NOTES AND RECORDS

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DRAWING MUSCLES WITH DIAGRAMS: HOW A NOVEL DISSECTION CUT INSPIRED NICOLAUS STENO'S MATHEMATICAL MYOLOGY (1667)

by

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In 1667, twenty years before Isaac Newton published his mathematization of physics, and more than ten years before the publication of Giovanni Borelli's *De motu animalium*, the Danish anatomist Nicolaus Steno published an entirely new geometrical theory of muscle motion in the book *Elementorum myologiæ specimen*. Historians of science have studied this book in recent decades, but the recent rediscovery of a seventeenth-century muscle atlas at the Bibliothèque interuniversitaire de Santé in Paris sheds new light on the largely overlooked origin of Steno's mathematical theory of muscles. In this article, we show that Steno's muscle diagrams result from a tension that Steno faced when combining his interest in illustrations with presenting his mathematical insights about the inner structure of muscle fibres. Furthermore, we argue that Steno's diagrams are deeply connected to observations through a new method of dissecting the muscles. The observational origins of Steno's mathematical insight are further confirmed by the strong correlation between Steno's depictions of the structure and function of skeletal muscles and the results of current biomechanical investigations.

Keywords: early modern science; scientific images; scientific observations; mathematization of science; Johannes Van Horne; anatomical atlas

In 1667, twenty years before Isaac Newton (1642–1727) published his mathematization of physics, and more than ten years before the publication of Giovanni Alfonso Borelli's (1608–1679) *De motu animalium* (Rome, 1680), the Danish anatomist Nicolaus Steno (1638–1686) published an entirely new mathematical theory of muscle motion in the book *Elementorum myologiæ specimen* (Florence, 1667), with diagram illustrations. To stress the novelty of his claims, Steno criticized contemporary anatomists for not 'delivering to posterity only things that were certain'.[1] Yet, alongside this criticism, Steno also praised a

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1 Steno, *Elementorum myologiæ specimen* (Florence, 1667), p. v: 'si, qui totam ætatem in exercitiis anatomicis contribuere, non nisi sola certa posteritati tradidissent.' Steno had previously made this case in relation to the muscles in *De musculis et glandulis observationum specimen* (Copenhagen, 1664), pp. 20–21: 'Quid prædicta musculorum fabrica ad morborum quorundam

particular group of persons who, in his opinion, contributed to a better understanding of muscles. Painters, he wrote, or 'those who have drawn the muscles[,] have often been more exact than those who described' them in words.[2] Indeed, he continued, 'the industry with which painters have approached nature's skill [*facilitas naturae*]' shows that the first step of anatomical investigations should be an ability to 'admire such a work of art [*artificium*]'.[3] But which painters and illustrations did Steno have in mind?

It is possible that he was thinking of the vivid and detailed illustrations of the muscle atlas made by Johannes Van Horne (1621–1670), which recently resurfaced at the Bibliothèque interuniversitaire de Santé (BIU Santé) in Paris.[4] Steno studied anatomy under Van Horne at the University of Leiden and saw the atlas plates with his own eyes. He probably also knew that the painter of the folio plates, Marten Sagemolen (d. 1669), 'examined and anatomized … various individuals' in order to make these drawings, as Sagemolen admitted himself.[5] Indeed, Sagemolen was following in the footsteps of painters such as Leonardo da Vinci (1452–1519), Michelangelo (1475–1564), and Peter Paul Rubens (1577–1640) who either dissected cadavers themselves or witnessed dissections before painting.[6] Therefore, Steno's praise of painters carried a deeper claim on how to practise anatomy: like a painter repeatedly observes what he intends to paint, so the anatomist should repeatedly examine the organs he wants to study.[7]

Ironically, Steno's emphasis on observing and describing the body like a painter contrasts with his actual diagram illustrations.[8] Diagrams cannot be observed in the body in the same way that a muscle drawn by painters can, regardless of how often one looks at it. How could Steno praise painters as examples while in the end he was drawing muscles with diagrams?

curationumque rationes facilius explicandas accedente ulteriori examine conferre poterit, ex sequentibus, velut ex ungue, dignoscere licet.' For a full English translation, see *Nicolaus Steno: biography and original papers of a 17th century scientist* (ed. Troels Kardel and Paul Maquet), 2nd ed. (Springer, Berlin, 2018) (hereafter BOP), at p. 651. All translations are the authors' unless otherwise noted.

2 Steno, *Elementorum myologiæ specimen*, p. 65: 'miror tamen, qui musculos delinearunt, sæpius iis, qui eosdem descripserunt, exactiores fuisse' (BOP, *op. cit.* (note 1), p. 696).

3 Steno, *ibid.*, p. 65: 'nec potuisse naturæ facilitati accedentem pictoris industriam ad tanti artificii admirationem, investigationis parentem, illos invitare' (BOP, *op. cit.* (note 1), p. 696).

4 The atlas was discovered in November 2016. See Jean-François Vincent and Chloé Perrot, 'Johannes Van Horne and Marten Sagemolen's myology', 2016. See https://www.biusante.parisdescartes.fr/histoire/medica/assets/pdf/van-horne_en.pdf.

5 As quoted and translated in Tim Huisman, *The finger of God: anatomical practice in 17th-century Leiden* (Primavera Pers, Leiden, 2009), p. 80.

6 Andrew Wear, 'Medicine in early modern Europe, 1500–1700', in *The Western medical tradition* (ed. Lawrence Conrad *et al.*), pp. 215–361 (Cambridge University Press, 1995), esp. pp. 264–268; Domenico Laurenza, *Art and anatomy in Renaissance Italy: images from a scientific revolution* (Metropolitan Museum of Art, New York, 2012); Martin Kemp and Marina Wallace, *Spectacular bodies: the art and science of the human body from Leonardo to now* (University of California Press, Berkeley, CA, 2000), esp. pp. 69–78; and K. Roberts and J. Tomlinson, *The fabric of the body: European traditions of anatomical illustrations* (Oxford University Press, 1992), esp. pp. 272–286.

7 See Lorraine Daston and Peter Galison, *Objectivity* (Zone Books, New York, 2007), pp. 55–113; Daston, 'The empire of observation', in *Histories of scientific observation* (ed. L. Daston and Elizabeth Lunbeck), pp. 81–113 (University of Chicago Press, 2011); and David Freedberg, *Eye of the lynx: Galileo, his friends and the beginnings of modern natural history* (University of Chicago Press, 2002), pp. 349–416.

8 For other studies on Steno's illustrations, see Egill Snorrason, 'Nicolaus Steno: the illustrative explorer', in *Nicolaus Steno 1638–1686: a reconsideration by Danish scientists* (ed. J. Poulsen and E. Snorrason), pp. 191–209 (Nordisk Insulinlaboratorium, Gentofte, Denmark, 1986), which lists other non-geometrical diagrams made by Steno; Flavia Marcacci, 'Mostrare, dimostrare, spiegare: la scienza visuale di Niels Steensen', in *Scienza, Filosofia e Religione nell'Opera di Niels Steensen* (ed. María Vitoria and Francisco Gómez), pp. 139–164 (Pagnini Editore, Florence, 2020). For more on diagrams in early modern science (mostly mathematics and astronomy), see *Observing the world through images: diagrams and figures in the early-modern arts and sciences* (ed. Nicholas Jardine and Isla Fay) (Brill, Leiden, 2014); Christoph Lüthy and Alexis Smets, '"Words, lines, diagrams, images: towards a history of scientific imagery"', *Early Sci. Med.* **14**, 398–439 (2009); and Michael Mahoney, 'Drawing mechanics', in *Picturing machines, 1400–1700* (ed. Wolfgang Lefévre), pp. 281–306 (MIT Press, Cambridge, MA, 2004).

The answer to this paradox lies in Steno's attitude towards illustrations in his research project on muscles. In this article, we show that Steno's diagrams result from a tension that Steno faced when combining a need for illustrations with novel abstract insights about the inner structure of muscle fibres. Furthermore, we argue that, rather than being detached from observations, Steno's diagrams are deeply connected to them through a new method of dissection. This article's structure is three-fold. First, we summarize Steno's years in Leiden as a student of Van Horne. We then explore Steno's initial research on muscles with an eye towards his interest in images; somehow, the absence of illustrations in Steno's first publication on muscles speaks about his intense awareness of their need. Finally, the article ends with Steno's decision to display the muscles with geometrical diagrams in Florence. In the conclusion we comment on the impact of this decision on his geological research, which followed soon after. It is our aim with this analysis to cast new light on the visual and observational aspects of mathematization in early modern science.

Illustrations and Nicolaus Steno's training and research in Leiden

Nicolaus Steno enrolled at the University of Leiden in July 1660 after medical studies in Copenhagen for three years and a few weeks in Amsterdam.[9] As an anatomy student, Steno was familiar with the usage of images in anatomical books. Then as now, anatomy textbooks were filled with images of bodily parts. The *Institutiones anatomicæ*, which was republished with updates by Steno's Copenhagen mentor Thomas Bartholin (1616–1680), is one among many examples.[10] But Leiden must have given Steno a greater awareness of the significance of anatomical images since they appeared in multiple cultural contexts and conversations.[11] By the early 1660s, Johannes Van Horne, Steno's professor of 'anatomy and surgery' in Leiden, had also developed new embalming techniques that allowed for better illustrations of bodily parts.[12] Van Horne showed the potential of this method by inviting students to his home, where he had embalmed organs on display. A result of this environment was the richly illustrated publications by Frederik Ruysch (1638–1731) and Jan Swammerdam (1637–1680), who also studied under Van Horne at Leiden.[13] Indeed,

9 Steno enrolled on 27 July 1660, see Leiden University Library, ASF 10, fol 585; as quoted in *Album studiosorum Academiæ Ludguno Batavæ* (The Hague, 1875), p. 482.

10 Thomas Bartholin, *Institutiones anatomicae* (Leiden, 1641, 1645, 1651; The Hague, 1655, 1660), also published in French (Paris, 1646), German (Copenhagen, 1648), Italian (Florence, 1651) and Dutch (Leiden, 1653). For more on images in the history of science, especially the history of anatomy, see *The power of images in early modern science* (ed. Wolfgang Lefèvre, Jürgen Renn and Urs Schoepflin) (Birkhäuser Verlag, Basel, 2003); K. Roberts and J. Tomlinson, *The fabric of the body, op. cit.* (note 6); Janice Neri, *The insect and the image: visualizing nature in early modern Europe, 1500–1700* (University of Minnesota Press, Minneapolis, MN, 2011); Domenico Bertoloni Meli, *Visualizing disease: the art and history of pathological illustrations* (University of Chicago Press, Chicago, IL, 2017); Bertoloni Meli, *Mechanism: a visual, lexical and conceptual history* (University of Pittsburgh Press, Pittsburgh, PA, 2019), pp. 25–78.

11 Eric Jorink, 'An eye for detail: art, science, and religion in seventeenth-century Leiden', in *An inner world: seventeenth-century Dutch genre painting* (ed. Heather Moqtaderi and Lara Yeager-Crasselt), pp. 47–62 (University of Pennsylvania Press, Philadelphia, 2021). On the wider commercial role of scientific images in Steno's environment, see Dániel Margócsy, *Commercial visions: science, trade and visual culture in the Dutch golden age* (University of Chicago Press, Chicago, IL, 2014).

12 Steno, *Observationes anatomicæ* (Leiden, 1662), pp. 80-81: 'Professoribus … D. Johnanni Van Horne, anatomiæ et chirurgiæ.' Harold Cook, *Matters of exchange: commerce, medicine and science in the Dutch golden age* (Yale University Press, New Haven, CT, 2007), p. 277; Huisman, *The finger of God, op. cit.* (note 5), p. 82.

13 Gijsbert van de Roemer, 'From *vanitas* to veneration: the embellishments in the anatomical cabinet of Frederik Ruysch', *J. Hist. Collect.* **22**, 169–186 (2010); Luuc Kooijmans, *Death defied: the anatomy lessons of Frederik Ruysch* (transl. Diane Webb) (Brill, Leiden, 2011); Saskia Klerk, 'Natural history in the physician's study: Jan Swammerdam (1637–1680), Steven Blankaart

Swammerdam later became famous in the history of science for his spectacular illustrations of insects.

In April 1661, Steno visited Van Horne's home with Ole Borch (1626–1690), Steno's former teacher in Copenhagen who also stayed in Leiden for some time.[14] Borch wrote in his detailed journal that during their visit, besides several anatomical samples, they saw 'all the muscles of the human body most accurately painted in their original colours'.[15] Moreover, Van Horne told them that 'he made sure that they [i.e. the images] were made by an extraordinary craftsman with great effort' and that he 'believed that nowhere else in the world has such a work of art existed'.[16] Borch confirmed their elegance in a letter to Bartholin in Copenhagen, in which he described the plates as 'most elaborate' and 'splendid'.[17] These plates were likely the images of the anatomical atlas of muscles that Van Horne had produced with the painter Marten Sagemolen.[18]

This atlas seems to have served as a means for Van Horne to develop new ways of studying and cataloguing muscles, as Borch's comments on Van Horne's teaching suggest. For instance, in January 1661 Borch mentioned a dissection led by Van Horne of a female corpse in Leiden.[19] During this dissection, Van Horne renamed a muscle of the neck usually known as 'sternohyoid' with the different name of 'cleptohyoid', 'because the muscle does not originate in the sternum but in the clavicle', he said.[20] The atlas plates that contain this muscle maintain the original name, but they also indicate that its origin is either 'from the sternum or the clavicle' (see figure 1).[21] On another day, Van Horne opened the abdominal muscles [*rectus abdominis*] in a male human body and explained to his students that this muscle had to be described in two parts: the actual abdominal muscle and what he called 'a white inscription', known as *linea alba*.[22] The atlas plates in which the abdominal muscles appear also emphasize this distinction (see figure 2).[23] Therefore, Van Horne's images and his comments while dissecting reveal a link between his dissections and the atlas.

As Steno started publishing his research in Leiden, he also had to think about images and how to draw them on paper. At the time, Steno was studying the glands of the head, in which

(1650–1705) and the "paperwork" of observing insects', *Br. J. Hist. Sci.* **53**, 1–29 (2020); Eric Jorink, *Reading the Book of Nature in the Dutch golden age, 1575–1715* (Brill, Leiden, 2010), esp. pp. 219–239.

14 On Steno's pre-university studies, see Gustav Scherz's biography translated in BOP, *op. cit.* (note 1), pp. 25–32. On Borch, see his autobiography as translated in *Olai Borrichii Itinerarium 1660–1665*, 4 vols (ed. H. D. Schepelern) (C. A. Reitzles Forlag, Copenhagen, 1983), vol. 1, pp. xv–xxi (hereafter OBI). For more on Steno and Borch's early stay in the Netherlands, see Eric Jorink, '*Modus politicus vivendi*: Nicolaus Steno and the Dutch (Swammerdam, Spinoza and other friends), 1660–1664', in *Steno and the philosophers* (ed. Raphaele Andrault and Mogens Laerke), pp. 13–44 (Brill, Leiden, 2018).

15 OBI, *op. cit.* (note 14), 8 April 1661, pp. 96–97: 'omnes humani corporis musculos acuratissime depictos. nativis suis colorib[us].' Steno mentions this visit briefly in a letter to Thomas Bartholin, 30 December 1661, in Thomas Bartholin, *Epistolarum medicinalium centuria III* (Copenhagen, 1667), pp. 262–266 (translated in BOP, *op. cit.* (note 1), pp. 501–503).

16 Borch to Thomas Bartholin, 21 April 1661, in Bartholin, *op. cit.* (note 15), p. 394: 'quas magna industria se per insignem artificem hic ait curasse perfici; creditque nusquam gentium tale opus artis extare.'

17 *Ibid.*: 'musculorum omnium corporis humani elaboratissimas figuras, colore nativo splendidas.'

18 Huisman, *The finger of God, op. cit.* (note 5), pp. 80–82.

19 OBI, *op. cit.* (note 14), 27 January, p. 69–71.

20 OBI, *op. cit.* (note 14), 27 January, p. 71: 'Quem sternohyoideum vacant musculum, ille cleptohyoideum appellavit, quia non a sterno sed claviculis oritur et quidem parte interni.'

21 Paris, Bibliothèque Interuniversitaire de Santé (hereafter BIU Santé), MS 27 (pl. no. 4), p. 6: 'DDDD: strenohyoides … aut ab sternum … aut clavicula.'

22 OBI, *op. cit.* (note 14), 24 February, p. 75: 'In pectorali musculo duas notavit partes. In abdomine censuit rectos habere illas albas inscriptiones, ut eorum actio reddatur fortior.'

23 BIU Santé, *op. cit.* (note 21) (pl. no. 2), p. 4.

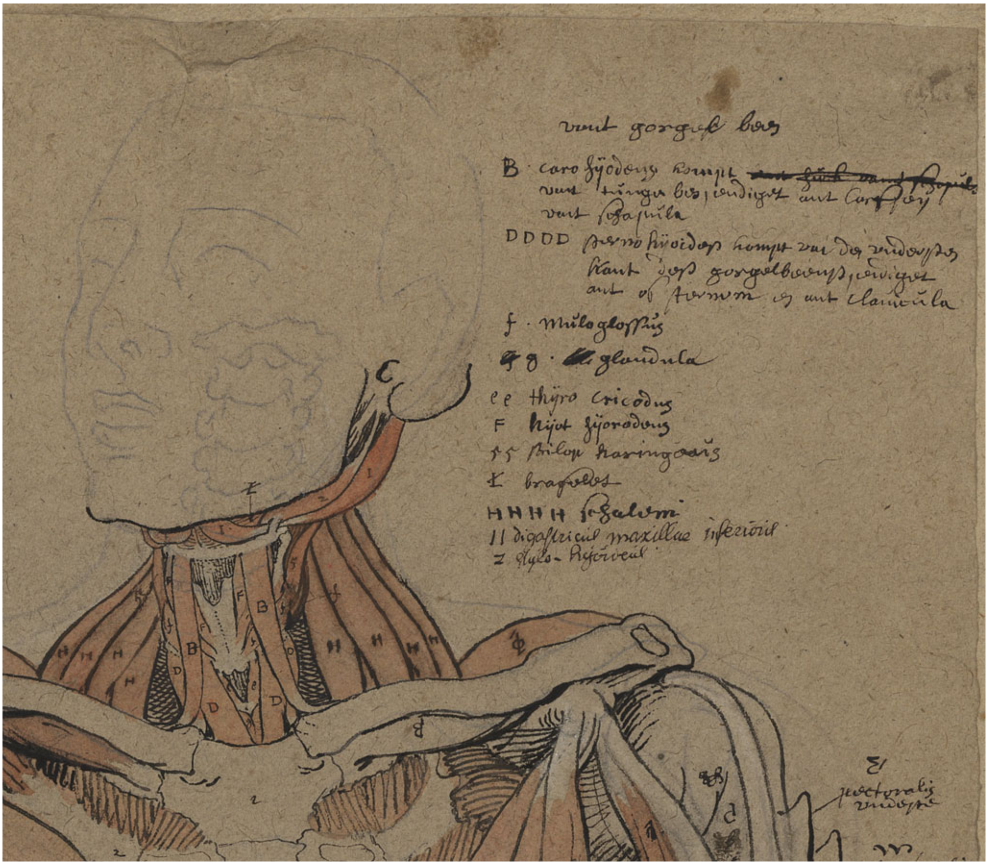

Figure 1. The sternohyoid muscles of the neck labelled with ‘D’. J. Van Horne, Muscle Atlas, BIU Santé, Paris, MS 27, p. 6, pl. no. 4. Courtesy of BIU Santé. (Online version in colour.)

he had discovered a new salivary duct linking the parotid gland to the mouth.[24] Van Horne himself named it ‘Steno’s duct’ [*ductus stenonianus*], which remains its name today.[25] As soon as Thomas Bartholin learned of Steno’s discovery, he wrote a letter to Steno encouraging him to publish it. Interestingly, rather than asking for a text, Bartholin asked Steno for ‘an image of the external salivary duct’.[26] Shortly after, Steno published his discovery alongside a detailed image of the parotid gland in his first academic dissertation at the University of Leiden (see figure 3). Not unlike Van Horne’s atlas, Steno’s images of the glands also relate to his dissection methods. As an example, Steno’s discovery of the parotid duct took place when Steno inserted a probe through the gland into the duct. The insertion of metallic or wooden probes inside vessels was a delicate process that could rip the vessels and damage the observation.[27] But, if done correctly, this process highlighted

24 Harald Moe, ‘When Steno brought new esteem to gland’, in *Nicolaus Steno, 1638–1686*, *op. cit.* (note 8), pp. 51–96.

25 Van Horne, *Mikrokosmos seu brevis manuductio ad historiam corporis humani* (Leiden, 1662), p. 23.

26 Steno to Bartholin, 22 April 1661, in Bartholin, *Epistolarum centuria III, op. cit.* (note 15), p. 87: ‘Cum vero ut ductus salivalis exterioris iconem edam in eadem epistola author mihi sis.’

27 On the different kinds of probes, see Michael Lyser, *Culter anatomicus*, 2nd edn (Copenhagen, 1665), p. 9.

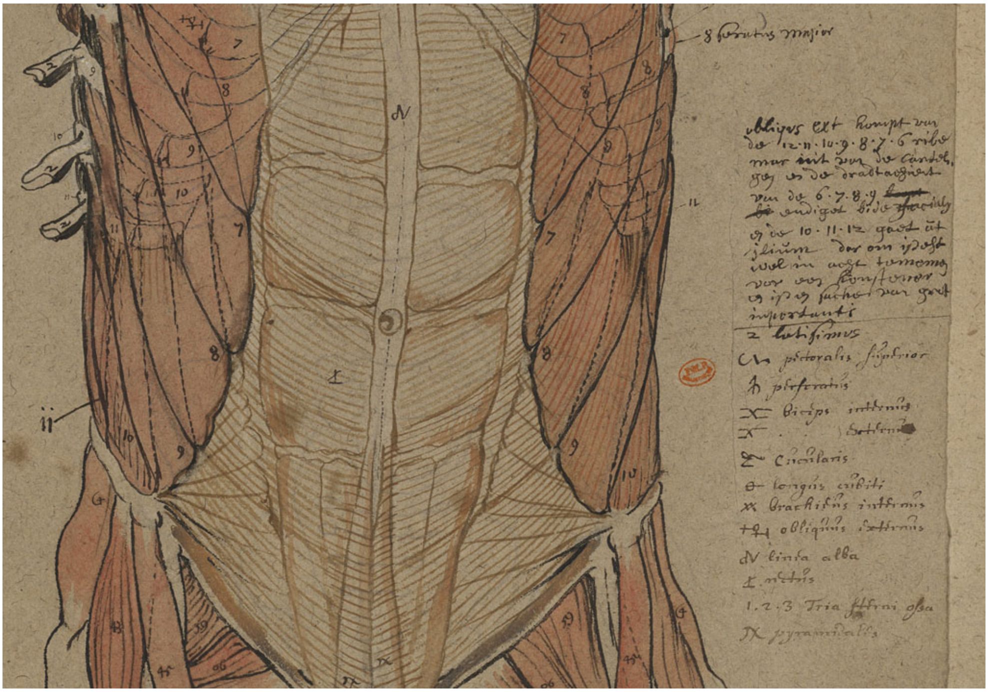

Figure 2. The white inscription in the abdominal labelled with ‘dV’ at the centre. J. Van Horne, Muscle Atlas, BIU Santé, Paris, MS 27, p. 4, pl. no. 2. Courtesy of BIU Santé. (Online version in colour.)

the anatomists’ dissection skills and familiarity with various investigative methods. Thus, the image used by Steno shows a probe inside the duct that exits it through the mouth, demonstrating a physical link between the parotid gland and mouth. Steno also argued that what anatomists until then called the parotid gland should be distinguished into a salivary gland and what is called today a lymphatic node, which is hidden behind the gland.[28] Indeed, he measured the weights of the parotid gland with and without the lymphatic node and compared them to the maxillary gland in order to support his case with a quantitative argument. Therefore, Steno portrayed this argument in the image by drawing an enlarged parotid gland in two parts, one on the right connecting to the duct, and the other on the left, which was the lymphatic node. But, as Steno’s research shifted towards the muscles—those body parts illustrated in Van Horne’s atlas—his illustrations also changed.

Early research on muscles in Copenhagen and Paris

Nicolaus Steno started dissecting and observing muscles in 1662, soon after he published his book on glands, the *Observationes anatomicae* (Leiden, 1662). He mentioned dissections of

28 Steno distinguished them as conglomerate and conglobate glands, following the method of his professor Franciscus Sylvius. See Nuno Castel-Branco, ‘Dissecting with numbers: mathematics in Nicolaus Steno’s early anatomical writings, 1661–64’, *Substantia* **5** (1), 29–42 (2021), esp. pp. 32–35.

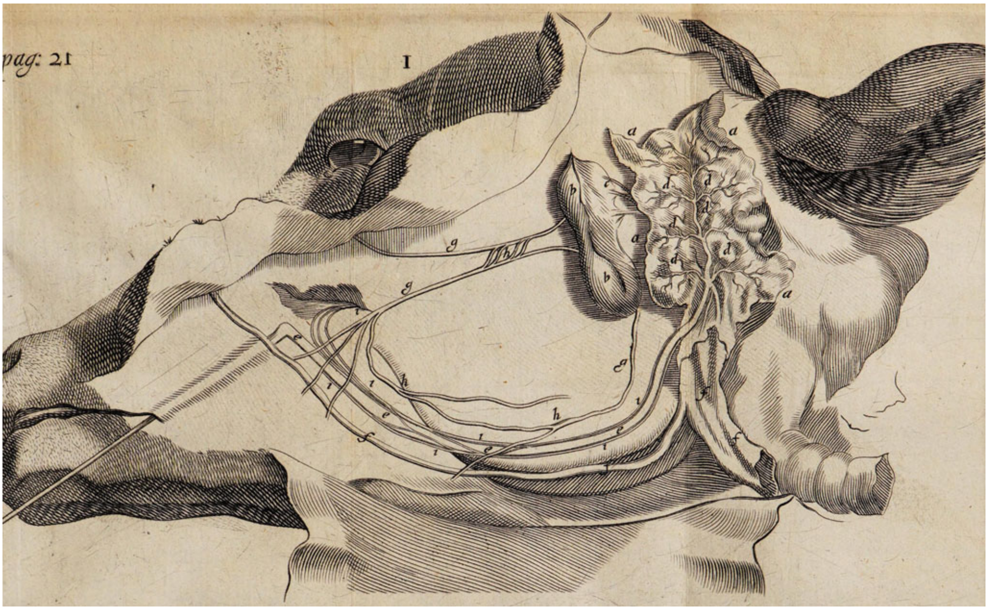

Figure 3. Parotid glands in the head of a calf. N. Steno, *Observationes anatomicae* (Leiden, 1662), p. 21. Courtesy of Wellcome Collection. (Online version in colour.)

muscles for the first time in a letter to Thomas Bartholin, adding that Van Horne was present when he opened muscles in the leg of a rabbit.[29] In this letter, Steno included three drawings of muscle fibres (see figure 4).[30] However, his findings on muscles were not as simple to illustrate as the salivary glands. In the end, his first publication on muscles, the *De musculis et glandulis* (Copenhagen, 1664), had no illustrations except for an elaborate frontispiece.[31] This lack of illustrations inside the book is particularly intriguing because one of Steno's intentions was to question the Cartesian doctrine of animal spirits. Descartes expanded on this doctrine with varied anatomical illustrations in the newly published posthumous editions of the *Treatise on man* (Leiden, 1662; Paris, 1664).[32] Indeed, Steno's first criticism against *De homine*, the Latin edition, was directed towards the illustrations. Steno wrote that they were 'not inelegant', but he doubted 'whether such images can be seen in any brain'.[33] Moreover, in the *Discours sur l'anatomie du cerveau* (Paris, 1669), written in 1665 while in Paris, Steno

29 Steno to Bartholin, 26 August 1662, in Bartholin, *Epistolarum medicinalium centuria IV* (Copenhagen, 1667), pp. 103–113 (translated in BOP, *op. cit.* (note 1), p. 519). For the importance of dissecting the leg of a rabbit, see Steno, *De musculis et glandulis*, *op. cit.* (note 1), p. 11; on Van Horne and Sylvius as witnesses, see Steno, 'Ex variorum animalium sectionibus', in *Acta Medica Hafniensia* (ed. Thomas Bartholin), vol. 2, p. 144 (Copenhagen, 1675) (BOP, *op. cit.* (note 1), p. 556).

30 Steno to Bartholin, 30 April 1663, in Bartholin, *Epistolarum medicinalium centuria IV* (note 29), pp. 415–416.

31 This frontispiece was not included in the Amsterdam edition of the same book, published in the same year.

32 Raphaele Andrault, 'Anatomy, mechanism and anthropology: Nicolas Steno's reading of *L'Homme*', in *Descartes'* Treatise on Man *and its reception* (ed. Delphine Antoine-Mahut and Stephen Gaukroger) (Springer, Switzerland, 2016), pp. 175–192. On the illustrations of the two editions of Descartes' work, see Claus Zittel, 'Conflicting pictures: illustrating Descartes' *Traité de l'homme*', in *Silent messengers: the circulation of material objects of knowledge in the early modern Low Countries* (ed. Sven Dupré and Christoph Lüthy) (Lit Verlag, Münster, 2011), pp. 217–260.

33 Steno to Bartholin, 26 August 1662, in Bartholin, *Epistolarum centuria IV, op. cit.* (note 29), pp. 115: 'in quo figuræ conspiciuntur non inelegantes quas ex ingenioso cerebro prodiisse certum est, an vero tales in ullo cerebro conspiciendæ valde dubitarem' (BOP, *op. cit.* (note 1), p. 516).

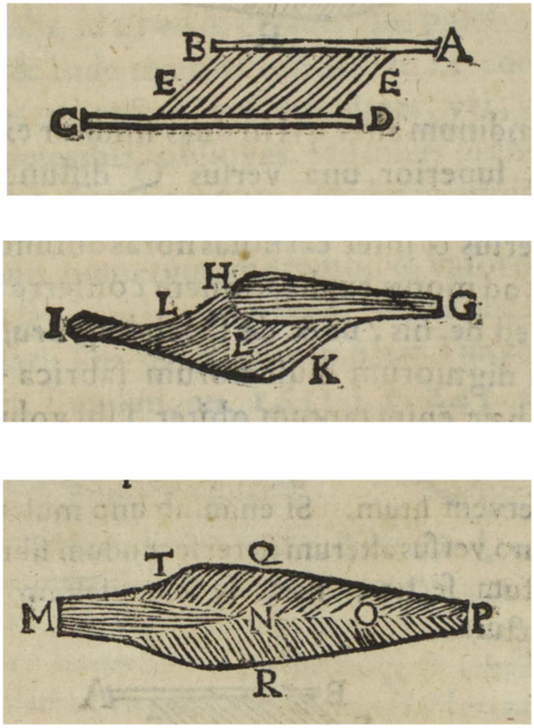

Figure 4. Steno's early drawings of the muscles. T. Bartholin, *Epistolarum medicinalium centuria IV* (Copenhagen, 1667), pp. 415–416. Courtesy of Göttingen State and University Library, ref. 8 MED MISC 474/37:4. (Online version in colour.)

used illustrations of dissection cuts of the brain to argue against Cartesian anatomy.[34] Why, then, did Steno not include any image in his 1664 book?

To be sure, there were practical problems related to the writing of this book. Steno stated that 'an unexpected event drew me away not only from my papers and dissections but also simultaneously erased all hope of returning to the same [thing] for some time'.[35] Indeed, early in 1664 Steno had to leave Leiden and return to Denmark for family matters.[36] Nevertheless, he still decided to publish his findings as a 'sample of anatomical observations'.[37] Moreover, perhaps due to the support of the Danish King Frederik III (r. 1648–1670)—the patron to whom Steno dedicated the book—Steno added a beautiful frontispiece to the book (see figure 5). In early modern intellectual culture, frontispieces were a strong means to convey a book's main ideas, due to their visual elements and the investment of time and money in making them.[38] Indeed, the images in the four corners of the frontispiece highlight the book's main research areas in clockwise order

34 Raphaële Andrault, 'Introduction', in Niels Stensen, *Discours sur l'anatomie du cerveau* (ed. Raphaële Andrault), pp. 7–74 (Editions Classiques Garnier, Paris, 2009).

35 Steno, *De musculis et glandulis*, *op. cit.* (note 1), p. 3: 'cum ecce casum inexspectatum, qui non à chartis modò et sectionibus me meis abstraxit, sed et omnem simul spem abstulit eodem ad aliquod tempus revertendi.'

36 See Scherz's biography in BOP, *op. cit.* (note 1), pp. 121–123.

37 The frontispiece of Steno, *De musculis et glandulis*, *op. cit.* (note 1), has the title 'Observationum anatomicarum specimen'.

38 See Gitta Bertram, Nils Büttner and Claus Zittel, 'Gateways to the books: early modern frontispieces—introduction', in *Gateways to the book: frontispieces and title pages in early modern Europe* (ed. G. Bertram, N. Büttner and C. Zittel) (Brill, Leiden, 2021), pp. 1–57, and references therein.

from the top left: muscles, tongue, yolk of a chicken embryo, and lymphatic vessels.[39] The inclusion of the yolk sac image confirms that he prepared the frontispiece after finishing the text, because he wrote about the yolk in the book's final letter, signed in June 1664.[40] Therefore, this frontispiece testifies to the importance Steno attributed to images. It is not clear who drew these four images, but, given their similarity to Steno's other drawings, Steno was most likely the artist.[41] Regardless, a frontispiece is distinct from images inside a book. Therefore, since most anatomical works of this time had interior illustrations, there were deeper reasons for Steno not to include them inside this book.

These reasons, we argue, relate to Steno's evolving research methods, and they can also be glimpsed in the book's frontispiece. In the frontispiece, on the centre left, besides the already mentioned images, Steno drew an original cross-sectional view of the heart's muscle (see figure 4).[42] He wanted to highlight that the heart's tissue is made of muscle fibres that surround the apex of the heart. Indeed, this was an illustration of the main novelty of his book—the ground-breaking claim against William Harvey that the heart is a muscle and not a special organ. Steno did the same with the muscles of the tongue, whose cross-sectional view he represents in the frontispiece's top right corner to show the course of the tongue's muscle fibres.[43] In short, these drawings show that Steno was playing with unusual dissection cuts of various organs to discern their inner structure.

In the case of skeletal muscles, which are only mentioned in the text, Steno's cut was not cross-sectional, but longitudinal. He cut, as he wrote, 'along the course of the fibres … not in a plane cutting everything transversely through the middle' but in a plane in which 'the tendons remain intact with the flesh'.[44] This longitudinal cut was a major deviation from Van Horne's practice because his atlas plates show a cut of the muscles through the extremities. Van Horne's cut, which was typical among anatomists, allowed the muscles to be separated and distinguished from each other. As far as we know, no one before Steno attempted to cut and describe muscles along the length of their fibres. With this new cut, Steno could not see the muscular structure of the limbs, which he already knew, but could glimpse the inner structure of muscle fibres. He concluded that muscle fibres form an 'oblique parallelogram or the figure of a rhomboid'.[45] He represented this geometrical figure in the frontispiece's top left corner.

In *De musculis et glandulis*, Steno wrote of his scepticism towards muscle research up to his time. Theories of muscle motion were based on the ancient tradition of animal spirits, which was carried into the early modern period by Fabricius d'Acquapendente

39 See Steno, *De musculis et glandulis*, *op. cit.* (note 1), p. 14 (muscle), pp. 12–13 (tongue), p. 37 (lymph), p. 71 (yolk).

40 *Ibid.*, p. 84. Another letter in the book was signed in April 1664.

41 For more details on these similarities, see Snorrason, *Nicolaus Steno, 1638–1686: the illustrative explorer, op. cit.* (note 8), p. 197. This claim is only about the four anatomical images, not the floral arrangements. The rest of the article takes Steno as the drawer of his books' anatomical drawings. Snorrason suggests a Danish name for the engraver, but Steno does not identify engravers by name.

42 This was first noticed in Snorrason, *Nicolaus Steno, 1638–1686: the illustrative explorer, op. cit.* (note 8), p. 196. We add that the wall of the right ventricle is just as thick as that of the left ventricle, suggesting this having been drawn from a case with chronic pulmonary arterial hypertension.

43 Steno comments on the tongue's muscle fibres in *De musculis et glandulis*, *op. cit.* (note 1), pp. 12–13.

44 Steno, *De musculis et glandulis*, *op. cit.* (note 1), p. 15: 'Binas musculus … sectiones juxta fibrarum ductum admittit, rectam alteram, alteram transversam, non quidem plano per medium transversim omnia secante, sed ita à latere ad latusacto, ut tendines cum carne maneant integri.'

45 *Ibid.*, p. 15: 'Eiusdem ordinis fibræ, in eodem plano sunt & parallelogrammum obliquangulum, seu rhoboideam exhibent figuram.'

Figure 5. Frontispiece. N. Steno, *De musculis et glandulis observationum specimen* (Copenhagen, 1664). Courtesy of Wellcome Collection.

(1533–1619), William Croone (1633–1684), and Descartes.[46] Rather than following them, Steno searched for a more accurate understanding of muscles by drawing on methods from

46 See Troels Kardel, *Steno on muscles: introduction, texts, translations* (American Philosophical Society, Philadelphia, 1994), pp. 3–11. The topic of animal spirits is too vast to be explored here. For more, see Maria Conforti, 'Succo Nerveo e Succo Seminale nella Macchina del Vivente di Giovanni Alfonso Borelli', *Medicina nei Secoli Arte e Scienza* **13**, 577–595 (2001); Matthew Cobb, 'Exorcizing the animal spirits: Jan Swammerdam on nerve function', *Nature Rev. Neurosci.* **3**, 395–400 (2002); C. U. M. Smith,

physico-mathematics, not unlike biomechanics today.[47] For instance, when speaking of the motion of the diaphragm, Steno compared its motion to that of a pulley.[48] He also proposed to distinguish the intercostal muscles according to 'the different angles towards the ribs'.[49] For Steno, this classification of the muscles carried an epistemological certainty almost as strong as attaining mathematical certainty, for 'the one who will not refuse to examine carefully the angles formed by the back, the ribs, the sternum and the muscles must find a demonstration of these muscles perhaps not less certain than by mathematics'.[50] Strikingly, the intercostal muscles and the muscles of the abdomen were those muscles mentioned by Van Horne in the dissections reported by Ole Borch. But how could Steno represent these mathematical insights with illustrations? Even though he did not explicitly state so, in light of his later diagrams it is possible to conclude that Steno was looking for a way to incorporate mathematics in his illustrations. He wished to combine mathematics with observations, almost as if he saw the geometrical structure of muscles with his new cuts.[51]

These ongoing difficulties in representing the muscles are confirmed in Steno's writings. A year before publishing *De musculis et glandulis*, when he was already studying the muscles, Steno wrote to Bartholin that he was 'busy with a thorough examination of the heart and muscles, [while] hoping … soon to complete [an account of] the structure of both with figures'.[52] In the actual book *De musculis et glandulis*, which lacked illustrations, Steno acknowledged that 'there is here a need of figures to demonstrate more clearly each of these things in particular'.[53] And a year later, when studying the brain in Paris, Steno also applied cross-sectional cuts, illustrated in the *Discours sur l'anatomie du cerveau* (Paris, 1669).[54] In that book, he said that 'we must use every means possible to have exact figures, which is why a good drawer is also more necessary than a good anatomist'.[55]

In Paris, ideas on how to draw the longitudinal cuts of muscle fibres remained in Steno's mind. André Graindorge (1616–1676), a physician mentored by Steno in Paris and later to become co-founder of the Académie Physique de Caen, included a sketch of Steno's idea

E. Frixione, S. Finger and W. Cover, *The animal spirit doctrine and the origins of neurophysiology* (Oxford University Press, Oxford, 2012).

47 For a survey of Steno's uses of mathematics in anatomy, see Castel-Branco, *Dissecting with numbers, op. cit.* (note 28). For more on physico-mathematics, see Peter Dear, 'Mixed mathematics', in *Wrestling with nature: from omens to science* (ed. Peter Harrison, Ronald Numbers and Michael Shank), pp. 149–172 (University of Chicago Press, Chicago, 2011).

48 Steno, *De musculis et glandulis*, *op. cit.* (note 1), p. 9: 'Nec enim, cum vel maxime tenditur, in rectam extensum est, nec, circa qvam moveatur, trochleam habet (nisi abdominis hic volueris nominanda contenta).'

49 *Ibid.*, p. 6: 'angulos cum costis constituunt diversos.'

50 *Ibid.*, pp. 9–10: 'Sed his missis quorundam musculorum describam in respiratione usum, quorum demonstrationem Mathematica forte non minus certam non poterit non invenire, qui, quos dorsum, costæ, sternum, musculi inter se conficiunt, angulos attente examinare non recusaverit.'

51 This geometrical structure is the origin of the mathematical model [*mensura*] used by Steno; see Troels Kardel, 'Niels Stensen's geometrical theory of muscle contraction (1667): a reappraisal', *J. Biomech.* **23** (10), 953–965 (1990), esp. p. 953.

52 Steno to Bartholin, 30 April 1663, in Bartholin, *Epistolarum centuria IV, op. cit.* (note 29), p. 414 (translation from BOP, *op. cit.* (note 1), p. 543).

53 Steno, *De musculis et glandulis*, *op. cit.* (note 1), p. 24: 'Sed figuris hic opus ad singula clarius demonstranda, quas in alia tempora differre coacto non convenient hic multis exponere quomodo in parietibus ventriculorum fibrarum variet ductus' (translation from BOP, *op. cit.* (note 1), p. 564).

54 Snorrason, *Nicolaus Steno, 1638–1686: the illustrative explorer, op. cit.* (note 8), pp. 192, 198–199.

55 Steno, *Discours sur l'anatomie du cerveau* (Paris, 1669), p. 52: 'C'est pourquoy il faut employer tous les moyens possibles, pour en avoir d'exactes, à quoy un bon dessignateur, est aussi necessair, qu'un bon Anatomist.'

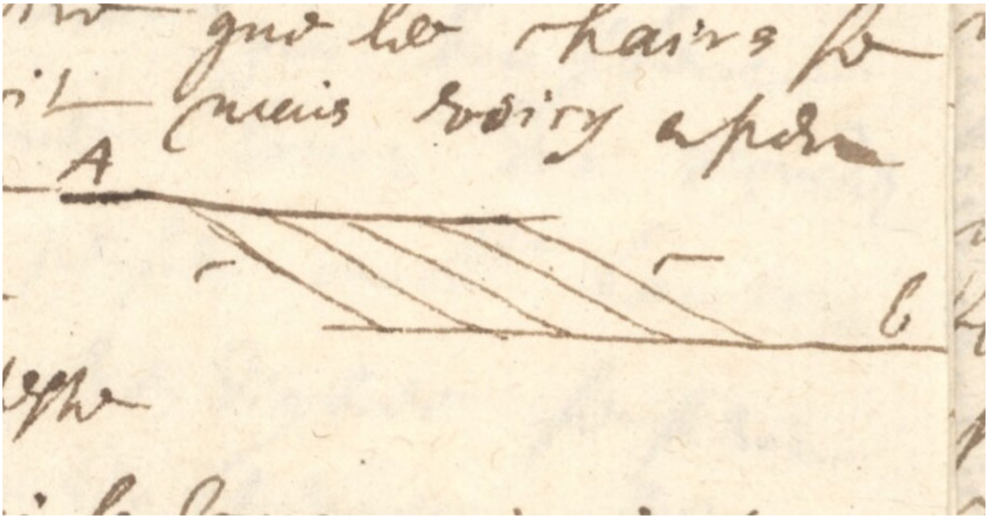

Figure 6. André Graindorge's sketch of Steno's diagram of the muscle structure. Royal Library of Denmark, NKS 4660 kvart, p. 47. Courtesy of Royal Danish Library. (Online version in colour.)

in a letter to Pierre Daniel Huet (1630–1721) (see figure 6).[56] Finally, Jean Chapelain (1595–1674), a courtier of Louis XIV (1638–1715) who helped select new members for the Académie Royale des Sciences, wrote of trying 'to force him [i.e. Steno] to give us a treatise of his new discoveries with images for greater clarity'.[57] Yet, despite these callings, Steno only made his longed-for illustrations in Florence.

Mathematical diagrams in Florence

Nicolaus Steno arrived in Florence in the spring of 1666.[58] A few months later, he had all the illustrations ready for his first Medici-sponsored book, as the book's first *imprimatur* shows.[59] Entitled *Elementorum myologiæ specimen* (Florence, 1667), this book was full of geometrical diagrams of various muscles. First, Steno showed the traditional depiction of a muscle as represented since antiquity (see figure 7); yet, he wrote that 'it seems to me most trustworthy to represent the structure of muscles the way I found it in many simple muscles' as well as in 'all compound muscles'.[60] Therefore, in his second illustration he represented 'a muscle through a

56 André Graindorge to Pierre Daniel Huet, 29 July 1665, in Royal Library of Denmark, Copenhagen, NKS 4660 kvart, p. 47. For more on Graindorge, see David Lux, *Patronage and royal science in seventeenth-century France: the Académie de Physique in Caen* (Cornell University Press, Ithaca, NY, 1989).

57 Jean Chapelain to Pierre-Daniel Huet, 6 April 1665, in *Lettres de Jean Chapelain, de l'Académie Française*, 2 vols (ed. Philippe Tamizey de Larroque) (Paris, 1880–1883), vol. 2, p. 393, n. 3: 'il faudra essayer avant qu'il nous quite de l'obliger à donner un traitté de ses nouvelles descouvertes avec leurs figures pour plus de clarté'; and André Graindorge to Huet, 29 July 1665, in Royal Library of Denmark, NKS 4660 kvart, p. 47.

58 See Scherz biography in BOP, *op. cit.* (note 1), pp. 163–177.

59 *Imprimatur* from 27 October 1666; see Steno, *Elementorum myologiæ specimen*, *op. cit.* (note 1), p. 123.

60 *Ibid.*, pp. 2–3: 'Mihi visum tutissimum eo modo fabricam musculorum repræsentare, quo in multis simplicibus musculis eam invenio, et in omnibus compositis me demonstraturum spero.'

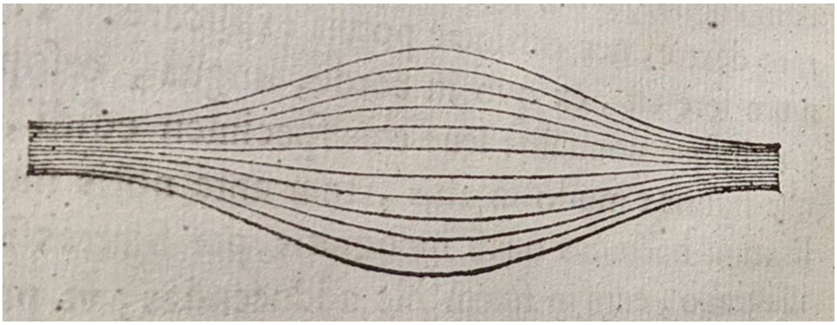

Figure 7. Traditional representation of a muscle. N. Steno, *Elementorum myologiæ specimen*, (Florence, 1667), p. 2. Courtesy of the Institute for the History of Medicine, Johns Hopkins University.

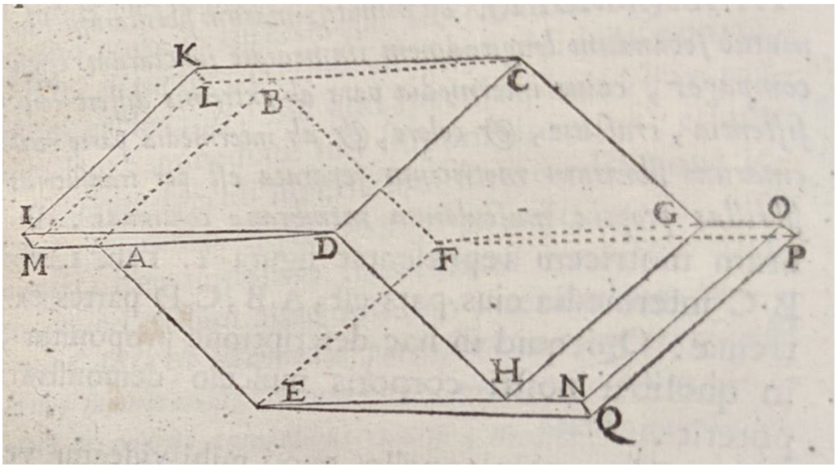

Figure 8. An oblique parallelepiped as a muscle. N. Steno, *Elementorum myologiæ specimen*, p. 3. Courtesy of the Institute for the History of Medicine, Johns Hopkins University. (Online version in colour.)

collection of motor fibres arranged in such a way that the middle flesh [part] forms an oblique parallelepiped, while the tendons form two opposite tetragonal prisms' (see figure 8).[61] In 1664, Steno had not yet decided how to represent the tendons, but now he opted for prisms, which shows that his understanding of the muscles evolved in these years.

Steno's fundamental contribution in this book was twofold.[62] First, he showed that muscle fibres looked like a two-dimensional parallelogram and a three-dimensional oblique parallelepiped or rhomboid. In his own words, 'I represent the muscle through a collection

61 *Ibid.*, p. 3: '*musculum repræsento per fibrarum motricium collectionem ita conformatam, ut mediæ carnes parallelepipedum obliquangulum constituant, tendines verò oppositi duo prismata tetragona componant*' (italics in the original).

62 For further analyses, see Kardel, *Steno on muscles, op. cit.* (note 46), pp. 17–24; Domenico Bertoloni Meli, 'The collaboration between anatomists and mathematicians in the mid-seventeenth century with a study of images as experiments and Galileo's role in Steno's myology', *Early Sci. Med.* **13**, 665–709 (2008), esp. pp. 696–706; and Raphaële Andrault, 'Mathématiser l'anatomie: la myologie de Stensen (1667)', *Early Sci. Med.* **15**, 505–536 (2010).

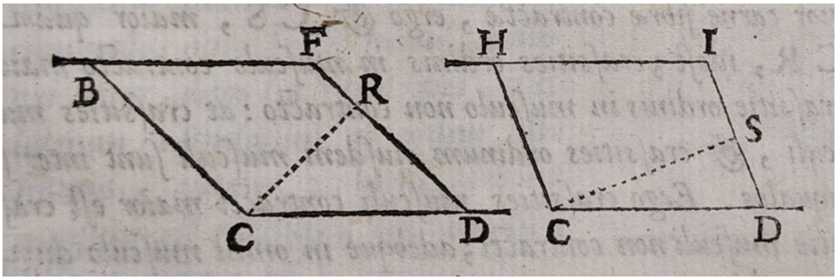

Figure 9. The lateral planes of a non-contracted muscle (right) and contracted muscle (left). According to Euclid, CS > CR without change of area. Thus, in three dimensions, the muscle swells without changing its volume. N. Steno, *Elementorum myologiæ specimen*, p. 25. Courtesy of the Institute for the History of Medicine of Johns Hopkins University.

of motor fibres shaped as if the middle flesh constitutes an oblique parallelepiped'.[63] He explained this comparison in the book's first part, which he entitled 'definitions'. In this part, the diagrams are geometrical representations of the muscle. Yet, even though geometrical diagrams are mental abstractions, Steno still argued with observations. For instance, to show that the parallelepiped had to be oblique, after describing some of his dissections, Steno wrote that 'it is clear by evident experiments that the extremity surfaces hold oblique angles with the perpendicular surfaces' of muscles.[64] Then he applied geometry from Euclid's *Elements* to show how the specific structure of a rhomboid works in a muscle undergoing fibre contraction and relaxation. Here, some of his diagrams are geometrical representations of Euclid's *Elements*. Thus, although similar, Steno's intentions in drawing geometrical figures differ throughout the book. Some are anatomical diagrams, partly based on observations, and others are Euclidean diagrams.

Steno used Euclid's *Elements* to show that muscles, like a varying rhomboid structure, do not change in volume even though there is an evident swelling to be seen and felt.[65] This geometrical structure of a parallelogram allowed Steno to demonstrate that the variation of oblique angles was sufficient to increase muscle thickness [*crassities*]. At stake is the proposition that parallelograms that are on the same base and same parallels are equal to one another (figure 9). In short, even though the muscle looked inflated when contracted, its volume remained the same as when relaxed. Therefore, he said, 'it is amply demonstrated in every muscle, that when contracted, it reaches a swelling, even though no new matter arrives at the muscles'.[66] Animal spirits were unnecessary: the inflated shape of a contracted muscle was a consequence of its inner geometry.

But Steno's insight that muscle contraction relied only on its shape and not on inflation from animal spirits was more complex than simply equating muscles with rhomboids. His argument included a time-dependent process associated with muscle contraction and depicted by

63 Steno, *Elementorum myologiæ specimen*, *op. cit.* (note 1), p. 3: 'musculum repræsento per fibrarum motricium collectionem ita conformatam ut mediæ carnes parallelepipedum obliquangulum constituant.'

64 *Ibid.*, p. 7: 'quod vero angulos obliquos attinet, plana extrema cum planis transversis obliquos angulos comprehendere evidentibus experimentis constat.'

65 Altogether Steno refers to one postulate, two axioms and 19 propositions from Euclid. For a list of all propositions, see Kardel, *Steno on muscles*, *op. cit.* (note 46), pp. 243.

66 Steno, *Elementorum myologiæ specimen*, *op. cit.* (note 1), p. 30: 'Atque ita quidem abunde demonstratum puto in omni musculo, dum contrahitur, tumorem contingere, etiamsi nulla nova musculo accederet materia.'

geometry. He opted to use several diagrams to guide the reader through various geometrical steps, just as in a treatise of mathematics. First, he began with definitions of a single fibre and a group of two-dimensional fibres. Then he defined three-dimensional fibres, as the muscles are supposed to be. He drew a diagram for each step of his geometrical reasoning to demonstrate several geometrical properties of the rhomboid. In short, Steno used geometrical diagrams to solve his dilemma of how to integrate a mathematical insight with observations by using geometrical diagrams. Indeed, Steno used a similar method to describe intercostal muscles, whose structure was especially hard to grasp. He had already proposed to distinguish them according to 'the different angles towards the ribs'.[67] Now, in Florence he added the illustrations that were missing. They were diagrams with lines distinguished by their angles (figure 10).

But were these diagrams the illustrations that he was looking for? In part yes, but Steno thought of more. After varied geometrical explanations, he said that he had 'to demonstrate their certainty with examples taken from Nature herself'.[68] Thus, he included 'figures of different muscles … displayed at the magnitude at which I have measured them in cadavers' (figures 11 and 12).[69] He used examples from several animals for different muscles, such as in a calf, a fish, lobsters and, most often, human bodies. Just as in Leiden, these images served mostly an illustrative purpose, but they also helped the reader to visualize what the dissector had himself seen. Moreover, these images represent the new longitudinal cut of muscles made by Steno in several animal species. That is, Steno shared Van Horne's interest in illustrating the muscles, but, as he progressed in his career, he deviated from his teacher precisely because of the importance of observations in his anatomical research.

Conclusion: making the invisible visible

In the preface to the *Elementorum myologiæ specimen*, Steno stated his main goal: 'I expose the true structure [of muscles] with a new method and I demonstrate that the mode of contraction through inflation of spirits such as proposed by the majority until now is built on an uncertain foundation.'[70] This method was the geometrization of muscle motion, whose originality has already been commented upon by Troels Kardel, Raphaele Andrault, and Domenico Bertoloni Meli. In this article, however, we argued that this 'new method' of geometry developed out of Steno's new and original longitudinal cut of muscles. He never saw the three-dimensional geometrical shape in muscles because muscle tissue is not transparent, but he became convinced that the two-dimensional parallelogram or the three-dimensional parallelepiped were good matches for the inner structure of skeletal muscles, since repeating parallel cuttings gives the same result, as he illustrated in four muscles (see figure 11). Steno then wished to bring his readers closer to this insight and let them visualize how a muscle contracts by variation of its oblique angles. In the end, Steno's geometrical diagrams and observations of muscles are much closer to one another than expected of a mathematical abstraction. This is confirmed by the similarity between his

67 Steno, *De musculis et glandulis*, *op. cit.* (note 1), p. 6: 'angulos cum costis constituunt diversos.'

68 Steno, *Elementorum myologiæ specimen*, *op. cit.* (note 1), p. 34: 'restat exemplis ex ipsa Natura depromptis eorundem certitudinem demonstrem, … .'

69 *Ibid.*, p. 34: 'figuras variorum musculorum ostendendo potius … .'

70 *Ibid.*, p. vi: 'ubi nova methodo veram eorum fabricam expono, contractionisque modum per spiritum inflationem a plerisque hactenus expositum incerto fundamento superstructum demonstro.'

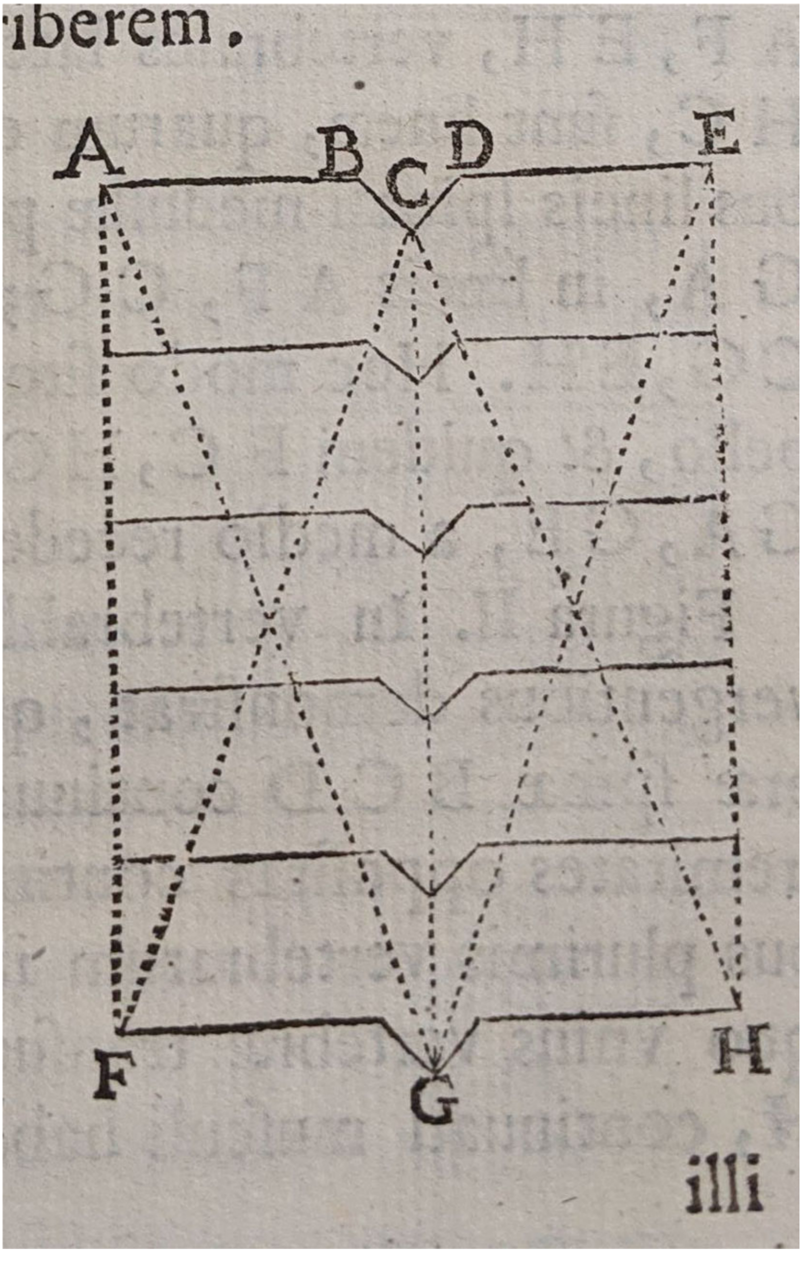

Figure 10. Diagram of the angles of intercostal muscles. N. Steno, *Elementorum myologiæ specimen*, p. 45. Courtesy of the Institute for the History of Medicine, Johns Hopkins University. (Online version in colour.)

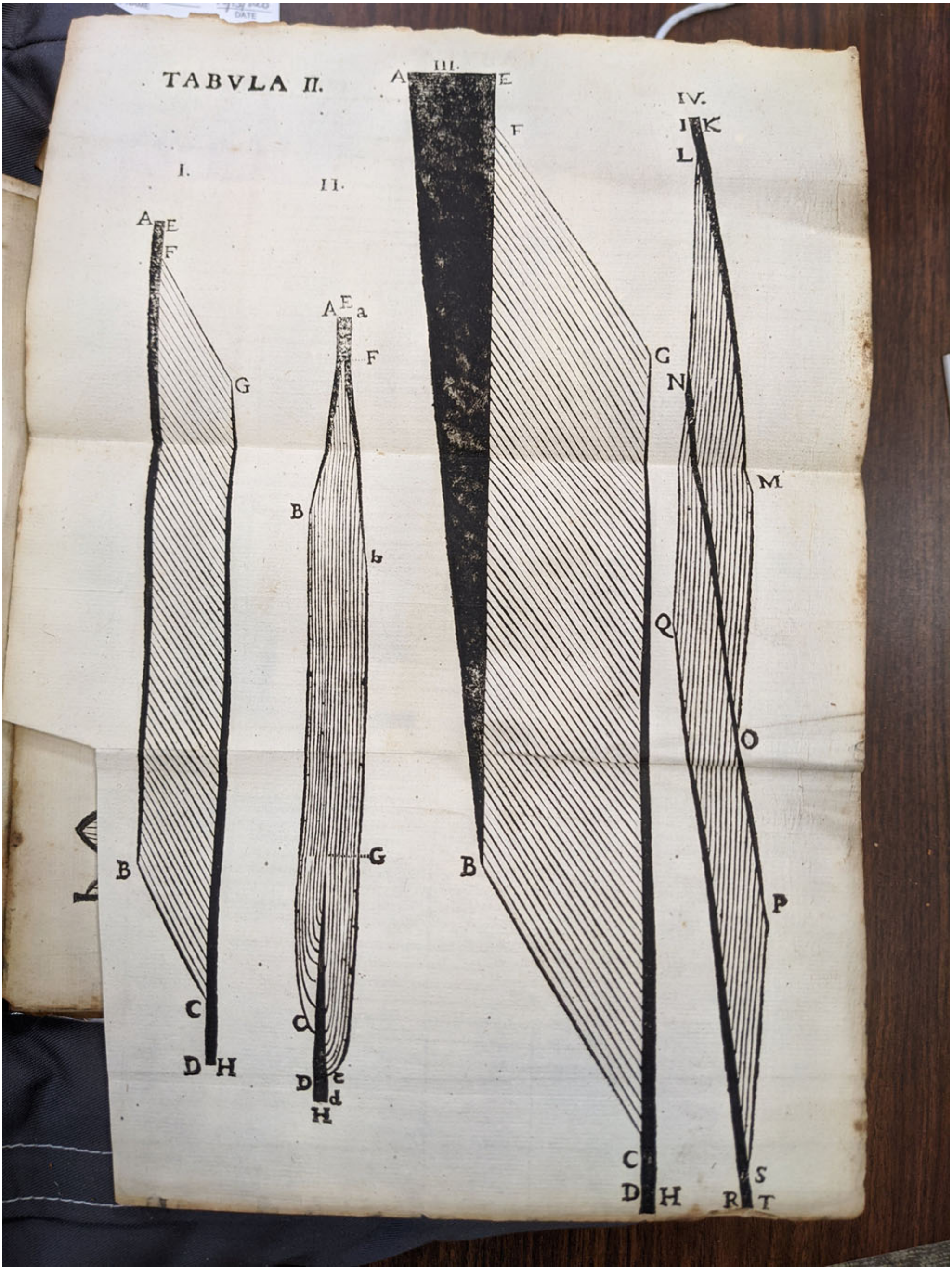

Figure 11. The inner structure of human gastrocnemius (I), biceps brachii (II), semimembranosus (III) and semitendinosus muscles (IV). N. Steno, *Elementorum myologiæ specimen*. Courtesy of the Institute for the History of Medicine, Johns Hopkins University. (Online version in colour.)

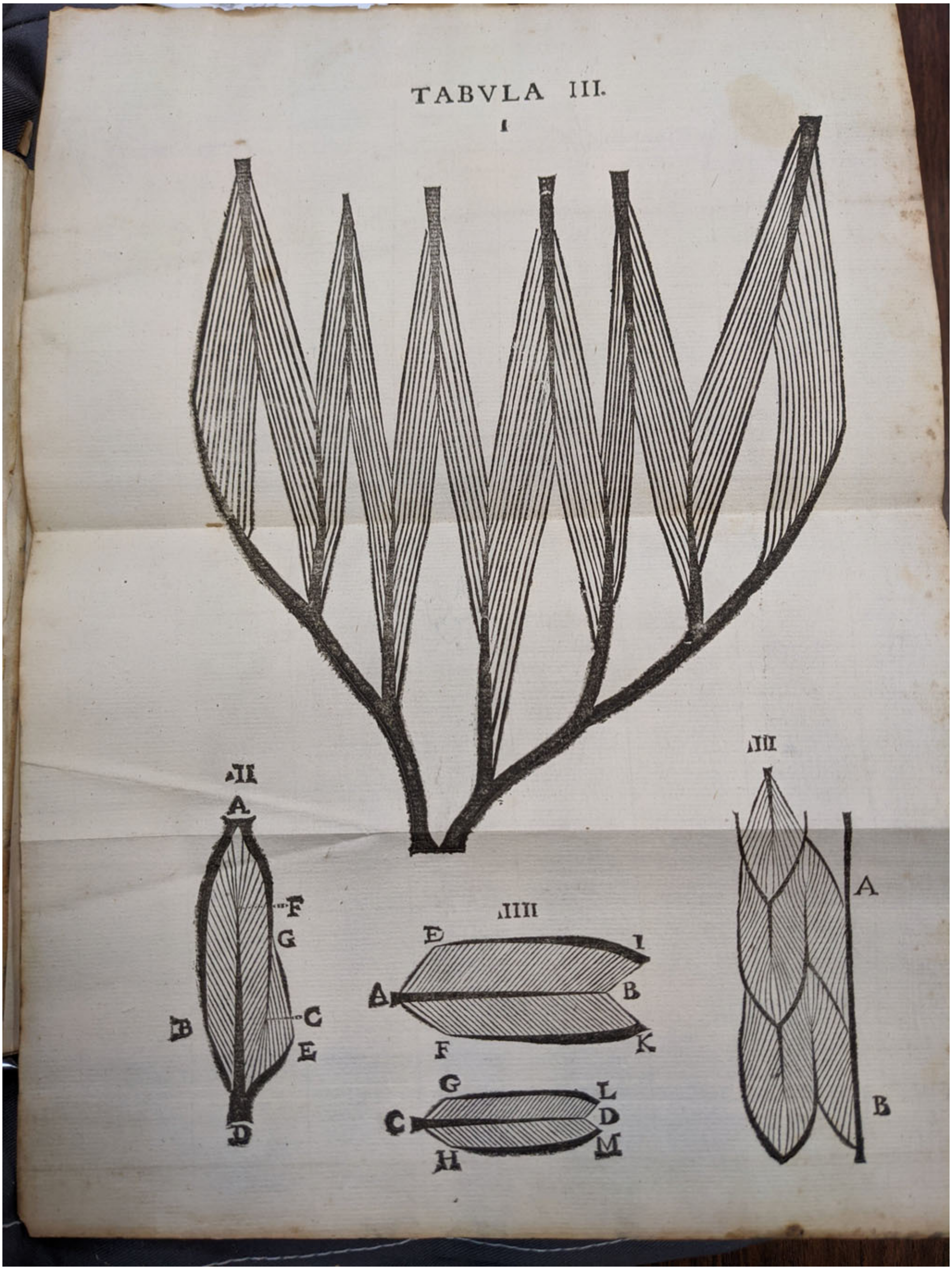

Figure 12. The human deltoid (I) and masseter (II) muscles, the costal muscles of fish (III) and the lobster claw's adductor and abductor muscles (IIII). N. Steno, *Elementorum myologiæ specimen*. Courtesy of the Institute for the History of Medicine, Johns Hopkins University. (Online version in colour.)

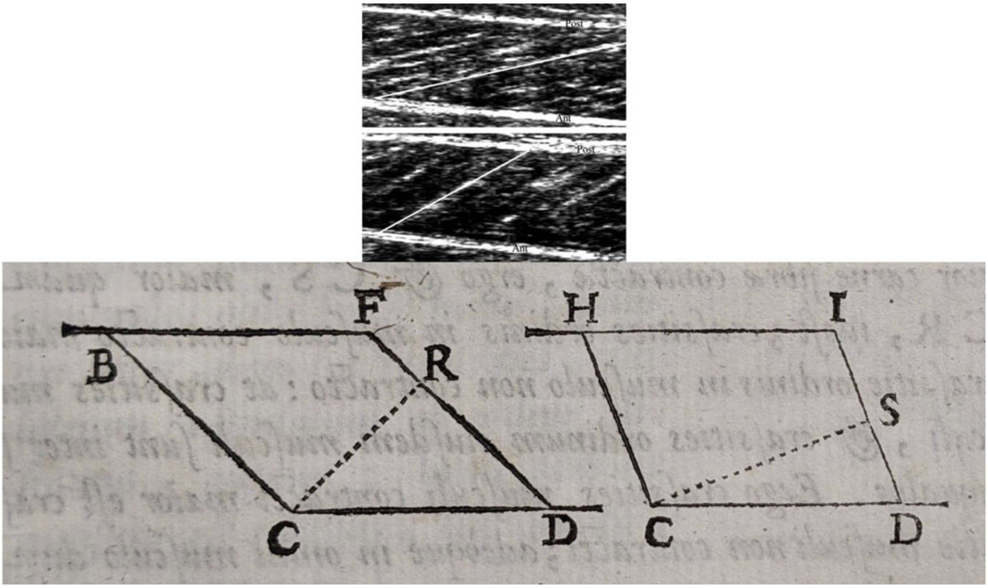

Figure 13. Ultrasound image of a muscle fibre in human gastrocnemius (top) and Steno's diagram (bottom). From Chow *et al.*, 'Sonographic studies of human soleus and gastrocnemius muscle architecture: gender variability', *Eur. J. Appl. Physiol.* **82**, 239 (2000); for Steno diagrams see figure 9.

diagrams and recent ultrasound recordings of contracted and relaxed muscle fibres and still-recording of the structure of a human biceps brachii muscle (figures 13 and 14).[71] The latter demonstrates what is not common anatomical teaching, even today: that the seemingly fusiform human biceps brachii hides an inner pennate structure only visible when cutting the muscle in the longitudinal sagittal plane.

Steno's use of geometrical diagrams as anatomical illustrations helped him to argue that the body can be understood in a mathematical language. That was, in fact, one of his main goals and achievements with his 1667 book. As mentioned above, Steno searched for more accurate knowledge about glands and muscles by applying methods from physico-mathematics. Now he argued that anatomy itself should become a mathematical discipline, like those that fit under the early modern category of mixed or physico-mathematics: 'why can we not give to the muscles what astronomers give to the sky, what geographers give to the earth and … what writers on optics concede to the eyes?'[72] For Steno, these writers 'treated natural things mathematically so that their knowledge may be more clear'.[73] Moreover, unlike a traditional drawing of muscles or glands, these series of diagrams allowed the reader to visualize with rigor a time-dependent process that they could not otherwise see, such as muscle contraction. Perhaps for this reason, except for Giovanni Borelli, who rejected

71 See also BOP, *op. cit.* (note 1), p. 198–203; and Troels Kardel, 'Steno's myology: the right theory at the wrong time', in *Steno and the philosophers*, *op. cit.* (note 14), pp. 138–173. For the ultrasounds, see R. Chow *et al.*, 'Sonographic studies of human soleus and gastrocnemius muscle architecture: gender variability', in *Eur. J. Appl. Physiol.* **82**, 236–244 (2000); and George Pappas *et al.*, 'Nonuniform shortening in the biceps brachii during elbow flexion', *J. Appl. Physiol.* **92**, 2381–2389 (2002).

72 Steno, *Elementorum myologiæ specimen*, *op. cit.* (note 1), pp. iii–iv: 'Et quidni musculis id daremus, quod cœlo astronomi, quod terræ geographi, et, ut ex microcosmo exemplum adducam, quod oculis rei opticæ scriptores concessere?'

73 *Ibid.*, p. iv: 'Res naturales mathematice tractarunt illi, quo distinctior earum esset cognitio.'

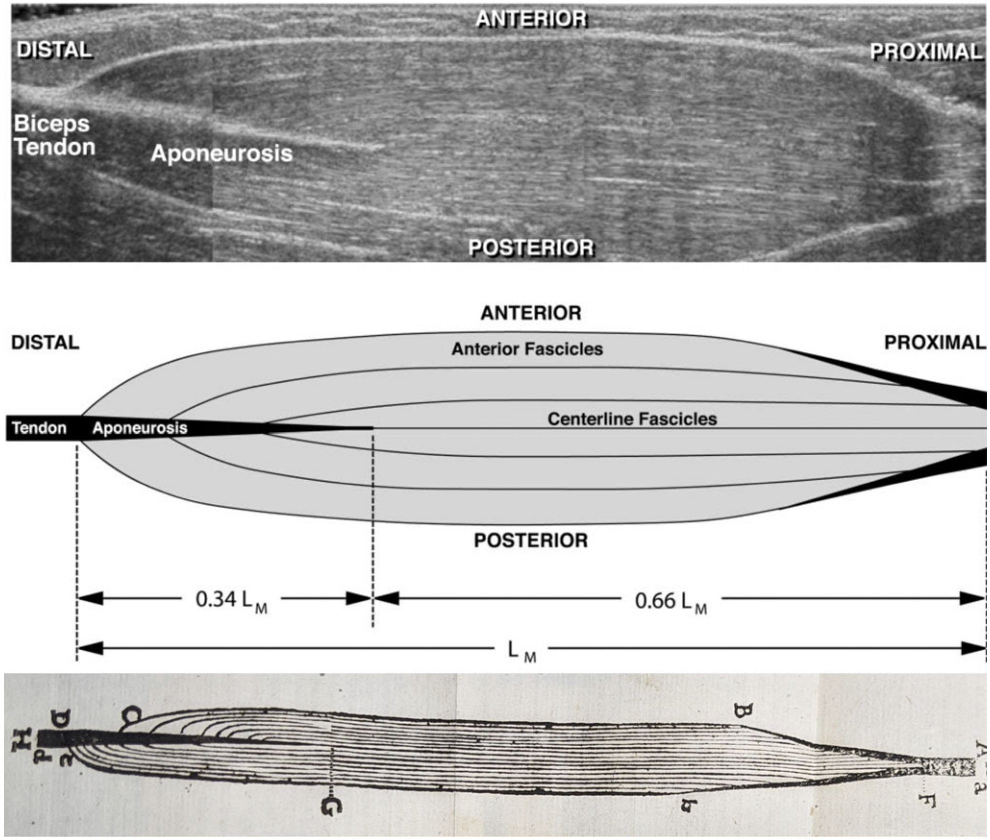

Figure 14. Ultrasound image of a human biceps brachii muscle (top), with a modern diagram of the same muscle (middle), and Steno's diagram (bottom), all cut in the sagittal plane. The ultrasound and modern diagram are from Pappas *et al.*, 'Nonuniform shortening in the biceps brachii during elbow flexion', *J. Appl. Physiol.* **92**, 2382 (2002). Steno drawing from figure 11.

Steno's geometrical theory of fibre shortening, Steno's book found praise among mathematically oriented scholars in the Italian Medici network.[74] Yet, precisely because of this, it is surprising that Johannes Van Horne did not seem to have commented on Steno's myology, although he knew something was under preparation.[75] In a letter one of us recently discovered, Van Horne wrote that he expected 'much from the most learned and famous Nicolaus Steno, who has leisure in abundance close to the Grand Duke of Tuscany'.[76] Steno's book had not yet arrived in Leiden at that time, because Van Horne said that 'there are also some Italian books which have not yet arrived to us'.[77]

74 See Nuno Castel-Branco, 'Steno, the traveling anatomist: physico-mathematics and the search for certainty in the seventeenth century', PhD thesis, Johns Hopkins University (2021), pp. 204–205. For Borelli's rejection, see Kardel, *Steno on muscles, op. cit.* (note 46), pp. 33–37.

75 Kardel, *Steno's myology, op. cit.* (note 71), p. 157. Van Horne may have commented on Steno's muscular theory without leaving a written record.

76 Johannes Van Horne to Caspar Bauhin, 24 October 1667, Universitätsbibliothek, Basel, UBH G2 I 9:Bl. 91: 'Plurima quotidie exspectamus à Cl. D. Doct. Nicolao Stenonis, qui pingui habet otium apud Serenissimum Magnum Hetruriam Ducem.'

77 *Ibid.*: 'In Italia quoque sunt Itali nonnulli, quorum tamen libelli ad nos nondum pervenerunt.'

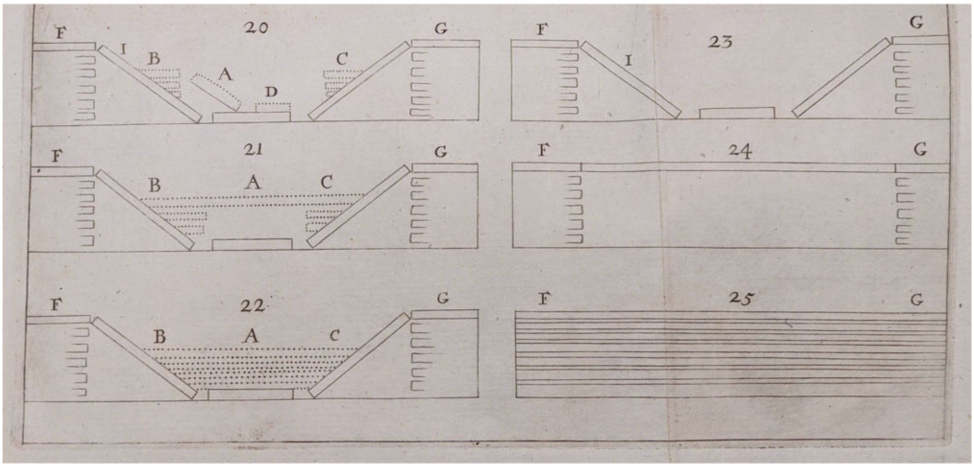

Figure 15. Diagram of the geological formation of the Earth's strata in Tuscany. N. Steno, *De solido intra solidum naturaliter contento* (Florence, 1669). Courtesy of Biblioteca Nazionale Centrale di Firenze. (Online version in colour.)

Perhaps not surprisingly, Steno continued to rely on diagrams and mathematics to describe processes that were hard to illustrate because of their time component. In his most famous book, the *De solido intra solidum naturaliter contento* (Florence, 1669), Steno also used geometrical diagrams when explaining the time-dependent formation of mountains and fossils.[78] Besides listing the observations that he made through Tuscany, Steno drew the process of superposition of the Earth's strata with diagrams, producing the first geometrical depiction of the history of the Earth and of modern geology (see figure 15). Although diagrams were not as real as a muscle atlas nor a mountain landscape, they were still intrinsically related to Steno's observations. Diagrams helped to visualize phenomena that were not easily observed, such as the dynamics of muscle contraction and the formation of the strata of the Earth. It is in this light that Steno's varied scientific illustrations and his commitment to observations need to be further investigated.

Data accessibility

This article has no additional data.

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78 For other parallels on time-dependent structures, see Kardel, 'Nicolaus Steno on solutes and solvents in time-related structural changes of muscles, fossils, landscapes and crystals, his Galilean heritage', *Substantia* **5** (1), 43–57 (2021).