Nicolaus Steno and the Cartesian Brain

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Abstract. Widely regarded as the founder of modern Western Philosophy, René Descartes (1596-1650) sought to look beyond the established Aristotelian traditions. His mechanistic interpretations of cerebral anatomy in *L'homme* (*Treatise on Man*) were heavily scrutinised by contemporary scholars. Nicolaus Steno (1638-1686), one of the most renowned Danish anatomists of the Scientific Revolution, launched powerful criticisms on Descartes' anatomical errors. This paper examines the contributions of Steno and Descartes to the intellectual evolution of neuroanatomy from late antiquity to the Renaissance. In particular, the paper explores Steno's classic, *Discours sur l'anatomie du cerveau* (The Discourse on the Anatomy of the Brain) to shed light on his reception of Cartesian philosophy.

Key words: René Descartes, Nicolaus Steno, Cartesian Philosophy, History of Medicine, Neuroanatomy

Introduction

The notion of Cartesian dualism stands on the principle that the soul and the body are distinct entities (1). Proposed by the French polymath, René Descartes (1596–1650), his metaphysical interpretations of anatomy in *L'homme* (*Treatise on Man*) reflects the rise of medical scholasticism during the Renaissance (2, 3). With his Platonic and anti-Aristotelian stance, Descartes separates the corporeal substance (*Res extensa*) from the mental substance (*Res cogitans*) – distinguishing the soul as an immaterial thought unexplainable by physics or mathematics (4). This dichotomous theory represents the core of Cartesian dualism, raising the issue of soul-body interaction. One could argue that Descartes' philosophy is fundamentally flawed by its anatomical inaccuracies – based on a misconception that the pineal gland is suspended within the ventricles and acts as a valve regulating the flow of animal spirits (5). Niels Stensen (Latinised to *Nicolaus Stenonis* or *Nicolaus Steno*), one of the most renowned Danish anatomists of the Scientific Revolution, objectively criticised these anatomical errors in *L'homme*. His classic, *Discours sur l'anatomie du cerveau* (The Discourse on the Anatomy of the Brain) survived and played a major role in discrediting Cartesian doctrines (6). Steno's lecture was first delivered in Paris in 1665 then subsequently published by Melchisédec Thévenot for the first edition in 1669 (7). The *Discourse*, a compendium of anatomy, contains chapters that highlight Steno's critical appraisal of Descartes' philosophy. This paper reviews the contribution of Nicolaus Steno and his predecessors to the early development of neuroanatomy, shining light on Steno's reception of Cartesian philosophy.

Historical Origins of the Pineal Gland

The intellectual evolution of neuroanatomy originated in the golden age of Greece. In the 3rd century BC, formal teaching through open dissection was in-

troduced at the Alexandrian school (8). Although human dissection was not routinely performed, this was a significant step forward in understanding the workings of the living body.

The earliest anatomical descriptions of the pineal gland are thought to be those of Galen of Pergamon (129-200), arguably the most influential powerhouse and proponent of the Hippocratic School of thought (9). The magnitude of his medical compendiums overwhelmed the Byzantine Empire and even modern editions of his work consist of twenty-two dense volumes. Having lived under the reigns of the two greatest emperors in ancient history, Antonius Pius (136-161) and Marcus Aurelius (161-180), Galen's scientific works flourished (10). As a physician to the gladiators of Pergamon, he closely observed the biomechanics of human anatomy and gained experience treating traumatic injuries. This catalysed his anatomical research through dissections on animals allowing him to make substantial contributions to neuroanatomy (11). Of particular interest, he wrote extensively on the pineal gland in his classic *De Usu Partium* (*On the usefulness of the parts of the body*) (12). Galen coined the term pineal (*kônarion* in Greek, *glandula pinealis* in Latin) due to its resemblance of a pine cone (*kônos, pinus pinea*). During the Greek and Early Byzantine period, a gland was postulated to have a purely mechanical role in supporting venous structures:

"…behind the middle [third] ventricle, let us examine the body [the pineal body] which lies at the beginning of the canal connecting the middle ventricle with the posterior encephalon and which is called conarium [little pine cone] …" (12).

Galenic theories of the pineal gland must be viewed in the context of his contemporary understanding of neurophysiology. As a disciple of the Hippocratic doctrines, Galen defined health as the homeostatic equilibrium between the four bodily humors: blood, yellow bile, dark bile and phlegm (12). Galen hypothesised that the human temperament was composed of different variations of these four elements. In regards to the brain, he speculated that the ventricles formed a unique cavity comprising of an anterior ventricle, middle ventricle (3rd ventricle) and a posterior ventricle (4th ventricle) (13). These ventricles were thought to contain volatile airy substances, named the *psychic pneuma*, closely associated with the human soul (the *sensus communis*).

Prior to Galen, the pineal gland was defined as a purely mechanical valve regulating the flow of *psychic pneuma* between the middle and posterior ventricles (3rd and 4th ventricles) (13). Galen challenged this ancient notion, describing the complex venous structures adjacent to the pineal gland – the internal cerebral veins and an eponymous vein known today as the vein of Galen:

"…I believe that this gland resembling a pine cone and filling up the bifurcation of the large vein [vein cerebri magna] from which nearly all the choroid plexuses of the anterior ventricles arise was formed for the same usefulness as other glands that support veins as they divide…" (12).

He reasoned that the pineal gland could not regulate the flow of *psychic pneuma* due to its extracranial positioning and structural features. In its place, he proposed that the cerebellar vermis (named *vermicular appendix*) as the likely valve facilitating the flow of *psychic pneuma*:

"The notion that the pineal body is what regulates the passage of the pneuma is the opinion of those who are ignorant of the action of the vermiform epiphysis [vermis superior cerebelli] and who give more than due credit to the gland… Since this gland, however, is by no means a part of the encephalon and is attached not to the inside but to the outside of the ventricle, how could it, having no motion of its own, have so great an effect on the canal?" (12).

Following Galen, many scholars attempted to define the role of the cerebral ventricles and its mechanisms. During the late 4th century, Posidonius of Bysance conjectured a ventricular somatotopic model where the imagination was held in the anterior ventricle, reasoning in the middle and memory in the posterior (13). This was furthered by the noted Arabic physician, Hunayn ibn Ishaq (809-873) who postulated that extending the neck would allow *"access to the posterior ventricle where the memory is stocked…"* while flexion would isolate these memories to the posterior ventricle allowing one to have *"clear unpolluted ideas."* (13). However, medieval scholars were also perplexed about the precise role of these structures – from the pineal gland to the cerebellar vermis, and even the choroid plexus.

It was not until the Middle Ages where the anatomical illustrations by Guido da Vigevano (1280-

1349), and in the Renaissance where Berengario da Carpi (1460-1530) and Andreas Vesalius (1514-1564) would further clarify the anatomy of these texts (14-16). In *Isagogae Breves* (published in 1522), Berengario provided an array of more advanced schematic anatomical drawings based on human dissections, more than 20 years before the publication of Vesalius' *De Humani Corporis Fabrica* in 1543 which contains much more accurate and detailed anatomical description and diagrams (14, 16, 17). It was also during this period the Italian anatomist, Niccolò Massa (1489-1569), confirmed the presence of cerebrospinal fluid within the ventricles, invalidating the theory of the *psychic pneuma* (18).

The significant milestones achieved prior to Descartes raises the question; how do we explain the anatomical misconceptions in *L'homme*? On another level, we are faced with a false dichotomy – should Cartesian dualism be considered as a purely anatomical work and therefore completely invalid? Or rather, a theoretical postulation to support his philosophy?

The Cartesian Soul and its Origins

Early works of the Persian polymath Avicenna (Ibn Sina) shed light on the historical origins of the Cartesian *cogito*. Widely regarded as one of the most influential scholars of the Islamic Golden Age, Avicenna made important contributions to the theories of the soul and self-awareness (19, 20). This is particularly evident in his notable works, *Maqala fi'l-nafs* (Compendium on the Soul) and *al-Isharat wa'l-Tanbihat* (The Book of Directives and Remarks) (21, 22). Avicenna's proof for self-existence stands on the principle that the soul is independent of the body and capable of abstraction. This notion precedes the Cartesian *cogito* by 600 years and arguably forms the foundation to the dualistic view of the soul.

In the beginning of *Maqala fi'l-nafs,* Avicenna presents his epistemology through an imagery of a man suspended in space – the so-called "Flying Man".[21] The thought experiment raises the following question; if a man is created perfectly mature, but blind and unable to perceive any senses while suspended in the air, would he be able to acknowledge his own existence? Given the man cannot affirm the existence of his body, Avicenna proposes a dualist view where the soul remains independent from the body. However, as the man is aware of his thoughts, he cannot doubt his own existence, and therefore, Avicenna affirms the self-awareness of the soul and its substantiality (19, 20).

Indeed, a detailed philosophical review of Descartes' *cogito* is beyond the scope of this paper. However, it is important to note the historical evolution of the Cartesianism and its lasting legacy. This is perhaps best explored through the works of Gilbert Simondon (1924-1989), one of the most influential thinkers of contemporary French philosophy. In his classic, *Deux leçons sur l'animal et l'homme* (Two Lessons on Animal and Man), Simondon provides valuable commentary on the rise of Cartesianism during the Renaissance (23). He explores Descartes' controversial view on animals as non-sentient automata:

"…according to Descartes, animals possess neither intelligence nor instinct. The animal is a machine, an automaton … Descartes is the first who said animal behaviours are not instinctive… they are mechanical." (23).

It is interesting to note that Descartes' mechanistic philosophy plays a significant role in his interpretations of human anatomy. We now review the impact of Cartesian dualism on his anatomical discourse.

The Cartesian Anatomy

Descartes' dualistic philosophy must be viewed in the context of his neuroanatomical knowledge. His inquisitive nature can be particularly seen in *Excerpta Anatomica*, a compendium of anatomy, written between 1631 and 1648. In the chapters concerning the brain, Descartes describes three distinct layers: the external (cerebral cortex), the inner surface of the cerebral ventricles (ependyma) and the substance in between (white matter) (24). Of particular interest, he describes the inner surface in great detail, highlighting its complex network of pores surrounded by hollow nerves. In doing so, Descartes distinguishes short nerves innervating the pial cortical vessels from long nerves that converge at the skull base forming the spinal cord and distributing to the limbs and trunk. In *L'homme*, he postulates that these hollow nerves are

filled with animal spirits, supporting the structural integrity of the brain:

"…the source which produces these spirits is usually so abundant that they enter these cavities in sufficient quantity to have the force to push out against the surrounding matter and make it expand, thus tightening all the tiny nerve-fibres which come from it." (5).

According to Descartes, a "man" is formed by the substantial union of the body and the soul. In the 5th chapter of his other notable work, *Discours de la M*éthode (Discourse on the Method), he describes this union in detail:

"…the rational soul…cannot be derived in any way from the potentiality of matter, but must be specially created. And I showed how it is not sufficient for it to be lodged in the human body…except perhaps to move its limbs, but that it must be more closely joined and united with the body in order to have, besides this power of movement, feelings and appetites like ours and so constitute a real man." (4).

On reviewing *L'homme*, it is evident that Descartes performed frequent dissections of sheep brains to provide a rational explanation for his dualistic philosophy (2). The pineal gland, in particular, was speculated to be the "seat of the soul" due to its central location within the brain and its peculiar shape. Its capacity to regulate the flow of animal spirits was thought to be due to its mobility, *"…for since it supported only by the little arteries which surround it, it is certain that very little will suffice to move it."* (4). Descartes' anatomical conceptions appear to be heavily influenced by his Jesuitical education as well as the teachings of Erasistratus, the Greek anatomist and pioneer of neurophysiology. Erasistratus had already established the concept of hollow tubular nerves carrying *psychic pneuma* to the brain, inspiring Descartes to continue his search for the soul (25). Interestingly, this was despite Vesalius' anatomical corpus becoming widely studied across occidental Europe.

Descartes' efforts to describe the soul-body interaction deserve recognition as a landmark in the study of cerebral localisation. Through his rationalist and mechanistic methods, Descartes proposed many interesting theories on the role of the pineal gland. Animal spirits carried by hollow peripheral nerves were thought to converge at the pineal gland to produce a 'message' that can be processed by the soul. This formed the basis for his theories on the nociceptive reflex (purely mechanical involving the pineal gland, excluding the spinal cord) and the coordination of eye movements and vision (4, 25). According to Descartes, the pituitary gland could not have a possible role in regulating the flow of animal spirits – due to its extracranial location confined within the sphenoid bone (sella turcica) making it immobile:

"…for the pituitary gland is not, like the pineal gland, in the brain, but beneath it and entirely separate, in a concavity of the sphenoid bone specially made to take it… Moreover, it is entirely immobile, whereas we experience, when we imagine, that the seat of the common sense, that is to say the part of the brain in which the soul performs all its principal operations, must be mobile." (4).

Following Descartes' death, his treatise was studied extensively by Cartesian scholars. This led to the publication of the first Latin edition in 1662 by Florentius Schuyl with remarkable copper engravings (4). Although Schuyl was praised for his artistic prowess, his illustrations were criticised by the Parisian editor, Claude Clerselier, who believed Schuyl's artworks to lack 'Cartesianism'. Clerselier solicited new illustrators – Gerard van Gutschoven and Daniel de La Forge, who were well versed in Cartesian philosophy. With new schematic drawings, Clerselier published the first French edition in 1664 (2). Interestingly however, in the preface of this edition, La Forge advises the readers that his anatomical drawings should be viewed in the context of Descartes' philosophy rather than an authentic representation of anatomy (2). For instance, the pineal gland was deliberately drawn larger to highlight its central role in Cartesian dualism. Modern scholars, should therefore recognise *L'homme* as a theoretical masterpiece, rather than a purely neuroanatomical work.

To highlight the early reception of Descartes' *L'homme*, we now review the contributions of Nicolaus Steno to this corpus.

Nicolaus Steno: His Life and Contributions to Neuroanatomy

Nicolaus Steno (a patronym for the Danish *Steensen, "son of Steen"*), was born in 1638 in Copen-

hagen. Although raised in a Lutheran church, he died as a Roman Catholic vicar apostolic in Schewerin in 1686. In 1656, Steno commenced his medical studies at Copenhagen University under the noted Danish anatomist and mathematician, Thomas Bartholin. As a student, he produced the most interesting collection of notes, known as the *Chaos*-manuscript, depicting his academic prowess from an early age (7).

Steno travelled abroad to conclude his studies. First to Amsterdam, where he made his first anatomical discovery, the parotid excretory duct (the *ductus stenonianus*, or Stensen's duct) (26). Then to Leiden, where his works flourished under François de le Boë Sylvius and van Horne. His research intensified following a dispute about his first discovery, and in 1661 published his classic, *On glands of the mouth and salivary ducts*, followed by *Observationes anatomicae* in 1662 with three additional papers on glands (27). Well versed in the works of René Descartes, Steno developed a deep interest in the discussion of Cartesian philosophy and became friends with Baruch Spinoza (Benedictus de Spinoza), arguably one of the foremost exponents of 17th Century Rationalism (7). Through his anatomical research however, Steno soon realised the flaws in their philosophical systems.

On his return to Denmark in 1664, he published one of his major works, *On muscles and glands* (28). Despite his efforts, he failed to receive professorship at the university and continued his travels across Europe. From 1664 to 1665, he lived in Paris where he worked alongside prominent scientists and quickly gained the reputation as the most distinguished anatomist. His famous lecture *The Discourse on the Anatomy of the Brain* was delivered at the Thevenot's house for a gathering of scholars (6). He then continued his travels to Montpellier, meeting distinguished English scientists William Croone, John Ray and Martin Lister. In the following years, Steno settled in Tuscany where he worked closely with members of the Cimento Academy, most notably Francesco Redi and Vincenzio Viviani (7).

In 1666, he received a head of a large shark for dissection which catapulted his research into a new direction. His particular interest in the shark's teeth led to the research into fossil shark-teeth and further into the field of geology. In 1669, he published his *Prodromus*, now considered a landmark geological treatise, in which he established the founding principles of crystallography and stratigraphy (29). He returned to Copenhagen between 1672 and 1674 where he worked as the "Royal Anatomist", delivering his famous inaugural lecture on his dissection findings of a female corpse (26).

Steno once again left Denmark with the intention of becoming a Catholic priest. In 1675, he was ordained to the priesthood in Florence and by 1677, was consecrated a bishop in Rome and appointed Vicar Apostolic of the Northern Missions. Steno was the first scientist of the modern age to be raised to the honour of the altars (7).

Steno's Critique of Descartes

Soon after the Latin translation of *L'homme* was published, scholars raised questions about the accuracy of Descartes' descriptions and Schuyl's illustrations. Such prompt discussions testify to the importance of Descartes' treatise for those who practiced anatomy in Europe at the time. Indeed, during the 17th century, many debates took place regarding the anatomy of the brain, most notably through the works of Thomas Willis (1621-1675) in his *De cerebri anatome* (1664) and Nicolaus Steno's *Discourse* (7). Interestingly, Steno remarked that *L'homme* contained *"some not inelegant figures"*, conceding that *"they have proceeded from a clever brain,"* but with doubts "*whether such images can be seen in any brain."* (7). He was the first to critically review Descartes' theory on the pineal gland, purely relying on objective anatomical facts. Steno's remarks were later misused by Spinoza to discredit Cartesian dualism – while Steno himself viewed Descartes' treatise as a purely theoretical construction to support his philosophy not as an academic anatomical work. This is exemplified by his humble clarifications in the *Discourse*:

"I should have been prevented from referring to the faults in this treatise by the respect that I feel is owed by everyone, myself included, to intellects of this order (Descartes, Vesalius), I would have been pleased to admire it, with the rest, as a description of a beautiful machine, invented entirely by him, if I had not met many persons who take it as quite the opposite and who wish to pass it off as a

faithful representation of what lies hidden in the compartments of the human body." (6).

In the first section of the *Discourse*, Steno defends the rationalist interpretations of Descartes. He invites other scholars to appreciate Descartes' anatomical approximations as a conceptual model rather than a factual treatise.

"There is no need, therefore, to condemn Monsieur Descartes if his system of the brain is not wholly in conformity with experience. The excellence of his mind, apparent chiefly in his "Treatise of Man", makes amends for the errors in his hypotheses. We note that very skilful anatomists, such as Vesalius and others, have made similar mistakes. If these great men, who passed the better part of their lives in dissection, have been pardoned for these faults, why should be less indulgent with respect to M. Descartes, who has spent his time very happily in other speculations?" (6).

Steno then continues to provide a systematic appraisal of Descartes' observations, particularly concerning the position of the pineal gland. He clarifies that animal spirits could not be regulated by the pineal gland as, *"…the posterior part…is so much outwith the cavities…without any visible passage by which air or other fluid might enter the ventricles."* (6). In regards to its mobility as proposed by Descartes, Steno objects that the gland is *"…so entangled among all the parts of the brain and so well attached to these parts on all sides"* that it could not possibly move side to side without tremendous force or without breaking the fibres it attaches to (6). All these objective criticisms were fundamental to refuting Descartes' philosophy. For instance, all theories proposed by Descartes on psychosomatic functions such as sensory perception, voluntary motion or attentiveness revolved around the pineal gland. Thus, with Steno's proof that the pineal gland cannot be moved, the entire Cartesian neurophysiology proposed in *L'homme* was challenged (25).

It is, therefore, not surprising that in the *Ethics*, Spinoza uses Steno's refutations to dismiss the Cartesian dualistic theory (30). Spinoza criticises the methods used by Descartes in describing the role of the pineal gland, highlighting the lack of empirical evidence to support his dualistic notions:

"Such is the doctrine of this illustrious philosopher…I could hardly believe to have proceeded from so great a man. Indeed, I am lost in wonder, that a philosopher, who had stoutly asserted, that he would draw no conclusions which do not follow from self-evident premises… could maintain a hypothesis, beside which occult qualities are commonplace." (30).

As illustrated above, it is evident that many neuroanatomical 'errors' are found in *L'homme*. However, from earlier correspondences, it is clear that Descartes was aware of the anatomical works of Galen, Vesalius and Caspar Bauhin (1560-1624). How then do we correlate the 'man' depicted by Descartes in *L'homme* to the 'man' observed by anatomists?

To address this incongruency, we now review the Cartesian anatomy in greater detail in light of Steno's criticisms.

The 'Man' of Descartes versus the 'Man' of Steno

Anatomical considerations of *L'homme* reveal two contradictory findings. On one hand, Cartesian anatomy could be regarded as eccentric and detached from true observations of human dissection. On the other hand, this treatise could be viewed as an attempt to correlate anatomical structures to their unique functions. Moreover, Descartes remains as a scholar who either neglected the anatomical science of the human body or attempted to provide descriptive value to anatomy itself. According to Descartes in *Discours de la méthode* (Discourse on the Method), the structural features of an organ dictates its physiologic functions (4). These judgements were clarified by the distinguished French historian, Jacques Roger, in his classic *Les sciences de la vie dans la pensée française du XVIIIe siècle* (The Life Sciences in Eighteenth-Century French Thought):

"…since for Descartes everything was a matter of shapes and motions, it was essential to discover the shapes of organs." (31).

It is important to note that Descartes himself acknowledged the hypothetic status of his 'man'. His treatise was not to provide a complete physiology of the human body, but rather to show that it is possible to account for human behaviour without occult qualities. To do so, Descartes used plausible bodily causes to explain the observed effects and functions of the living body. By strict definition, these possible 'causes' pro-

posed by Descartes were not found in anatomical texts – as they were rather invisible elements that could not be scientifically proven. This is particularly evident in Descartes' explanation of cerebral functions:

"[The] functions…do not depend at all on the external shape of the visible parts which the anatomists distinguish in the substance of the brain and in its concavities, but solely on three factors, namely, the spirits that come from the heart, the pores of the brain through which they pass, and the way in which the spirits are distributed in these pores." (32).

Such hypothetical-deductive reasoning is a key feature of Descartes' treatises. On many occasions throughout *L'homme*, Descartes goes beyond the limits of anatomical observations to explain the 'unknown' mechanisms of the brain (2, 25). Consequently, Cartesian physiology cannot be dismissed by simply disputing anatomical facts – as Descartes' 'man' is rather a conceptual model that cannot be explained by the power of observation (32).

Steno acknowledged *L'homme* as an interesting theoretical modelling of the human body – not as an accurate reconstruction of anatomical mysteries. He agreed on many occasions that the 'man' described by Descartes does not correspond to the 'man' he observes in anatomical theatres (32). However, common misinterpretations of Steno's criticisms lead to the assumption that Steno completely dismissed the Cartesian philosophy. In the *Discourse*, Steno clarifies his stance:

"As far as Mr Descartes is concerned, he knew too well the shortcomings of the description

that we have of man to explain his true structure. Therefore, he does not undertake to do that

in his Traité de l'homme but he explains to us a machine that would do everything men are

able to do… Mr Descartes thus must not be condemned if his system of the brain is not strictly in agreement with experience." (7).

Steno further elaborates that to truly understand the physiologic functions of the brain, one must, *"… dismantle it piece by piece and consider what these can do separately and together."* (7). Thus, for Steno, it is necessary – not sufficient – to observe the structures of the brain to precisely understand its functions. To do so, Steno reiterates that anatomists must not rely simply on the external features; but include more complex experiments to reveal subtle divisions of parts, targeted excisions and deductions from comparative anatomy.

On the one hand, Descartes argues that there are many elements within our body that our senses do not perceive. Therefore, it would be inappropriate to dismiss Descartes' treatise with purely anatomical observations, but also to explain all living functions of the human body by means of anatomy. On the other hand, Steno provides an analogy between the body and a machine that can be 'dismantled' to explain its functions. In both cases however, for Descartes and Steno, they do not attempt to define the true physiological process but rather demonstrate that autopsy alone cannot provide explanations for all of the body's living functions.

Conclusion

Anatomists of the Renaissance exemplified an era of scholarship and dedication to improve the understandings of the living body. This review of René Descartes' *L'homme* and its reception by Nicolaus Steno highlight the evolution of neuroanatomy throughout the course of history. As described in this paper, their works illustrate the significant milestones in the early development of anatomical and functional knowledge of the brain. It is clear that Descartes proposed a conceptual model of a 'man' to provide a rational explanation for his dualistic philosophy. Although *L'homme* was widely criticised by contemporary anatomists and philosophers, Steno's *Discourse* implores that Descartes' treatise deserves recognition as a theoretical masterpiece, not a factual treatise on neuroanatomy. Metaphysical and theological interpretations of these texts have led to complex philosophical debates; however, it is their contributions to neuroanatomy that should also be remembered. It is on the shoulders of giants such as René Descartes and Nicolaus Steno that we base our current understanding of the nervous system.

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