# Niels Stensen: A 17th Century Scientist with a Modern View of Brain Organization

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**ABSTRACT:** In 1665 the Danish scholar Niels Stensen (1638-1686) reached Paris, where he pronounced a discourse on brain anatomy that was to orient neuroscientists for years to come. In his lecture, Stensen rejected ancient speculations about animal spirits and criticized René Descartes and his followers who, despite a poor knowledge of brain anatomy, elaborated complex models to explain the multifaceted function of what he considered the principal organ of the human mind. He advocated the need for studying the brain through a comparative, developmental and pathological convergent approach and called for appropriate dissection methods and accurate illustrations. His own careful anatomical studies permitted him to precisely depict many brain structures. After pioneering works in paleontology and geology, he devoted himself to theology. In 1677 Stensen converted from Lutheranism to Catholicism and, while working relentlessly as a bishop and apostolic vicar in Northern Europe, he died in self-imposed poverty at age 48.

**RÉSUMÉ: L'organisation anatomique et fonctionnelle du cerveau selon Sténon.** En 1665, le savant Danois Nicolas Sténon (1638-1686) arrive à Paris où il prononce un remarquable discours sur l'anatomie du cerveau. Dans cette allocution, il dénonce d'abord l'ancienne théorie des esprits animaux pour ensuite critiquer vertement les philosophes comme Descartes qui, malgré une piètre connaissance de l'anatomie du cerveau, développent des modèles complexes pour expliquer le fonctionnement de ce qu'il considère être l'organe suprême. Il souligne l'importance d'utiliser une approche multidisciplinaire, impliquant l'anatomie comparée, l'embryologie et la pathologie et insiste sur la nécessité de méthodes de dissection et d'illustration adéquates. Ses propres études anatomiques lui permettent de décrire très précisément et pour la première fois plusieurs structures cérébrales. Après des travaux remarquables en géologie, il délaisse définitivement la science pour la théologie. Consacré évêque et vicaire apostolique en 1677, Sténon, l'un des plus grands esprits de son temps, meurt dans une pauvreté extrême à Schwerin en Allemagne à 48 ans.

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This historical review is devoted to Niels Stensen or Steensen (Nicolaus Stenonis in Latin, often shortened to Steno in English), a singular 17th century scholar who made a brief but enduring contribution to the field of brain research. Although the modernity of his discourse has been underlined on several occasions, his exact contribution to brain anatomy has received surprisingly little attention. Our goal here is to provide an overall picture of this exceptionally gifted scientist, with an emphasis on his view about brain anatomy and function that will be critically examined and compared with those of some prominent contemporary figures. We will briefly allude to the strong impetus that this multifaceted scholar gave to paleontology and geology, but a detailed consideration of his religious convictions or philosophical thoughts regarding the relationship between faith and science is beyond the scope of the present paper. A brief account of Stensen's life is provided below to better appreciate the role he played in the development of scientific knowledge in the 17th century. More details about Stensen's biography can be found in the works of the distinguished Danish researchers and historians of science, Gustav Scherz[1,2] and Troels Kardel.[3,4]

## The birth of a celebrated anatomist

Niels Stensen (Figure 1) was born in Copenhagen, Denmark, on January 11, 1638. He was the son of a devoted Lutheran goldsmith working for Denmark's King Christian IV (1577-1648). His poor health condition did not prevent him from acquiring a deeply rooted humanist education, thanks to the efforts of Ole Borch (Olaus Borrichius; 1626-1690), a young and highly devoted professor who would later become a close friend. In 1656, Stensen entered the medical school in Copenhagen, where he began studying natural science and anatomy under the learned tutorship of the famous anatomist Thomas Bartholin (1616-1680) and the botanist and court physician Simon Paulli (1603-1680). During the war with Sweden and the siege of Copenhagen (1658-1660), teaching was interrupted at the University of Copenhagen and Stensen choose that time to undertake a long study journey throughout Europe, as was common practice for scholars at that time. Following Bartholin's recommendation, he headed toward Amsterdam to perfect his knowledge of anatomy under Gerhard Blaes (Blasius, 1625-

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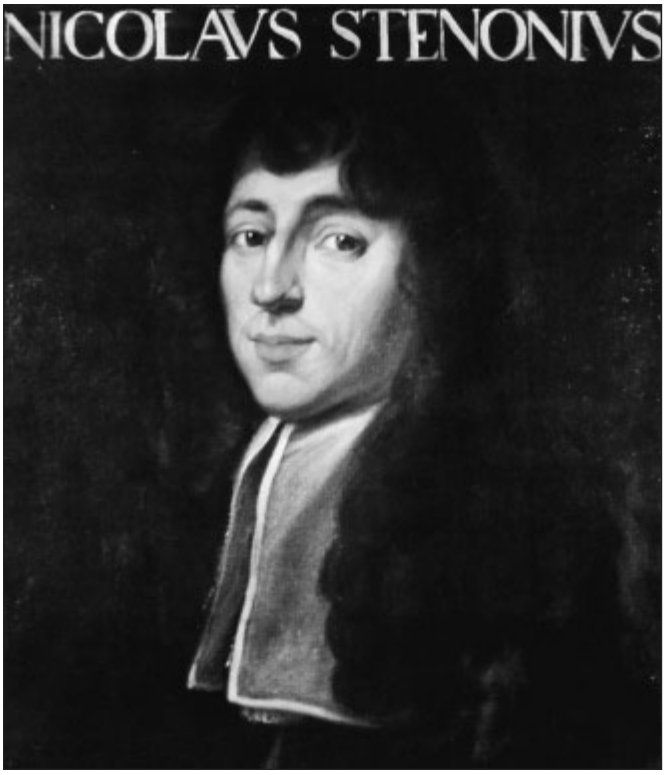


***Figure 1:*** *A portrait of Niels Stensen as a scientist at the Court of the Grand Duke of Tuscany. Unsigned, attributed to the Tuscan court painter Justus (Jan) Sustermans (1597-1681). Ufizi Gallery, Florence, Italy.*

1692). After a series of dissections of human bodies directed by Blaes, Stensen was permitted to dissect alone the head of a sheep on April 7, 1660. This single event allowed the young scientist to make his first anatomical discovery – the excretory duct of the parotid gland (still called *ductus stenonianus* or Steno's duct) – a finding that Blaes immediately claimed as his own. The priority dispute lasted several years and drove Stensen from Amsterdam to Leiden, where he was introduced to brain anatomy by the celebrated Franz de le Boë (Fransciscus Sylvius, 1614-1672), while continuing his work on excretory ducts and glands under the supervision of Johannes van Horne (1621-1670).[1-4]

Stensen made several fundamental discoveries while in Leiden, including the lachrymal gland and excretory duct. This led him to realize that tears were not a secretion of the brain, as suggested by the then commonly accepted principles of Galenic medicine. He also initiated a series of brilliant studies on the nature of muscular tissue and the mechanics of muscular contraction. In contrast to what was commonly believed, he showed that muscle contraction did not involve a volume increase due to the influx of some hypothetical animal fluid circulating within hollow nerves, but was the result of a simple geometric shortening of muscular units. He challenged another ancient view – the one that considers the heart as the source of all vital spirits – by showing that this organ was nothing else than a simple muscle. In a letter to Bartholin, who had difficulty accepting this new concept, Stensen offered the following: "There is nothing in the heart which is not in the muscle and nothing is missing in the heart that is found in the muscle".[5] Besides fame for his scientific discoveries, Stensen acquired notoriety as an anatomy teacher by performing several public dissections of human cadavers while in Leiden.

Late in 1663, Stensen had to interrupt his brilliant studies in Leiden because of the death of his stepfather Johann Stichmann, and his mother, who was seriously ill, died shortly thereafter. While in Copenhagen, Stensen published a treatise summarizing his work on glands and muscles.[6] He dedicated it to Frederick III (1609-1670), King of Denmark, expecting to receive the vacated seat in Copenhagen's *Domus anatomica*. For various political reasons, however, Stensen did not succeed in obtaining this prominent position that was finally offered to Thomas Bartholin's nephew Matthias Jacobæus (1637-1688). Despite his growing reputation as an anatomist, Stensen was unable to secure any academic position in Denmark and had to resume his travels through Europe.[1-4]

**In the learned circles of Paris**

After a short detour though Amsterdam and Cologne, Stensen went to Paris, where his former teacher Ole Borch and his Amsterdam and Leiden schoolmate Jan Swammerdam (1637-1680) were already staying. Not long after his arrival in Paris in November 1664, the University of Leiden conferred on Stensen the doctorate of medicine diploma *in abstentia*. At about the same time, Stensen was asked to perform dissections of human bodies at different Parisian amphitheaters, including that of the Medicine School on *Rue de la Bucherie*. These extraordinary sessions attracted the attention of many physicians as well as laypersons and they were reported with praise in the newly created *Journal des Sçavants*.[7]

Besides dissecting cadavers, Stensen also performed various experiments on living animals, as reported in Ole Borch's diary.[8] In one of these experiments, he showed that tying the descending aorta in a dog led to paralysis of the hindquarters, movement being restored immediately after ligation removal. This ligature study revealed the importance of blood supply in muscular activity and Stensen provided a brief account of it his 1667 treatise that summarizes his work on muscles.[9] A copy of this book eventually attracted the attention of the London physician William Croone (1633-1684), one of the founding members of the Royal Society, who asked Richer Lower (1631-1691) to repeat the experiment in front of the Society members. Lower was a close collaborator of Thomas Willis (1621-1675) at Oxford and a skillful researcher renowned for his work on blood transfusion and cardiopulmonary system. However, it was not before detailed information was obtained from Stensen himself that another famous member of Willis's circle of friends and collaborators, the surgeon Sir Edmund King (1629-1709), was able to reproduce the experiment, hence contributing to Stensen's reputation in England.[10]

These studies were undertaken at the domain of Melchisédec Thévenot (1620-1692), where Stensen, Swammerdam and Borch spent happy and fruitful days devoted to research. Thévenot was a well-known scholar who had previously served as French ambassador to the Republic of Genoa and was to become the Chamberlain and Royal Librarian to King Louis XIV (1638-

1715). At Thévenot's Parisian house on *Rue de la Tannerie* in the *Marais* or at his country domain at Issy were held the learned meetings that eventually led to the establishment of the *Académie royale des* Sciences.[2,10] It is at one of Thévenot's meetings held early in 1665 that Stensen presented his remarkably insightful *Discours sur l'anatomie du cerveau* (Lecture on the Anatomy of the Brain).[11] At only 26-years-old and having to deliver his lecture in French, Stensen succeeded in impressing a high-minded assembly composed chiefly of learned physicians and surgeons interested in brain anatomy, but also concerned about various philosophical problems related to the development of scientific knowledge. The major issues raised by Stensen in his lecture will now be reviewed and discussed in turn.

**Debunking ancient theories**

Stensen began his lecture by admitting how ignorant he was of the anatomy of the brain, which he considered the most beautiful masterpiece of nature and the principal organ of our mind. Yet, he recognized that the human mind has its own limits: "The Soul which imagines it can penetrate into everything without it; and that nothing in the world can set bounds to its knowledge, is nevertheless utterly at a loss to describe its own habitation, and is no where more to seek than at home".[11] He further stated that "it would be a great blessing to mankind if this most delicate part, and which is liable to so many dangerous diseases, were as well understood as the generality of anatomists and philosophers imagining it to be […] as if they had been present at the formation of this surprising machine, and had been let into all the designs of the Great Architect. […] We need only view a dissection of the large mass, the brain, to have ground to bewail our ignorance. Let us without flattering ourselves any longer, freely acknowledge our ignorance, that we may not first deceive ourselves and others afterwards, by promising to show them the true structure of this organ".[11]

Stensen criticized the ancient theories that attributed to the cerebral ventricles a crucial role in brain function: "The Ancients were so far prepossessed about the ventricles as to take the anterior for the seat of common sense, the posterior for the seat of memory, that the judgment which they said was lodged in the middle, might more easily reflect on the ideas which came from either ventricle. I would only ask those who are still of the same opinion, to give us the reason why should we believe them for there is nothing satisfactory in all that has been hitherto said in favor of it".[11] Stensen argued that the brain cavities are as poorly known as the brain substance itself and he considered farfetched the concepts of the cerebral ventricles as being the seat of animal spirits or the receptacle of brain excrements that are to be expulsed by either the nose, mouth or eyes.

He also blamed the dissection methods used by ancient authors as well as by contemporary investigators. He warned about the possibility of creating artifacts while dissecting the brain because "the substance of the brain is so soft, and the fibers so tender that they can hardly be touched without breaking".[11] He believed that sectioning the brain into slices provided little information about the internal organization of this organ, whereas the method consisting of unwrapping the various folds of the brain yielded more useful information, but only for the outer surface of the material under investigation. A third approach, which involved separation of the grey matter from white, in addition to the unfolding of the convolutions, went a little further but did not allow to penetrate beyond the surface of the medulla (subcortical white matter). He suggested adding to these three methods of dissections, which have been combined in various ways throughout the years, a variety of longitudinal and transverse sections. However, he held that the most useful procedure would be one that would enable the careful tracing of nerve filaments though the substance of the brain to see where they pass, where they originate and where they terminate.

Stensen then criticized the lack of coherence regarding the anatomical nomenclature in which he saw a major source of confusion that could be easily eliminated by the establishment of a general consensus among scholars. He condemned contemporary authors who were still using ancient terms such as *nates* (buttocks), *testes, anus, vulva,* and *penis* to describe brain structures. About such terms, he stated: "they have no relation at all to the parts express by them in the anatomy of the brain, and in support of his contention he stated that "what one author calls *nates*, another calls *testes*, etc.".[11]

Just a year before Stensen's pronounced his celebrated lecture, two major works dealing with the anatomical and functional organization of the brain had been published. The first opus was *Cerebri* anatome,[12] the celebrated brain anatomy treatise of the English physician Thomas Willis, and the second work was *L'Homme* (The Treatise of Man),[13] a treatise expounding the mechanistic view of the working of the human body developed by the French philosopher René Descartes (1596-1650). These two influential contributions, particularly Descartes' treatise, were the talk of the day in Paris, and yet Stensen did not hesitate to criticize both of them on the ground that they contained speculations unsupported by direct observations.

**On Thomas Willis**

As noted by the distinguished historian of medicine who worked at Oxford, Kenneth Dewhurst (1919-1984), the remarkable careers of Stensen and Willis had a strikingly similar initial course.[14] First, the two famous scholars saw their medical studies interrupted by war: Willis had to participate in the defense of Oxford against the army of Oliver Cromwell (1599-1658) in 1643, while Stensen was involved in the protection of Copenhagen against the Swedish invaders led by Charles X Gustav (1622-1660) in 1658. Second, both individuals were highly devoted Christians: Willis became an active member of the Anglican Church and Stensen was initially a convinced Lutheran who later converted to Catholicism. Third, some of their most significant scientific works were accomplished while they were members of a "private club" that later became a renowned scientific institution: Willis was a central figure of the Oxford group (the *virtuosi*), whose efforts led to the creation of the Royal Society of London in 1660, while Stensen belonged, at one time, to the Thévenot's circle, which laid the ground for the founding of the *Académie royale des sciences* in 1666.[14,15]

Although they were both physician with a major interest in brain anatomy, their way of approaching the study of the central nervous system differed radically. Willis was a busy and highly successful physician doing anatomy largely on a part time basis, whereas Stensen was more of a scientist than a physician and, as a fulltime researcher, he was entirely devoted to the study of

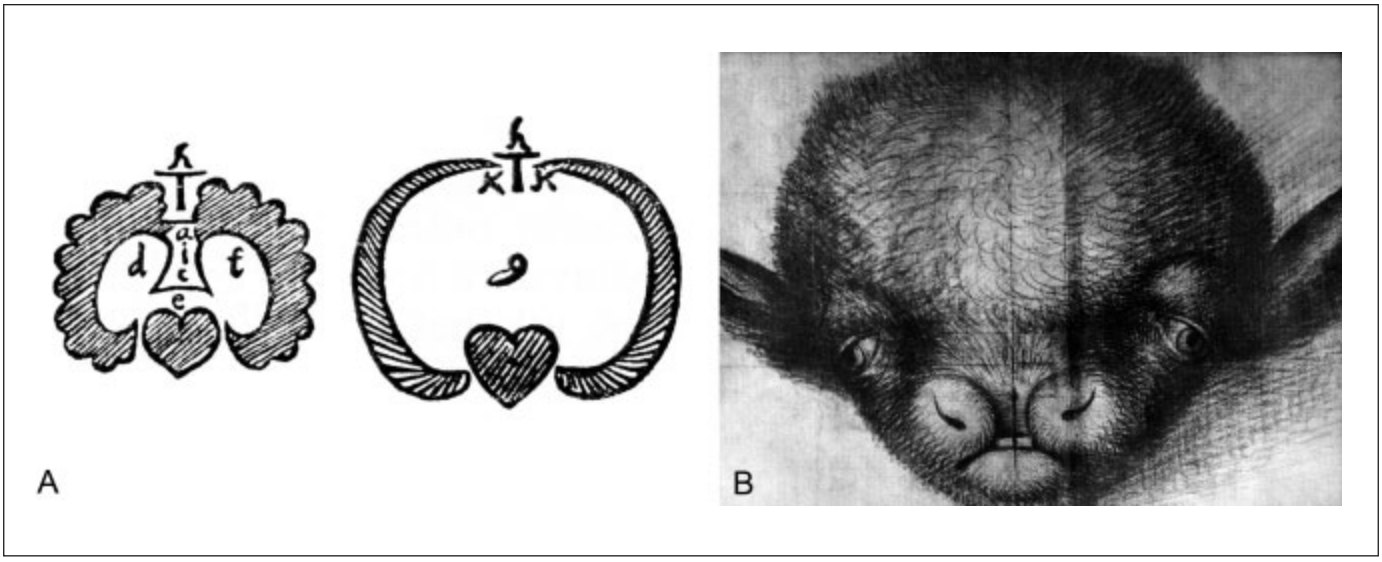


***Figure 2:*** *A: Reproductions of figures 3 and 4 of Stensen' letter on hydrocephalus published in 1673[16]. They provide highly schematic views of coronal sections through the forebrain, as it appears in normal condition (left) and in the hydrocephalic calf (right). The latter drawing clearly shows lateral ventricle enlargement, which led to the agenesis of the corpus callosum and the flattening of cerebral sulci. Stensen noted that the markedly enlarged lateral ventricles could hold four pounds of water "with the same color and taste as that which usually enters the cavities of the brain in healthy animals"[16]. B: Reproduction of the red-chalk drawing of the head of the hydrocephalic calf that was joined to the scientific report on hydrocephalus written in Italian by Stensen. The Archduchess Anna de' Medici sent this material to her brother Ferdinand II, Grand Duke of Tuscany, at the end of the summer of 1669. Achivo di Sato. Florence. Italy.*

anatomy.[14] In his 1665 lecture, which is characterized by a healthy skepticism that gives it a truly modern flavor, Stensen made it clear that he was not ready to sacrifice scientific objectivity on the altar of clinical speculation. The major reproaches that Stensen addressed to Willis concerned his unsupported speculations about the localization of brain functions. For Stensen, Willis was "the author of a very singular hypothesis. He lodges common sense in the corpora striata, the imagination in the corpus callosum, and the memory in the cortical substance. […] How can he then be sure that these three operations are performed in the three bodies which he pitches upon? Who is able to tell us whether the nervous fibers begin in the corpora striata, or if they pass through the corpus callosum all the way to the cortical substance? We know so little of the true structure of the corpus callosum that a man of tolerable genius may say about it, whatever he pleases".[11] Later, Stensen brought support to these criticisms by dissecting the brain of a calf suffering from obstructive hydrocephalus (Figure 2). This occurred on June 1669 at the summer castle of Anna de' Medici (1616-1676), Archduchess of Austria, near Innsbruck. The scientific letter that ensued[16] is considered by many as the first pathophysiological explanation of the development of hydrocephalus.[17-20] In this very fine piece of pathological anatomy, Stensen reported that the accumulation of cerebrospinal fluid into the lateral ventricles has led to marked brain malformations, including corpus callosum agenesis, cerebral cortex thinning and corpus striatum atrophy. Despites such a massive reduction of both cortical and basal hemispheric structures, Stensen noted that the animal had lived for many years without displaying motor or sensory deficits. He concluded that these brain regions were not absolutely necessary for animal sensation and movement. Having presumably Willis in mind, he terminated his letter by saying that those who have based their physiology of sensation and movement on the presence of the corpus striatum should have some doubt about it.[16]

In his lecture on the anatomy of the brain, Stensen raised some serious concerns about the status of medical iconography. He thought that the anatomical illustrations were too often copied from one book to another (error included) rather than being based on actual dissections. He called for clearer and more informative illustrations: "We ought therefore to leave nothing undone to produce exact figures; in order to which a good drawer is as necessary as a good anatomist".[11] While admitting that Willis' diagrams – many of which were drawn by the famous architect Christopher Wren (1632-1723) – were the best then available, he did not hesitate in pointing out several inaccuracies in these drawings. For example, he found unfaithful the representation of cross-sections of the striatum in Willis's seventh and eight illustrations of *Cerebri anatome* because they do not accurately depict ascending and descending fibers. He also noted the absence of the trochlear nerve and the lack of a clear demarcation between the pons and the medulla in Willis' third illustration (Figure 3A).

While some of these negative remarks are obviously justified, Stensen's overall critical attitude toward Willis can be attributed, at least in part, to his youthful enthusiasm that tended to blind him to the merits of contemporary neuroanatomists. A scientist as eminent as Thomas Willis, who literally opened the path to modern neurology, as advocated by Kenneth Dewhurst[14] and Robert Martensen,[21] did not deserve such harsh treatment. True

to his noble nature, however, Willis accepted positively the criticism formulated by Stensen. He even praised the young Danish scientist for the pertinence of his work in his treatise on the Souls of Brutes (*De Anima Brutorum*) published only a few years after Stensen's lecture.[22] Willis recognized that his "pleasant speculations" about brain functions, such as the role he attributed to imaginary animal spirits, were not based on direct observations. At the same time he ingenuously admitted that he could not easily refrain himself from speculating widely about the possible significance of his findings. According to one of Willis most prominent biographers, the Swiss physician Hansruedi Isler, the latter attitude was typical of pre-Newtonian scientists, whose boundless scientific optimism allowed them to overthrow their scholastic adversaries, but prevented them from recognizing the limits of their own endeavors.[23]

**On René Descartes**

Stensen was highly critical of the limitation of contemporary science, but he was even more severe toward philosophies based on faulty premises, like the one proposed by Descartes and his followers. When he was student in Copenhagen, Stensen enthusiastically espoused the major principles that should guide scientific investigation, such as they were first formulated by Descartes in his *Discours de la méthode*.[24] Later, however, he was greatly disappointed by the content of Descartes' Treatise of Man, whose first edition (Latin: *De Homine*) appeared in Leiden 12 years after the death of his author.[25] He thought that Descartes' treatise expressed views on brain anatomy and physiology that were acquired by reading rather than by direct experience. In a letter to Bartholin dated August 1662, Stensen wrote about Descartes' *De Homine*: "There we see fairly elegant drawings which are certainly a product of the mind of a genius, but I strongly doubt whether one would ever find them in a normal brain" (Figure 3B).[26]

In his lecture on brain anatomy, which he pronounced less than a year after the French version of Descartes treatise (*L'Homme*) was published in Paris,[13] Stensen did not hesitate to blame the famous philosopher for not having applied his own method to the study of the brain. Despite his admiration for the heuristic value of Descartes' man-machine concept, he condemned Cartesian arbitrary speculations at the expense of facts of observation. Stensen was particularly critical of Descartes' idea of the pineal gland acting as a functional interface between mind and body. Through careful dissections of the human brain, whose results he illustrated in the published version of his lecture (see below), Stensen was able to demonstrate that Descartes had a poor knowledge of the anatomy of the pineal gland. Among other things, he demonstrated that, in contrast to what was advocated by Descartes: a) the pineal gland was embedded in the substance of the brain and, as such, could not move; b) there was no cavity dotted with nerve endings surrounding it; and c) the blood vessels connected to the gland were not arteries but veins, carrying the blood from the brain to the heart and not the other way round.[27] In this regards, Stensen stated: "The supposed connection of this gland [pineal] with the brain by means of arteries is likewise groundless: for the whole basis of the gland adheres to the brain, or rather the substance of the gland is continuous with that of the brain, though the contrary be affirmed by M. Descartes".[11]

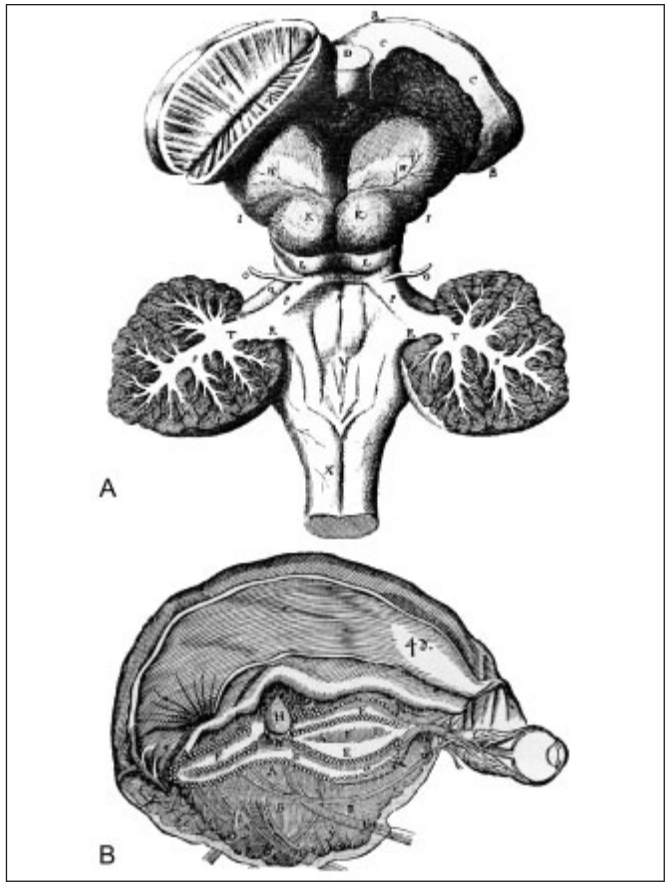


***Figure 3:*** *A: Reproduction of plate VIII in Willis' Cerebri Anatome[12], which shows a dorsal view of the brainstem and basal ganglia in a sheep. The hemispheres have been removed to better illustrate the basal ganglia, and the corpus striatum on the left side has been cut in half to show its characteristic striations. B: Reproduction of a diagram that appears on page 63 of the 1662 edition of Descartes' L'Homme[13]. It provides a rough sketch of the human brain with the pineal gland (labeled "H") drawn inside the cerebral ventricles, whose walls are shown as being literally covered with small pores.*

Stensen also expressed some concerns about the Cartesian materialistic view of man as a machine: "Such of M. Descartes' friends who look upon his man only as a machine, will be so good as to believe that I do not here speak against his machine, the contrivance of which I have admired; but as for those who pretend to demonstrate that M. Descartes's man is made like other men; anatomical observations may easily convince them that this is a fruitless attempt".[11] Stensen was one of the first scholars to foresee the possibility that Descartes' model offered to study the working of the human brain within a mechanistic context. At the same time, he realized the futility of attempting to extend this concept to human beings, which he considered much more complex than Descartes' man-machine. Like Willis before him and despite his strong religious faith, Stensen was sufficiently prudent not to address directly the problem of the body-mind duality raised by Descartes. Apart from saying that the brain is the major organ whereby the human soul exerts its

bodily function and by asserting that this action is not mediated by the pineal gland, he did not speculate further on how the influence of the soul upon the human body might be exerted. He believed that this issue lay beyond the realm of direct observations. Detailed discussions on these philosophical themes can be found in the excellent reviews provided by Thomas Hall,[28] François Duscheneau,[29] and Elizabeth Williams.[30]

With such a clear refutation of Descartes' view of the role of the pineal gland in the control of brain function, together with his previous demonstration that the heart is no "furnace" but simply a muscle that contract and expands like all other muscles, Stensen seriously undermined large parts of Descartes' man-machine concept.[27-30]

## A change in paradigm

Stensen terminated his lecture on a much more positive note: he proposed nothing less than a detailed program designed to guide researchers in their future studies of brain. After a clear warning against self-certainty and superficiality, Stensen called for a serious reappraisal of the methods currently used for dissecting the brain. In order to avoid artifacts in the manipulation of such a malleable organ, he suggested a combination of various dissection methods, with an obvious preference for the one that permits the tracing of ascending and descending fiber tracts, which he himself used to produce the drawings that were appended to the printed version of his lecture (see below).

For Stensen, a proper knowledge of the functional anatomy of the brain, the most complex of all human organs, could only come from the work of fulltime researchers who devoted their entire life to this gigantic task. He argued that physicians were too busy with their clinical work and anatomy teachers too engaged in transmitting ancient knowledge through rigidly programmed human dissections. They did not have the time and freedom of thought necessary to embark on such a demanding endeavor. In that regard, Franciscus Sylvius, who introduced Steensen to the field of brain anatomy in Leiden and whose name is mentioned at least seven times in the lecture, appears to have been his model.

Stensen then recommended avoiding speculations, such as Descartes' pinealist view of brain function, until a precise knowledge of how the various brain parts were interconnected was secured. He insisted on the importance of keeping the best of the teaching of the Ancients upon which the new knowledge should be built. This new knowledge would have to be acquired with proper methods and illustrated by faithful diagrams. He insisted that anatomy should always precede physiology and called for the development of a multidisciplinary approach in which pathology, comparative anatomy and embryology would become major convergent sources of learning about brain organization. He argued that valuable information can be obtained by studying the brain under various pathological conditions, and by comparing the brains of different animals, from the lowest level to the higher, as well as several developmental stages of the brain in the same animal, from fetus to adult individual. He even recommended experiments on living animals, whose brains would be examined while different drugs or poisons were administered systemically or applied directly to the organ under study. He concluded his lecture by expressing a frank desire to see the emergence of experimental teams working in close collaboration to produce new knowledge that would progressively replace the current blind belief in authority.

## The *Discours'* illustrations

The content of Stensen's lecture was reported in detail in a publication that appeared in Paris four years after his presentation at Thévenot's house.[11] In addition to long excerpts from Descartes's *L'Homme*, Stensen's paper contains four original plates (Figure 4). Except for the first illustration, these figures are highly schematic and esthetically much less impressive than those of Willis' *Cerebri anatome*, which were cruelly lacerated by Stensen in his public lecture. Despite their poor esthetic value, Stensen's figures are scientifically highly meritorious because they display information about brain organization that had never been revealed before.

Stensen's Plate I provides the very first detailed depiction of a parasagittal section of the human brain, a drawing that is surprisingly accurate although adequate fixation procedures were unavailable at that time (Figures 4A,5). Since the Renaissance, anatomists had minimized distortion problems due to unfixed brains simply by keeping the organ in place in the cranium and dissecting it along the horizontal plane in a top-down manner. Sylvius was one of the first to favor the use of midsagittal sectioning, but he did not provide examples of such a dissection procedure that Stensen probably adopted while in Leiden. Admittedly, Stensen's depiction of the cerebral sulci and gyri is sketchy, but the topographical location, relative proportion and general form of subcortical forebrain structures and brainstem segments are remarkably exact. The brain illustrated here is still in place, with the dura mater attached to the cortical tissue and the falx cerebri and tentorium cerebelli intact and well delineated. Among the structures that are clearly illustrated for the first time are the splenium, body, genu and rostrum of the corpus callosum, the fornix columns, the septum pellucidum, the anterior commissure, the lamina terminalis, the optic chiasma, the posterior and anterior lobe of the hypophysis, the mammillary bodies, the thalamus with the interthalamic adhesion (massa intermedia), the cerebral aqueduct (of Sylvius), the pineal gland, the midbrain tegmentum, the pons and the medulla oblongata (Figure 5).

Plate II (Figure 4B) offers another midsagittal view of an entire human brain, but this time the organ is entirely enclosed in the cranial vault. The drawing is crude compared to the first one. The sulci and gyri of the medial surface are illustrated in a highly schematic manner and the corpus callosum is reduced to its rostral and splenial parts. The fornix columns and septum are lacking and the anterior commissure is wrongly located above the preoptic recess (Figure 4B). The hypophysial stalk and the mammillary bodies are missing, the cerebral aqueduct too large, and the medulla oblongata not properly aligned.

Plate III (Figure 4C) offers a line drawing and a halftone rendition of a coronal section though the posterior portion of the diencephalon that passes behind the pineal gland dorsally and the mammillary bodies ventrally. Although highly schematic, the drawing displays interesting novel features, including a rather accurate depiction of the lateral fissure (of Sylvius), the insula and the hippocampal formation in the temporal horn of the lateral ventricle. The lateral ventricles themselves, however, are

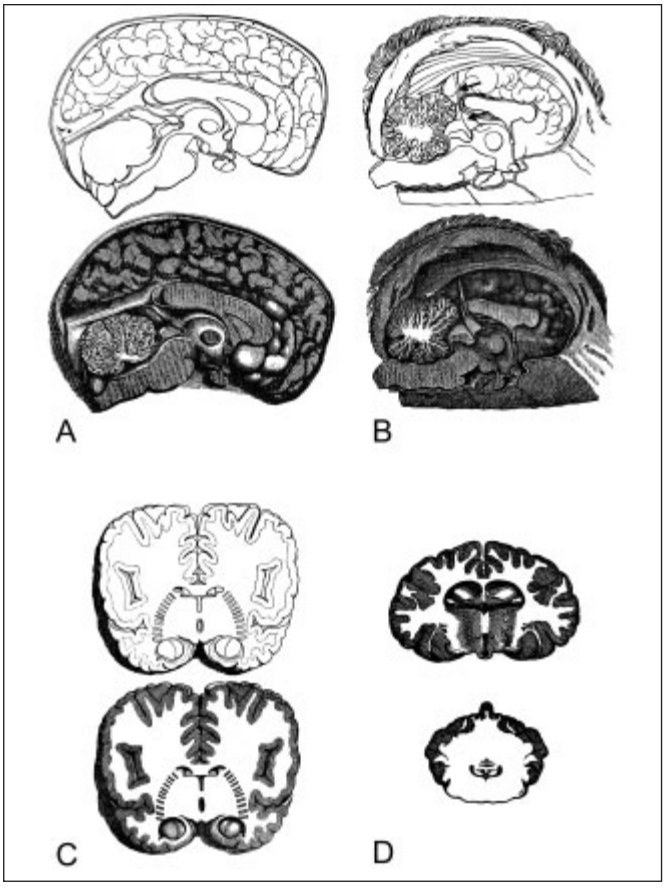


***Figure 4:*** *A-D: Reproductions of the four plates appended to Stensen's Discours sur l'anatomie du cerveau[11]. Plates I to III (A-C) comprise a line drawing (upper panel) and a half-tone rendition (lower panel) of the same section. Plates I and II (A, B) display midsagittal sections, whereas plate III (C) shows a coronal section through the posterior portion of the thalamus, caudal to the pineal gland and mammillary bodies. Plate IV (D) depicts two coronal sections: the upper one passes through the middle portion of the thalamus and infundibular region of the hypothalamus, whereas the lower one transects the medulla oblongata and the cerebellum. Stensen used plate II essentially to describe Descartes' pinealist view of brain function, with an emphasis on the putative arteries emerging from the pineal gland (arrows added to Stensen's original drawing).*

too small and, although a structure that appears to correspond to the caudate nucleus can be seen along the lateral border of the lateral ventricles, the major portion of the basal ganglia is missing. The hatched line separating the diencephalon from the lateral portion of the hemisphere is one of the very first illustrations of the internal capsule (Figure 4C).

Plate IV (Figure 4D) provides a crude rendition of two coronal sections: the upper one passes through the middle portion of the thalamus and infundibular region of the hypothalamus, whereas the lower one transects the medulla oblongata and the cerebellum. The upper drawing gives a rather accurate view of the choroid plexus in the lateral ventricle and of the interthalamic adhesion, but the fornix is slightly overweight. The basal ganglia are here again totally missing. This absence is surprising particularly in face of the critics that Stensen formulated in his lecture regarding Willis' inadequate depiction of the corpus striatum. The lower drawing in plate IV provides a fair representation of the fourth ventricle and a valuable appreciation of the relative size and location of the cerebellum and medulla oblongata, but no further information can be gathered from this drawing because only the inner and outer contours of the section are clearly delineated (Figure 4D).

We do not know when, how and by whom these figures were produced and their relationship with the content of the lecture is not always obvious. For example, none of the figures provide fiber trajectory diagrams, as one could have expected from the dissection procedure advocated by Stensen in his lecture. The second illustration is probably the only one that serves his argument. This figure summarizes the pinealist view of brain function and, to emphasize Descartes' poor knowledge of brain anatomy, Stensen added a depiction of the blood arteries that the philosopher thought to originate from the pineal gland and ascend toward upper venous sinuses, but whose existence he denied in his lecture. However, the first figure is the only one to which Stensen refers to in his talk. It is also the most informative one, with a first clear depiction of a multitude of brain structures visible on the medial surface of the human brain. Stensen did not precisely identify or name these structures in his lecture and since he left his illustrations without a legend, it is difficult to comment further on Stensen's exact knowledge of all the

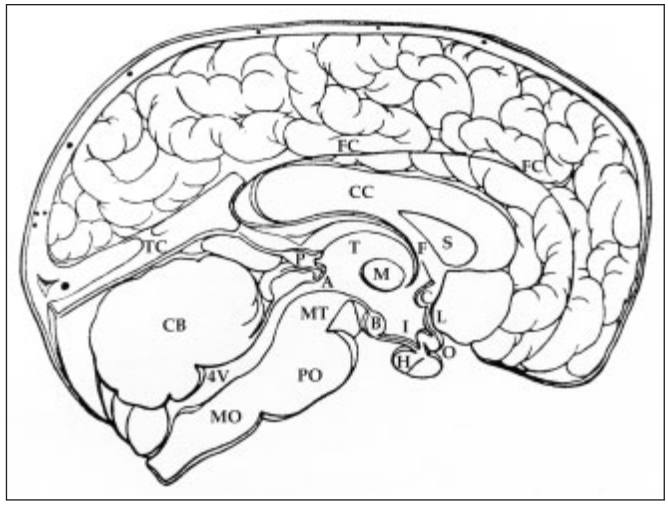


***Figure 5:*** *Reproduction of the upper panel (line drawing) of plate I of Stensen's Discours sur l'anatomie du cerveau[11]. It provides one of the first depictions of a parasagittal section of the human brain. The following abbreviations were added to Stensen's original drawing to facilitate structure identification: A: Cerebral aqueduct (of Sylvius); B: Mammillary bodies; C: Anterior commissure; CB: Cerebellum; CC: Corpus callosum (with its splenium, body, genu and rostrum parts); F: Fornix columns; FC: Falx cerebri; H: Hypophysis (with its anterior and posterior parts); I: Infundibular recess; L: Lamina terminalis; M: Massa intermedia (interthalamic adhesion); MO: Medulla oblongata; MT: Midbrain tegmentum; O: Optic chiasma; P: Pineal gland (epiphysis); PO: Pons; S: Septum pellucidum; TC: Tentorium cerebelli; T: Thalamus; 4V: Fourth ventricle.*

anatomical entities he illustrated at a level of precision never attained before.

**A lasting contribution**

Stensen was perfectly fluent in French, as well as in several other languages, as his correspondence with multiple European scholars testifies.[7,10] Yet, the published version of the *Discours* contains several typographical and grammatical errors (for example, Sylvius' name is often misspelled), indicating that Stensen had probably not revised the text in detail before he handed it to Thévenot. As for Thévenot, he was apparently too busy at that time with its own work to take care of manuscript, which he neglected for several years before entrusting it to the well-known Parisian editor and publisher Robert de Ninville (c. 1632-1688). Although De Ninville had already secured all the necessary permissions (*Privilèges du Roy*) for releasing the book by December 19, 1667, the first printed copies of the *Discours* became available only on February 6, 1669. Thévenot's name is absent from De Ninville's preface, which is dedicated to Marin Cureau de la Chambre (1594-1669), who was personal physician to King Louis XIV and one of the first members of the *Académie des sciences*, a man who had "the power of life and death on everything published in the medical field".[1]

The influence of Stensen's *Discours* on French anatomists did not pass though the Paris School of Medicine, a staunch defender of Galenic tradition. It came from physicians and freethinkers like Pierre Bourdelot (1610-1685) and Joseph Duverney (1648-1730), who had access to Stensen's book well before its publication. Except for a Latin translation that appeared in Leiden in 1671 and was incorporated into the 1685 and 1699 editions of the *Bibliotheca Anatomica*,[7] Stensen's *Discours* had little echo in the 17th century. As it is the case for his work in paleontology and geology, his lecture on the anatomy of the brain attracted attention only after it was rediscovered in the 18th century. One of the first to pay attention to this unique contribution was the Danish-born French anatomist Jacques Benigne Winslow (1669-1760), who incorporated Stensen's *Discours* into his own human anatomy treatise that appeared in Paris for the first time in 1732.[31] Winslow was Stensen's great-nephew and like him he later converted from Lutheranism to Catholicism and attributed his conversion to Stensen's intercession. Winslow's anatomical treatise went through at least 12 re-editions. In 1733, George Douglas published in London an English version of Winslow's treatise, which included Stensen's Discours.[31]

The physician and anatomist Pierre Tarin (1725-1761), who collaborated with Denis Diderot (1713-1784) on the writing of some of medical entries for the *Encyclopedia*, was one of the first to recognize the historical significance of Stensen's *Discours*. His gratitude went so far as to "borrow" five of Stensen's drawings that he included in his own anatomical treatise published in 1750.[32] However, the absence of a figure legend bothered Tarin, who stated: "How is it possible that Stensen did not provide explanations for his figures; this is inconceivable, particularly since he intended to indicate parts of these by means of a new method". In his celebrated brain anatomy treatise published in 1786,[33] Félix Vicq d'Azyr (1748-1794), a member of the *Académie des sciences* and the Perpetual Secretary of the *Académie de* medicine,[34] also blamed the poor quality of some of Stensen's figures. He also found the figure legends provided later by Thomas Bartholin unworthy of Stensen, whom he considered the greatest anatomist of his time.[33] Vick d'Azyr's comments might reflect, at least in apart, the poor rendition of Stensen's figures in the copy of the *Discours* that he had in hand. Indeed, Stensen's illustrations have been reproduced in a somewhat erratic manner over time. In many exemplars of the *Discours*, including the 1673 Latin edition and the French version that was included in Winslow's treatise, the figures were simply absent. Errors also occurred with the reproduction of some of the plates, particularly plate IV, which have posed particular problems to printers. In some exemplars of the work, the two drawings that form this plate have been interchanged, whereas in other cases, the entire plate has been printed upside-down.[35] A detailed figure legend would have certainly minimized such printing errors. Modern legends for Stensen's figures, as well as interesting information on the place they occupy in the history of brain depiction was provided in the 1960s by the Swiss anatomist Adolf Faller (1913-1989),[36] and further comments have been added more recently.[37]

Jacques René Tenon (1724-1816), a former student of Winslow who later became a celebrated surgeon and a member of the *Académie des sciences*, was another 18th century scholar who greatly admired Stensen as an anatomist. In a memoir on the progress of anatomy published in Paris in 1785,[38] Tenon used Stensen's arguments to request freedom of work for anatomists, whose careers should not be impeded by medical, surgical or pedagogical preoccupations. He went as far as attributing to Stensen's *Discours* a crucial role in the creation of the anatomy section of the *Académie des sciences*. Another member of the *Académie des sciences*, who was also professor of anatomy at the *Collège Royal*, (the actual *Collège de France*), the surgeon Antoine Portal (1742-1832), spoke highly of Stensen in his monumental history of anatomy and surgery that appeared in Paris between 1770 and 1773.[39] Portal devoted no less than 24 pages of his treatise to Stensen's various anatomical investigations that he analyzed in detail. His careful reading of the *Discours* lead him to conclude that "Stensen dethroned ancient and strongly held views by the simple exposition of facts that were unquestionable by virtue of their evidence"[39]. He supported Stensen's arguments against Descartes and, to some extent, against Willis as well, he approved Stensen's dissection technique and concluded by saying: "This Discours contains multiple views that are useful to the exercise of anatomy, as well as the most faithful method to use; in fact, Stensen proposes his opinions with so much modesty and simplicity that he fully deserves the tribute of Mr. Haller [Albrecht von Haller (1708-1777)]".[39]

Hence, the 18th century consecrated Stensen as a one of the greatest anatomists of all times and this recognition continued without interruption throughout the 19th century. This is exemplified by the laudatory comments about Stensen made by the physiologist Pierre Flourens (1794-1867) in a book that he published in 1854.[40] Flourens considered Stensen a man of genius and, paraphrasing one of his colleagues who recognized the remarkable contribution of Stensen to the study of earth formation by calling him "the first genuine geologist," Flourens stated: "as for myself, I called him the first genuine brain anatomist, because he was the first who clearly visualized the

fibers of the brain, which is the most important feature to note in the structural organization of this organ".[40] Closer to us, the Viennese medical historian Max Neuburger (1868-1955) expressed deep admiration for Stensen's *Discours* to which he referred to in the following terms: "These words, which are among the finest of the medical literature of the seventeenth century, formulated a program of research aimed at a precise physiology of the nervous system, applicable not only at that time but even today. Just like lightening flashing in a dark night and illuminating the clouds' turmoil with sudden brightness, so Steno towered over his contemporaries, who believed their gross errors to be the truth; and he endeavored to remove the blindfold from the eyes of the select few who were capable of seeing".[41]

The nearly continuous re-edition process which Stensen's *Discours* underwent during the last 350 years is an eloquent testimony of its enduring influence. This small fascicle was translated in many languages, including Latin, English, Italian, German, Danish and Dutch. The original French version was re-edited in 2009, with interesting comments and annotations.[42]

**From sharks and fossils to sanctity**

Stensen left Paris in the fall of 1665 and, after a brief visit to Montpellier, moved to Florence, Italy, at the invitation of Ferdinand II de' Medici (1610-1670), Grand Duke of Tuscany. He rapidly joined the selected group of scientists who revolved around the prestigious *Academia del Cimento* (Academy of Experimental Sciences)[43] and became progressively interested in geology and crystallography. His dissection of the head of a great White Shark (Figure 6A) in 1666 was instrumental in the reorientation of his career. Stensen summarized the results of this dissection in a monograph that appeared as a supplement to its 1667 treatise on muscles.[9] This work allowed him to explain the true nature of glossopetræ (or tongues stones) and of fossils in general.[44,45] His detailed studies of Tuscan landscapes helped him to understand that fossils are remnants of earlier organisms and that many rocks are the result of a process that he called *sedimentation*. In so doing, he became one of the founders of paleontology and geology.[45-47] Stensen's geological observations were summarized in a highly influential memoire entitled *De Solido Intra Solidum Naturaliter* (Of solids naturally contained within solids)[48] that he published in 1669 in Florence and which he dedicated to Ferdinand II. Since its rediscovery in the 18th century by Alexander von Humboldt (1769-1859), this book has exerted a marked influence upon geologists and paleontologists. It has progressively acquired a reputation similar to that of his lecture of the anatomy of the brain, and modern scholars consider both treatises as Stensen's major contributions to the field of natural science.

This was to be the last major scientific incursion of Stensen, whose attention became progressively captured by theological issues. He converted to Catholicism in 1667, was ordained priest in 1675 and consecrated bishop of Titiopolis (*in partibus infidelium*) and apostolic vicar of northern missions by Pope Innocent XI (Benedetto Odescalchi, 1611-1689) in 1677 (Figure 6B). He served the Catholic Church in various cities of northern Germany, including Hannover, Munster, Hamburg and finally Schwerin, capital of the Mecklenburg Land, where self-imposed poverty and religious renunciation reduced him to a state of abject misery.[49] Neglected and spurned by his coreligionists,


***Figure 6:*** *A: A woodcut from Stensen's Canis carchariæ dissectum caput[9] describing the head of a White Shark similar to the one he dissected in 1666, a work that ultimately helped him reveal the true nature and significance of glossopetræ (tongue stones) and fossils. Some of the shark teeth are shown at the bottom of the figure. The drawing is from the unpublished work (Metalothecca vaticana) of Michele Mercati (1541-1593) that Stensen borrowed through the intermediary of Carlo Roberto Dati (1616-1672), a member of the Academia del Cimento. B: A portrait of Stensen as Bishop of Titiopolis by the Danish painter Christian August Lorentzen (1749-1828). Anatomy Institute, Copenhagen, Denmark. C: The antique Christian sarcophagus in which Stensen's body rests in a side chapel (Capella Stenoniana) of San Lorenzo Basilica in Florence, Italy. Photograph taken by the author in 2011.*

Stensen died in this small northern city on December 5, 1686 at the age of 48. When the news of his death reached Florence, Cosimo III de' Medici (1642-1723), who succeeded to his father Ferdinand II as Grand Duke of Tuscany, made the necessary arrangements to have his body brought back to Florence and buried among the tombs of his own ancestors in San Lorenzo Basilica.[1-4,47,49]

On October 1953, Stensen's remains were exhumed from the church's crypt as part of a canonization process initiated several decades before. When the lid of his coffin was opened, Stensen's skeleton appeared dressed in bishop's robes, with a crosier laid alongside. The examination of the remains revealed that the cranium was missing. Hence, if the initial portion of Stensen's career was similar to that of Thomas Willis, the last portion resembled more that of René Descartes, whose head was found

missing when his remains were exhumed in Stockholm, where he died in 1650. After the examination of Stensen's remains, his body was carried through the streets of Florence in a solemn procession and enshrined in a 4th century Christian sarcophagus, excavated some years earlier from the sediments of the Arno river and donated by the Italian government. The sarcophagus was placed in a small chapel off the nave of San Lorenzo. This humble chapel was renamed *Capella Stenoniana* and that is where the celebrated 17th century scientist still rests (Figure 6C). On October 1998, Pope Jean Paul II (Karol Joseph Wojtyla, 1920-2005) beatified Niels Stensen, a last step before canonization.

Sir William Osler (1849-1919), the celebrated Canadian born neurologist who finished his career as Regius Professor of medicine at Oxford, was delighted when Stensen's collected scientific works were published in their original language in 1910 under the learned editorship of the Danish medical historian Edvar Vilhelm Emil Maar (1871-1940).[35] He praised this two-volume treatise in his chronicle entitled *Men and Books* that appeared on a regular basis in the Canadian Medical Association Journal. In this particular book review published in 1912, Osler alluded to Stensen in the followings terms: "No one should have a warmer place in our memory than the anatomatist [sic], geologist and theologian, whose name is on our lips daily in connexion with the duct of the parotid gland. […] A strange figure, one of the strangest in our history … ".[50]

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