NOTES AND RECORDS

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CASTING LIFE, CASTING DEATH: CONNECTIONS BETWEEN EARLY MODERN ANATOMICAL CORROSIVE PREPARATIONS AND ARTISTIC MATERIALS AND TECHNIQUES

by

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Although the historical connections between anatomy and the visual arts have been explored in quite some depth, especially in the cases of early modern anatomical drawing, sculpting, the making of wet preparations and wax modelling, the role of artistic techniques in the creation of corrosive preparations has received little attention thus far. This is remarkable, as there appear to be significant similarities between casting techniques like those employed by the influential artist Wenzel Jamnitzer (1508–85) and anatomical corrosive techniques. This paper explores the connections between the two domains and argues that, although artistic and anatomical techniques were often very similar in terms of the materials used, the skills that had to be developed to apply them successfully, and the visual results, there were distinct materialities and techniques in each realm. It is demonstrated that the creation of corrosion casts, particularly wax-based casts, required particular skills that were unlike others in the period. The paper does so by analysing the material and technical qualities of corrosive preparations from the period 1700–1900, and by comparing the results of this analysis with written instructions for making corrosive preparations and making casts from the same period in both anatomical and artist handbooks.

Keywords: history of anatomy; art history; technical art history; corrosion casts; injection wax; reconstruction research

Introduction

Exchanges and interactions between artisans and medical practitioners in the early modern period have been studied in quite some detail over the past decades.[1] Drawings, prints and

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[1] See e.g. Marina Wallace and Martin Kemp, *Spectacular bodies: the art and science of the human body from Leonardo to now* (University of California Press, Los Angeles, 2000). There is also a substantial corpus on the history of medical and anatomical collections and museums, which often included drawings, prints and models too. See e.g. Samuel Alberti and Elizabeth Hallam (eds), *Medical museums: past, present, future* (Royal College of Surgeons of England, London, 2013); Anita Guerrini, *The courtiers' anatomists: animals and humans in Louis XIV's Paris* (University of Chicago Press, Chicago, 2015); Marieke M. A. Hendriksen,

wax models of human anatomy in particular have received ample attention from historians of art and science alike. Excellent research has been done on the creation and use of anatomical drawings and prints by historians of science such as Sachiko Kusukawa and Carin Berkowitz.[2] Anna Maerker, Rebecca Messbarger and Lucia Dacome have done outstanding work on anatomical wax modelling practices.[3] Quite possibly these objects have been at the centre of attention because they were created using techniques—drawing and sculpting—that are firmly rooted in the art historical canon, thus making it easier for historians to interpret them, if not as works of art, then at least as artistic products. Yet in order to fully understand early modern anatomical modelling techniques, materials and meanings, we need to explore the possible technical and epistemic connections to artisanal practices not only of drawings, prints and sculptures but also of objects such as corrosion casts.

Even though the histories of art and science have become increasingly entangled since the mid 1990s, other products of collaborations between artisans and medical practitioners—such as models in wood, plaster or mixed media—have received less attention.[4] Possible reasons for this might be that few have survived, and the ones that did are sometimes not very aesthetically pleasing or visually interesting. A kind of model for which survival rate definitely has played a role in the limited attention they have received are so-called corrosion casts: casts of vascular systems in human and animal bodies, created through injecting them with a fluid, hardening mass, such as an alloy, a wax or a resin, after which the body tissue is corroded either through natural decay or, more quickly, by boiling or submersion in a caustic solution. Although the technique of corrosion casting was documented as early as the seventeenth century, these models are incredibly fragile, and very few early modern examples remain. This article uses extant corrosion casts, and descriptions and depictions of those that have disappeared, to investigate the transmission and adaptation of technical, material and natural philosophical knowledge and skills between early modern artisans and medical men.

Corrosion casts in context

How were techniques that were used by both artists and anatomists in the eighteenth century—such as drawing anatomical structures, wax modelling and plaster casting—exchanged and transmitted in writing and practice between those two groups? The most famous example are probably anatomical Venuses, wax models made by artisans for the study and teaching of anatomy, about which Anna Maerker, Rebecca Messbarger, and most recently Lucia Dacome have published thoroughly researched

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Elegant anatomy: the eighteenth-century Leiden anatomical collections (Brill, Leiden and Boston, 2015); Rina Knoeff and Robert Zwijnenberg (eds), *The fate of anatomical collections* (Ashgate, Farnham, 2015); Kaat Wils, Raf de Bont and Sokhieng Au, *Bodies beyond borders: moving anatomies 1750–1950* (Leuven University Press, Leuven, 2017).

[2] Sachiko Kusukawa, *Picturing the book of nature: image, text and argument in sixteenth-century human anatomy and medical botany* (University of Chicago Press, Chicago, 2011); Carin Berkowitz, *Charles Bell and the anatomy of reform* (University of Chicago Press, Chicago, 2015).

[3] Rebecca Messbarger, *The lady anatomist: the life and work of Anna Morandi Manzolini* (University of Chicago Press, Chicago, 2010); Anna Maerker, *Model experts: wax anatomies and enlightenment in Florence and Vienna, 1775–1815* (Manchester University Press, Manchester, 2011); Lucia Dacome, *Malleable anatomies: models, makers, and material culture in eighteenth-century Italy* (Oxford University Press, Oxford, 2017).

[4] On the changing relation between the histories of art and science, see Alexander Marr, ‘Knowing images’, *Renaissance Quart.* **69**, 1000–1013 (2016). Notable exceptions are Elizabeth Hallam (ed.), *Designing bodies: models of human anatomy from wax to plastics* (Royal College of Surgeons of England, London, 2015); and Margaret Carlyle, ‘Phantoms in the classroom: midwifery training in Enlightenment Europe’, *Know: A Journal on the Formation of Knowledge* **2**, 111–136 (2018).

Figure 1. Adriaan de Lelie, *The Drawing Room at Felix Meritis*, oil on canvas, 1801. Andreas Bonn was professor of anatomy at Leiden University and one of the founders of the drawing academy at Felix Meritis. (Courtesy of the Rijksmuseum.) (Online version in colour.)

books.[5] Other concrete examples of this were the study of anatomy in drawing academies (figure 1), and anatomists visiting plaster artists' workshops to learn casting techniques.[6]

However, there are many more such exchanges and transmissions between artisans and anatomists that are less obvious. Analysing these can give us much more insight into how artisanal techniques were understood and learned in this period, when the boundaries between the arts and the sciences were much more fluid than they are today. The use of the term 'artisanal' rather than 'artistic' here is deliberate, because the concept of artistic genius as we understand it today, like that of technique, only first emerged in the period 1700–1850.[7] It is important to keep in mind that people whom we now routinely describe as artists, such as sculptors and painters, fought a long rhetorical and institutional battle to elevate their work to the same status as the traditional liberal arts, such as logic and music. They were frequently perceived by others as skilled makers not that different from

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[5] Maerker, *op. cit.* (note 3); Messbarger, *op. cit.* (note 3); Joanna Ebenstein, *The anatomical Venus: wax, God, death & the ecstatic* (Distributed Art Publishers, New York, 2016); Dacome, *op. cit.* (note 3).

[6] Marieke M. A. Hendriksen, 'Of artists and anatomists: early nineteenth-century plaster casts in the RCSEd's collections', *Surgeons' News: the Magazine of the R. Coll. Surg. Edin.* March, 28–31 (2017).

[7] On genius and ingenuity, see Alexander Marr, Raphaële Garrod, José Ramon Marcaida and Richard J. Oosterhoff, *Logodaedalus: word histories of ingenuity in early modern Europe* (Pittsburgh University Press, Pittsburgh, 2018). On technique, see Marieke M. A. Hendriksen, '"Art and technique always balance the scale": German philosophies of sensory perception, taste, and art criticism, and the rise of the term Technik, ca. 1735–ca. 1835', *Hist. Humanities*, **2**, 201–219 (2017).

Figure 2. Robert Edge Pine, *Portrait of William Hunter*, oil on canvas, 1760s. (Courtesy of the Royal College of Surgeons of England, RCSSC/P 136.) (Online version in colour.)

craftspeople like carpenters and jewellers, with similar skills and technical knowledge.[8] Technical, material and natural philosophical knowledge and skills were frequently exchanged between and adapted by early modern artists and medical men, yet, in the case of corrosion casting, these connections have remained largely unstudied thus far.

Were artisanal techniques from other fields used to make corrosion-cast preparations? Corrosion casting was a popular method of studying the detailed anatomy of arteries and veins around 1800, as these are difficult to discern in dissection.[9] Unfortunately, the resulting objects are very fragile, and many—especially early—specimens have been lost. Two examples are a corrosion cast of a heart from the collection of William Hunter (1718–83), now lost, and one of the few remaining corrosion casts in the cabinet of Jan Bleuland (1756–1838) at Utrecht University, made around 1800 (figures 2 and 3). Even

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[8] See e.g. Pamela H. Smith, *The body of the artisan: art and experience in the Scientific Revolution* (University of Chicago Press, Chicago, 2004); and Matteo Valeriani (ed.), *The structures of practical knowledge* (Springer, Cham, 2017). The distinctions between artist and artisan, art and craft, were emerging and shifting in this era, making it difficult to both use actors' categories and be consistent. In this paper, I will therefore refer to people whose primary source of income was medical research, treatments and teaching as medical men, and to those whose primary source of income was the creation of objects that we would now describe as either artistic or artisanal as artisans.

[9] The technique is frequently described in anatomical handbooks of the time: see e.g. Thomas Pole, *The Anatomical Instructor; or an Illustration of the Modern and Most Approved Methods of Preparing and Preserving the Different Parts of the Human Body and of Quadrupeds by Injection, Corrosion, Maceration, Distention, Articulation, Modelling, &c.* (Couchman & Fry, London, 1790).

Figure 3. Corrosion preparation of the lung vessels, wax mixture, Bleuland Cabinet, Utrecht University Museum, *ca* 1800. (Utrecht University Museum, inv. no. 0285-107744.) (Online version in colour.)

though we have so few left, it is remarkable that the role of artisanal techniques in the creation of corrosive preparations has received little attention thus far, as at first sight there appear to be significant similarities between casting techniques and materials used by artisans and anatomical corrosive techniques. This paper discusses the similarities and differences between techniques that we now understand as artistic, such as life-casting, versus the anatomical technique of corrosion casting, by analysing the material and technical qualities of corrosive preparations from the period 1700–1900, and by comparing written instructions for making corrosive preparations and making casts and other, visually similar, artistic objects from the same period in both anatomical and artisanal handbooks.

Although the making of corrosion casts was primarily intended to teach anatomy to medical students, the study of anatomy was also incredibly important to artists, and anatomical preparations were sometimes primarily commodities, not aimed at acquiring and exchanging anatomical knowledge, but at impressing visitors and at making money through selling them.[10] The eighteenth century saw a huge rise in the publication of printed artisanal manuals and handbooks in a wide range of fields, including the visual arts and medicine. Artisans producing anatomical models sometimes explicitly refused to share their craft knowledge in writing or were only willing to do so if the price was right.[11] Yet, even if they did circulate their practical knowledge in print, recent research has shown that such manuals could often only be used effectively within the context of established routes to craft learning, such as apprenticeships.[12]

Moreover, even if there were no commercial motives, anatomists often cared deeply not just about the anatomical correctness but also about the beauty of their preparations.[13] The famous Leiden professor of anatomy Bernard Siegfried Albinus (1697–1770) opened his 1736 dissertation on the arteries and veins of the human intestines with the words: ‘First, I will deal with the arteries and veins in man’s intestines, now that I have obtained the opportunity to show these matters with exceptional skill and elegance’.[14] He was referring to the injected preparations he had created of human intestines. The quest for models and preparations that were both informative and beautiful continued well into the nineteenth century, as shown by the work of Joseph Hyrtl (1810–94), who wrote about making corrosion preparations in his 1860 handbook on anatomical preparations: ‘Such corrosions require a degree of attention that not everyone will be willing to invest in an anatomical preparation just to make it beautiful. I however suffer from the weakness that I believe the beauty of my work to be essential.’[15] Hyrtl was known for his love of corrosion preparations, and this quote shows that he was very concerned with the aesthetic quality of his preparations (figure 4).

The similarities between anatomical corrosion casts and artistic techniques run deeper than their similarly pleasing appearance though, and can be traced back much further than Hyrtl’s work. Early examples of corrosion preparations of anatomical structures appear to have shown striking visual similarities to both contemporary life casts and (imitations of) coral. For example, a print made by Gerard de Lairesse (1641–1711) of Govaert Bidloo’s (1649–1713) soldering tin cast of a branch of a lung is reminiscent of the life-cast foliage on the foot of a silver table ornament made by the master goldsmith Wenzel Jamnitzer (1508–85) in the mid sixteenth century (figures 5 and 6).[16] Another early example of a corrosion

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[10] Marieke M. A. Hendriksen, ‘Anatomical mercury: changing understandings of quicksilver, blood, and the lymphatic system, 1650–1800’, *J. Hist. Med. Allied Sci.* **70**, 516–548 (2015), at p. 532; Dániel Margócsy, ‘A museum of wonders or a cemetery of corpses? The commercial exchange of anatomical collections in early modern Netherlands’, in *Silent messengers: the circulation of material objects of knowledge in the early modern Low Countries* (ed. Sven Dupré and Christoph Lüthy), pp. 185–216 (LIT Verlag, Berlin, 2011).

[11] Frederik Ruysch is a well-known example of an entrepreneurial medical man who guarded his recipes and techniques. See Daniel Margócsy, *Commercial visions: science, trade, and visual culture in the Dutch golden age* (University of Chicago Press, Chicago, 2014), pp. 128–132.

[12] Thijs Hagendijk, ‘Learning a craft from books: historical re-enactment of functional reading in gold- and silversmithing’, *Nuncius* **33**, 198–235 (2018).

[13] On the general importance of aesthetic considerations in the creation of anatomical preparations, see Hendriksen, *op. cit.* (note 1).

[14] B. S. Albinus, *Dissertatio de Arteris et Venis Intestinorum Hominis. Adjecta Icon Coloribus Distincta* (Theodor Haak, Leiden, 1736), p. 1: ‘Primum autem faciam in arteriis et venis intestiorum hominis, nactus opportunitatem artificio singulari, eoque eleganti… expressas exhibendi.’ See also Hendriksen, *op. cit.* (note 1), p. 16. All translations are mine unless noted otherwise.

[15] Joseph Hyrtl, *Handbuch der praktischen Zergliederungskunde als Anleitung zu den Sectionsübungen und zur Ausarbeitung anatomischer Präparate* (Wilhelm Braumüller, Vienna, 1860), p. 640.

[16] Jamnitzer was a Nuremberg goldsmith with a profound interest in natural philosophy and mathematics. He published a book of prints, the *Perspectiva corporum regularium* (1568), in which he truncated, stellated and faceted the five Platonic regular solids (polyhedra) to produce 120 variations, 24 of each solid.

Figure 4. Joseph Hyrtl, wax corrosion preparation of a human kidney, mid nineteenth century. (Mödling Museum, Austria.) (Online version in colour.)

preparation, this time in wax, incorporated in an anatomical still life by Frederick Ruysch, shows a striking visual similarity with the manner in which coral, either artificial or real, was displayed in early modern cabinets of curiosities (figures 7 and 8). Are these apparent similarities merely visual and enhanced by contemporary rhetoric, or do the connections run deeper? What about the underlying techniques, materials and meanings? Did the creation of corrosion casts require particular technical skills that were unlike others used during the period? Were there clear artisanal, technical or epistemic connections, or is it impossible to determine how such practical knowledge and skills circulated?

LIFE CASTING, DEATH CASTING?

The plant casts in figure 6 have been made through a process called life-casting, in which plants or recently killed small animals are encased in a mould, from which they are subsequently burned or removed. Then the moulds are filled with molten metal. This process dates back to antiquity, and has been documented in various early modern sources. It was recently described and reconstructed by Pamela Smith and Tonny Beentjes, who argue that life-casting in the sixteenth century was viewed in part as a means to obtain knowledge of nature.[17] What are the differences and similarities between this particular method of life casting and corrosion casting? In life-casting, the plant or animal that is used to make the cast is turned to ashes and shaken out of the cast in the firing process, after which the cast can be filled with metal. In corrosion casting, by contrast, the veins and arteries of a human or animal body serve as the mould. They are filled by pouring or injecting them with a hardening substance, such as a mixture based on molten wax or metal. After the material has hardened, the tissue is

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[17] Pamela H. Smith and Tonny Beentjes, 'Nature and art: making and knowing: reconstructing sixteenth-century life-casting techniques', *Renaissance Quart.* **63**, 128–179 (2010).

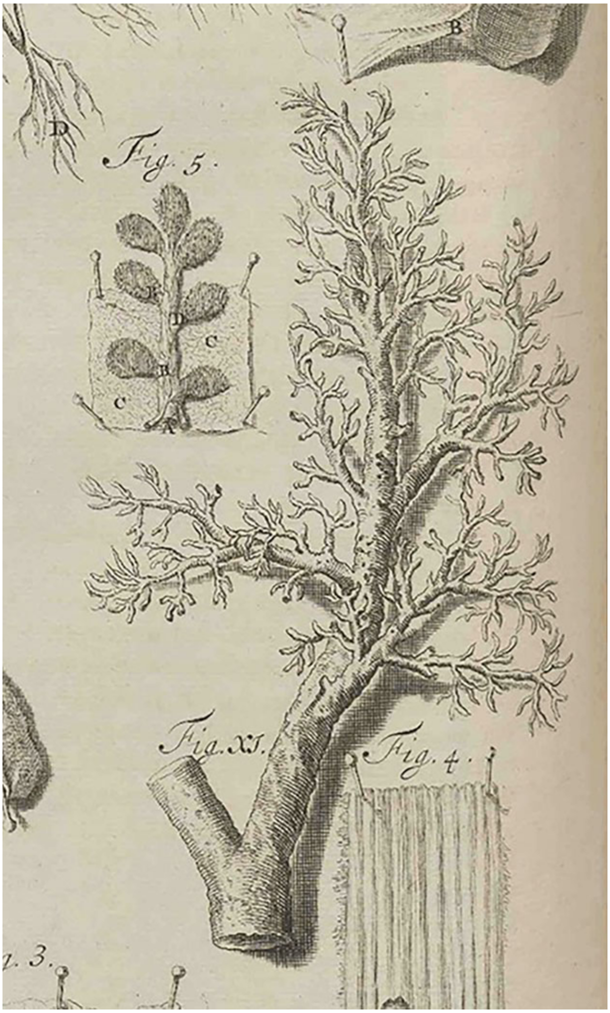

Figure 5. Cast of a branch of the lung in soldering tin. (Gerard de Lairesse and Govaert Bidloo, *Ontleding des menschelyken lichaams* (Jacob van Poolsum, Utrecht, 1728; reprint of the 1690 edition), detail of p. 82, fig. XI.) (Online version in colour.)

removed, usually by boiling or maceration—slowly decomposing and washing it away in water, often with the help of an acid. Although life and nature casts show a striking visual similarity to corrosion casts of veins and arteries from the second half of the seventeenth century, and the actual body that is represented by both is destroyed in the process of making, on closer inspection there are a number of important differences between the two.

First, while the life and nature casts form a mimesis of a living form—a plant or an animal—the corrosion casts are a mimesis of an otherwise invisible structure from inside a living being—a human or an animal. Second, whereas in life-casting the organic body is used to make a mould, in corrosion casting the inside of the body is itself the mould. Moreover, the materials that are used are different. Life and nature casts were mostly part of larger prestigious artisanal objects, like Jamnitzer's table pieces, and are therefore

Figure 6. Wenzel Jamnitzer (attributed), four nature casts of plants, c*a* 1540. Silver, all ca 5.8 cm high. (Nuremberg, Germanisches Nationalmuseum, inv. no. HG 11137–42.) (Online version in colour.)

usually made of bronze, gold or silver—relatively expensive and durable materials. Corrosion casts were made mostly with wax and occasionally with tin or a mixture of tin and lead—materials that were fairly cheap and readily available, resulting in fragile objects, which partly explains why we have so very few early examples of them.

Based on this analysis alone, it seems unlikely that there was a relationship or an exchange of knowledge and skills between the makers of life casts and other kinds of artisanal casts on the one hand, and the makers of anatomical casts on the other, either personally or indirectly, through written instructions and recipes. Yet other sources suggest that there probably *were* connections between these practices: for example, the fact that Leonardo da Vinci in his notebooks from the late fifteenth century describes how to make a wax cast of the ventricles of the brain, which he thought housed the *sensorium commune*. He writes:

> Make 2 air-holes in the horns of the great ventricles and put the melted wax by means of the syringe, making a hole in the ventricle of the *memoria*, and fill through such hole the 3 ventricles of the brain; and then, when the wax has curdled, split up the brain, and you will distinctly see the form of the three ventricles. But first put the tiny tubes into the air-holes, that the air which is in these ventricles may escape and give room to the wax which enters the ventricles.[18]

Strictly speaking, this is not a corrosion preparation as the brain is sawed in half to obtain the wax cast, rather than corroded over time. Yet the idea and goal are similar to those of a

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[18] Leonardo da Vinci, *Quaderni d'Anatomia* (ed. Ove C. L. Vangensten, A. Fonahn and H. Hopstock), 6 vols (Dybwad, Christiania, 1911–16), vol. 4, f. 7r.

Figure 7. Frederik Ruysch, Still life of human stones, veins, arteries and infant skeletons. (Frederik Ruysch, *Opera omnia anatomico-medico-chirurgica, hucusque edita* (Jansson-Waesberge, Amsterdam, 1737[–1744]), Table 1 of *Thesaurus anatomicus octavus*, 1727.)

corrosion preparation: to make a lasting, three-dimensional model of an anatomical structure that remains invisible otherwise. After Da Vinci's description of this wax cast, there is no known documentation of anatomical casting methods for more than a century and a half. Only in the last decades of the seventeenth century, when a number of Italian and Dutch anatomists started to experiment with injecting veins and arteries with coloured fluids and subsequently with hardening fluids to make them more visible, did instructions for making, descriptions and depictions of corrosion casts appear. The first mention of a hardening injection mass is found in 1666, when Jan Swammerdam (1637–80) developed solidifying fluid wax masses and succeeded in creating lasting corroded preparations of anatomical structures, which could be preserved either dried or in fluid.[19]

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[19] Jan Swammerdam, *Miraculum Naturae, Sive Uteri Muliebris Fabrica* (Johannes van Horne, Leiden, 1672), p. 33.

Figure 8. Cabinet of corals, second half of the sixteenth century. (Schloss Ambras Innsbruck, PA 961; www.khm.at/de/object/36be42bc7b/.) (Online version in colour.)

The first illustrated instructions for making a corrosion preparation of the lung vessels are found in a 1685 book by the anatomist Govaert Bidloo. In his *Anatomia humani corporis*, we find an illustration by Gerard de Lairesse of what is described as a cast of a branch of the lung in soldering tin (see figure 5). By 'soldering tin', Bidloo probably meant a mixture of about 60% tin and 40% lead. This relatively affordable alloy has a number of benefits over using either pure tin or pure lead. Whereas the persistent choice for a combination of red wax for blood vessels and a mercury mixture for the lymphatic system was at least partly inspired by alchemical understandings of mercury and the mercury-based red pigment vermilion, as I have shown elsewhere, the choice to use a tin–lead alloy to create corrosion casts of the lungs has no clear roots in alchemical understandings of these metals.[20] Although alchemical 'trees' could be grown from metals, this was a procedure requiring gold and

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[20] Hendriksen, *op. cit.* (note 10).

mercury, rather than tin and lead.[21] It is possible that Bidloo learned this casting method from another anatomist who had experimented with it before him, yet there are no indications that he did so. There definitely is evidence that practical skills and knowledge required to make successful preparations and models were exchanged between medical men, and that studying models and preparations was a crucial part of medical training around 1700. Yet casting and modelling practices were not a formal part of medical education at this time.[22] Moreover, in this case, practical considerations appear to have played a key role in the choice of materials, implying that Bidloo may have sought advice from a professional assayer to select the specific alloy he used.

Soldering tin has a number of beneficial properties for the specific aims of corrosion casting. First of all, there is weight—lead is about 1.5 times as heavy as tin. Whereas pure tin might not be heavy enough to reach the furthest branches of the organ to be cast, metals like lead or mercury could be too heavy, destroying fragile anatomical structures rather than making them visible. Another important consideration is temperature. A pure substance, such as tin or lead, generally has a melting range—the difference between the temperature where the substance starts to melt and the temperature where it is completely melted—of one or two degrees, whereas this soldering tin alloy has an exact melting point, making it easier to handle. Moreover, soldering tin is a eutectic alloy, meaning that it melts at a much lower temperature (183°C) than either pure tin (231.93°C) or pure lead (327.46°C). This not only makes it easier to handle but also prevents the metal from scorching the organic tissue that is used as a mould, as a reconstruction of Bidloo's experiment, described below, confirmed.[23] Remaining solid up to 183°C, after cooling, the soldering tin-filled lungs that Bidloo describes can thus be boiled in water to speed up the maceration process, so that the cast can be completed in three to four hours.

A relatively new approach in historical research, reconstruction research, can enhance our understanding of the past; it can lay bare inadequacies of modern classifications for understanding historical ideas about sensory and cultural experiences that shaped hypotheses, taxonomies and knowledge systems.[24] Reconstruction research is methodologically complex and potentially problematic—after all, it is impossible to exactly replicate historical making processes, let alone experiences. For this reason, some practitioners argue that it is better to speak of 'construction' rather than 'reconstruction'.[25] Yet, as this paper also shows, reconstruction of historical practices can undeniably provide us with a deeper, more holistic understanding of historical practices, as long as we do not mistake them for exact relived historical experiences.

As Bidloo's own preparations and models were lost, it is difficult to tell from de Lairesse's illustration how strong the visual resemblance of this tin corrosion cast of the lung to Jamnitzer's life casts of foliage was in reality. Only a late nineteenth-century metal corrosion cast of a lung is known, but that model was made using a mixture of bismuth, lead, tin and cadmium, rather than a simple tin–lead alloy, and it seems more

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[21] Lawrence M. Principe, 'Apparatus and reproducibility in alchemy', in *Instruments and experimentation in the history of chemistry* (ed. Frederic L. Holmes and Trevor Levere), pp. 55–74 (MIT Press, Cambridge, MA, 2000).

[22] See e.g. Hendriksen, *op. cit.* (note 10).

[23] Discussed by the author in an email conversation with the metals conservator Tonny Beentjes, 27 August 2018.

[24] Donna Bilak *et al.*, 'The making and knowing project: reflections, methods, and new directions', *West 86th* **23**, 35–55 (2016).

[25] For a detailed discussion of these issues, see Sven Dupré *et al.* (eds.), *Reproduction, replication, re-enactment* (*in press, Amsterdam University Press*).

detailed and extensive than de Lairesse's depiction of Bidloo's cast suggests.[26] Therefore, it was decided to reconstruct the process described by Bidloo. As using human lungs for this reconstruction experiment would create all kinds of ethical and practical problems, two pairs of lamb lungs were bought from a local butcher. Sheep lungs have a very similar anatomical structure to human lungs and using lamb lungs limited the amount of soldering tin needed. For health and safety reasons, the reconstruction was created in a professional museum conservation lab with the help of Tonny Beentjes, an experienced metals conservator.

Bidloo's description of the tin-casting process is very succinct:

> The internal appearance of the lung pipes can ably be traced in tin, which is called soldering tin, by pouring it into the lung pipe. To clean the vesicles and membranes of this tin, the aforementioned tin-filled lung should be boiled in water for so long that all the parts of the lung tear and the tin branches can be found uncovered; which happens in three to four hours of boiling at the most. Its appearance is shown in Figure XI.[27]

Pouring molten soldering tin into a lung pipe is easier said than done. The fluid metal is around 200°C, and heavy: a half-full saucepan can only be lifted with both hands. The lung is a slippery organ and cannot easily be suspended or held in the hand while pouring in the soldering tin because of the risk of tearing from the suddenly added weight or burns respectively. There are no clear indications how Bidloo solved the issue of holding the lung. Some of the plates in the *Anatomia* show specimens secured by pins, hooks and needles, and it is possible that he suspended the lung using such implements, but we cannot be certain. To work around these problems, an incision was made in the lung pipe and a copper tube with a slightly smaller diameter was stuck into it, down to the point where the main pipe splits into the lungs (figure 9). This construction created a 'handle'—the upper part of the airpipe—allowing a safe pouring in of the soldering tin. Through these preparations, it immediately became clear that Shapin's invisible technician must have played a significant role in Bidloo's casting process: this is a four-hand job, and without Tonny Beentjes' expert knowledge and the tools and materials available in the lab, this reconstruction would have been a much more arduous and risky process.[28]

As it was feared that the hot metal might cause the lung to explode when it was poured in, the first lung was submerged in a bucket of cold water, although this had two potential downsides. First, the cold water might cool down the metal too swiftly, preventing it from reaching the smallest branches of the lungs; second, it is impossible to remove all the air from the lung, which means that it floats in water, creating a 90° angle with the lung pipe. This too could prevent the metal from reaching the smallest branches, as it slows down the flow and limits the beneficial effect of gravity. For safety reasons, it was nonetheless decided to try this set-up first—if the exterior of the lung remained intact, the second lung could be cast without submerging it in water. Indeed, when the soldering tin was poured into the first lung, some

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[26] Samuel John Mixter (1855–1926), 'Corrosion cast of bronchi and trachea, possibly from rabbit, sheep or dog', Center for the History of Medicine, Countway Library of Medicine, Boston, *OnView: Digital Collections & Exhibits*, https://collections.countway.harvard.edu/onview/items/show/13120 (accessed 30 November 2018).

[27] Govaert Bidloo, *Ontleding des menschelyken lichaams* (Utrecht, 1728; first published 1692), p. 83: 'De inwendige gedaante der Luchtpypen kan zeer bequaamelyk nagespoord werden met tin, het welk men Soldeertin noemd, gesmolten in de Longpyp gegooten werdende. Om nu de blaaskens en vliezen van dit tin te zuiveren, moet de voornoemde met tin gevulde Long in water zoo lang gekookt werden, tot dat al de deelen des Longs scheuren en de tinne takken ontdaan gevonden werden; het welk in drie, ten hoogsten vier uuren kookens, geschied. Des zelfs gedaante vertoond de XI. Uitbeelding.'

[28] Steven Shapin, 'The invisible technician', *Am. Scient.* **77**, 554–563 (1989).

Figure 9. Lamb's lung with copper pipe inserted in airpipe through incision, 19 October 2018. (Photo: author.) (Online version in colour.)

spluttering, sizzling and smoke occurred, but the outside of the lung remained stable (figure 10). This encouraged us to cast the second lung while suspending it over a metal tray to catch any spills, with me holding it in mid air by the part of the airpipe above the copper pipe while the molten metal was poured in by Tonny Beentjes (figure 11).

Once the soldering tin was poured into the lungs, it hardened quickly—after only 10 minutes the lungs had cooled down enough to touch them, and a hard mass could be felt through the tissue. For logistical reasons, the cooking of the lungs could not be done until two days after the pouring. After three hours, the first lung was very soft, but did not tear until the tissue was carefully slit with a scalpel and torn off by hand. The last tissue fibres were removed with a toothbrush under running water, revealing a metal cast of the branches of the lung that does indeed resemble Bidloo's cast (figures 12 and 13). Although neither cast was as detailed as the one depicted in Bidloo's work, the second cast was clearly more detailed than the first, confirming the hypothesis that submerging the lung in water would negatively influence the resulting cast (figures 14 and 15). It is likely that a more detailed cast could be created if the lung were hung upside down for a night before casting it, draining it of superfluous moisture that may prevent the metal from reaching the smallest branches of the lung.

It is not clear why Bidloo decided to include a 'recipe' for making a tin cast, as he did not do anything similar for other methods for creating preparations and models—the book is

Figure 10. Pouring the first cast, 19 October 2018. (Photo: author.) (Online version in colour.)

essentially an anatomical treatise, not a recipe book aimed at facilitating replication. Possibly he was pleasantly surprised at the ease of the method, or he may have included this relatively easy 'recipe' as a rhetorical strategy, to stress the fact that he performed anatomical dissections and experiments himself, and to suggest that other anatomists should do so too.

Bidloo's description of the use of soldering tin to make corrosion preparations raises the question whether anatomists developed these independently, or whether they consulted artisan friends, artisanal texts or both as a starting point. Bidloo was deeply involved in Amsterdam's cultural life and frequently collaborated with artists such as Gerard de Lairesse.[29] As a medical man, he would also frequently visit instrument makers' workshops, as instruments such as surgical tools and the newly improved syringe were made on demand rather than sold ready-made. He was familiar with contemporaries such as Reinier de Graaf and Jan Swammerdam and their work on using coloured injections to make anatomical structures visible.[30] Having studied medicine at the University of Franeker, Bidloo probably also had access to written sources that documented the composition and applications of soldering tin: such information was already available in Pliny and Agricola's 1556 *De Re Metallica* for example.[31] What or who exactly gave Bidloo the idea to use soldering tin for his lung cast we will never know, but it is clear that it may well have been more than one person or source.

My own lack of knowledge of the material properties of soldering tin meant that I needed to consult a specialist in order to acquire the correct materials. Yet the distinct nature of the process of making a cast of a lung meant that neither the expert nor I could predict the process and its result in detail. If anything, we were both sceptical of the possibility that such a minimal instruction could yield an interesting result. Reconstruction of the process

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[29] Rina Knoeff, 'Moral lessons of perfection: a comparison of Mennonite and Calvinist motives in the anatomical atlases of Bidloo and Albinus', in *Medicine and religion in Enlightenment Europe* (ed. Ole Peter Grell and Andrew Cunningham), pp. 121–143 (Ashgate, Aldershot and Burlington, VA, 2007).

[30] Reinier de Graaf, *Korte Beschryving Van 't Gebruyk Der Spuyt in D'Ontleedt-Konst* (Reinier de Graaf Stichting, Delft, 1989; first published 1668). On the development of hardening injection fluids by Swammerdam, see Hendriksen, *op. cit.* (note 10).

[31] Georgius Agricola, *De Re Metallica* (trans. Herbert Clark Hoover and Lou Henry Hoover) (New York: Dover Publications, 1950; first published 1556), p. 473, n. 33.

Figure 11. Pouring the second cast, 19 October 2018. (Photo: author.) (Online version in colour.)

thus demonstrates persuasively that, although it must have been repeated multiple times to obtain the refined result depicted in Bidloo's book, and that he must have had assistants to execute it, it is indeed a relatively simple, if somewhat risky and unhealthy, method to make a successful cast of a lung.

BRANCHING OUT: ARTIFICIAL CORAL AND CORRODED ARTERIES

A year after Bidloo documented his casting methods, similar techniques were described by the Amsterdam physician Stephen Blankaart. Blankaart advised washing out the lungs with warm water before injecting the various branches with red, black, green and white wax of undefined composition. In a later Latin edition of his book, he advises using a mixture of sheep tallow, terebinth spirit and a pigment such as red lead or verdigris. Once the wax has hardened, Blankaart says, the tissue should be left to rot and washed in water every day, until a clear model of the lungs remains. The same can be done with a liver.[32]

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[32] Govaert Bidloo, *Anatomia Humani Corporis* (Sumptibus viduae Joannis Someren, Amsterdam, 1685), Table 25. Steven Blankaart, *De Nieuw Hervormde Anatomie, Ofte Ontleding Des Menschen Lichaams* (Jan ten Hoorn, Amsterdam, 1686), p. 609. Steven Blankaart, *Anatomia Reformata* (Leiden, 1695), p. 758.

Figure 12. Boiling the lungs, 21 October 2018. (Photo: author.) (Online version in colour.)

The man who was probably the first to fully develop this technique, and one of the most productive creators of wax-injected and corrosion preparations, was the previously mentioned Amsterdam anatomist Frederik Ruysch, nicknamed ‘the artist of death’—although it should be kept in mind that the Dutch words *konst* and *konstenaar*, which we now translate as ‘art’ and ‘artist’, simply meant ‘skilful’ and someone skilled at making or doing something, so could also apply to a wide range of craftspeople, such as goldsmiths and physicians. Ruysch was extremely skilled in making wax-injected preparations; his collected works mention at least 175 of them, and he also frequently made corrosion preparations.[33] His preparations, including his ‘memento mori landscapes’ (see figure 7) were a perfect amalgam of moral and anatomical lessons.[34] He only made a few of these landscapes, and described one as follows:

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[33] The works include 41 instances of preparations injected with red wax (*roodwassige stoffe*), 4 with white wax, 5 with yellow wax, 1 with mercury, and 125 with waxy substances (*waschagtige stoffe*) of various colours (red, white, yellow and undefined). (There are more, but they are hard to count owing to variations in description and spelling.)

[34] See also Gijsbert de Roemer, ‘From vanitas to veneration: the embellishments in the anatomical cabinet of Frederik Ruysch’, *J. Hist. Collect* **22**, 169–186 (2010); Rina Knoeff, ‘Touching anatomy: on the handling of preparations in the anatomical cabinets of Frederik Ruysch (1638–1731)’, *Stud. Hist. Philos. Biol. Biomed. Sci.* **49**, 32–44 (2015); and Hendriksen, *op. cit.* (note 1), p. 186.

Figure 13. Cleaning the tissue of the cast, 21 October 2018. (Photo: author.) (Online version in colour.)

Figure 14. Cast of the first lung, 21 October 2018. (Photo: author.) (Online version in colour.)

Figure 15. Cast of the second lung, 21 October 2018. (Photo: author.) (Online version in colour.)

> A tomb, containing an aborted child of about six months gestation, which has been prepared as a mummie, about twenty years ago. Said tomb is made from human bone, and mostly from small children's bones, and from stones, connected by tissue through which innumerable arteries run, as well as from trunks and branches of arteries, *which represent trees, or rather red coral*, surrounding this grave.[35]

Ruysch's description of his corrosion casts of veins and arteries as representing red coral suggests another possible connection between anatomical injection masses for corrosion casts and artisanal techniques, namely the creation of artificial coral.

Ruysch's reference to red coral 'trees' is not as outlandish as it may seem if we consider how both real and artificial coral were used and understood in the early modern period, not only in luxury collector's items such as a coral cabinet resembling Golgotha (see figure 8), but also in art and science more generally. As Marlise Rijks has recently pointed out, coral

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[35] 'Een Grafstede, onthoudende in zig een onvoldrage kintje van ontrent zes maanden dragts, 't welk tot een Mumie toebereyd is, omtrent twintig jaren geleeden. Deze gezeyde Tombe is gemaakt uyt Menschen beenderen, en wel voornamentlyk uyt die van kleene kinderkens, als meede uyt steentjens, aan een gehegt met vliezen, waar door heen ontelbare Slagaderkens loopen, ook uyt stronken en takken van slagaderen, verbeeldende alzoo eenig geboomte, of liever rood coraal ontrent dit graft.' Frederik Ruysch, *Alle de ontleed- genees- en heelkundige werken* (Amsterdam, 1744), p. 771, emphasis added.

was simultaneously a commodity with classical mythological and biblical connotations, a motif for painters and a problematic material that raised questions about the classification of nature, the nature of matter and the possibility of material transformations.[36] It was described as an originally soft material that turned into a stone-like substance after being lifted from the water in Pliny's *Historia Naturalis* from the first century CE, a description that incorporated Ovid's metamorphosis of sticks from the sea or seaweeds that were touched by Medusa's severed head into coral.[37] This idea proved persistent, not helped by the fact that there are indeed both soft and stony kinds of coral. For example, Georg Eberhard Rumphius (1627–1702), a German-born botanist employed by the Dutch East India Company in what is now eastern Indonesia, stressed in his *D'Amboinische Rariteitkamer* (*The Ambon Cabinet of Curiosities*), which was published posthumously in 1705, that there were many different kinds of coral-like 'sea trees' and 'stone-like sea crops' that resembled plants.[38]

Around the same time, in 1706, the Italian naturalist Luigi Ferdinando Marsigli (1658–1730) published an account of his observations of 'flowering' corals in aquariums, arguing that they were plants rather than stones. It was not until 1723 that his former student Jean André Peysonnel (1694–1759) suggested that corals were animals.[39] Even after Peysonnel sent his 400-page manuscript on the subject to the Royal Society in 1751 and an abridged and translated version was presented at a Society meeting and published in the *Philosophical Transactions*, debate on the true nature of corals persisted.[40] Moreover, until the early eighteenth century, most people in northern Europe would have thought of coral as a mineral, and would only have seen dead and polished coral. Although other colours were known, red or precious coral, a species now known as *C. rubrum* (formerly *Gorgonia nobilis*), was the most appreciated and thus most valuable variety. This species grows on dark, rocky sea floors in caves or crevices, and its bright red or pink–orange skeleton was incorporated in jewellery and other luxury objects such as the Ambras cabinet as a desired commodity for collectors of curiosities and natural history. In the seventeenth-century Low Countries, not only real but also artificial coral became a popular collector's item, because of the emergence of what Rijks has coined 'process appreciation': an increasing appreciation of artisanal making processes, which sometimes included counterfeiting.[41] Imitation of natural materials such as coral in the decorative arts continued to be broadly accepted and appreciated in the eighteenth century.[42]

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[36] Marlise Rijks, 'Unusual excrescences of nature: collected coral and the study of petrified luxury in early modern Antwerp', *Dutch Crossing* **41**, 1–29 (2017).

[37] Susannah Gibson, *Animal, vegetable, mineral? How eighteenth-century science disrupted the natural order* (Oxford University Press, Oxford, 2015), p. 117.

[38] G. E. Rumphius, *Het Amboinsche kruid-boek: dat is, beschryving van de meest bekende boomen, heesters, kruiden, land- en water-planten, die men in Amboina en de omleggende eylanden vind…, mitsgaders van eenige insecten en gediertens, voor 't meeste deel met de figuren…* (François Halma, Amsterdam, 1705), pp. 193–202.

[39] Gibson, *op. cit.* (note 37), pp. 118–128.

[40] See e.g. Job Baster, *Natuurkundige Uitspanningen behelzende eenige waarnemingen over sommige zee-planten en zee-insecten*, 2 vols (J. Bosch, Haarlem, 1760), vol. 2, pp. 61–71. Baster argued that corals were a distinct category of hybrid plant–animals, rather than one or the other.

[41] Rijks, *op. cit.* (note 36), pp. 3–4.

[42] Reed Benhamou, 'Imitation in the decorative arts of the eighteenth century', *J. Design Hist.* **4**, 1–13 (1991); Marjolijn A. H. Bol, 'Coloring topaz, crystal and moonstone: factitious gems and the imitation of art and nature, 300–1500', in *Fakes!? Hoaxes, counterfeits and deception in early modern science* (ed. M. Beretta and M. Conforti), pp. 108–129 (Science History Publications, Sagamore Beach, MA, 2014).

It is highly likely that Ruysch was familiar with the phenomenon of imitation coral, and in fact, he also owned several pieces of the real thing himself. The 1710 catalogue of his collection of naturalia, for example, lists 'red tube-like coral', as well as 'the flowers of the coral tree' on the lid of a phial containing an exotic caterpillar.[43] This description clearly shows that Ruysch, in keeping with the state of the art, believed coral to be a plant, not a mineral. Considering this context and given the fact that Ruysch was famous for his incorporation of contemporary moral, religious, medical and natural philosophical understandings and meanings of materials and phenomena in his anatomical work, it is not so surprising that he described his wax corrosion casts of veins and arteries as trees of coral. But is it possible that he based his infamous secret injection masses on recipes for imitation coral?

The focus here will be on recipes for red substances, since both the most coveted kind of coral and many early arterial corrosion casts were red. If we compare recipes for red anatomical injection masses to other artisanal recipes for red waxes and artificial coral from the period 1600–1900, some striking similarities and differences can be discerned (see appendix). Some ingredients, like white or yellow beeswax, appear in many recipes, both in the anatomical recipes and in other artisanal recipes. The same goes for turpentine or terebinth.[44] Other ingredients, such as (gum) resin or rosin, only start to appear in the second half of the eighteenth century, even though the material was definitely known and available well before.[45] Meanwhile, the recipes for artificial coral (appendix, recipes 3 and 7) contain completely different ingredients, which we find in none of the recipes for injection masses, such as animal horn (keratin) and pearl (from potash) or lye (from wood) ash, both forms of potassium carbonate. These recipes most likely produced a paste that was too thick to inject into an anatomical specimen. This shows that, although Ruysch and his contemporaries were well aware of the visual similarities of coral and corrosion preparations of veins and arteries, the artisanal recipes used to create them were two distinct categories.[46] Similarly, sealing waxes (recipe 6) upon closer inspection are not waxes at all, but hardening pastes based on shellac, the spirit varnish produced from lac, a resinous substance excreted by the female of the lac insect.[47]

The anatomical injection masses thus form a distinct category, with a precursor in a sixteenth-century generic recipe for red wax (recipe 1). With the exception of Blankaart's

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[43] 'Operculum, ut antecedentia, gaudet inter caetera quoque flore arboris Corall', 'Corallii Rubri Tuberlosi'. Frederik Ruysch, *Thesaurus animalium primus* (Jan Wolters, Amsterdam, 1710), pp. 16, 34.

[44] Terebinth is an old name for turpentine, an organic solvent originally won from the oleoresinous exudation of the small cashew tree, *Pistacia terebinthus*, native to southern Europe and the Mediterranean region, although it can also be obtained from other kinds of pine trees. It has been used in varnish recipes since antiquity. See http://vocab.getty.edu/page/aat/300375601 (accessed 19 February 2019).

[45] Resin or rosin is a vegetable secretion of shrubs and trees, consisting of a resin mixed with gum mucilage. Gum resin is generally insoluble in water, but soluble in alcohol. See http://vocab.getty.edu/page/aat/300012940 (accessed 19 February 2019). It occurs in European artisanal recipes as early as the fourteenth century: see e.g. http://artechne.hum.uu.nl/node/87011 (accessed 19 February 2019).

[46] Although Ruysch was notoriously secretive about the composition of his injection masses, there is nothing that suggests that his red injection masses contained ingredients that were dramatically different from those listed in contemporary recipes for injection masses. As he himself wrote, the success of his preparations was a result of his skills rather than his injection mass. See Hendriksen, *op. cit.* (note 1), p. 81.

[47] The lac resin is placed in alcohol to produce a product that creates a smooth finish and a high polish that is tough but not completely water-repellent. Shellac is a natural thermoplastic. See http://vocab.getty.edu/page/aat/300014918 (accessed 19 February 2019).

recipe, which uses sheep's tallow as its base, and the recipes for fine injections, which call for glue or spirit varnish, they are all based on (bees)wax. They also all contain some form of turpentine and a red inorganic pigment. Why these ingredients? Beeswax was a popular modelling material in the early modern period. It was used all over Europe in sculpting (lost-wax casting), and to create portraits and dolls, decorative fruits and cake decorations.[48] In the eighteenth century, it became a hugely popular material for anatomical models because of its malleability and the way in which it resembles human tissue because of its slight translucence, a use rooted in the production of wax votives, religious scenes and portraits in southern Europe and the German lands.[49] Beeswax was also frequently used to create medicinal plasters.[50] Hence it is no surprise that Swammerdam suggested its use as an injection mass as early as 1672.

Swammerdam did not yet add turpentine, but this addition can be explained from the fact that, when mixed with turpentine, wax becomes more fluid, hence making it more suitable as an injection mass. In later recipes for anatomical injection waxes, sometimes fixed amounts are given, but others suggest that the ratio of turpentine (and occasionally animal fats) to wax should be varied according to the climate in which the mixture is to be used—less in hot weather, more in cold.[51] The choice for inorganic red pigments such as vermilion (mercury-based) and minium (lead-based) may at first glance be inspired by a desire for stability: to prevent decolouration. However, other stable red pigments were also already available and, as I have demonstrated, the choice for these inorganic pigments, particularly vermilion, was most likely a symbolical rather than a purely practical one.[52] The specific material requirements for creating coral-like corrosion casts were thus clearly distinct from those for creating artificial coral, and documented in writing in the early modern period, but to what extent might these texts have been used by anatomists to teach themselves this skill?

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[48] For dolls and wax fruits, see Hans-Jürgen Lechtreck, 'A history of some fruit models in wax and other materials: scientific teaching aids and courtly table decorations', *Arch. Nat. Hist.* **30**, 299–216 (2003); and Jacoba Van Veen, 'Receptenboek / Nemo artifex nascitur' (1625–75), Royal Library, The Hague, 135K 44, f. 237. For the culinary decorations, see e.g. Gerrit van den Brenk, *Het Tweede Deel Der t'Zaamen-Spraak Tusschen Een Mevrouw En Confiturier*… (Wed: J. van Egmont: op de Reguliers Breêstraat, Amsterdam, 1753), p. 17.

[49] On wax sculpture, see Roberta Panzanelli (ed.), *Ephemeral bodies: wax sculpture and the human figure* (Getty Publications, Los Angeles, 2008); Alicia Sánchez Ortiz and Sandra Micó Boró, 'Manufacturing and the art of wax modelling: from the sculptor's studio to the anatomical workshop', in *Making and transforming art: technology and interpretation* (ed. Hélène Dubois *et al.*), pp. 86–94 (Archetype Publications, London, 2014); Ethel Stanwood Bolton, *Wax portraits and silhouettes* (Society of the Colonial Dames of America, Boston, 1915); Marjan Sterckx, 'Pride and prejudice: eighteenth-century women sculptors and their material practices', in *Women and material culture, 1660–1830* (ed. Jenny Batchelor and Cora Kaplan), pp. 87–102 (Palgrave Macmillan, Basingstoke, 2007), 87–102. On anatomical wax modelling, see Dacome, *op. cit.* (note 3); Anna Maerker, 'Turpentine hides everything: autonomy and organization in anatomical model production for the state in late eighteenth-century Florence', *Hist. Sci.* **45**, 257–286 (2007); Maerker, *op. cit.* (note 3); Messbarger, *op. cit.* (note 3).

[50] Beeswax is frequently listed as an ingredient for medicinal plasters in the early modern period: see e.g. 'De Emplastris' and 'De Cerata', in Wouter van Lis, *Gualtheri van Lis Pharmacopoea Galeno-Chemico-Medica*… = *Wouter van Lis Meng- Schei- En Geneeskonstige Artseny-Winkel* (Jan Morterre, Amsterdam, 1747), pp. 148–160. Archaeological finds confirm its use in practice: see e.g. Jan Baeten *et al.*, 'Application of a multi-analytical toolset to a 16th century ointment: identification as lead plaster mixed with beeswax', *Microchem. J.* **95**, 227–234 (2010).

[51] Jaime Bonells and I. Labaca, 'Del arte de trabajar piezas anatómicas en cera', in *Curso completo de anatomía del cuerpo humano*, vol. 5 (Imprenta de Sancha, Madrid, 1800), p. 500: 'La cantidad, así de la manteca de puerco como de la trementina, que deben mezclarse con la cera, no se puede fixar, porque ha de ser diferente segun el temple de la estación, respecto que solo se añaden á la cera con el fin de darle la flexibilidad necesaria para trabajar las piezas.'

[52] Hendriksen, *op. cit.* (note 10).

LEARNING CORROSION CASTING FROM TEXT

As mentioned before, the number and availability of printed handbooks and manuals in all kinds of disciplines grew considerably during the early modern period. There is no clear cause for this phenomenon.[53] Technical improvements of the printing press lowered the price of books, the growing amount of knowledge and information required new ways of recording and circulating it, increasing literacy and the emergence of a middle class meant that there was a greater demand for books, and the disappearance of guild structures and growth of academies and universities influenced the way in which crafts and trades, including medicine, were learned. All these factors played a role, but none can be held exclusively responsible for the increased availability of printed instructions to create anatomical preparations and models. Yet one thing is clear: such texts did circulate, and traces of use of such as stains and annotations clearly show that they were used.

To develop a more thorough understanding of how texts on creating wax corrosion casts functioned in anatomical practice, a reconstruction of a corrosion cast of a heart was created using Thomas Pole's 1790 *The Anatomical Instructor; or an Illustration of the Modern and Most Approved Methods of Preparing and Preserving the Different Parts of the Human Body and of Quadrupeds by Injection, Corrosion, Maceration, Distention, Articulation, Modelling, &c*.[54] Pole (1753–1828) was an American-born Quaker, surgeon and medical doctor who moved to England in 1775 and spent the rest of his life there. His book is an interesting source as it saw two reprints (1813, 1824), an indication of its popularity, and traces of use and annotations can be found in various copies.[55] These traces prove that the book was used by anatomists and medical students to learn corrosion casting and other techniques for anatomical model-making.

For example, a copy of the 1824 edition kept at the Fisher Rare Book Library at the University of Toronto contains a manuscript *ex libris* Edwin Henwood, a resident apothecary at the Toronto Hospital in the first half of the nineteenth century, and a note in the same hand is stuck between the pages that list the recipe for 'coarse injections'.[56] It is very well possible that Henwood created corrosion casts in his capacity as apothecary, and spent considerable time perfecting the method. In his manuscript note, he wrote that it was better to mix the pigment with linseed oil before adding it to the wax, to add lime water or lead white to harden the injection, and to only add the turpentine at

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[53] See e.g. William Eamon, *Science and the secrets of nature: books of secrets in medieval and early modern culture* (Princeton University Press, Princeton, 1994); Pamela H. Smith, 'Why write a book? From lived experience to written word in early modern Europe', *Bull. Germ. Hist. Inst.* **47**, 25–50 (2010); Elaine Leong and Alisha Rankin (eds), *Secrets and knowledge in medicine and science, 1500–1800* (Routledge, Oxford, 2011); Ann M. Blair, *Too much to know: managing scholarly information before the modern age* (Yale University Press, New Haven, 2010).

[54] Pole, *op. cit.* (note 9).

[55] Thomas Pole, *The Anatomical Instructor: Or, An Illustration of the Modern and Most Approved Methods of Preparing and Preserving the Different Parts of the Human Body, and of Quadrupeds, by Injection, Corrosion, Maceration, Distention, Articulation, Modelling, &c., with a Variety of Copper-Plates* (J. Callow, London, 1813); Thomas Pole, *The Anatomical Instructor, or, An Illustration of the Modern and Most Approved Methods of Preparing and Preserving the Different Parts of the Human Body and of Quadrupeds, by Injection, Corrosion, Maceration, Distention, Articulation, Modelling, &c.: With a Variety of Copper-Plates / by Thomas Pole. A New Edition, with Additional Notes, by a Gentleman, Who Has Assisted Mr. Bell, in the School of Windmill Street, Where, of Late, a Very Splendid Addition to Lymphatic Preparations Has Been Made* (Printed for Burgess and Hill, Medical Booksellers, London, 1824).

[56] Fisher Rare Book Library, shelf mark acad 01594. The note is stuck between pages 16 and 17. Henwood is mentioned in William Canniff, *The Medical profession in upper Canada, 1783–1850: an historical narrative, with original documents relating to the profession, including some brief biographies* (W. Briggs, Toronto, 1894), pp. 191, 421–422.

the very last moment before injecting. Such detailed observations and modifications suggest that Henwood must have tried multiple variations of the recipe before concluding that this was the most successful one.

To gain a better understanding of Henwood's and other users' reasons to modify Pole's recipes, a reconstruction of the original was attempted. A corrosion cast of a heart was chosen as reconstruction project, rather than veins or arterial structures, in order to explore the use of Pole's wax-based coarse injection mass and the difficulties it may have caused Henwood. Two lamb hearts were purchased from a local butcher, and the materials listed by Pole collected: yellow beeswax, white resin, turpentine varnish, pigments, brass pipes, thread and needle, syringes, earthenware pots and wooden spoons. Small adjustments had to be made in terms of the materials. Pole recommends wooden pestles, to make sure that the pigment could be mixed in properly, but, as these were unavailable, wooden spoons were used instead. Our syringes were plastic rather than the metal or glass ones that Pole and his contemporaries must have used. The vermilion from Pole's recipe was replaced with cochineal red as a red pigment for health and safety reasons (vermilion is toxic). For the blue wax, blue verditer pigment was used. Finally, instead of an open fire, a hotplate was used. The turpentine varnish was prepared several weeks earlier, by mixing larch turpentine oil, white colophony and Venice turpentine, and leaving it out in the sun for a day. As Pole mentions on the second page of his book that the wax for corrosion injections should be harder than regular injection wax, it was decided to add a little less turpentine varnish to the mixture.[57]

First, the hearts were cleaned, following Pole's instructions, cutting away excess tissue, picking out as much 'coagula' as possible, and washing the chambers out with cold water. Then they were held upside down for a couple of minutes, to get as much water and remaining blood out as possible. Subsequently the hearts were placed upside down on kitchen towel to let them drip out. Small pieces of brass pipe were inserted into the superior cava and into one of the pulmonary veins of each heart. The other veins and arteries were stitched closed with thread and needle, so that the injection mass would not leak out of them (figure 16).

The wax, resin (white colophony), and turpentine varnish for the red wax were mixed in an earthenware pot on the hotplate on a low heat. Dissolving the colophony in the beeswax takes quite some time. As the melting substance is very sticky, stirring has to be done very carefully. It took about 45 minutes until the ingredients were properly mixed. Then the cochineal pigment was added, which immediately created a beautiful, deep blood-red colour (figure 17). Initially the wax was poured directly from the pot into the copper pipes, which was surprisingly easy. The earthenware was cool enough to handle, and the wax remained fluid long enough. Subsequently, some more wax was added using small plastic syringes with nozzles rather than needles. When no more wax could be added, the pipes were removed from the hearts to prevent them from getting stuck in hardening wax. The same procedure was then repeated for the blue wax. The blue verditer did not dissolve in the wax mixture as well as the cochineal had, but it did not seem to impair the fluidity of the wax otherwise. The wax-filled hearts were then left to harden for a day, before they were put into a mason jar filled with 30% hydrochloric acid.

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[57] Pole, *op. cit.* (note 9), p. 2.

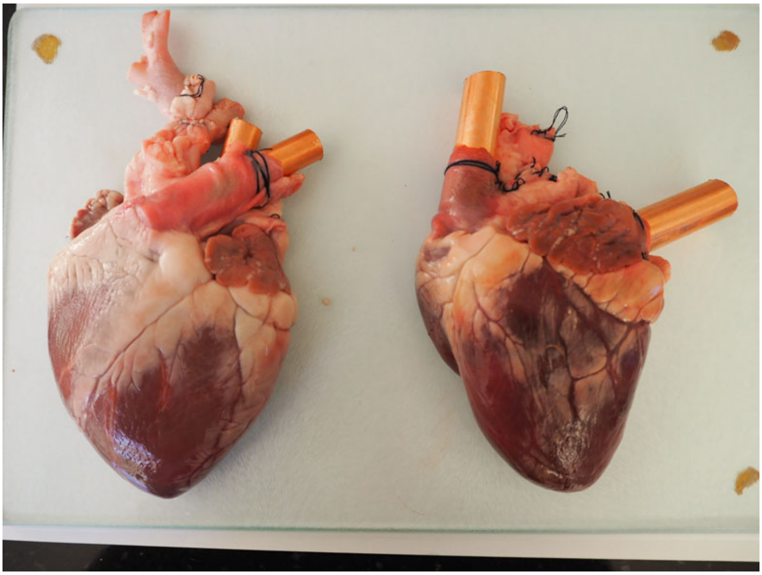

Figure 16. Prepared lamb hearts, 8 November 2018. (Photo: author.) (Online version in colour.)

Figure 17. The red wax mixture, 8 November 2018. (Photo: author.) (Online version in colour.)

Figure 18. Corrosion cast of a heart after cleaning off the remaining tissue, 21 November 2018. (Photo: author.) (Online version in colour.)

According to Pole, the corrosion cast should be left in the acid for four weeks, but after 12 days all the tissue appeared to have corroded, and the wax casts were taken out of the jar with tongs and then cleaned of small remaining bits of disintegrated tissue under running water. Only one cast appeared to have been successful, and even for that one some imagination was needed to see how this represented the inner structure of the heart (figure 18). The corrosion cast smelled distinctively of turpentine, and remained sticky to the touch, even after several days of drying it. This is most likely why Pole advises varnishing the cast and putting it under a glass dome, yet this also explains why Henwood felt that it was more helpful to add a drying agent such as lime water or white lead.

Although the corrosion cast resulting from this reconstruction was less than perfect, the process of creating it allowed a deeper understanding of the difficulties of mastering this particular anatomical modelling technique. My limited experience of creating wax injections and corrosion casts, attempting to replicate the steps from Pole's recipe, helped me to form an idea of the considerable time, practice and resources that medical men would need to invest to create successful corrosion preparations. Even with quite detailed instructions such as Pole's available, and assuming that this book would have been used by medical students and practitioners with foundational anatomical knowledge and reasonable manual skills, the successful creation of corrosion preparations using wax mixtures must have been challenging—much more difficult than making a lung cast from soldering tin. Numerous factors, such as the quality of the available ingredients and materials and the local climate, influence the end result, and some steps in the procedure, such as pouring and injecting the wax into the specimen, require at least four hands. As it is almost impossible to assess whether the specimen has been sufficiently filled with the wax mixture, this procedure is one of trial and error, until tacit knowledge of how full is full enough has been developed. Thus, we may conclude that, although it is not impossible that someone like Henwood would have learned wax-based corrosion casting purely from Pole's book rather than from a mentor, it is highly unlikely that he did so on his own, and it must have taken him considerable time to refine Pole's recipe and adjust it to his own needs.

Conclusion

In the case of corrosion preparations, it appears that the relationship and the exchange of artistic techniques, recipes and knowledge between early modern anatomists and other artisans are less straightforward than they are in the cases of anatomical drawing, and wax and plaster modelling, where we have clearly documented collaborations between visual artists, artisans and anatomists. Although such collaborations may have played a role, no concrete evidence has been found thus far, and a complex interplay of studying textual and visual sources, trial and error, and ad hoc consultation of specialist artisans such as assayers, as well as medical colleagues, appears to have been a more likely scenario in the development of anatomical corrosion-casting practices.

Moreover, the fact that there are almost two centuries between a generic recipe for red wax and almost identical recipes for making wax injections for anatomical corrosion casts suggests that we may have to rethink our current understanding of the transmission of artisanal techniques as something that occurred almost without exception at least partly through master–apprentice or workshop instruction.[58] In the case of anatomical corrosion preparations, there does not seem to have always been a one-on-one exchange of knowledge between anatomists and other artisans, but a partial transmission of artistic techniques, knowledge and skills through written sources. The reconstructions of seventeenth- and eighteenth-century anatomical corrosion-casting techniques created as part of the research for this paper demonstrate that artistic and artisanal skills always consisted at least partly of tacit, relational knowledge that could only or should mostly be transmitted by demonstration and learned by doing. Written sources very likely played a role in the transmission and acquisition of at least some anatomical modelling techniques but, as Henwood's annotation as well as my own experiences suggest, it would often have been necessary to diverge from the written instructions and recipes—if not because information was incomplete or incorrect, then because geographical, seasonal, temporal, material, economic or practical limitations meant that instructions could not be followed to the letter.

Although artistic and anatomical techniques were often very similar in terms of the materials used, the skills that had to be developed to apply them successfully, and the visual results, this paper has shown that there were distinct materialities and practices in each realm. The metal corrosion casts created by anatomists may have been inspired by existing life-casting practices and developed in consultation with assayers, and workshop experiments and textual sources also appear to have played a role. Something similar goes for wax-based corrosion casts, which, although explicitly linked to (artificial) coral by

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[58] Hagendijk, *op. cit.* (note 12).

their earliest creators, are materially and technically significantly different from coeval artificial coral. They appear to have been exclusively created by medical practitioners who dedicated considerable amounts of time, effort and resources to the development of these techniques.

This analysis of two kinds of anatomical corrosion-casting practices in the early modern period shows that we may need to rethink the relations between artists or artisans as contractors and medical practitioners as patrons. It appears that medical practitioners routinely worked with professional visual artists, not just by employing them but by acquiring those aspects of their knowledge and skills that they could apply and adjust to their own purposes. Henwood's note suggests that textual sources could play a significant role in the development of practical skills and material knowledge in the absence of a skilled master, but as a starting point for experimentation or for use in the broader context of medical training, rather than as a step-by-step guide. Finally, the case of corrosion casting shows us that some early modern medical practitioners developed distinct materialities and techniques to create three-dimensional models for research and teaching, most likely relying on a complex constellation of textual, visual, experiential and intrapersonal resources.

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APPENDIX

	Year	Title of recipe	Source	Ingredients
1	16th C	Ain annder Rot wax	Staatsbibliothek Berlin Ms. germ. qu. 417	Wax, oil, turpentine, cinnabar
2	1672	—	Jan Swammerdam, *Miraculum Naturae, Sive Uteri Muliebris Fabrica* (Leiden: Johannes van Horne, 1672), p. 33.	White wax, red colourant
3	1684	Pour le coral	Antoine D́Emery, *Recueil Des Curiositez Rares [et] Nouvelles Des plus Admirables Effets de La Nature [et] de l'art . . .* (Leiden: Pierre Vander Aa, 1684), p. 153–154.	Paste made from cow's horn, lye ash, water, and cinnabar
4	1695	—	Steven Blankaart, *Anatomia Reformata* (Leiden: Cornelium Boutesteyn & Jordaanum Luchtmans, 1687), Vol. II, p. 286.	Sheep tallow, terebinth spirit, red lead
5	1710	—	Polycarp Gottlieb Schacher, *Diss. Inaug. de Anatomica Praecipuarum Partium Administratione* (Lipsiae: Brandenburger, 1710), p. 27–28.	Wax, red lead (minium) or cinnabar, terebinth oil
6	1775	Sealing wax (First of 9 recipes, all but one based on shellac)	*Valuable Secrets Concerning Arts and Trades. . .* (London: William Hay, 1775), p. 65.	Shellac, benzoin (resin), black rosin (solid winter resin), vermilion, sweet almond oil
7	1775	A Counter-Faction of Coral	*Ibidem,* p. 184	Ground goat's horn, lime, pearl ash, water, and cinnabar or dragon's blood (a plant pigment).
8	1790	(1) Formulae for fine injections. Red. (2) Formulae for coarse injections. Red.	Thomas Pole, *The Anatomical Instructor. . .* (London: Couchman & Fry, 1790), p. 21, 26–27.	(1) Brown spirit varnish, white spirit varnish, turpentine varnish, vermillion (2) Yellow bees wax, white resin, turpentine varnish, vermillion
9	1836	(1) Size or fine injection (2) Varnish, or fine injection (3) Wax or coarse injection	Frederick John Knox, *The Anatomist's Instructor, and Museum Companion. . .* (Edinburgh: Black, 1836), p. 27, 29,30.	(1) Glue, water, vermillion (2) Spirit varnish, turpentine varnish, vermillion (3) Beeswax, resin, turpentine varnish, vermillion

Recipes for red waxes. The recipes from anatomical handbooks are in red, those from arts and crafts manuals are in white.