Philip J. Peyton, M.D., Ph.D., M.B.B.S., F.A.N.Z.C.A.
Melbourne Medical School, University of Melbourne, Melbourne, Australia; Austin Health, Heidelberg, Australia; Institute for Breathing and Sleep, Heidelberg, Australia.
phil.peyton@austin.org.au

DOI: 10.1097/ALN.0000000000004447

References

1. Grigoryan A, Khorasani A, Salem MR, Knezevic NN: Diffusion limitation of volatile anesthetic uptake: Comment. Anesthesiology 2022; 138: 567–8
2. Peyton PJ: Gas phase diffusion does not limit lung volatile anesthetic uptake rate. Anesthesiology 2022; 137:176–86
3. Stuart-Andrews C, Peyton P, Walker T, Humphries C, Robinson G, Lithgow B: Continuous measurement of multiple inert and respiratory gas exchange in an anaesthetic breathing system by continuous indirect calorimetry. J Clin Monit Comput 2009; 23: 41–9
4. Lowe HJ,Viljoen JF: Nomogram for anaesthetic uptake. Anaesth Intensive Care 1994; 22:374–5

(Accepted for publication November 14, 2022. Published online first on January 24, 2023.)

Aortic Biomechanics: Comment

To the Editor:

We read with interest the recent review of aortic biomechanics and their clinical applications by Gregory *et al.*[1] The authors should be congratulated for addressing this important but often underappreciated subject. Nevertheless, we are obligated to mention that the authors did not acknowledge or discuss a series of pertinent studies conducted in chronically instrumented dogs describing the effects of anesthetics on aortic biomechanics. This canine model is highly relevant to the review,[1] because the cardiovascular effects of anesthetics are virtually identical in dogs and humans. We and others used aortic input impedance spectra in the frequency domain[2] that were interpreted with a three-element Windkessel model of the arterial circulation, incorporating aortic mechanical properties,[3] to quantify the effects of anesthetics on left ventricular afterload.[4–13] We first demonstrated that isoflurane reduces total arterial resistance in a concentration-dependent manner and modestly increases total arterial compliance (primarily determined by the aorta and proximal great vessels[14]), but does not affect characteristic aortic impedance (the resistance of the aorta itself).[4] In contrast, the potent vasodilator sodium nitroprusside decreased total arterial resistance and markedly increased total arterial compliance when the drug was administered at infusion rates that resulted in levels of hypotension equivalent to those observed during the administration of isoflurane. The findings with sodium nitroprusside confirmed previous observations in dogs[15] and humans.[16,17] Taken together, these data indicated that the primary effect of isoflurane on the determinants of left ventricular afterload was related to its well-known actions on arteriolar resistance vessels and not on the aorta itself, whereas sodium nitroprusside altered left ventricular afterload through its effects on both arteriolar vasomotor tone and the mechanical properties of the aorta. Similar findings with isoflurane were also reported in an acutely instrumented open-chest swine model.[13] We further showed that desflurane also reduces total arterial resistance but does not substantially affect total arterial compliance and characteristic aortic impedance, actions that were indistinguishable from those of isoflurane.[6] However, sevoflurane did not affect total arterial resistance but caused small increases in total arterial compliance and characteristic aortic impedance,[6] observations that mirrored those seen with the obsolete volatile anesthetic halothane.[4]

Isoflurane increased aortic distensibility (concomitant with reductions in aortic pressure) and did not affect characteristic aortic impedance when these parameters were calculated using simultaneous measurements of aortic diameter, pressure, and blood flow.[5] These findings reinforced the conclusion that alterations in the aortic mechanical properties are not responsible for the actions of isoflurane on left ventricular afterload. In contrast to the findings with isoflurane in dogs with normal left ventricular function, this volatile anesthetic did not exert beneficial changes in total arterial resistance, characteristic aortic impedance, and total arterial compliance in a canine model of heart failure with reduced ejection fraction induced by chronic rapid ventricular pacing.[7] We conducted additional investigations in normal and cardiomyopathic dogs with the anesthetic noble gas xenon,[8] and with the intravenous anesthetics propofol,[9,10] etomidate,[11] and dexmedetomidine[12] that revealed unique insights into the actions of these medications on the contributions of altered aortic mechanics to left ventricular afterload *in vivo*. These studies document that the impact of anesthetics on aortic biomechanics has been examined previously in clinically relevant animal models, contrary to the article's assertion.[1]

Downloaded from http://asa2.silverchair.com/anesthesiology/article-pdf/138/5/570/685622/20230500.0-00022.pdf by guest on 23 February 2024

Copyright © 2023, the American Society of Anesthesiologists. All Rights Reserved. Unauthorized reproduction of this article is prohibited.

Competing Interests

The authors declare no competing interests.

Paul S. Pagel, M.D., Ph.D., George J. Crystal, Ph.D., Douglas A. Hettrick, Ph.D.
Clement J. Zablocki Veterans Affairs Medical Center, Milwaukee, Wisconsin (P.S.P.). pspagel@mcw.edu

DOI: 10.1097/ALN.0000000000004468

References

1. Gregory AJ, Di Martino ES, Fedak PWM, Dobson GM: Aortic biomechanics and clinical applications. Anesthesiology 2022; 137:351–63
2. Milnor WR: Arterial impedance as ventricular afterload. Circ Res 1975; 36:565–70
3. Burkhoff D, Alexander J Jr, Schipke, J: Assessment of Windkessel as a model of aortic input impedance. Am J Physiol 1988; 255:H742–53
4. Hettrick DA, Pagel PS, Warltier DC: Differential effects of isoflurane and halothane on aortic input impedance quantified using a three element Windkessel model. Anesthesiology 1995; 83:361–73
5. Hettrick DA, Pagel PS, Warltier DC: Isoflurane and halothane produce similar alterations in aortic distensibility and characteristic aortic impedance. Anesth Analg 1996; 83:1166–72
6. Lowe D, Hettrick DA, Pagel PS, Warltier DC: Influence of volatile anesthetics on left ventricular afterload in vivo: Differences between desflurane and sevoflurane. Anesthesiology 1996; 85:112–20
7. Hettrick DA, Pagel PS, Kersten JR, Lowe D, Warltier DC: The effects of isoflurane and halothane on left ventricular afterload in dogs with dilated cardiomyopathy. Anesth Analg 1997; 85:979–86
8. Hettrick DA, Pagel PS, Kersten JR, Tessmer JP, Bosnjak ZJ, Georgieff M, Warltier DC: Cardiovascular effects of xenon in isoflurane-anesthetized dogs with dilated cardiomyopathy. Anesthesiology 1998; 89:1166–73
9. Lowe D, Hettrick DA, Pagel PS, Warltier DC: Propofol alters left ventricular afterload as evaluated by aortic input impedance in dogs. Anesthesiology 1996; 84:368–76
10. Pagel PS, Hettrick DA, Kersten JR, Lowe D, Warltier DC: Cardiovascular effects of propofol in dogs with dilated cardiomyopathy. Anesthesiology 1998; 88:180–9
11. Pagel PS, Hettick DA, Kersten JR, Tessmer JP, Lowe D, Warltier DC: Etomidate adversely alters determinants of left ventricular afterload in dogs with dilated cardiomyopathy. Anesth Analg 1998; 86:932–8
12. Pagel PS, Hettrick DA, Kersten JR, Warltier DC: Dexmedetomidine produces similar alterations in the determinants of left ventricular afterload in dogs before and after the development of pacing-induced cardiomyopathy. Anesthesiology 1998; 89:741–8
13. Heerdt PM, Gandhi CD, Dickstein ML: Disparity of isoflurane effects on left and right ventricular afterload and hydraulic power generation in swine. Anesth Analg 1998; 87:511–21
14. Westerhof N, Bosman F, De Vries CJ, Noordergraaf A: Analog studies of the human systemic arterial tree. J Biomech 1969; 2:121–43
15. Little WC, Cheng CP: Left ventricular-arterial coupling in conscious dogs. Am J Physiol 1991; 261:H70–6
16. Pepine CJ, Nichols WW, Curry RC Jr, Conti CR: Aortic input impedance during nitroprusside infusion: a reconsideration of afterload reduction and beneficial action. J Clin Invest 1979; 64:643–54
17. Gundel W, Cherry G, Rajagopalan B, Tan LB, Lee G, Schultz D: Aortic input impedance in man: acute response to vasodilator drugs. Circulation 1981; 63:1305–14

(Accepted for publication December 8, 2022. Published online first on January 16, 2023.)

Aortic Biomechanics: Reply

In Reply:

We thank the authors for their thoughtful letter and informative review regarding the effects of anesthesia on the cardiovascular system.[1] This previous work using animal models has been foundational in framing our understanding of arterial physiology and the effects of anesthetic agents. Our omission of these previous works in our recently published review on aortic biomechanics was not meant to diminish their importance.[2] Rather, the purpose of our review was to focus on concepts related to the material properties of the aorta itself in health, disease, surgery, and anesthesia, and to propose that local aortic changes may have both physiologic and clinical ramifications through the aorta's relationship with the heart and distal arteries.

Certainly, the previous studies highlighted by Dr. Pagel *et al.*, using a three-element Windkessel model in animals, have provided important details on the effects of anesthesia on aortic biomechanics. But we respectfully submit that it may not tell the whole story. First, compliance, as calculated in the Windkessel model, is total arterial compliance, not exclusively aortic.[3] The contribution of small arteries

Downloaded from http://asa2.silverchair.com/anesthesiology/article-pdf/138/5/570/685622/20230500.0-00022.pdf by guest on 23 February 2024

Copyright © 2023, the American Society of Anesthesiologists. All Rights Reserved. Unauthorized reproduction of this article is prohibited.

to compliance is considerable and, in humans, increases with age-related aortic stiffening, thereby "blurring the distinction between large and small artery function."[4] As such, the described changes to compliance from the Windkessel model likely cannot be attributed to the aortic biomechanical properties alone. Second, we disagree with the contention that characteristic aortic impedance is "the resistance of the aorta itself." Although aortic impedance has the units of resistance, it exists only with pulsatile flow and pressure and is a function of the modulus of elasticity and radius.[3] Similar to compliance, there is no exact anatomical aortic correlate to aortic impedance, although it characterizes the vessel in close proximity to the measurement. Therefore, although we agree that left ventricular afterload can be modeled using the Windkessel, we believe that aortic biomechanics as defined by the authors is only partly responsible.

Aortic biomechanics, at the level of local aortic microstructure and mechanical behavior, has until now been limited to bench-top testing on excised tissue. With recent advancements in imaging technology, there are new opportunities to explore the aorta *in vivo* and hopefully gain new insights into local aortic biomechanical properties in the clinical anesthesia environment. As we assert in our review, this work has yet to be done.

Our understanding of cardiovascular physiology has greatly benefitted from the previous scientific work of Dr. Pagel and others who have published using similar arterial system models. They have put together much of the puzzle as it pertains to anesthesia and cardiovascular physiology. We believe that the additional perspectives on aortic biomechanics described in our review hold potential to add a piece to said puzzle, not replace it altogether.

Competing Interests

The authors declare no competing interests.

Alexander J. Gregory, M.D., F.R.C.P.C., Gary M. Dobson, M.D.C.M., M.Sc., F.R.C.P.C.
Cumming School of Medicine, University of Calgary, Calgary, Alberta, Canada (A.J.G.). alex.gregory@albertahealthservices.ca

DOI: 10.1097/ALN.0000000000004469

References

1. Pagel PS, Crystal GJ, Hettrick DA: Aortic biomechanics: Comment. Anesthesiology 2023; 138:570–1
2. Gregory AJ, Di Martino ES, Fedak PWM, Dobson GM: Aortic biomechanics and clinical applications. Anesthesiology 2022; 137:351–63
3. Westerhof N, Lankhaar JW, Westerhof BE: The arterial Windkessel. Med Biol Eng Comput 2009; 47:131–41
4. Mitchell GF: Clinical achievements of impedance analysis. Med Biol Eng Comput 2009; 47:153–63

(Accepted for publication December 8, 2022. Published online first on January 16, 2023.)

A Picture Is Worth a Thousand Words: Infographics in the New Era of Medical Education

To the Editor:

As first-year resident physicians, we are still at the beginning of our journey to becoming conscientious consumers of research and data. This, combined with our appropriately basic knowledge and context for anesthesiology topics at this stage of training, makes it somewhat difficult to envision how to apply concepts from today's research to our future practices. One page of Anesthesiology that we can turn to in this early stage of training is the "Infographics in Anesthesiology" section.

Infographics can distill complex concepts or large amounts of data into easily understood and easily remembered visual representations.[1] The recall ability of visually presented information is often explained by the picture superiority effect. The picture superiority effect suggests that 6.5 times more information is retained after 3 days when presented with a relevant picture compared with text alone.[2]

Medical students and medical educational companies today have harnessed the power of the picture superiority effect. The most popular resources are picture-based and video-based programs aimed at increasing retention. Anecdotally, many medical students find these visual learning tools to be far more effective than reading traditional textbooks. Trainees are now entering residency from the highly visual-based learning environment of medical school. As with all resources, caution must be practiced when interpreting infographics, as a recent cross-sectional study demonstrated that the majority of infographics do not sufficiently report study findings.[3]

Integrating infographics from trusted sources of information as Anesthesiology has done is a great way to meet our new generation of trainees in the way that they have learned. As a new resident myself, I find the infographics

Downloaded from http://asa2.silverchair.com/anesthesiology/article-pdf/138/5/570/685622/20230500.0-00022.pdf by guest on 23 February 2024

Copyright © 2023, the American Society of Anesthesiologists. All Rights Reserved. Unauthorized reproduction of this article is prohibited.