotaxis. The leaves grown follow a pattern conform the Fibonacci sequence. (41,53)

The most (in-) famous part of his book is Chapter XVII, on the theory of transformations, or the comparison of related forms[45]. In this chapter he showcases linear and non-linear mathematical functions that transform the shape of one creature into a genetically related one and thus abridge evolution to simple calculations and functions. For instance he used simple shear mapping, a linear function, to display the similarity between two familiar fishes belonging to a different genus (figure 7). Using landmarks in a Cartesian coordinate system of the left fish and putting it at a 70 degree angle you have mathematically described the changes that form the second, related fish.

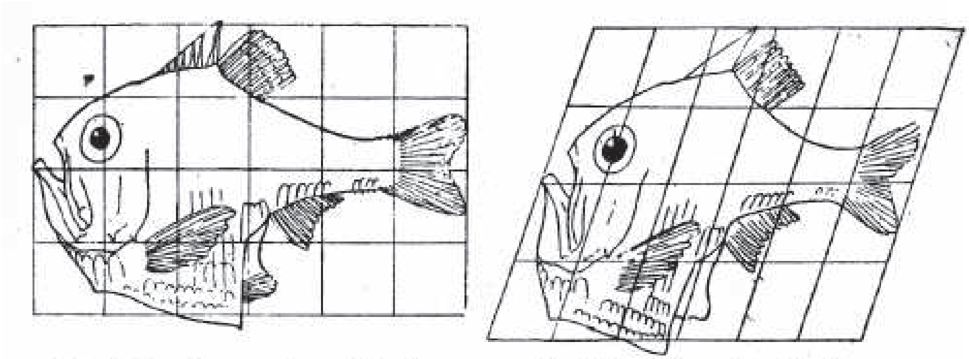

Figure 7. Shear mapping one genus of fish into another.
Argyropelecus Olfersi (left) and Sternoptyx diaphana (right)
From "On Growth and Form"[43]

When regarding human anatomy he related the human skull to that of a chimpanzee (higher ape) and a baboon (lesser ape) (figure 8). He uses the human skull as a reference, defining its shape by certain landmarks and creating a grid. When the same landmarks are defined on the chimpanzee and connected by smoothly curved lines a projection of the human skull emerges over the chimpanzee visualising the changes evolution made over time. Interestingly, when the same thing is done to the skull of a baboon it is clear that the transformation shown only differs in an increased intensity. The areas of the grid that represent the skull, mandibula, etc. increase gradually over evolution, following an approximately logarithmic order. This shows that the different parts of the skull all follow a continuous and integral process that can be mathematically explained.

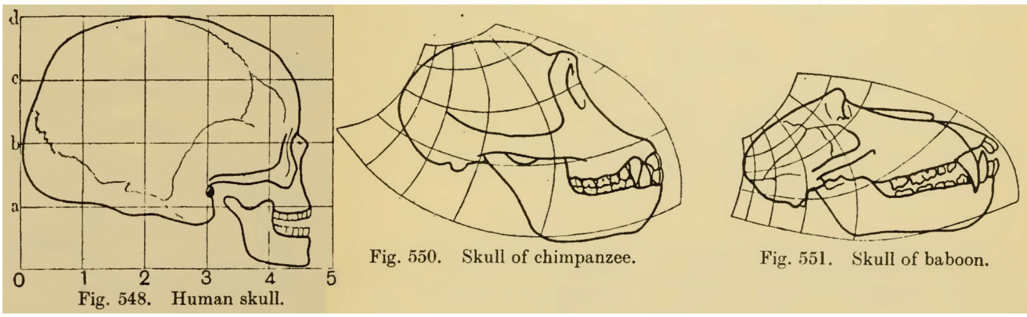

Figure 8. The human skull compared to that of a chimpanzee and a baboon.
From "On Growth and Form"[43].

This conclusion however is controversial as it contradicts with Darwinism. In Darwinism form is changed by environment. The environment however is subject to violent and abrupt changes and therefore form should also be subject to sudden changes; contrasting Thompson`s statement that form changes continuously following mathematical and mechanical functions.

In a way Thompson also laid the foundation for comparative anatomy mapping; he compared the Caucasian scapula (shoulder bone) to that of what he called “older or more remote races” showing the regularity of transformations over time (figure 9). Subsequently he demonstrated the inter-human variation of bony anatomy and laid the groundwork for quantifying anatomical differences using mathematical functions. In essence he explained warping in the year 1917, before images were even digitised.

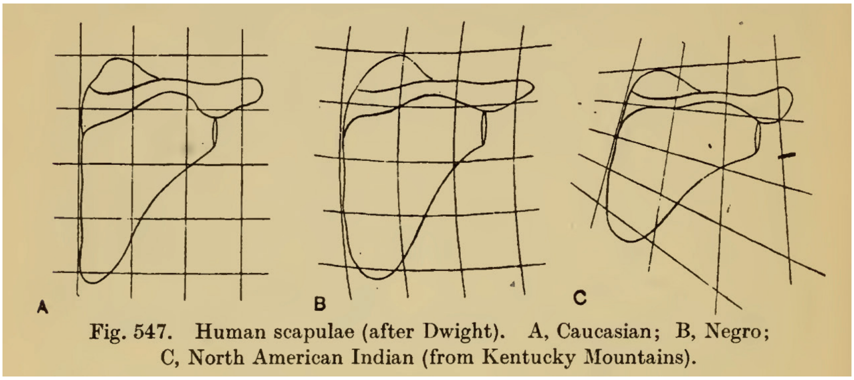

Figure 9. Human scapulae. a) Caucasian, of which the grid is used as a reference. b) African. c) North American Indian.
From “on growth and Form”[43].

Unsurprisingly, the works of Thompson inspired many people including biologists such as Julian Huxly, mathematicians such as Alan Turning and many artists and painters.

CT and (f)MRI

Another recent development in the mapping of 3D anatomy also uses geometry and mathematics. In computed tomography (CT) “digital geometry processing” is used to compute a 3D rendition from a series of circular 2D x-rays. The three-dimensional equivalent to a pixel in CT-scanning is called a Voxel. First developed by British engineer Geoffrey Hounsfield[46] the original CT took hours for the raw data to be collected and computing a single slice often took days. Currently however CT-scanning has evolved immensely and is part of regular diagnostic practice. Magnetic resonance imaging also is a novel way of mapping the 3D anatomy, mainly of soft tissues. First introduced by Paul C Lauterbur in 1971[47] it uses strong and uniform magnetic fields to measure water molecules inside the body. The gathered data are then used to compute a 3D image.

Algorithms similar to those used in CASAM, such as the thin-plate-splines, are used when 3D renditions of CT and MRI images are being compared or combined to visualize structures best captured by either one of the techniques (bones for CT and soft tissues for MRI).

These algorithms are also used in the computation of a generic, average brain, using MRI, CT and anatomical data[48-50]. Such a brain can be used as a reference to identify, for example the area that is active when a functional (fMRI) is made. The department of Biomedical Engineering in Eindhoven (The Netherlands) already used these algorithms to map the anatomy of a brain (derived from basic anatomy dissections) to the MRI of patients so that specific parts of the brain are easier to identify[51,52].

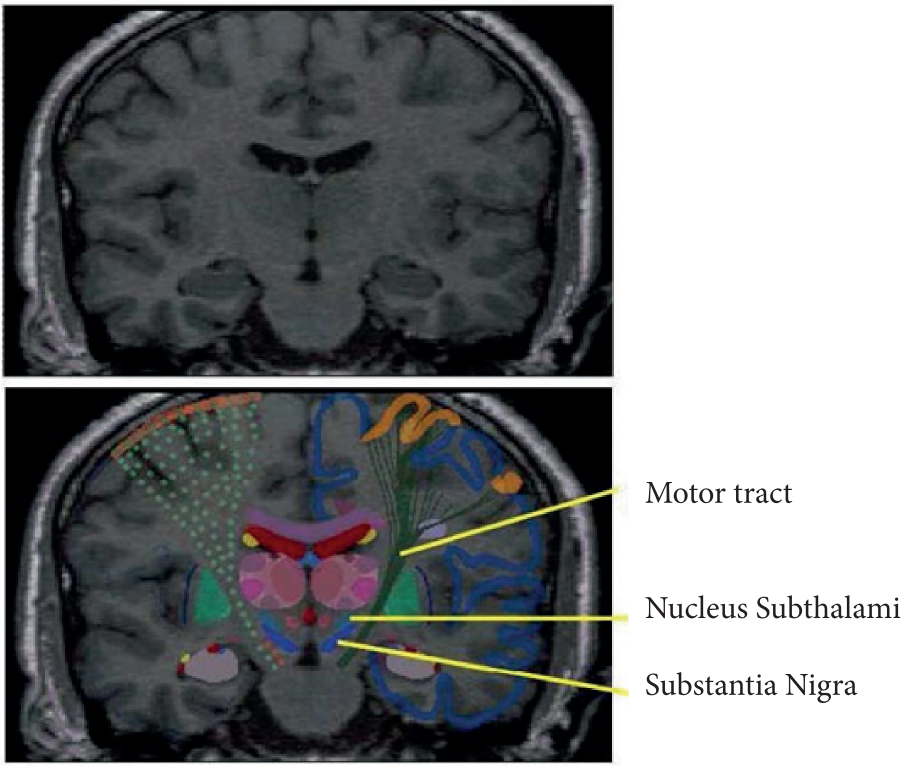

Figure 10. warping a neuro-anatomy atlas on 3D MRI data[51]

Further examples of the use of algorithms in everyday clinical practice will be discussed in the discussion of this thesis. However, these applications of geometry and mathematics in the imaging of 2D and 3D anatomy illustrate that these algorithms are becoming a part of everyday diagnostics and surgical procedures. Interestingly, although most clinicians use CT and or MRI images and their renditions on a regular basis, they are not informed on how these algorithms are being applied.

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