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Aristotle On Respiration: the Origins of Functional Anatomy

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Therefore we devote this treatise to the stomach, intestines, throat, bowels and the muscles of the anus and abdomen—however we are pursuing these things πρὸς δ' ἀκριβειαν and not πρὸς τὴν ὄψιν (as Aristotle uses these terms in *On Respiration*), that is, exactly and most thoroughly and not for the eyes only and in as I might say popular anatomy. And for this reason we will explore as we usually do three things concerning each organ: *historia* or structure or anatomy; then the action of the organ; and third its utilities. (Fabricius ab Aquapendente, *Opera omnia anatomiea et physiologica*)

1. Introduction: From *On Inquiry* to *On Respiration*

Book II of the *Posterior Analytics*, which I think of as *On Inquiry*, opens by telling us that the things about which we inquire are equal in number to those about which we have scientific knowledge, and that we inquire about four things: the “that”, the “reason why”, if it is and what it is. (89b23-25) These four objects of search appear to be paired, and sequential: the paradigmatic “that” is a predicative relationship, and the paradigmatic “reason why” is some more fundamental fact about the world that explains that predicative relationship: Is it the case that the moon undergoes eclipse? If so, we go in search of the cause of the moon undergoing eclipse. One moves from securing an answer to the “that” question to seeking its causal explanation. Analogously, the paradigmatic “if it is” question is existential—once you have successfully determined whether some kind of thing exists, you are prepared to determine what it is. ‘Centaur’ and ‘god’ are his examples in this chapter, but here is an actual example of an early stage in an ‘if it is’ inquiry, from the *Historia animalium*:

But if we are to believe Ktesias, there is [a creature with multiple rows of teeth]; for he claims there is this beast in India known by the name ‘Martichoras’ that has, in both upper and lower jaw, three rows of teeth; that it is as large as a lion

and similarly hairy, with human-like face and ears, blue eyes, cinnabar in color; that it has a tail like a scorpion in which there is a stinger, a voice alike at once to a shepherd's pipe and a horn; that it runs as fast as a deer; and is wild and a man-eater. (*HA* II.1 501a24-b1)

To use David Charles' formula for what has been achieved at this stage of inquiry: One knows that the kind Martichoras, *if it exists*, possesses a truly alarming set of properties! But does such a thing exist? Aristotle sounds decidedly skeptical.¹ But were we able to verify Ktesias' report, we ought then to try to determine *what it is* about the nature of these creatures that explains their strange collection of attributes.

In *APo.* II.2, however, a more integrated picture of the relationship among these inquiries emerges:

But we are seeking, when we *seek* the “that” or² the unqualified “if it is”, whether there is a middle for it or not; while when, having come to know either the “that” or “if it is”, either partially or without qualification, we seek the reason why or the what-it-is, we are then seeking what the middle is. (89b37-90a1)

This passage intentionally blurs the distinctions so clearly drawn in chapter one in three respects. First, Aristotle is now *downplaying* the distinction between the two ‘preliminary’ inquiries, the distinction between “that it is” and “whether it is” inquiries; there is now a *partial* (ἐπὶ μέρους) version of the “if it is” inquiry which appears to be identified with the “that it is” inquiry. (This was already hinted at in chapter 1 at 89b33.) Moreover, both are seen as attempts to find out *whether there is a middle*—that is, both are, though preliminary, guided by the goal of demonstrative knowledge. Likewise, the differences between the *second* two inquiries, between “what it is” and “why it is” inquiries, are also downplayed; both are now described as attempts to discover *what that*

¹ Charles 2000 35, 39-40: This is what Charles refers to as his ‘springboard’ view of the first stage of inquiry.

² How should one read this “or”? Is it the “or” of explication, of qualification (“or rather”) or of alternative? In fact this passage forces us to face this question not once but *four* times. This is not the place to defend an answer, but I am reading all of them as presenting alternatives, though not always exclusive alternatives.

*middle is!*³ This is of great interest, since having read chapter one it would have been reasonable to suppose that the search for a middle term would only be appropriate if one were searching for the explanation of a *predication* that had been established. But here, in chapter 2, as he puts it a few lines later, in *all* our inquiries we are asking either whether there is a middle or what the middle is: “for the middle is the cause, and *in all cases this is what is sought.*” (90a5-6) But that statement amounts to a *third* blurring, of the distinction between a preliminary, purely fact or existence establishing stage of inquiry and a later stage of inquiry in search of causes—those preliminary inquiries now seem to be preliminary stages in the search for causes.

Two features of chapter 2, then, complicate the account given in chapter 1: While Aristotle has not abandoned his claim that there are four distinct inquiries (in fact the chapter opens by referring back to them), he is nevertheless claiming that even as we inquire whether some kind of thing exists or whether a subject has some attribute or other, we are involved in some sort of *causal*, or anyway explanatory, inquiry.

But he also seems to be suggesting that as soon as we begin to attempt to answer questions like “Are there Martichorai?” or “Do all Martichorai have three rows of teeth?” we are *already* engaged in a search for answers to questions such as “What are Martichorai?” and “Why do Martichorai have three rows of teeth?” Moreover, he is also suggesting, by saying that in *either* of these cases we are seeking whether there is a middle, that the existential, “if it is” inquiry and the predicative, “that it is” inquiry, are, at the very least, intimately related. And finally, in saying that all such inquiries are causal, he is suggesting that, in seeking an answer to the “what is a Martichoras?” question I am also engaged in trying to answer questions such as why such a creature would have three rows of teeth.

It is interesting to consider a passage in *On Respiration*⁴ in light of this puzzling aspect of Aristotle’s understanding of the process of scientific inquiry. To set the context: *On*

³ Cf. 90a14-15: “In all these cases it is apparent that ‘what it is’ and ‘why it is’ are the same.”

⁴ I use this title as a convenience. Ross (1955, 2-3) lays out the case for this not being a separate work but, as is clearly indicated by *Juv.* 1, 467b10-13, continuous with the prior

Respiration begins with an introduction that is highly critical of investigations of the subject by previous thinkers, some of whom claim *all* animals breathe. Aristotle allows that all animals with a lung certainly do, and notes variations in respiration correlated with differences in the lung. Chapter 2 focuses on the view, shared by Anaxagoras and Diogenes, that all animals breathe, and particularly on their views about how fish do so. In chapter three, after firing off a barrage of criticisms of the claim that fish take in air “from the water by means of the mouth”⁵, he offers a diagnosis of why these thinkers went so badly off track:

The most significant reason for [these thinkers] not discussing these things well is a combination of (τε) their being inexperienced with the internal parts and (καὶ) not grasping that nature makes them all for the sake of something; for seeking what respiration belongs to animals for, and examining this question in the presence of the parts, e.g. in the presence of gills and lungs, they would have discovered the cause more quickly. (*Resp.* 3. 471b23-29)

What I find significant here, suggested by the τε...καὶ construction, is this: Aristotle seems to be recommending that the preliminary, “that”-seeking investigation, the *historia*, the gaining of hands-on experience of the relevant bodily parts, ought to take place within the context of a causal inquiry—specifically an inquiry into “that for the sake of which”, the “proper function” of respiration. Aristotle appears to be insisting that there is a single, complex reason why Anaxagoras and Diogenes were unsuccessful: they did not carry out a proper examination of the relevant parts, which *proper* investigation would have been guided from the beginning by asking “what is that for?”. But there is

discussion of youth and old age, and the later discussion of life and death. See too Hannon 2011, 5-14, Morel 2000 51. See below, pp. 11-12 for one especially telling piece of textual evidence for this continuity.

⁵ The view apparently is that the water leaving by way of the gills leaves a vacuum and that air, which is somehow coming in with the water, fills the void. Aristotle points out that breathing involves both inhaling and exhaling, and these thinkers only discuss the inhaling but provide no mechanism for exhaling; they don’t explain where the air goes or what it does for the fish (since they have no lung, and they don’t see the gills as playing any role in breathing). It is also a puzzle on their view why fish would have problems breathing out of water, since the air would be even easier to obtain; or why we land animals can’t derive air in the same way as fish do underwater.

something very puzzling about this passage that is especially relevant for our theme—the “what for?” question is *not* about lungs and gills—it is about *respiration*.

Moreover, there is another, closely related, puzzle: the fact that gills are mentioned at all. Gills do not *in the least* resemble lungs. And as far as Aristotle’s reports of his predecessors go, no one before him thought of gills as fulfilling the same function as lungs.⁶

So why mention them at all? Aristotle has already made it quite clear that those who claim that fish breathe are wrong. Gills, he insists, are *not* for respiration. And yet he mentions *both* gills and lungs as objects of investigation for those seeking to answer the question, “What is *respiration* for?”. This, as it turns out, is an early clue of the importance of teleologically guided dissection to biological investigation.

Before we pursue that important clue however, I want to flag a concern about whether this passage is in tension with certain other passages about stages of inquiry in the biological works. Its recommendations would appear to sit comfortably with what I was suggesting is the message of *APo*. II. 2: that is, you can analytically distinguish figuring out which animals have lungs and which have gills, with all that entails, from figuring out what activities they perform and what those activities are for; however, these should be thought of as two moments in a single, causally focused inquiry. But this message may seem to conflict with passages that suggest a more discreet boundary between these two stages of inquiry. Take the well-known passage in *Historia animalium* I. 6.

These things have now been stated in outline, in order to provide a taste of which things, and about which things, we need to study in order that we may first grasp in all cases the differences that are present and the attributes. (We will speak with greater precision later.). After this we must attempt to discover their causes. For

⁶ Interestingly, though gills are mentioned often in *HA*, only once, at *HA* VII. 2 589b19 in an aside about animals that take in water by mouth as they feed, does Aristotle even hint at any functional relationship between gills and lungs. The only lengthy discussion of gills is at II. 13, 504b28-505a21, and is a survey of differences in the number of gills in different kinds of fish, and whether the gills are covered or not. Other references or discussions of gills are found at 489b2, 506a12, 507a5, 509b4, 511a5, 535b21, 566b3 and 589b25-28.

this is the natural way (κατὰ φύσιν) to carry out the inquiry (τὴν μέθοδον), when the *historia* about each thing is present; for it is from these things that both the things *about which* there needs to be demonstration and the things *from which* there needs to be a demonstration become apparent. (491a7-14)

As is often noted, there is a remarkable similarity in the mode of expression here and in the closing lines of *Prior Analytics* I. 30, where *historia* again refers to being in possession of the facts that truly hold in each of the things being studied, which then prepares an investigator to find the demonstration of what is by nature demonstrable (46a22-27). A very similar distinction introduces *On the Parts of Animals* II (646a8-11); and *On the Locomotion of Animals* 1 concludes its review of the questions about animal locomotion in language that explicitly lines up what was accomplished in natural history with an inquiry ὅτι:

About all these things, and others akin to them, we must study the causes. For *that* (ὅτι μὲν) these things happen to be so is clear from the natural history, but *the reason why* (διότι δέ), we must now investigate. (704b8-10)

The possible tension between these passages and *Resp.* 3 arises because in them the preliminary, ‘fact gathering/establishing’ stage of inquiry appears not only *preliminary* to a search for causes, but one that is completed *independently* of the search for causes. I believe a close look at the argument in *On Respiration* goes some way towards resolving this tension. I will make a case for viewing *On Respiration* as, in part, a discussion of the right and wrong ways to investigate *an organic activity*, that is, the activity of certain organs or systems of organs.

2. Where Aristotle’s Predecessors Went Wrong.

On Length and Shortness of Life concludes by looking forward to the topics ‘common to body and soul’ remaining to be covered:

It remains for us to study youth, old age, life and death; for having defined these things, our inquiry concerning the animals would have achieved its end (τέλος ἂν ἢ περὶ τῶν ζώων ἔχοι μέθοδος).” (467b6-9)

Interestingly, respiration is not mentioned. This accounts for the way in which it is introduced, almost as an afterthought, in the next lines of *PN*, traditionally marked as the opening lines of *On Youth and Old Age*:

We must now discuss youth, old age, life and death; *and presumably at the same time it is also necessary to discuss the causes of respiration*; for in some animals living and not living are dependent on this. (467b10-13)

As he puts the point in a later criticism of one of his predecessors we will look at shortly (p. 10): “And yet surely we see these things to be *sovereign over* (κύρια) *life and death*; for when animals that breathe are unable to do so, at that moment they begin to pass away.” (*Resp.* 5. 472b24-29)

This much is an unquestionable datum of common sense, something familiar to us—animals that breathe, if prevented from doing so for any length of time, die. This gives one good reason to investigate it from a teleological perspective—it clearly is doing something upon which life depends; but *what*, precisely? As we know, Aristotle’s answer is that it helps to moderate the heat in the region around the heart. Thus the investigation into the question of why those animals that breathe do so is transformed gradually into an investigation of methods of *cooling* across the animal kingdom, of the need for a *variety* of methods of cooling, and of the importance of effective cooling for the preservation of life. That discussion, in turn, will depend heavily on the central topic of *Juv.*, the intimate relationship between the nutritive soul and internal, natural or psychic heat—and the physical changes in old age that lead to natural heat no longer serving as an effective agent of nutritive soul.

All of this suggests that *Resp.* is a discussion embedded within these wider concerns. Indeed, when one considers what are, according to the Prussian Academy edition, the closing lines of *De Juventute* and the opening lines of *De Respiratione*, one realizes just how embedded! The former closes by setting up the coming discussion of respiration with these words:

Since some of the animals are water-dwellers, while others pass their time in the air, and they [both] accomplish the task of cooling from and by means of these,

i.e. some by water and some by air, we must discuss in what manner and how they do this, by becoming better acquainted with the debate about it (τὸν λόγον). (470b2-6)

While the opening words of the latter are:

For (γὰρ) a few of the natural philosophers have spoken previously about respiration; yet for what purpose (τίνοσ...χάριν) it belongs to animals, some have said nothing, while others, though they have spoken, have done so poorly, due to lack of experience with the facts (ἀπειροτέρως τῶν συμβαινόντων).⁷ Further they say all animals breathe, but this is untrue. So it is necessary first to review their claims, in order that we not appear to level an empty accusation in their absence. (470b6-13)

The γὰρ not only makes it clear that these remarks are continuous with those at the end of *Juv.*, as Ross notes—it also clarifies the otherwise somewhat puzzling reference to becoming acquainted with a *logos* at the close of *Juv.* The sentence that opens *Resp.* explains which *logos* it is about which we must become better acquainted. There is an on-going discussion—a *logos*—about what respiration is, which animals breathe and how they do so, a debate into which Aristotle is entering, and we need to become better acquainted with that *logos* before moving forward.

Ross is certainly right to conclude, then, that the balance of evidence supports the conclusion that the discussion from the beginning of *Juv.* on is one continuous discussion, though with clearly demarcated sub-sections.⁸ Moreover, the introduction to *De sensu*, with which our *Parva naturalia* begins, lists a sequence of studies of attributes common to body and soul, a sequence which begins with an investigation of perception and concludes with an investigation of four paired attributes: sleeping and waking, youth and old age, breathing in and out, life and death. (436a1-17) Notice that in this preview of coming attractions, the discussion of life and death is listed where it actually appears, *after* a long discussion of respiration (and other forms of cooling).

⁷ I note in passing that these two criticisms correspond to the two normative recommendations Aristotle makes at the end of ch. 3 discussed earlier.

⁸ Ross 1955, 2-3.

Nevertheless, it is worthwhile considering Aristotle's discussion of respiration on its own—he does distinguish it from the related topics, and it contains a rich discussion of how inquiries into nature can go wrong, and what you need to do to stay on track, in the study of a biologically important process and the organs that accomplish it.

Given the passage with which this section began, it will come as no surprise that a recurring theme of his review of his predecessors' accounts of respiration is their failure to ask “What is respiration for?”. We have already seen that he mentions this as a common failing in the opening lines of *Resp.*; and our focal text concludes a review of the errors of Diogenes and Anaxagoras. In addition, the following comments about the efforts of Democritus, Plato and Empedocles take each of them to task for ignoring the ‘what for’ question in their attempts to understand respiration:

Chapter 4. 471b30-472a3

Democritus says that *something results* from respiration for those that breathe, when he claims that it prevents the soul being squeezed out; *yet he said nothing about nature doing this for the sake of something*, for generally, just like the other natural investigators, he doesn't touch at all on this sort of cause.⁹

Chapter 5. 472b24-29

Again, those¹⁰ who discuss the matter in this way have said nothing about what these things (by which I mean both inhaling and exhaling) are present in animals for the sake of (τὸ τίνοϛ ἔνεκα ταῦθ' ὑπάρχει τοῖς ζῴοις), but make proclamations as if speaking about something merely coincidental. And yet surely we see these things to be sovereign over life and death; for when animals that breathe are unable to do so, at that moment they begin to pass away.

Chapter 7. 473a15-17.

⁹ The Loeb translator W.S. Hett makes a glaring misstep here, translating: “Democritus states that respiration serves a certain purpose in animals that respire...but he never says that this is why nature evolved respiration...”, which comes close to stating the exact opposite to what Aristotle's Greek says about Democritus.

¹⁰ An earlier comment makes the reference clear: “The circulation written about in the *Timaeus*...” (5. 472b6).

Empedocles also speaks about breathing, yet certainly does not discuss what it is for the sake of; nor does he make it clear, about all the animals, whether they breathe or do not breathe.

But why would these investigators carry out their investigations with this question in mind? If they were of the conviction that what these parts do as part of the animal's 'machinery' has nothing at all to do with why these parts come to be, they would consider an investigation governed by this question wrong-headed. Aristotle insists that, had they asked the teleological question while investigating the parts, they would have discovered the cause more quickly or sooner. But to start investigating with that question in mind, you must at least be open to the idea that answering that question is relevant to understanding whatever it is you are investigating. The claim that those who were not looking for the final cause of respiration would have found it sooner had they decided to look for it is trivially true, *assuming that there is one*. Is this all Aristotle is saying? Decidedly not: His message is that you will not succeed in figuring breathing out at all, you won't even get the material or mechanical story right, if your investigation is not guided by questions regarding what the process—and the parts required for it—are for. Or so I aim to show.

By the end of chapter 7, he has completed his consideration of previous accounts of respiration:

So then, such and so many are the troubling difficulties (*δυσχέρεια*) to be found in the things said by others about breathing. (474a23-4)

3. Comparative Anatomy and the Function of the Heart

As we've seen, throughout the critical discussion he has repeatedly stressed that previous thinkers almost all ignored the question of what respiration is for. And the one view that does consider the question of function suggests breath is a sort of fuel for the internal heat. He now begins his own account:

We have said previously that living and the disposition of soul is conjoint with a certain warmth; for concoction, through which nutrition comes about in animals,

occurs neither in the absence of soul nor in the absence of warmth; for everything works (ἐργάζεται) by means of fire. (474a25-8; see τὸ ἐργαζόμενον, *De An.* II. 4, 416a14)

The reference to what was said previously is almost certainly to the discussion of the role of the heart in nutrition in chs. 4-6 of *Juv.*, which immediately precedes his investigation of respiration.¹¹ He first reminds us of the reasons why the nutritive soul and the primary nutritive part must be in the middle region of the body (474a28-b1; cf. *Juv.* 2 468a13-18). That primary nutritive part, he asserts, is nameless in bloodless animals but is *the heart* in blooded animals (474b1-4). He then recapitulates the argument from *Juv.* 3-4 for this claim:

...the nourishment from which the parts come to be in animals is the nature of the blood. And there must be a source (ἀρχή) of both the blood and the blood vessels, for the latter are for the sake of the former, as [its] vessel and receptacle. (474b4-8; cf. *PA* III 5, 667b17-18)¹²

He concludes:

But the heart is the source of the blood vessels in blooded animals, for they do not run through it, but all in fact extend from it. And this is clear to us from the dissections. (474b8-9)¹³

This is the first reference to dissections in *Resp.*, and is a textbook example of how dissection, if done with a teleological focus, can reveal answers about function. What is the ‘this’ that is clear from ‘the dissections’? It is the fact that the blood vessels are the receptacle for blood and that the heart is their origin. Why would this be in need of

¹¹ Hannon 2011, 75, titles this chapter ‘Reiteration of the First Principles of the Theory’.

¹² Note, by the way, the claim that one part is present for the sake of another part. This is a form of causal dependence explicitly defended in *PA* I. 5: “...if some actions are in fact prior to, and the end of, others, *it will be the same way with each of the parts whose actions are of this sort.*” (645b30-32)

¹³ *HA* III. 2-4 quotes extensively from previous accounts of the blood vessels and discusses in detail problems in observing the vascular system via dissection.

support from dissections? Because of a point Aristotle makes regularly in arguing for the heart's function: it is by a comparative anatomical study of many different internal organs and their connections to the blood vessels in many different blooded animals that you learn that the relationship of the blood vessels to the heart is unique, and unlike their connections to any other visceral organ.

PA III. 4-5 return over and over again to the fact that dissection will reveal to you that, while the blood in all the other organs is within blood vessels, and that in all other organs blood vessels permeate the organ, in the case of the heart the blood is stored in the heart's own cavities, and the aorta and vena cava grow out of those cavities. Readers of *PN* had already been referred to this background in the discussion of youth and old age:

That the heart is the source of the blood vessels has been said previously in our works on the parts of animals (ἐν τοῖς περὶ τὰ μέρη τῶν ζώων)... (*Juv.* 3 468b31-469a1)

The *PA III* discussion begins by stressing the differences between the heart and the other viscera in relation to the blood vessels (I've placed in italics all of the references to what would be seen by means of dissection):

And as we said [at 665b14-16], *while the blood vessels run through the other viscera, no blood vessel extends through the heart*; whence it is also clear that the heart is a part, in fact an origin, of the blood vessels. And this is reasonable; for *the middle of the heart is a body which is naturally dense and hollow*; and further, it is full of blood, in as much as the blood vessels originate there; it is hollow to serve as the receptacle for blood, and dense in order to guard the origin of heat. For *in this part, alone of the viscera and of the body, is there blood without blood vessels, while each of the other parts has blood in its blood vessels*. This is also reasonable; for the blood is conducted from the heart and into the blood vessels, but not to the heart from elsewhere; for this is the origin and spring of blood or its first receptacle. *These things are more manifest (κατάδηλα μᾶλλον) with the help of the dissections and the generations; for the heart, which comes to be first of all the parts, is immediately blooded.* (*PA III. 4 665b31-666a11*)

The closing γὰρ clause is added as explication of what specifically the study of

generation adds by way of evidence; two additional points you learn by studying animal generation closely is that the heart is constituted directly from blood and that it is the very first organ to appear.

Wherefore the heart becomes apparent first as a distinct part in all blooded animals; for it is the source in all blooded animals of the uniform and non-uniform parts. ... And this is clear (δῆλον δὲ τοῦτο) from the histories and the dissections. (*GA* II. 4 740a18-24, selections, cf. *Resp.* 20 480a6-7)

It is worth spending some time over the reference to dissections in these passages. Aristotle has discovered that, in all blooded animals, the blood vessels permeate the visceral organs, and he argues that this is because those organs are constituted out of blood, as their ‘final nutrient’¹⁴; and in support of *that*, dissection reveals that as the vessels get smaller and smaller, they virtually merge with that which they feed. As he explains during his discussion of the blood vessels in *PA* III. 5:

...just as during irrigations the largest of the trenches remain, while the smallest are first quickly obliterated by the mud, but when it is removed they once again become evident, *so in the very same way the largest of the blood vessels remain, while the smallest become in actuality flesh, though potentially they are blood vessels no less. For this reason too when the flesh is in any respect preserved, blood flows when it is cut; and though without blood vessel there is no blood, yet no blood vessel is manifest*, just as in aqueducts the trenches are not manifest until the mud has been removed. The blood vessels always proceed from the greater to the lesser, until the channels have become smaller than the thickness of the blood. (668a27-b3)

Juv. 3 makes a clear reference to this discussion as Aristotle begins his argument for the primacy of the heart, and the middle part of the body, as the seat of nutritive, locomotive and sensitive soul.¹⁵ He concludes:

¹⁴ “It is, then, apparent from these and like considerations that blood is present in blooded animals for the sake of nourishment.” (*PA* II. 3 650b2-3)

¹⁵ “That the heart is the source of the blood vessels has been said previously in our works on the parts of animals (ἐν τοῖς περὶ τὰ μέρη τῶν ζώων)...” (468b31-469a1)

So it is necessary for the source (ἀρχή) of the perceptive and nutritive soul in the blooded animals to be in the heart; for the functions (ἔργα) of the other parts concerned with nourishment are for the sake of (χάριν) its function; for the authoritative part should strive toward that for the sake of which, as a doctor is related to health, and should not be found in those things for the sake of this. (469a6-10)

On the basis of what must have been a quite extensive and systematic series of dissection, Aristotle has apparently noticed the following patterns emerging across the entire range of blooded animals:

- In each case, the blood vessels are very large at the heart and get smaller and smaller as they reach the viscera.
- The vessels essentially permeate and disappear in all the visceral organs except the heart, while in the case of the heart, they seem to be extensions of its hollow cavities, which contain blood.
- The material of the blood vessels is similar to that of the heart but not to that of any of the other organs.
- In contrast to the heart, the blood in the other viscera is always *inside* the blood vessels that permeate those organs.
- During embryogenesis, the heart comes to be before the other viscera, and the blood vessels seem to grow out from the heart, after which the viscera gradually form at the extremities of systems of these vessels.

Only by doing careful, comparative dissection across a wide range of animals will you be become confident that this essential difference in the way the blood vessels are connected to the heart in comparison to the way they are connected to the other viscera is true of blooded animals *qua* blooded. But it is Aristotle's view, as we've seen, that an inquiry involving systematic comparative dissections should be guided, from the beginning by teleological questions about these differences between the heart and the other viscera. Indeed, it is likely that iterated functional questions of this kind would guide every step of

the investigation. In the end, he concludes that all of these differences are present because in all blooded animals the heart is the *source* of the nutritive blood for all the other visceral parts.

That was a long digression away from respiration, I realize, but it provides us with two different pieces of background that we need in order to deal with his investigation of it. First, the texts we have been looking at in *PA* and *GA* give us a rich idea of how Aristotle draws conclusions about biological function by using dissection to carefully study anatomical similarities and differences between parts, and anatomical connections among them. Second, it will turn out that it is how structures are related to the heart (related both ‘physically’ and ‘extensionally’), against the background of what Aristotle feels he has already established about the function of the heart and how it accomplishes that function, that will be central to Aristotle’s account of respiration. Based on background in *De anima* II. 4, reviewed quickly in *De juventute*, Aristotle begins his investigation of respiration already confident that the hearts of all blooded land animals are a source of heat that is used by the nutritive soul in preparing blood for distribution to the rest of the body as its nourishment. And that critical role played by the heart, and the need for psychic heat in playing that role, underlies the need for respiration.

4. Why We Breathe: Getting the Extensions Right

Beginning in chapter 9, the argument proceeds to make the case for that conclusion, by arguing that the heat required by the organism for nutrition gives rise to a subsequent need for cooling. Interestingly, this chapter is focused almost exclusively on the bloodless animals, arguing that they have relatively little heat and can therefore be adequately cooled by their surroundings. That is, it is governed by the implicit question: ‘Why do these creatures *not* have organs of respiration?’ But the chapter also looks forward, making a number of *comparative* comments about animals that cool themselves by gills or lungs. The following ‘chapter’ opens¹⁶ by drawing a line on that discussion,

¹⁶ “Concerning the bloodless animals, then, we have stated that they are aided in relation to living in some cases by the surrounding air and in others by the surrounding water.” (475b15-17). Once again we are reminded of the unreliable nature of these chapter

and begins the work of specifying as precisely as possible the *extension* of the relevant attributes, in a form reminiscent of *HA*—the discussion opens, for example, with the following claims:

...in those that are blooded and have a heart, *as many as* have a lung, *all*¹⁷ take in air and cool themselves by inhaling and exhaling. And all that are both internally, and not merely externally, live bearing have a lung (for selachians, while live bearing, are not so internally); as do, among the egg layers, both those that are feathered, such as birds, and those that are scaled, such as tortoises, lizards and snakes. (475b17-24)

The care with which groups are correlated here, identified by differentiae relevant to how cooling is accomplished, is remarkable. The widest background group of interest is now the *blooded* animals, all of which have been established to have a heart. Among that group, the group with a lung is co-extensive with those that cool themselves by inhaling and exhaling air. And the sub-group with a lung consists of those that are *truly* either live bearing, feathered egg-layers, or scaly¹⁸ egg-layers. Aristotle has carefully specified the egg-layers with lungs so as to exclude fish, without ever mentioning them. He segues into discussing fish by first considering animals with lungs that spend a good deal of time in the water, yet either birth their young on land or take measures to insure their newborn can breathe. He then goes on:

But¹⁹ *as many as* have gills, *all* cool themselves by taking in water; both the kind consisting of the so-called selachians and the other footless animals.²⁰ And all the

breaks that were introduced in the Renaissance; this reads much better as the conclusion of the previous discussion.

¹⁷ The use of the double quantifier ὅσα...πάντα is common in Aristotle and particularly common in the *Historia animalium*, and appears to be used to identify co-extensive or counter-predicated attributes such as lungs and the taking in of air for cooling and (in the next quotation) gills and the taking in of water for cooling. For some discussion of its use cf. Lennox 2001, chs. 1 and 3; Gotthelf 1988 [in Gotthelf 2012, 307-342]. This passage should be compared with *HA* II. 15 505b32-506a8.

¹⁸ The point is not as clear in English as in Greek which has distinct words for ‘fish scale’ (λεπίς) and for the scale of a reptile (φολίς).

¹⁹ The δὲ at 476a2 is in fact coordinate with the μὲν at 475b18. The background class is the animals with blood and heart, and within that class he is distinguishing those that

fish are footless; and indeed what part they have [for locomotion] is named for its likeness to wings.²¹ (476a2-5)

He then notes that of those so far studied (τῶν τεθεωρημένων) only one animal with feet also has gills, “the so-called *kordulos*.”²² But he notes that it has no lung²³, and in fact, “[n]o animal has yet been seen (οὐδεν ὄπται πω) possessing both lungs and gills.” ‘Why not?’, one might ask, and (of course) Aristotle has an answer:

have a lung and cool themselves with air from those that have gills and cool themselves with water; and then within those two he is distinguishing various sub-divisions. The “ὅσα... πάντα” in those two cases is to stress the co-extensive relationship between the organs and the medium of cooling.

²⁰ In case you are wondering about snakes or cetaceans, the background class here is animals with gills, so it is only footless animals with gills that are under consideration.

²¹ The Greek for ‘fin’ is πτερύγιον and for ‘wing’ πτέρυξ, the plural of which is πτερύγια.

²² Most salamanders have a larval stage during which they breathe with external, feathered gills and lack lungs. In an attempt to be clearer about the sort of organism Aristotle was observing and the data behind the claims he makes about the *kordulos* I have been greatly aided by Dr. J. W. Arntzen. In email correspondence he has put forward a most interesting and plausible conjecture, which I reproduce with his permission:

“Dear Prof. Lennox – I discussed your points with Ben Wielstra. [His notes on Aristotle’s five references are omitted] Altogether the most likely explanation is that Aristotle is referring to a so-called *paedomorphic* newt. So, it would then concern an adult sized specimen with gills. In SE Europe three newt species are found. The smallest is *Lissotriton vulgari*; *Ichthyosauara alpestris* has intermediate size and *Triturus macedonicus* is the biggest. Also the three species have very different colorations but without descriptions of size and colour [which Aristotle does not provide], this information is of no use. Taxonomic note – more species are recognized than I here mention – let me know if you need details. What remains is that the phenomenon of paedomorphosis is more regularly found in mountain populations of *Ichthyosauara alpestris* than in the other two species.

I hope this is of some help. Sincerely yours,

Pim Arntzen, Netherlands Centre for Biodiversity Naturalis, Leiden”

Paedomorphosis refers to the retention into adulthood of features of the larval stage, in this case including the presence of gills and lack of lungs, which occurs in some but not all members of this species. The most thorough discussion I have found of the salamanders of southeastern Europe is STEINFARTZ, S., S. VICARIO, J. W. ARNTZEN, A. CACCONE (2006): A Bayesian Approach on Molecules and Behavior: Reconsidering Phylogenetic and Evolutionary Patterns of the Salamandridae with Emphasis on *Triturus* Newts. *J. Exp. Zool. (Mol. Dev. Evol.)* 306(2): 139-162.

²³ And how is he sure about that? Another instance where dissection is clearly playing a role.

A cause is that the lung is for the sake of (ἔνεκα) cooling by breath... while the gills are related to (πρὸς) cooling by means of water; and there is one instrument for one use, and one is sufficient for cooling in all cases. So since we see nature doing nothing in vain, while having two, one would be in vain, on this account some animals have gills, some lungs, but none have both. (476a7-15)

There are a variety of interesting features of this argument for our topic. First, Aristotle goes out of his way to stress the inductive basis of the *explanandum*: *none has yet been seen* with both lung and gills. Indeed, *until now* only one animal equipped for walking on land *has been seen* with gills.²⁴ Given the plausible conjecture mentioned in note 20, it is possible that Aristotle had seen two otherwise similar adult animals, one with lungs and the other with gills. Second, there are subtle distinctions between the functional characterizations of the lung and gills: the former is present for the sake of (ἔνεκα) cooling by (ὑπό) breath; the latter are related to (πρὸς) cooling by way of (ἀπό) water. Aristotle is not yet committing himself to the claim that gills are *for the sake of* cooling. Up to this point, it has been mentioned a number of times without justification that fish cool by means of gills but there has not been any argument that cooling is the function for the sake of which fish have gills. What *has* been clearly established is that the class of animals with a cardiovascular system, and the heat generated by it, is of wider extension than breathing and the parts that are necessary to perform the activity of breathing; and that the class of animals with a cardiovascular system is co-extensive with the animals that breathe *plus* the animals with gills.

5. From Breathing to Cooling: the Value of Functional Anatomy

At the beginning of chapter 13, Aristotle announces that he must speak “about *cooling*, in what way it comes about both for those that breathe and for those having gills.” (477a11-12) This is a central theme of the remainder of the treatise, though it is *interwoven* with discussions of the intimately connected topics of generation, life and death, and the movements of the heart and blood vessels. Because of this paper’s theme, I will focus on what the discussion in chapter 16 may tell us about the connection insisted

²⁴ The same stress can be found at *HA* VII 589b26-7: ἐν δὲ μόνον νῦν ὥπται τοιοῦτον, ὁ καλούμενος κορδύλος; οὗτος γὰρ πνεύμονα μὲν οὐκ ἔχει ἀλλὰ βράγχια...

upon in the passage that closes chapter three, the connection between teleological inquiry into respiration and the use of dissection.

In this chapter, Aristotle refocuses the inquiry in a number of closely related respects:

[i] The inquiry has shifted to a *more universal* level, to the mechanisms of cooling in *all* the blooded animals.

[ii] That shift is a consequence of having focused, from the beginning of the investigation, on the *purpose* of respiration.

[iii] Once the purpose of respiration is properly understood, it follows that cooling *must be shared by all blooded animals*.

[iv] But since fish are blooded and therefore have hearts, their hearts must use heat for the same nutritive purposes as all blooded animals and distribute that blood to the other parts of the body by means of blood vessels

[v] And given all that, *they have the same need for cooling* as all blooded animals.

By focusing on the *function* of respiration then, recognizing that it is a function that must be shared by all blooded animals, and realizing that lungs are *not* co-extensive with the entire class of blooded animals, Aristotle is poised to grasp the analogical identity between lungs and gills. In what follows I present evidence that what led Aristotle to shift the inquiry to this higher, functional/analogical level, was holding a constant teleological focus while he was carrying out his comparative anatomical studies. That is, the argument from this point on is an illustration of the value of following the normative recommendation that closes chapter 3—and may well have been intended as such.

6. Proving Gills are for the sake of Cooling

Chapter 16 makes the case for gills being present for the sake of cooling. But it does so in a way that is rich in hints about the methodology he followed in reaching this conclusion, and it is on these hints that I shall focus. Let us begin with a sentence that actually closes *Resp.* 15 (*Juv.* 21) in Bekker, followed by most modern editors.

And for what reason those breathe most that have a bloody lung is clear from these facts. For those that are warmer have need of greater cooling, but at the same time the breath is transported easily to the source of the heat in the heart. And the way in which the heart has a passageway to the lung needs to be studied from the things that have been dissected [ἐκ τῶν ἀνατεμνομένων; cp. ἐκ τῶν ἀνατομῶν, 478a35-b1] and from what has been written in the inquiries [τῶν ιστοριῶν τῶν περὶ τὰ ζῷα γεγραμμένων]. (478a21-28)²⁵

The opening line refers back to facts established in the immediately preceding discussion, regarding the large network of blood vessels (connected ultimately to the heart) and the large network of tubes filled with air (and ultimately connected to the windpipe) lying side by side one another in the lungs of all lunged animals.²⁶ These facts, he claims, help us understand why animals that breathe most also have more blood in their lungs—Aristotle infers that this is because they are warmer and have a greater need for cooling. In these animals there is both a system that allows for easy transport of air to the lung and, as he is now going to discuss, a passageway to the lung for the blood.

This chapter has two references to dissections²⁷; the first one, here, recommends that the student/investigator look at dissected animals to observe the connections between the

²⁵ Καὶ διότι δὴ μάλιστα ἀναπνέουσι τὰ ἔχοντα τὸν πνεύμονα ἔναιμον, ἐκ τούτων δῆλον· τό τε γὰρ θερμότερον πλείονος δεῖται τῆς καταψύξεως, ἅμα δὲ καὶ πρὸς τὴν ἀρχὴν τῆς θερμότητος τὴν ἐν τῇ καρδίᾳ πορεύεται τὸ πνεῦμα ῥαδίως. Ὅν δὲ τρόπον ἡ καρδία τὴν σύντηρσιν ἔχει πρὸς τὸν πνεύμονα, δεῖ θεωρεῖν ἐκ τε τῶν ἀνατεμνομένων καὶ τῶν ιστοριῶν τῶν περὶ τὰ ζῷα γεγραμμένων.

²⁶ *Resp.* 478a12-14: “the lung is sponge-like and filled with tubes, and of all the so-called viscera this part is the most filled with blood (ἐναιμότερον).” There is another detailed discussion of the vascular connections between the heart and the lung in *HA* III.3 513a35-b1, 513b11-25. Unfortunately it does not have a parallel discussion of the vascular connections between heart and gills.

²⁷ Of the explicit references to dissection in Aristotle, the two in this chapter, along with those in the *PA* III and *GA* II discussed above in section 3. and one previous one in *PN* (*De Somno* 3. 456b2) are all there are about the heart in relation to the blood vessels. That is, however, more references about one organ system than any other, except for the male and female reproductive organs, which, if we include things like the movement of embryos and the number of offspring in the womb, account for 15 of 28 references. This may tell us something about how far along the process of producing anatomical ‘atlases’ was during Aristotle’s lifetime. From the perspective of the author of *PA* and *GA*, these

lung and the heart.²⁸ This reference is unusual in that it uses the past participle of the verb ἀνατέμνω, while Aristotle typically refers the reader to what can be observed “in the dissections” using the plural of the noun ἀνατομή. This first reference, then, suggests that the reader is being directed to what one observes when dissections are performed rather than to collections of diagrammatic representations that seem to be the implied reference of the noun.²⁹ Both here and in the later reference (where the dative plural noun *is* used) there are conjoint yet contrastive references to histories and dissections. In the first reference there is an implicit contrast in the restriction of what has been *written* to the histories; but in the second we are explicitly told that there are distinct *epistemic* reasons for consulting the histories and the dissections. Recommending consulting histories and dissections for distinct reasons is not uncommon. Surprisingly, however, on a number of occasions it is the *dissections* that are recommended to improve ἀκριβεία, rather than, or along with, the histories.³⁰

To this point, then, his functional anatomy has established that, in animals with lungs, there is a system of blood vessels within the lung, originating in the heart, that allows the blood in the lung to be contiguous with a system of tubes, originating in the windpipe, that transport breath to and from the lungs. He goes on:

So then: generally speaking [ὅλως] the nature of animals has need of cooling on account of the setting of the soul aglow in the heart [διὰ τὴν ἐν τῇ καρδίᾳ τῆς ψυχῆς ἐμπύρευσιν³¹]. As many animals as have not only a heart but a lung as

would be two obvious places to start, given the importance of the functions of the cardiovascular and reproductive systems to his overall understanding of animals.

²⁸ Since Aristotle has no concept of a circulatory system and thus of a functional difference between our ‘arterial’ and ‘venous’ systems, I suppose he would be referring to both the network of blood vessels stemming from the pulmonary artery and those leading to the pulmonary vein.

²⁹ E.g. *GA* II.7 746a15 refers to *paradeigmata*, *HA* I.17 497a32, IV.1 525a9 refer to *diagraphai*, and *HA* III.1 511a12-13 refers to *schemata*.

³⁰ E.g. at *HA* III.1 511a14-15, *PA* III.4 666a9, and IV.13 696b15-16.

³¹ The majority of mss. have ἐμπύρωσιν, but Ross defends ἐμπύρευσιν (which is found in two mss.) on grounds that the spelling of the verb used by Aristotle is ἐμπύρευω. Ross doesn’t mention a strong piece of evidence supporting his recommendation, namely the use of the phrase ἡ φύσις ἐμπεπύρευκεν αὐτήν [= τὴν ψύχην] earlier in *Resp.* at 474b13,

well, produce this <cooling> by respiration. However, those having a heart but *not* a lung, as with the fish, on account of their nature being aquatic, produce cooling by the water passing through the gills.³²

There are echoes here of the framework established in chapter 8, esp. of *Resp.* 474b7-13. In that passage, after stating that it is clear from the dissections that the heart is the starting point of the blood vessels, which contain the blood, Aristotle refers to the *De anima* as having established that the other capacities of the soul depend on the nutritive soul, which in turn depends on ‘natural fire’—and “in this nature has set the soul aglow”. Based on our passage one might take the reference of “in this” to be the heart, but that does not work grammatically, and I think we need to read the ἐν τούτῳ instrumentally: “*by means of this* [ie. the natural fire] nature sets the soul aglow”. The heat thus generated by that natural fire must be moderated, and in all animals with lungs as well as hearts that moderating cooling is accomplished by means of respiration. But fish too are blooded animals with hearts, and so need cooling as well. And here Aristotle asserts, without argument, that “on account of their nature being aquatic, [fish] produce cooling by the water passing through the gills.” As so often with Aristotle, the evidence in support of this very broad and bold causal claim *follows* its assertion. He next reviews what one learns by doing a careful dissectional study of the relationship between hearts and gills in fish. The review begins with a point about the orientation of the heart in fish.

Now how the heart is positioned in relationship to the gills, one ought to study for purposes of visualizing from the dissections, and for purposes of precision from the histories³³; but to speak summarily and for present purposes, they are related in following manner. While it might seem that the position of the heart in the

which uses the verb as opposed to the noun based on it to express exactly the same thought.

³² Καταψύξεως μὲν οὖν ὅλως ἢ τῶν ζώων δεῖται φύσις διὰ τὴν ἐν τῇ καρδίᾳ τῆς ψυχῆς ἐμπύρευσιν. Ταύτην δὲ ποιεῖται διὰ τῆς ἀναπνοῆς ὅσα μὴ μόνον ἔχουσι καρδίαν ἀλλὰ καὶ πνεύμονα τῶν ζώων. Τὰ δὲ καρδίαν μὲν ἔχοντα, πνεύμονα δὲ μὴ, καθάπερ οἱ ἰχθύες διὰ τὸ ἔνυδρον αὐτῶν τὴν φύσιν εἶναι, τῷ ὕδατι ποιοῦνται τὴν κατάψυξιν διὰ τῶν βραγχίων.

³³ There is one very brief account of the connection between heart and gills at *HA* II.17 507a3-10, but it more or less duplicates what is said here.

footed animals and in the fishes is not alike, in fact it is. For the direction in which their heads face is where the apex of the heart is situated. But since the heads in the case of walking animals and fish do not point in the same way, the heart <in the case of fish> has its apex toward the mouth. (478a34-b7)³⁴

It is the visual evidence from dissection, as descriptively interpreted in the *historia* that is based on it, that will be critical for his case that the gills play the same functional role in fish that lungs do in all other blooded animals. The dual references to the dissections and the histories are quite common (obviously, only outside the *History of Animals*) and sometimes stress that the former provides a visualization and the latter a written description.³⁵ It is easy to assume that Aristotle thinks of the first as providing a rather vivid, concrete illustration of the point he is making while the *historia* captures the universal nature of the phenomenon in question, but caution is needed. We don't know what was being provided for "visualization", but the words that are used to characterize what one sees "in the dissections", such as *διαγραφή* and *παράδειγμα*, can refer to quite abstract representations. For example, just as a geometric illustration might be drawn in such a way as to represent a truth about all triangles, so too a diagram of the vascular connections between heart and lung or heart and gills can be illustrated in a way that prescind from all details specific to particular kinds of animals—indeed, that is what textbook or website illustrations typically do today. In our passage the crucial point Aristotle is making is that the orientation of the body of a fish might mislead you into thinking there is a fundamental difference in the location of the apex of the heart in fish compared to other blooded animals. This is a first step in Aristotle's case that the cardio-

³⁴ Ὡς δ' ἡ θέσις ἔχει τῆς καρδίας πρὸς τὰ βράγχια, πρὸς μὲν τὴν ὄψιν ἐκ τῶν <478b> ἀνατομῶν δεῖ θεωρεῖν, πρὸς δ' ἀκρίβειαν ἐκ τῶν ἱστοριῶν· ὡς δ' ἐν κεφαλαίοις εἰπεῖν καὶ νῦν, ἔχει τόνδε τὸν τρόπον. Δόξειε μὲν γὰρ <ἂν> οὐχ ὡσαύτως ἔχειν τὴν θέσιν ἢ καρδία τοῖς τε πεζοῖς τῶν ζῴων καὶ τοῖς ἰχθύσιν, ἔχει δ' ὡσαύτως. Ἡ γὰρ νεύουσι τὰς κεφαλὰς, ἐνταῦθ' ἢ καρδία τὸ ὀξὺ ἔχει. Ἐπεὶ δὲ οὐχ ὡσαύτως αἱ κεφαλαὶ νεύουσι τοῖς τε πεζοῖς τῶν ζῴων καὶ τοῖς ἰχθύσι, πρὸς τὸ στόμα ἢ καρδία τὸ ὀξὺ ἔχει.

³⁵ Cp. *HA* I.17 497a32: ὧν ἢ μὲν ὄψις θεωρεῖσθω ἐκ τῆς διαγραφῆς ἐν ταῖς ἀνατομαῖς...; *PA* IV.5 680a1-4: ὃν δὲ τρόπον ἔχει τούτων ἕκαστον, ἐκ τε τῶν ἱστοριῶν τῶν περὶ τὰ ζῶα θεωρεῖσθω καὶ ἀνατομῶν; τὰ μὲν γὰρ τῷ λογῷ τὰ δὲ πρὸς τὴν ὄψιν αὐτῶν σαφηνίζειν δεῖ μᾶλλον; and *GA* II.7 746a14-16: Δεῖ δὲ ταῦτα θεωρεῖν ἐκ τε τῶν παραδειγμάτων τῶν ἐν ταῖς ἀνατομαῖς καὶ τῶν ἐν ταῖς ἱστορίαις γεγραμμένων.

vascular system in fish is fundamentally like all other blooded animals. More detail on the similarities comes next.

A tube, sinu-vascular (φλεβονευρώδης) in character, extends from the top of the heart to the mid-point where all the gills connect to one another. So this is the largest tube, but on either side of the heart others too stretch to the uppermost point of each of the gills, through which the cooling comes about in relation to the heart, by means of the water continuously flowing through the gills. In like manner, in those that breathe the chest frequently moves up and down when breath is taken in and expelled, like the gills in the fish. (478b7-15)³⁶

Two important analogical identifications are noted as the result of functionally focused dissection: first, in fish there is a tube extending from the top of the heart³⁷ composed of the same sort of uniform substance as the blood vessels in lunged animals, which extends out from the heart to a point between the gills on the two sides of the fish; second, there are other blood vessels extending to each of the gills so that water can cool the blood as it flows over them³⁸; and finally, there appears to be a reference to the ‘fanning’ of the gills, since he says “the chest frequently moves up and down when breath is taken in and expelled, like the gills in the fish.”³⁹

³⁶ Τείνει δ' ἐξ ἄκρου τῆς καρδίας αὐλὸς φλεβονευρώδης εἰς τὸ μέσον, ἧ συνάπτουσιν ἀλλήλοις πάντα τὰ βράγχια. Μέγιστος μὲν οὖν οὗτός ἐστιν, ἔνθεν δὲ καὶ ἔνθεν τῆς καρδίας καὶ ἕτεροι τείνουσιν εἰς ἄκρον ἐκάστου τῶν βραγχίων, δι' ὧν ἡ κατάφυξις γίνεται πρὸς τὴν καρδίαν, διαυλωνίζοντος ἀεὶ τοῦ ὕδατος διὰ τῶν βραγχίων. Ὅσαύτως δὲ τοῖς ἀναπνεύουσιν ὁ θώραξ ἄνω καὶ κάτω κινεῖται πολλάκις δεχομένων τὸ πνεῦμα καὶ ἐξιέντων, ὡς τὰ βράγχια τοῖς ἰχθύσιν.

³⁷ Today referred to as the *conus* or *bulbus arteriosis*.

³⁸ It is difficult to be certain what he is referring to here; Ogle conjectures that he is generalizing from examining a ray (p. 131, note 136) in which the aortic arches are idiosyncratic, but that seems unlikely. Ogle assumes that Aristotle is only referring to the aortic arches stemming from the *conus arteriosis* to the gills. But since Aristotle doesn't make our functional distinction between veins and arteries, and it seems clear he is discussing vessels that are not connected to the *conus arteriosis*, it occurs to me that he may be referring to the blood vessels that we think of as taking oxygenated blood *from* the gills to the body.

³⁹ This is more explicit in the discussion of gills in *PA* IV.13 (which refers to our discussion): “A cause of the number of gills being larger or smaller is a larger or smaller amount of heat in the heart; for the movement must be more rapid and stronger for those

Aristotle provides a bit more detail to the analogy in chapter 21, once again drawing attention to the reason why respiration should be discussed as part of an investigation of youth, old age, life and death:

And the air enters into many ducts in the lungs, like channels, and alongside each of [these ducts] blood vessels are extended, so that the whole lung seems to be filled with blood. And we call the inhaling of the air 'respiration' and its exhaling 'expiration.' And this always takes place continuously, and the animal lives so long as this part moves continuously. And for this reason life depends on respiration and expiration. And in the same way motion arises in the gills of fish. For when the heat in the blood throughout the parts increases, the gills also rise up and water flows through [them]. And when water is allowed to flow in relation to the heart through these channels, the gills are also cooled and collapse, and the water is expelled. Thus whenever the heat of the heart increases water is always taken in, and when it is cooled again the water flows out. For this reason too the final authority⁴⁰ concerning living and not living for those with lungs rests with breathing, and for those with gills with the taking in of water. (480b6-20)

Engaged as he is in a comparative anatomical study governed by teleological norms, Aristotle is searching for analogies between gills and lungs because, given that fish are blooded animals with hearts, but lack lungs, they must have a way of cooling the heart region. It has been determined that that is what lungs are for, and since everything with a cardio-vascular system needs that cooling, and fish lack lungs, they must accomplish it by some other means. But Aristotle is not satisfied with *imagining* or *supposing* that fish accomplish this by means of gills—he makes his case based on a careful comparative anatomical study of the vascular connections between heart and lungs and those between heart and gills, and finds that, superficial appearances notwithstanding, they have much in common.

with more heat. And those with more gills and double gills have a nature of this sort more than those with simpler and fewer gills.” (696b15-20)

⁴⁰ τὸ τέλος here, as is recognized by LSJ (sv. τέλος I. 2) has the sense of the final authority over decision-making (indeed, their recommended translation for its use here is “decisive difference between”).

Finally, he concludes his discussion of respiration with one final analogy between gills and lungs, which provides a clever segue into the topic of life and death.

And breathing animals are suffocated in a small amount of air that remains the same; for each of them rapidly becomes hot since contact with the blood heats each animal. And being hot, the blood prevents cooling; and when, owing to sickness or old age, the lung in the case of breathing animals, or the gills in the case of water-dwelling animals, is unable to move, at that point death results.⁴¹

This, it will be recalled, was the initial justification, at the beginning of *On Youth and Old Age*, for including respiration in this discussion. But there is an important difference between what was said at the beginning of the inquiry and what is said here: there, it will be recalled, Aristotle stressed that it was necessary to discuss respiration at the same time as youth, old age, life and death because in some animals whether they live or not is dependent on respiration (467b10-13); and a few pages later, as he initiates his discussion of respiration, one of his very first complaints about previous accounts is that they claim all animals breathe, and in particular that fish do—which, he insists, is not true. (470a8-10) But by keeping our focus on the question of the *goal* of respiration while engaged in our comparative anatomy, we have established that its function, cooling the region where the heart concocts the blood into its final, nutrient form, is a function shared by all blooded animals, including fish. And that has led us to the discovery that the gills in animals with gills—in their structure, in their vascular connections to the heart, in their movements, and finally in their age-related pathology, are the same by way of analogy with the lungs in all the other blooded animals.

7. Summative Conclusion

Aristotle begins with the obvious importance of breathing to life for all animals that breathe—that breathing is of life and death importance is obvious; but *why* it is so

⁴¹ Καὶ τὰ μὲν ἀναπνέοντα ἐν ὀλίγῳ ἀέρι καὶ τῷ αὐτῷ ἀποπνίγονται· ταχέως γὰρ ἑκάτερον αὐτῶν γίνεται θερμόν (θερμαίνει γὰρ ἢ τοῦ αἵματος θίξις ἑκάτερον), θερμόν δ' ὄν <τὸ αἷμα> κωλύει τὴν κατάψυξιν· καὶ μὴ δυναμένων κινεῖν τῶν μὲν ἀναπνεόντων τὸν πνεύμονα τῶν δ' ἐνύδρων τὰ βράγχια διὰ πάθος ἢ διὰ γῆρας, τότε συμβαίνειν <δεῖ> τὴν τελευτήν.

important is not at all clear. Aristotle approaches that question having already determined to his satisfaction that the nutritive soul acts by means of heat in the heart to produce the blood that is the final nutrient in blooded animals. And we have seen that he repeatedly stresses the crucial importance of dissection of the visceral organs in his having reached that conclusion. The heart, then, performs its nutritive function by means of a ‘natural fire’ or an ‘inborn heat’. But that ‘natural fire,’ without constant moderation, would simply burn itself out. As we’ve seen, he reaches the conclusion that in animals with heart and lungs, that moderation is achieved by respiration, while in animals with heart and gills, it is achieved by the gills bringing in and expelling water.⁴² My concern has been whether Aristotle is right to insist on the importance for a natural inquiry that the anatomical study of the parts be governed by teleological questions about their functions. But I’ve also been at pains to stress the importance of comparative anatomy in such a teleologically motivated investigation. Aristotle reaches an answer to his initial question, why animals breathe, by starting with an already established theory about the heart as the source of the nutritional blood and the blood vessels and then carefully examining, by means of dissection, the internal anatomy of the lungs and their complicated connections to the windpipe and to the heart. But then, by noting *comparative* facts such as that many kinds of blooded animals with cardio-vascular parts do *not* have lungs and spend most or all of their time in water; and that many kinds of water animals *do* have lungs and breathe, he realizes two things: certain animals with hearts, and thus with the same need for moderating the heat generated by the heart, cannot do so by breathing, since they do not have the appropriate equipment to do so; and that is not because it is impossible for a footless, aquatic animal to be properly equipped to do so: Aristotle is well aware, and impressed by the fact, that whales, dolphins and porpoises prove that it is possible. Thus armed with an answer to the question “What is breathing for?” and with these revelations from comparative dissection about which

⁴² There is an interesting question, tangential to this discussion, about why the brain is never mentioned in this discussion. Of course it is not involved in respiration, but according to *PA* II.7 it too is a means for moderating the temperature of blood, and as such you might expect Aristotle to at least mention it, given that such moderation is the ultimate reason for breathing and for that actions of gills. Equally puzzling, that chapter makes no mention of the lung as performing a similar function.

viscera are and are not co-extensive with which and details about physical and physiological connections among parts, he is able to answer the question about how animals without lungs but with hearts accomplish that cooling function so important to the maintenance of life for blooded animals. It is this constant interplay that we see in these texts, between comparative anatomy and teleology, that is, as I now see it, the key to the success of his inquiry.

By insisting that the ‘What is it for?’ question set the terms for his anatomical study of the parts (i.e. the material nature) by which certain blooded animals take in and expel air, the inquiry with which Aristotle begins is taken to a level of universality and causal depth that it would not have achieved otherwise.

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Appendix: Schematic Outline of Aristotle's Inquiry into Respiration

Ch 1. Others have spoken about breathing, but not well. Among other errors, many seem to claim all animals breathe. Clearly all with lungs do, but there are differences even there.

Ch. 2-3. Anaxagoras and Diogenes. What is wrong with their ideas about fish breathing. Their failure to ask teleological questions while performing dissections.

Ch. 4. Democritus. Like others, D. also doesn't consider what respiration is for, and there are lots of problems with his account.

Ch 5. Plato in the *Timaeus* gets things all wrong and also doesn't say what respiration is for.

Ch. 6. Some say it *nourishes* the intrinsic fire. Lots of problems with that idea.

Ch. 7. Empedocles has much to say, much of it is quoted, and many problems in his account are identified. He also fails to consider the question of what breathing is for.

Ch. 8. A reminder of the views about heat, soul and nutrition in *On Youth and Old Age*. Final nutrient is blood, blood is produced in the heart which is the source of blood vessels as well. (On this point, the Dissections need to be consulted.) All of this requires inherent heat, which is the instrument of the nutritive soul.

Ch. 9. Given the conclusion of ch. 8, there is a subsequent need for cooling. Bloodless are sufficiently cooled by the surroundings. A few comparative comments are made about those who cool by gills or lungs.

Ch. 10. A review of the universal generalizations/correlations in the blooded animals related to lungs and gills

Ch. 11. Nourishment needed for being, cooling for preservation—how the organs for feeding and cooling work together

Ch. 12. The cetaceans would seem to present an *aporia*: footless, water dwelling, take in water, yet have a lung—how that integrates with the rest. Also a discussion of cooling in the cephalopods and crustaceans.

Ch. 13. How exactly do lungs and gills bring cooling about?

Ch. 14. Empedocles is wrong about this as well—but his error serves to introduce us to the relationship between an animal's constitution, where it lives, and thus how it must cool itself.

Ch. 15. Why does the part that receives and expels the air have so much blood, as lungs do; and the rate of breathing seems related to the amount of blood. (This receives further development in ch. 21)

Ch. 16. Cooling and the communication between heart and lungs, heart and gills. The importance of dissection for understanding this. The important parallels between the heart/lung relation and the heart/gills relation.

Ch. 17. Old age, death and their relation to respiration and condition of the lungs and gills. A number of references to death due to disease.

Ch. 18. *Genesis* defined. And “What *genesis*, life, and death are, and due to what cause they belong to animals, has been stated.”

Ch. 19. Why fish can’t live for long without water, and lunged animals can’t live for long without air.

Ch 20. How are pulse, heartbeat, heart palpitations and breathing related?

Ch. 21. Breathing and the nutritive principle, how breathing works like a bellows, the interface of air and blood, water and blood in lungs and gills. A most interesting closing passage about the relevance of all of this to the subject of health and disease, i.e. to medicine.