Machines and the Body between Anatomy and Pathology

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1. Introduction

The second half of the XVIIth century was the golden age of mechanistic anatomy: an increasing number of anatomists sought to explain the operations of the body in terms of machines of varying nature and complexity. These machines responded to shifting criteria of intelligibility at the time: whereas Aristotelian or Galenic faculties of the soul or of nature were deemed not only acceptable but necessary modes of explanation up to the middle of the XVIIth century, after that time an increasing number of anatomists sought new ways of understanding how human and animal bodies work by looking at their structure and microstructure. Canonical texts such as Galen's *On the Natural Faculties* drew a sharp distinction between nature's operations and artificial machines with regard to generation, growth, and nutrition, for example. Whereas this tradition was the norm up to the Renaissance, in the course of the XVIIth century it became the exception. Of course, analogies between specific operations of the body and machines date from Antiquity and, more generally, even those anatomists, who can in no way be classed as mechanists, did adopt explanations inspired by mechanics in this or that domain, such as the motion of animals, for example. However, what distinguishes the second half of the XVIIth century from previous times is the growing emphasis on a systematic program for explaining not

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simply this or that operation, but most or even all aspects of the animal body – and of the human body as well, except those linked to the rational soul – mechanistically. Thus the mechanistic program went beyond the natural faculties and extended to higher functions, such as sensory perception[1].

Traditionally, the mechanistic understanding of the body has been linked for the greatest part to its normal operations, what we would call physiology, an area that poses already a number of interesting issues. However, in this paper I wish to argue that XVIIth-century anatomists of different persuasions used the analogy between bodies or body parts and machines in order to conceptualize and investigate disease as well. Thus machines assumed a pathological significance besides a physiological one.

I start by providing in the briefest possible way some background information on mechanistic anatomy, about ways in which machines were used in order to conceptualize bodily operations and processes, relying on some especially interesting perspectives by Danish anatomist Nicholas Steno and Italian anatomist and physician Marcello Malpighi. I then move on, also very briefly, to some reflections on disease due to Malpighi: although he sought to conceptualize disease from a mechanistic standpoint, his reflections emphasize different perspectives to do with the relationship between the body and the soul and the role of disease as a tool of investigation.

Lastly, I move to the key point of my work and examine the relationships between mechanistic anatomy and pathology, or the usage of machines in order to conceptualize and investigate disease. We are fortunate that, as part of a dispute about the significance of the new mechanistic anatomy to medicine, Malpighi provided a survey of this area, including a list of devices or models that were employed to study the diseases of several body parts, from the eye to the thorax.

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1. Galen, *On the Natural Faculties*. Translated by Arthur John Brock. Cambridge, Mass.: Harvard University Press, 1916. The classic Theodore M. Brown, *The Mechanical Philosophy and the "Animal Œconomy"*. New York: Arno, 1981 is still useful. For a recent collection see Domenico Bertoloni Meli and Rebecca Wilkin, eds, *Observation and Experiment in mechanistic Anatomy*, special issue of *Early Science and Medicine*, 13 (2008), 531-709.

In some cases it is possible to identify Malpighi's sources. Malpighi's text brings together a number of authors, such as the Württemberg physician Salomon Reisel, who proposed a striking and elaborate device or statue to display bodily operations; the Dutch anatomist Jan Swammerdam, who relied on a simple piece of apparatus to display diseases of the lungs; and even non-mechanists, such as William Harvey, who mentioned a simple mechanical device to investigate several diseases. Thus Malpighi's survey opens a new window onto the little-studied domain of mechanistic pathology, at the intersection between machines and disease. I shall argue that it is especially significant that such devices were used not simply to establish analogies with diseased states, but also as experimental apparatus with which to investigate disease and also as teaching devices.

Thus my contribution touches not only on the three Ms at the center of this workshop, Models, Machines, and Marvels, but also on a fourth M, namely Medicine.

2. Bodies, machines, and their components

René Descartes occupies a major position in the rise of mechanistic anatomy: his first publication, *Discours de la methode* of 1637, includes a section in which he outlined a program for explaining all the operations of the human body, with the exception of those related to the rational soul, in mechanistic terms; his account included a rather peculiar version of the motion of the heart and an account of many operations of the brain, especially those associated with sense perception, memory, sleep, and wake. By the time Descartes's *De homine* appeared in 1662, and then in the original French as *L'homme* two years later, the mechanistic program was well under way with a number of works, notably by Steno and Malpighi. Unlike Descartes, both Steno and Malpighi were distinguished anatomists who cared not only about a philosophical program but also about anatomical details[2].

2. René Descartes, *De homine*, translated with an introduction and figures by Florentius Schuyl. Leiden: P. Leffen & F. Moyardum, 1662; *L'homme. De la formation du foetus*, with remarks by Louis de la Forge. Paris: Girard, 1664. See also section 5

The appearance of *L'homme* was a major event in Parisian intellectual circles. In a discourse on the structure of the brain pronounced in 1665 at the Academy of diplomat Melchisedech Thévenot in Paris, Steno adopted a complex attitude to Descartes: on the one hand, he challenged his detailed views on the brain, including his figures with all those rather fanciful strings and ropes. On the other hand, Steno accepted the mechanistic program concerning the brain. More specifically, he argued that it is impossible to grasp the internal structure of a machine by observing its outer motions, because those motions could be performed in different ways. Rather, it is necessary to take it apart and examine all its minute components – *ressorts* is his term. Similarly with the brain:[3]

> Now since the brain is a machine, we should not hope to find its artifice [*artifice*] by other ways than those one uses to find the artifice of other machines. There is therefore nothing left to do besides what would be done to any other machine, I mean to dismantle piece by piece all its components [*ressors*, sic] and consider what they can do separately and together.

Here Steno is applying the way to understand a machine to the brain, in the form of grasping the relations between the individual components and the whole, a key aspect of mechanistic understanding. It is especially striking that Steno's statement refers to the brain, the site of key functions associated with consciousness and thinking. By "mechanical" Steno and other anatomists understood "machine-like" rather than based on the laws of mechanics. This interpretation goes hand in hand with a view of XVIIth-century mechanics according to which objects such as levers and springs take center stage and embody more abstract relations. As in mechanics, in anatomy too understanding a complex structure meant decomposing it and recognizing

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of the *Discours de la Méthode*, Leiden, Ian Maire, 1637. Gustav Scherz, ed. *Steno and Brain Research in the Seventeenth century*. Oxford: Pergamon Press, 1968. Volume 3 of *Analecta Medico-Historica*. Domenico Bertoloni Meli, ed., *Marcello Malpighi, anatomist and physician*. Florence: Olschki, 1997.

3. Nicolaus Steno, *Discours*, 32-3; I have modified the English translation in Scherz, *Lecture*, 139. Dennis Des Chene, *Spirits*, chapter 4.

in it elements associated with simpler, already known objects that could be understood and handled separately[4].

The opening of Malpighi's 1673 treatise too, *De formatione pulli in ovo*, on the formation of the chick in the egg, focuses on mechanistic understanding. Malpighi outlined his program by reference to the habit of artisans, who fashion in advance the individual components of the machines they want to build in order to see them separately before they are fitted together. Some naturalists, according to Malpighi, hoped that nature would behave in a similar fashion in the formation of the animal so that one could see not the whole organism already formed, but its individual components before they are assembled. In this way the organism's structure could be disentangled, as in a machine:[5]

> In building machines artisans are accustomed to fashion the individual parts in a preparatory stage of the work, so that the components, which must afterwards be assembled, may be viewed first separately. Many of Nature's scholars [*Mystae*] interested in the study of animals, hoped that the same would happen in Her work, because, since it is very difficult to disentangle the complex structure of the body, it was thought helpful to examine the formation of the single parts in their earliest stages, when they are still separate.

Alas, matters turned out to be more complicated because, as Malpighi states, we do not capture the origin of the parts in isolation but rather the animal appears almost already formed. Steno focused on an organ of the fully formed animal, whilst Malpighi sought – albeit unsuccessfully – to exploit the formation process as a tool of investigation, on the example of the formation of machines. Both, however, believed that understanding a machine implied grasping the interrelations between its component parts and the whole. Possibly Malpighi had in mind the assemblage process too, since this concern

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4. Domenico Bertoloni Meli, *Thinking with Objects. The Transformation of Mechanics in the XVII*th *century*. Baltimore: Johns Hopkins University Press, 2006. See also the work by Sophie Roux in this volume.

5. I have modified the translation in Howard B. Adelmann, *Embryology*, II, 935; Marcello Malpighi, *Opere scelte* (hereafter *MOB*), edited by Luigi Belloni. Turin: UTET, 1967, at 223.

would go well together with his study of the process of formation. Thus we see here different aspects of mechanistic understanding, both concerning the healthy body.

3. Bodies, machines, and disease

How did mechanistic anatomists deal with the issue of disease? Let me try to address the issue starting from a fiercely non-mechanist physician and philosopher: the Fleming Johannes Baptista van Helmont, following Paracelsus, argued that bodily operations were governed by the *archei*, non-material principles broadly corresponding to the classical faculties of the soul that governed the activities of the body. As Guido Giglioni has recently reminded us, disease resulted from a deficiency in the *archei* and was cured by treating them. In some cases, however, some processes occurring inside the body could be reproduced in vitro with the alchemist in the role of *archeus* of the outer world. In this way processes like distillation, for example, shed light on healthy and diseased states, by showing how organs operate and how defects in the process produce unwanted results[6].

Matters, of course, were rather different from a mechanistic standpoint, since disease was located in the material body rather than in non-material entities. In a revealing passage found in his posthumous works but broadly representative of his earlier views as well, Malpighi addressed precisely this question when he argued that in humans the soul operates through the body and is forced to act in conformity to the machine to which it is applied: his analogy is extended to the notion of disease and its cure. He argued that even in those areas for which we have not fully understood the mechanical way of operation of organs, as for the brain for example, the physician can remove those mechanical obstructions that affect the minute structures nature employs for her operations. We witness here an application

6. Guido Giglioni, *Immaginazione e malattia. Saggio su Jan Baptiste van Helmont*. Milano: FrancoAngeli, 2000, especially sections III and IV. Walter Pagel, *Joan Baptista van Helmont, Reformer of Science and Medicine*. Cambridge: Cambridge University Press, 1982. Bruce T. Moran, *Distilling knowledge. Alchemy, chemistry, and the scientific revolution*. Cambridge, Mass.: Harvard University Press, 2005, 74-9.

to disease and therapy of Steno's views about the brain conceived as a machine that can be understood by taking it apart and grasping how the individual components operate in isolation and together. Malpighi's passage is taken from his *Risposta* to Giovanni Gerolamo Sbaraglia, an anti-mechanist colleague at Bologna University who defended the role of the soul and its faculties:[7]

> In those parts then in which thus far we have not fully understood the mechanical way with which nature operates—as in the operations of the brain—it is sufficient at present for the physician to grasp those mechanical ways that prevent and affect the minute structure employed by nature. The manners in which those ways are altered are many, and the physician must cure not the faculties of the acting soul, but remove the impediments and that which alters the movements of the part.

The reference to a physician here is quite significant, as is the reference to the faculties of the soul. Although in other instances Malpighi questioned the existence of those faculties, here he did not deny the existence of a soul, but rather bracketed it off as irrelevant to understanding health and disease. It seems plausible that he would have had in mind apoplexy and other diseases whose causes were attributed to the obstructions of the minute parts. It is significant from our perspective that Malpighi conceived disease to be located in the minute component parts: therefore therapy consisted in removing the obstructions in those parts. Once again, the relationships between individual components and the whole come into play, though this time from a pathological standpoint.

In the same work Malpighi provided the often quoted simile of the mill: in the operations of vegetation, including growth, nutrition, and generation, as well as in sense perception and motion, the soul has to act in accordance with the machine to which it is tied, and a clock or a mill are moved in the same way by an attached weight or a stone, an animal, a man, or even an angel. His conclusion is that if the mill is

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7. *MOB*, 516. On Malpighi and Sbaraglia see Domenico Bertoloni Meli, "Mechanistic Pathology and Therapy in the Medical *Assayer* of Marcello Malpighi", *Medical History*, 51 (2007), 165-80.

broken, one has to repair its wheels, whose structure is known, rather than the moving angel or the faculties of the soul, whose mode of operation is unknown. This observation has a pathological relevance in line with that of the whole *Risposta* to Sbaraglia:[8]

> A clock or a mill is equally moved by a lead or a stone pendulum, or by an animal, or by a man; in fact, if an angel moved it, it would move the same way with the change of sites, as if moved by an animal. Thus, since I do not know the mode of operation of the angel, but [I know] the exact structure of the mill, I would understand this motion and action; and if the mill went out of order, I would seek to repair the wheels and their faulty arrangement, neglecting to investigate the mode of operating of the moving angel.

Although at one point Malpighi stated that the study of plants had a role in philosophy and natural history rather than medicine, he also stressed the pathological and therapeutic significance of the study of plants, especially for surgery, as for the generation and cure of tumors. Thus we have another instance in which a mechanistic understanding of processes such as growth – that Malpighi investigated in plants – could have medical implications.

In a work of 1668 on the origin of heart polyps – formations found in the heart of dead patients that started forming when the patients were alive – Malpighi relied on the uniformity of nature as a tool to investigate a diseased state and at the same time to shed light on the nature and constitution of blood. He could proceed this way because nature's way of proceeding is the same in both cases. In a crucial passage we read:[9]

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8. *MOB*, 516, 596-7, 606-7. François Duchesneau, "Malpighi", 113-4.

9. Domenico Bertoloni Meli, "Blood, monster, and necessity", 518-9. An earlier passage at 518 is also of interest: "I have always believed that the morbid states, which we see frequently arising in the bodies of animals due to the jokes of Nature or the strength of aberrant disease, shed much light on the investigation of Her true norm and method of operation. In fact those morbid states indicate a *necessity of matter, and determined inclination* revealed in the construction of the animal body. Thus monsters and other mistakes dissipate our ignorance more easily and reliably than the remarkable and polished machines of Nature: hence the present century has learnt more from studying insects, fishes, and the first unformed *warps* in the development of animals, than have all the preceding ages exclusively interested in the bodies of perfect animals."

> These things will not seem insignificant to anyone who, by assiduously dissecting animals, comprehends the industry of nature equally in morbid tumors and in the creation of the parts' *warps*, because her method of proceeding is nearly identical. Thus I recall noticing that an iron needle bursting out of the fleshy stomach of a hen was covered with a strong double membrane and a coating of fat as well. Moreover, we can consider whether all these things happen by the *sole necessity of matter and motion, without a guiding mover for the animal's benefit*. Similarly, in certain tumors arisen in the lungs, liver, and elsewhere, integuments or multiple bladders are joined, in which the larger encloses the smaller and thus they fit together successively; the conglobation of similar tumors can be regarded as similar in nature to that of polyps, for the matter and mode of production in both cases is presumably the same: in fact, following the usual *law of nature*, from a network of *threads* several layers can be formed, which can remain everywhere separate if what lies between them is not congealable but is the watery fluid which abounds in tumors of this species.

This passage argues that nature operates in the same way in health and disease, following the same laws. Moreover, Malpighi speculates that there is no guiding mover or principle acting to the animal's benefit, but rather everything happens according to the necessity of matter and motion, the animal body working as a machine that can malfunction. Thus it seems necessary to identify two levels of organization: that of laws of nature, which are universally observed – except in miracles – and that of the machines of the body, which can malfunction and stop working depending on a variety of factors, like all other machines.

4. Disease, machines, and experimental devices

In the late 1680s Malpighi became the object of a series of attacks by his Bolognese colleagues, notably Sbaraglia: a key subject of those attacks was that his investigations of plants, insects, and the microscopic structure of many organs, were irrelevant and useless to the art of healing. In opposition to Malpighi's views, Sbaraglia defended an empirical approach to medicine, whereby the effectiveness of a

therapy was established by its success, not through anatomy – least of all microanatomy – and the search for causes. Malpighi responded in his *Opera posthuma*, published in 1697, seeking to defend his work and the achievements of microscopic and mechanistic anatomy not only in understanding the operations of the body but also and especially in the study and cure of disease. Malpighi's *Risposta* is an extremely valuable document on the state of the field at the time, in that Malpighi surveys the achievements and results of previous decades in many areas, such as the understanding of the structure of the main organs, as well as new therapies stemming from those findings[10].

In a justly celebrated passage, Malpighi argued that since nature operates by an ever-constant necessity, we can grasp her "artifici", or, we could say, mechanisms, by investigating different domains, such as lower animals and even plants. In addition, this is also why studying machines can be of help to medicine. Implicit in his claim is the removal of the boundary between natural and artificial. He then listed a number of mechanical devices such as threads, beams, levers, cloths, fluids, cisterns, canals, and filters, forming the machines of our body. By examining those devices by means of anatomy, natural philosophy, and mechanics, we have grasped their structures and built "models" – to use his own word – which have enabled us to study a priori the causes of the effects we observe. In this way we grasp nature's mode of operation and establish the basis of physiology, pathology, and the art of medicine. In this crucial passage Malpighi tied machines not only to physiology, but also to pathology and medicine, including therapeutics[11].

Following this list of mechanical devices and explanation of their role, Malpighi proceeded to provide concrete examples of models, including: the *camera obscura* for the eye; canals – by which he probably meant bladders – filled with fluids representing arteries; the

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10. *MOB*, 491-631. Domenico Bertoloni Meli, "The medical *Assayer*".

11. *MOB*, 512-3. Andrew Cunningham, "The pen and the sword: recovering the disciplinary identity of physiology and anatomy before 1800", *Studies* in *History and Philosophy of Science, Part C, Biological and Biomedical sciences*, 33 (2002), 631-65; 34 (2003), 51-76.

articulations of the bones with threads attached to them, displaying the causes of motion, swimming, and flying; a machine simulating the thorax that expands and contracts filling and emptying with air; and the *statua humana circulatoria* by the archiater to the Duke of Württemberg Salomon Reisel, displaying blood circulation, the chymical and mechanical processes associated with digestion, and the filtration of blood in the kidneys. For most of these examples Malpighi referred not only to anatomy or physiology but also to medicine more generally. Hence nature's uniformity provides the philosophical underpinning for this approach, whereby studying the machines of the body helps both physiology and pathology[12].

The passage on the articulation of the bones, especially the reference to walking, swimming, and flying, seems a reference to Malpighi's philosophical mentor Giovanni Alfonso Borelli, who in the first part of *De motu animalium* (1680) dealt precisely with these topics in relation to mechanical devices (fig. 2). Although Malpighi did not refer to pathology with regard to the mechanical devices for representing motion, it seems that such machines would have had immediate surgical applications. The role of tendons in moving muscles was well known since antiquity and had been singled out by Vesalius at the 1540 Bologna anatomical demonstration, when he warned barbers of the dangers of accidentally damaging the sinews or tendons during venesection (fig. 3)[13].

Let's examine Reisel's *Statua* more closely, probably the most spectacular item in the list. As it appears from his 1693 essay in

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12. *MOB*, 513-4. On the usage of "chymical" see William R. Newman and Lawrence M. Principe, "Alchemy vs. chemistry: the etymological origins of a historiographic mistake", *Early Science and Medicine*, 3 (1998), 32-65. On three-dimensional models see Renato G. Mazzolini, "Plastic anatomies and artificial dissections"; Thomas Schnalke, "Casting skin: meanings for doctors, artists, and patients", in Soraya de Chadarevian and Nick Hopwood, eds, *Models. The third dimension of science*. Stanford: Stanford University Press, 2004, at 43-70 and 207-41. Schnalke's essay is especially pertinent to my work since it concerns models for teaching pathologies of the skin, but also for investigating and comparing similar cases.

13. Ruben Eriksson, *Andreas Vesalius' first public anatomy at Bologna. 1540. An eyewitness report by Baldasar Heseler*, Uppsala and Stockholm: Almqvist & Wiksell, 1959, 252-5.

Miscellanea curiosa, unlike Jacques Vaucanson with his duck, Reisel wished to build the *Statua* but he did not actually do so; rather, he discussed the most appropriate materials for its construction, such as the skeleton of wood or iron, the blood vessels near the heart of elder-tree, and, as Luigi Belloni has emphasized, the pineal gland of conical glass or crystal held by a silk thread inside a spherical glass globe (see 6 in fig. 4). Reisel's remarkable plates show the kidneys (8), bladder (9), sphincter (10), penis (11), and larynx (14). Reisel discussed digestion and the filtration of urine but his primary aim was to convince the skeptics of the truth of the circulation of the blood, which he illustrated with the detail of blood squirting out of openings in the foot and hand[14].

It would be reductive to take Malpighi's examples as mere marvels or even instantiations of anatomical structures. It has not been sufficiently appreciated that Malpighi framed his examples as part of a general reflection on pathology as well as physiology, thus extending the notion of nature's uniformity from machines to organs and from healthy to diseased states. Malpighi's anatomical publications and medical consultations display his chymical and mechanical thinking in understanding many of the operations described by Reisel's machine and of the related diseases. In *De polypo cordis*, for example, he reported several experiments based on aspersing different chemical on blood poured in a vessel in order to ascertain their properties. Malpighi was especially concerned with the change of color and fluidity of blood, arguing that those chemicals making the blood more fluid would be potentially effective against affections decreasing the blood's fluidity, such as the plague. His experiments pointed to a therapy, though one none of use would be eager to test. Similarly, in a medical consultation of 29 March 1687 for a case of gout, he sought to explain what happens inside the body, the cause of the disease being an excess of acids in the chyle. Then he also stated: "All this can be seen in proportion also mechanically mixing spirit

14. Salomon Reisel, "De statua humana circulatoria", 232-3; ib., "Statua humana circulatoria", at 9 and 12. Luigi Belloni, "Schemi e modelli", 292-6. Ralf Bröer, *Salomon Reisel (1625-1701)*, especially 54-72.

of vitriol, or another acid that is especially austere, with different fluids." In this passage Malpighi used the term "mechanically" rather broadly, in conjunction with a chymical operation. It is especially significant from our perspective that he reproduced in vitro processes occurring inside the body in order to investigate disease and to devise suitable therapies. This consultation echoes Malpighi's description of Reisel's *Statua*, thus providing strong evidence that he envisaged it as a material device and interpreted it – unlike Reisel himself – from a pathological and medical standpoint as well (fig. 5) [15].

In several other cases we do not need to have recourse to other texts because the passage from Malpighi's *Risposta* to Sbaraglia discussed above provided specific instances of machines employed to investigate disease. For example, he mentioned that the *camera obscura* could serve to understand sight and its lesions: [16]

> An evident prove of this is the *camera obscura*, in which the mathematician produces all those effects that are observed in the sight in healthy and diseased states of the animal, displaying *a priori* the necessity of those effects that occur from the variety of the figures of the lens and the excessive distance or nearness of the parts. Therefore the way of seeing and its lesions are demonstrated by means of the cognition of the man-made machine analogous to the eye.

We know from a deleted passage of the manuscript version of his *Vita* that Malpighi experimented together with the astronomy professor Giandomenico Cassini on the operations of the eye and its parts. It is especially interesting to notice the reference to a mathematician in the passage above. A further reference to the *camera obscura* and its role in the investigation of sight and the formation

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15. Marcello Malpighi, "*De polypo cordis*. An Annotated Translation", by John M. Forrester, *Medical History*, 39 (1995), 477-92, at 490-2. Marcello Malpighi, *Correspondence*. Ithaca: Cornell University Press, 1975, ed. by Howard B. Adelmann, 5 vols, vol. 3, 1268-9, Malpighi to Tarantino, 29 March 1687. *MOB*, 514. Domenico Bertoloni Meli, "The archive and consulti of Marcello Malpighi", in *Archives of the Scientific Revolution*, ed. Michael Hunter. Woodbridge: The Boydell Press, 1998, 109-20. On the notion of machine in XVIIth-century anatomy see the essay by Sophie Roux in this volume.

16. *MOB*, 513.

of images can be found in an essay by Reisel in the same issue of *Miscellanea curiosa* as his *Statua*[17]. In addition to the *camera obscura*, one wonders whether Malpighi was familiar with the model of the eye constructed and described by the Venice instrument maker Giovanni Battista Verle in collaboration with the Padua anatomist Antonio Molinetti for Ferdinand II of Tuscany[18]. Malpighi's interest in microscopy suggests some familiarity with the property of lenses and their different arrangements. In the passage above Malpighi uses the terms *a priori*, a key expression in his *Risposta* to Sbaraglia. By *a priori* Malpighi meant a medicine based on the study of the causes rather than based empirically on the effects: those causes could be investigated by mechanical devices.

The model of the artery, closely resembling one mentioned by Harvey in the second reply to Jean Riolan, *De circulatione sanguinis*, would enable us to study blood circulation and its diseases. It is worth examining Harvey's passage here:[19]

> If you take what length you will of the inflated and dried intestines of a dog or wolf (such a preparation as you find in an apothecary's shop), cut if off and fill it with water, and tie it at both ends to make a sort of sausage, you will be able with a finger-tap to strike one end of it and set it a-tremble, and by applying fingers (in the way that we usually feel the pulse over the wrist artery) at the other end to feel clearly every knock and difference of movement. And in this way (as also in every swollen vein in the living or dead body) anyone will be able to teach students, by demonstration and verbal instruction, all the differences occurring in the amplitude, rate, strength, and rhythm of the pulse. For just as in a long full bladder and an oblong

17. On Cassini and Malpighi see Domenico Bertoloni Meli "The collaboration between anatomists and mathematicians in the mid-XVIIth century. With a study of images as experiments and Galileo's role in Steno's *Myology*", *Early Science and Medicine*, 13 (2008), 665-709", at 693. Reisel, *De visionis distinctissimae loco*. Ralf Bröer, *Salomon Reisel*, 72-3.

18. Giovanni Battista Verle, *Anatomia artifiziale dell'occhio umano*. Florence: per il Vangelisti, 1679. A copy of the book with the accompanying model of the eye from the Wellcome library is on deposit at the Science Museum, London.

19. William Harvey, Second Essay to Riolan, in Circulation, 124-5.

> drum every blow to one end is felt simultaneously at the other, so in dropsy of the belly, as also in every abscess filled with liquid matter, we are accustomed to distinguish anasarca from tympanites.

Thus Harvey suggests a usage of the intestines sausage going even beyond the diseases of the circulatory system: anasarca is a swelling up of the entire body and tympanites is a distension of the abdomen. It seems appropriate to recall here several references to accumulation of mineral deposits in aqueducts mentioned in *De polypo cordis* to explain other diseases of the circulatory system[20].

The artificial thorax serves to study what happens when the lungs fill with fluid or solid bodies and therefore "helps to uncover a priori nature's way of operating and the phenomena in the diseased states of respiration". Probably Malpighi was referring to what Swammerdam had done in *De repiratione*, when he had used a mechanical apparatus consisting of a bladder attached to a tube inside a glass phial (fig. 6) to understand what happened in a punctured thorax. Swammerdam's example too had a pathological significance in showing instances when respiration is hindered[21].

Although one could only wish that Malpighi had been more forthcoming in his account of the pathological role of mechanical devices, the examples he provided are quite striking and offer a novel perspective on the role of machines in XVIIth-century medicine, namely as investigation and teaching devices for pathology.

5. Concluding reflections

Analogies between bodies and machines had been used since Antiquity and had become especially prominent in the XVIIth century. Contrary to most examples limited to healthy states, however, the message of Malpighi's list of devices in his *Risposta* to Sbaraglia is that they are useful in understanding and displaying the operation of certain organs as well as of their diseases. Malpighi's preoccupation is

20. Malpighi, "*De polypo cordis*", at 485, 492.

21. *MOB*, 512-6. Jan Swammerdam, *De respiratione*, 29-31, 36-7. Abraham Schierbeek, *Swammerdam*, 67-71.

in line with the general thrust of the whole text, with its emphasis on the role of the new anatomy in pathology and therapeutics as well[22].

The main examples provided by Malpighi that I have discussed in this paper do not simply constitute cases in which abstract analogies could be established between machines and the body in relation to disease; rather, they provide instances of machines that had been actually built and used with the objective of investigating disease and therapies. Lenses and portions of the eye possibly employed by Malpighi and Cassini, Harvey's bladders or "channels" – as Malpighi called them –, and Swammerdam's bladder inside a glass phial were physical objects instantiating organs and were used as experimental and possibly also teaching devices in order to investigate their diseases. However, also the other devices mentioned by Malpighi, such as the articulations of the bones with threads attached to them and Reisel's *Statua* – in conjunction with investigations Malpighi referred to in his medical consultations – have immediate pathological and therapeutic applications and instantiations. It is especially significant that in his medical consultation Malpighi moved from in vitro eperiments to the etiology of disease and eventually to therapeutics.

Thus this study broadens our understanding of the role of mechanical devices from anatomy to pathology and the art of medicine; such devices challenge the distinction between art and nature in the understanding and investigation of healthy and diseased states, providing mechanist anatomists and even those like William Harvey, who were prepared to use mechanistic accounts only in very limited and specific cases, with a surprising and philosophically significant tool of investigation[23].

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22. Malpighi's successor at Bologna, Ippolito Francesco Albertini, argued that aneurysms could be cured by bloodletting and by reducing food intake. Albertini compared the heart and large arteries to a mill and water to blood. Although he too relied on a mechanical analogy in pathology and indeed therapy, he did not construct water mills in order to test how they work. See Saul Jarcho, ed. *The Concept of Heart Failure from Avicenna to Albertini*. Cambridge, Mass.: Harvard University Press, 1980.

23. I wish to thank participants to the Vaucanson conference for the many conversations and exchanges, especially Paolo Quintili, Elly Truitt, and Charles T. Wolfe.

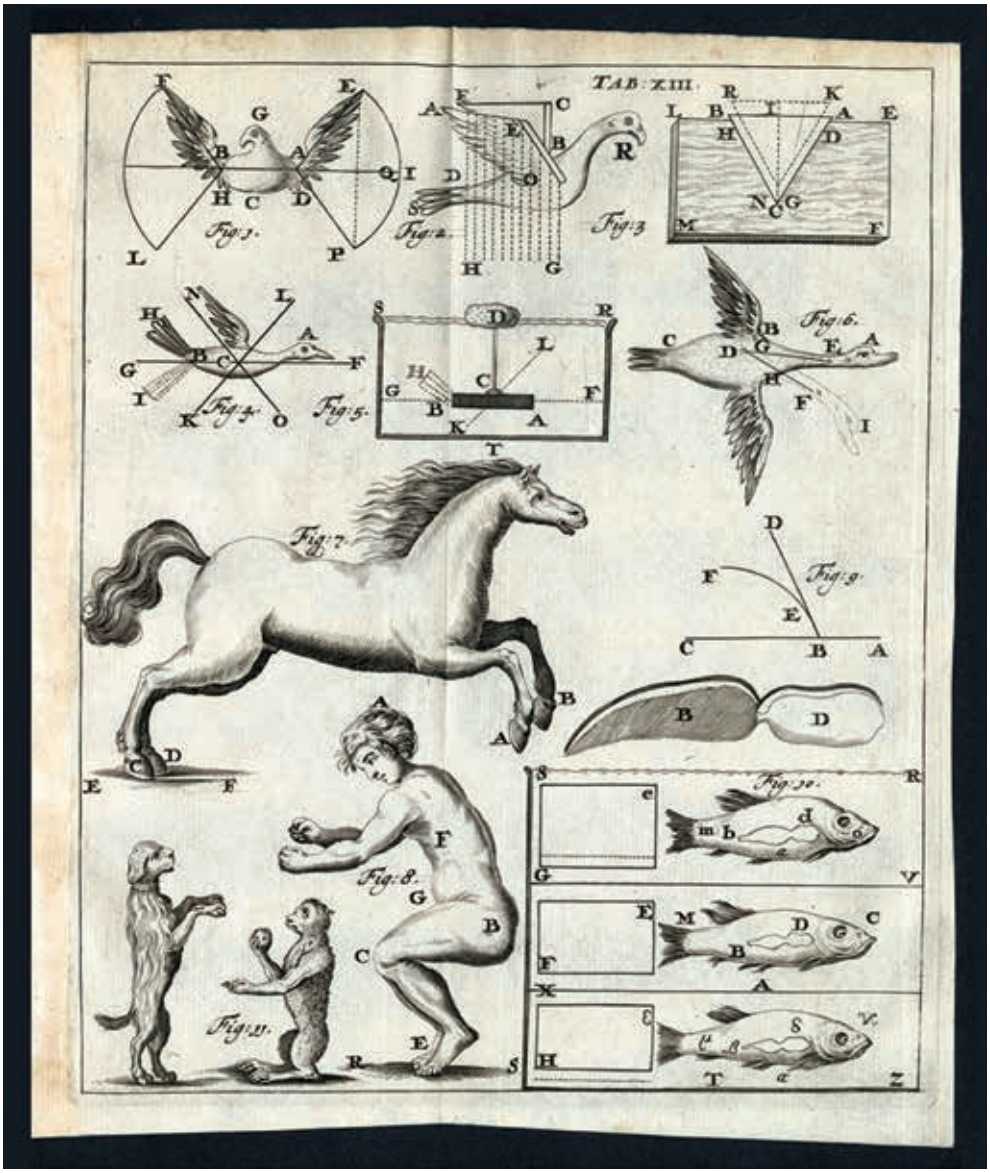

Fig. 2. – **G. A. Borelli. Le corps mécanique (*De motu animalium*, 2 vol., Rome, Angeli Bernabò, 1680-81)**. © Coll. et cliché Max Planck Institute for the History of Science (Berlin).

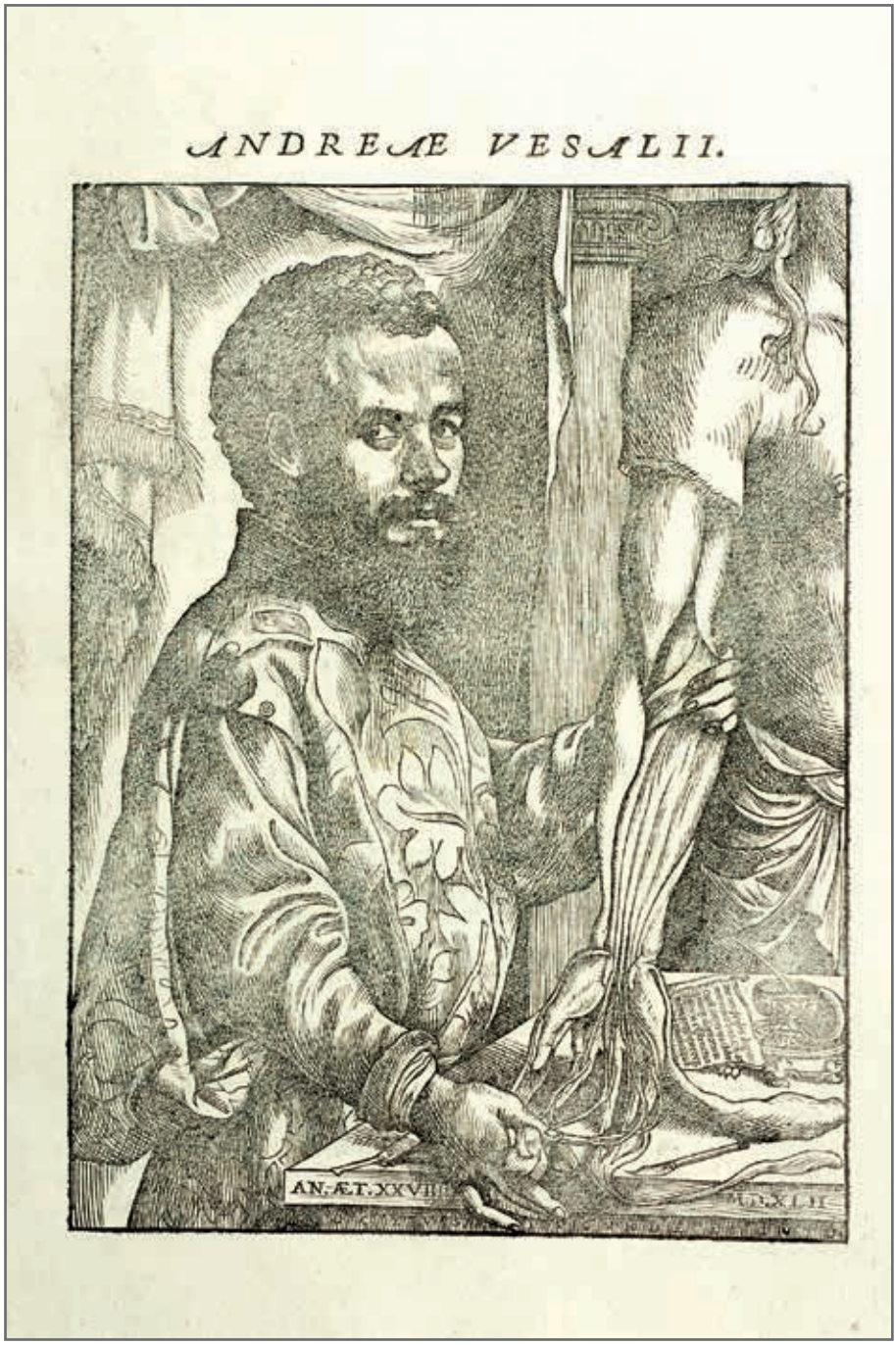

Fig. 3. – **A. Vesalius. La main et le bras (*De humani corporis fabrica*, Basel, Ex officina Joannis Oporini, 1543).** © Coll. et cliché de l'auteur.

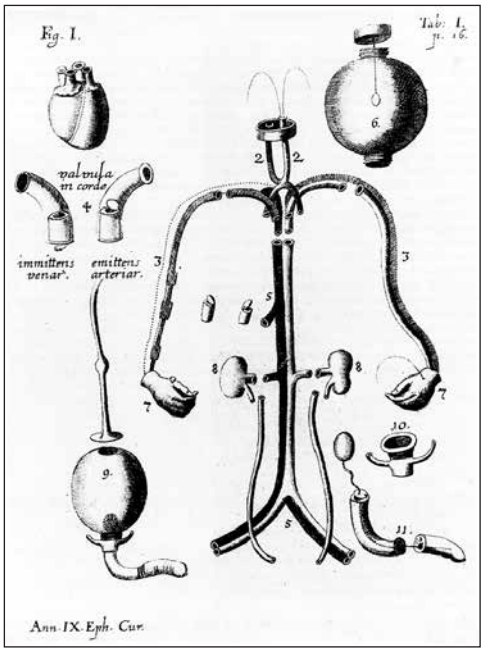

Fig. 4. – **S. Reisel.** ***Statua humana circulatoria*** **(*Miscellanea curiosa*, decuria I, anni IX-X, 1678-79, Nuremberg, 1693, pl. 1, p. 16).** © Coll. et cliché de l'auteur.

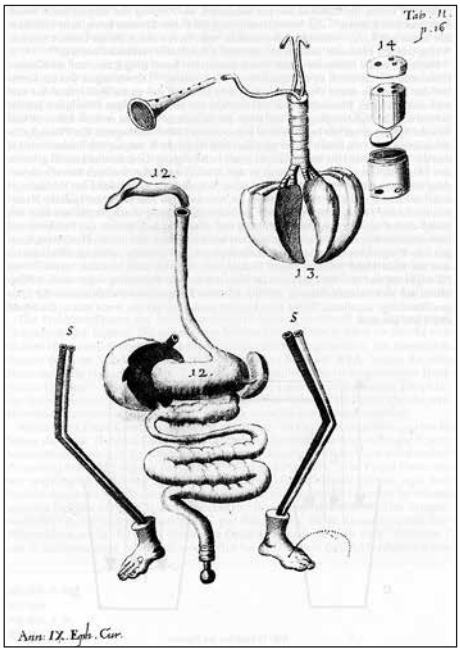

Fig. 5. – **S. Reisel.** ***Statua humana circulatoria*** **(*Miscellanea curiosa*, decuria I, anni IX-X, 1678-79, Nuremberg, 1693, pl. 2, p. 16).** © Coll. et cliché de l'auteur.

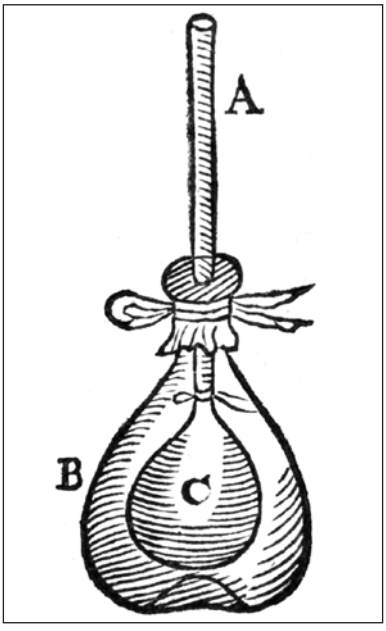

Fig. 6. – **J. Swammerdam.** ***Tractatus physico-anatomico-medicus de respiratione usuque pulmonum*** **(Leiden, Apud Danielem, Abraham. & Adrian. à Gaasbeeck, 1667, fig. 1).** © Coll. et cliché de l'auteur.