Host: Welcome to the *ANESTHESIOLOGY* journal podcast, an audio interview of study authors and editorialists.

Dr. James P. Rathmell: Hello. I'm Jim Rathmell, Professor of Anesthesia at Harvard Medical School and Chair of the Department of Anesthesiology, Perioperative and Pain Medicine at Brigham and Women's Hospital. I'm one of the Executive Editors for *ANESTHESIOLOGY* and you're listening to an *ANESTHESIOLOGY* podcast that we've designed for physicians and scientists interested in the research that appears in the journal.

Today we're going to talk with one of the authors of an original research article and the author of an accompanying editorial that appear in the December 2021 issue. With us today is Dr. Forbes McGain. Dr. McGain is Professor in the departments of Anesthesia and Intensive Care at Western Health and the University of Melbourne in Melbourne, Australia. Dr. McGain is the first author on an article that appears in the December 2021 issue of the journal titled, "Carbon Footprint of General, Regional, and Combined Anesthesia for Total Knee Replacements." Dr. McGain, thanks for joining us.

Dr. Forbes McGain: Thank you, Professor Rathmell, and hello to Professor Michel Struys for writing the editorial associated with our paper. I'd very much like to thank the team who's involved in this research project: Nicole Sheridan, Kasun Wickramarachchi, Simon Yates, Brandon Chan and Scott McAllister, all from Melbourne, Australia.

And I'd just like to make mention that this life cycle assessment has been really truly an evolution and a journey over the last few years.

Dr. James P. Rathmell: We also have with us today Dr. Michel Struys. Dr. Struys is Professor and Chair of the Department of Anesthesiology at the University Medical Center Groningen in Groningen, Netherlands. Dr. Struys authored an editorial that accompanies Dr. McGain's original research article in the December 2022 issue of the journal and it's titled, "Environmental Footprint of Anesthesia: More than Inhaled Anesthetics!" Dr. Struys, welcome and thank you for joining us.

Dr. Michel Struys: Thank you for having me. It's a pleasure.

Dr. James P. Rathmell: Dr. McGain, congratulations on the publication of your study. I want to start by reading just a few lines from the introduction of your paper. You tell us: Health care itself contributes to climate change. Anesthesia is a "carbon hotspot," yet few data exist to compare anesthetic choices.

So, you and your coauthors examined the carbon dioxide equivalent emissions associated with general anesthesia, spinal anesthesia and combined general and spinal anesthesia during total knee replacement. Of course global warming and the carbon footprint of everything we do is being closely examined these days. Tell us why you chose to focus your efforts in this area of general versus spinal anesthesia.

Dr. Forbes McGain: So for me it's been a dozen years of sustainability research and a real evolution of that study beginning with relatively simple looks at recycling and reducing and reusing and then moving into life cycle assessment or cradle to grave and looking at the entire life cycle of different products.

And we began with something relatively simple there with a comparison of drug or pharmaceutical trays that anesthetists used to place their medications on and then into central venous catheter insertion trays and then onto other equipment that anesthetists use like breathing circuits and laryngeal masks and face masks, for example.

And so what we were doing was building a story of what was going on, common things that all anesthetists use. In addition to that, simultaneously Jodi Sherman's group from the United States was carefully looking at similar things and at pharmaceutical data was well.

So, the story was gradually being built and it was about four or five years ago that I realized, "Well, we really need to get on and look at what an anesthetist, a practicing anesthesiologist would be interested in here." And that is, "Well, on my day-to-day practice, what are the important parts of that story?"

So it was moving to another level and so an obvious one would be this thought that perhaps regional or spinal anesthesia was a much lower carbon footprint and we moved into this study from that longer trajectory.

Dr. James P. Rathmell: It makes perfect sense. So, what was the hypothesis of your study when you set out to do this?

Dr. Forbes McGain: Yes. I think that we hypothesized very much that regional spinal anesthesia would have a lower carbon footprint than general anesthesia, but when you think a bit more carefully about that you could say, "Well, it's just a needle that you're putting in someone's back to do spinal anesthesia." But this is then what we call the functional unit in life cycle assessment.

In other words, it's not just the needle in the back that matters; it's everything else that you would do as the anesthesiologist caring for the patient, everything from warming the patient with a blanket through to the given medications that have been used for that patient, the anesthetic gases if required, oxygen, et cetera, et cetera.

So, although the original assumption in our hypothesis was that regional anesthesia would have a lower carbon footprint, that's why we went to explore these further looking at the broader footprint, I suppose, that all of us would have when we're caring for a patient.

Dr. James P. Rathmell: Let's delve a little deeper. How did you go about conducting the study? And specifically I'm hoping you can explain to listeners what life cycle assessment software actually is and how is it used to convert inputs to their carbon footprint?

Dr. Forbes McGain: Yes. So, everything has an environmental footprint that we do, every process and product and so that could be looking at, as we said in the past, a breathing circuit, for example, the manufacture of that, the transport of it, the cleaning of it required or disposal of it as single use. And they're associated with all the given things that you would be using as an anesthesiologist in the operating theatre, there will be footprints with those.

What we did was we took about 10 patients in each arm of the three arms and we looked at everything that was being done for that patient right down to the syringes that were being used and medications through to the electricity consumption of the air warmer or the oxygen use, et cetera.

And so then you start to build a library, in a sense, of what is being used and then you will know the type of things that are being used within that, so the plastic would be, let's say, polypropylene or polyethylene and there is a carbon footprint associated with that. So, you have primary data which is gathering the weight and type of material that the anesthesiologist is using.

Then you have secondary data which is not information that you directly gather but is gathered from life cycle inventories such as the Australian life cycle inventory or Ecoinvent which is a large Swiss-based one. And they would say, "Well, okay, you've got – this syringe weighs 50 gm"—for example—"and it's made of polyethylene/polypropylene combination and here is the – we know that the approximate carbon footprint of that is a certain amount, X, and then we'll be able to calculate." Well, we know the mass and we know what it's made of so we can see what the carbon footprint of that syringe is.

It's not feasible to actually run around gathering primary data for everything so I'm not going to go to the petrochemical factory and work out what the carbon emissions of manufacturing plastics are, so you need that secondary data otherwise all life cycle assessments would be actually impossible.

Then once you obtain that information, so from the inventory along with your primary data you move towards what you talk about life cycle assessment software and we used SimaPro which is actually a Dutch-based company and with that you can start to model how much is the total being used for, let's say, a general anesthesia for a knee replacement as well as the total amount.

You can start to factor in what we call the competency interval but using a different technique a Monte Carlo assessment which is really it's trying to give you a confidence interval actually without the access to direct data in a sense because, as you'd imagine, for all the inputs, even if we just looked a syringe—and I choose that because at least then I'll be able to follow that

more easily—in a plastic syringe there are many hundreds of different components that make up – that are used as processes to go into that syringe.

So it's not just like here is a little bit of petrochemical. With that there is natural fossil gas, there will be products that are required to manufacture that at the plant, the transport of it, et cetera, et cetera.

So there are many different variables that add up to make your input and it's the software that is used to turn those inputs into outputs. And so there's some things they are relatively straightforward.

So, for example, in Victoria, Australia where our study was done, we have brown coal as a major source of electricity, the knowledge of that carbon footprint per kilowatt hour used for electricity is very robustly known, so the variability of that is quite limited. And it's local geographical data which is what you called the pedigree matrix so it's trying to build into the story how much variability there are in your data.

For something that is less well-known, so, for example, if you're not able to clarify exactly which country a product is from then that becomes – you have to use the global average and so there's more variability and so you can start to see – you build a picture of all the different things that go into this anesthetic that's required for a knee replacement.

Another little example beyond the plastic syringe and brown coal for electricity, for example, would be the compression of air or the use of medical oxygen which is – as long as there's no liquid oxygen, and that has an electricity footprint associated with that but is actually relatively well-defined because it's pretty common worldwide to have the same process of using it.

Dr. James P. Rathmell: So you collected data for 29 patients having one of those three anesthetic techniques: spinal, general or combined anesthesia. What did you find?

Dr. Forbes McGain: Yes. So, it was really interesting. There was similar carbon footprints for general anesthesia, spinal anesthesia and a combination of the two which was very intriguing, in a sense. As I said, though, remember, this is taking account of everything that goes into caring for a patient in the operating theatre and anesthesia bay for the knee replacement anesthetic component.

Importantly, I mention now that the spinal and combination anesthesia were on average around 20% longer than the general anesthesia and that's important because there are certain factors that go into that lengthening carbon footprint, in a sense: more use of electricity required for the air warmer for the patient, for example.

So, we're talking around about 17 kg as an average across the three groups. This – I've done some numbers is about 1.5 gallons of petrol and that's driving your average US car around 42 miles. So, that's what the total carbon footprint is for in the average of those three groups; give or take a little bit.

The surprises in our minds in a sense were the electricity for patient warming, which was around 15% of the total, actually more than the pharmacological footprints, so all the medications: propofol, antibiotics, for example, tranexamic acid, et cetera, only making 10%, so less than the patient warming. The single-use equipment not unexpectedly being around 20% or 1/5th the total.

And then looking at it a bit more closely on different groups for the general anesthesia groups, the sevoflurane was about 1/3rd of the total for the group, not that surprising, really, because we know already from prior work from Sulbaek Andersen and Jodi Sherman in the past that sevoflurane is a greenhouse gas but certainly a lot less than nitrous oxide and desflurane.

The really interesting one, though, was for the spinal anesthesia we saw 15% to 20% was actually just the oxygen required for spinal. The reason why it was much higher for spinal anesthesia than general – so for general anesthesia was because in spinal anesthesia you tend to run much higher flows: 6 liters in every (inaudible), though we did notice some people were delivering 10 liters of oxygen per minute rather than the 1 or 2 liters per minute for general anesthesia in the circle circuit.

Importantly, of course, was the washing and sterilizing of reusable equipment for the spinal itself, so your tray that you use to perform the anesthetic as well as the gown. Interestingly enough, I know that in many other countries there would be single use of those equipment: the gown and the tray. So, we have reusables in our hospital.

But nevertheless although our waste is much less we need to change our energy source, electricity, because it's mainly brown coal here in Victoria which is a lot – it's like the lignite you have in Deutschland, in Germany, where there's a fair amount that's still being used although that is changing rapidly now in that country.

So, I think that there is important differences that came out of that which I think we'll go to in the next question, but it's important to reveal what our results were.

Dr. James P. Rathmell: You've already hinted at this, but you tell us that modeling showed that intercountry carbon dioxide equivalent emission variability was less than intragroup variability. Can you explain and elaborate on that?

Dr. Forbes McGain: Yes, I'll pick up on intragroup variability, so comparisons within the group of, say, general anesthesia or within the group of spinal, within the group of combination general and spinal.

So, the minimum for a general anesthetic carbon footprint was around 8 kg of CO_2 and the maximum was about double that. And it's interesting to think about why that is; it's not just the duration of the procedure that did vary by about 25% within that group, but the other important points are what the anesthesiologist is doing during that period of time.

And that will boil down to how many syringes they're using, are they using total intravenous anesthesia versus sevoflurane to either producing, certainly, a great deal less than sevoflurane and the general approach of how much single-use equipment was being used because that is really important as well.

The same intragroup variability occurs with spinal anesthesia and combination, but for spinal it isn't so great and I think that's because once you've done the spinal anesthesia you don't need as much stuff (inaudible) to continue with the anesthesia, most of the actual anesthetic is being provided, of course, by the spinal itself.

Now, when we talk about intercountry variability, we modeled Australia and China, Europe, and the USA and since we have data to the life cycle inventory and life cycle assessment data, you can compare inventory data between the carbon footprint of doing the same thing for your anesthetic in Australia versus those other countries and areas.

And as we all know fairly well, the European union leads the way in terms of having more renewable electricity overall than, say, Southern China. China is very similar to Australia with a great reliance on coal, the US being somewhere in between Europe and Australia and China.

And so if you look at some of the figure in our paper, you'll see that certainly in particular for spinal anesthesia the carbon footprint is at least 50% lower than Australia or China and that's because if you're using reusable equipment in Europe, you'll be having it much longer because of the washing and sterilizing of that equipment as well as the electricity for the air warmer has a much lower footprint.

The effects of that are less, though, for other things like sevoflurane, for example, so that the variability for a general anesthesia was not as great between the different countries because as you'd imagine the manufacture of sevoflurane only occurs in a couple places and that's the same whether you're in Europe or US or other countries.

What I think really the important takeaway message here is that you have agency as an anesthesiologist to make change. People say, "Well, it's all this, but I can't do anything about this." Well, no, you can. It's not just about the different electricity mixes or different countries; that is something that needs a much greater collaborative effort at much higher levels, but you as an anesthesiologist, as long as you continue your safe practice, you can use less.

Dr. James P. Rathmell: Well, I think you've said it, but let me have you summarize it again. What did you conclude from your study?

Dr. Forbes McGain: Yes. So, in addition to that concept of having agency, I think that there's some other important points I wanted to get across. We already know if you want to have a lower carbon footprint avoiding nitrous oxide and desflurane is known, avoiding high-flow sevoflurane is known as well. Going to low-flow sevoflurane, interestingly, so going from 2 liters from fresh gas flow to 1—we'll use our car analogy in the US—is about going from 2 to 1, is about 3 miles per hour less driven. Going from 1 liter of sevoflurane a minute to [total intravenous anesthesia] is about another 3 miles per hour less.

And going from – our groups there we were talking about intragroup variability; going from the maximum use of single-use equipment to the minimum will be another 3 miles per hour. And I think that's a really important point that people just say, "Well, it's just because of – we'll just change our gas." Well, no, there's a lot more here. If you use less single-use equipment, it really does have an effect.

Similarly, if you drop your oxygen flow from 10 down to 6 units per minute and I'm sure you go lower in safe cases otherwise, that's another mile per hour. So, all of these miles per hour from the car are real numbers. They're actually reductions of how much you're actually driving your car.

And similarly, I do mention, of course, though, that it's going from Australia to Europe if you were using the reusables and the warming blanket was on the European electricity mix, you'd be another 4 or 5 miles per hour less driven in the car. So, that one's a bit harder to change but it then requires much greater effort but then you certainly have a lot of agency as the anesthesiologist, not the other, driving of the car.

Dr. James P. Rathmell: Lots of choices to make. So, Dr. Struys, I want to turn to your editorial. It also appears in the December 2021 issue of the journal and, again, it's titled, "Environmental Footprints of Anesthesia: More than Inhaled Anesthetics!" You do a terrific job of putting Dr. McGain's article into perspective. How big a role do the inhaled anesthetics have in the overall carbon footprint of health care?

And, of course, Dr. McGain just told us a little bit but I want you to elaborate on that.

Dr. Michel Struys: Yes, indeed. It's correct what Dr. McGain stated earlier in this broadcast. Inhaled anesthetics have certainly a significant contribution to the carbon footprint of anesthesia as most of these drugs are typically until now vented to the atmosphere. And along with nitrous oxide these halogenated ethers all absorb radiation at wavelength that overlap with the spectrum of the outgoing radiation from earth making them potential greenhouse gases with significant global warming potential.

Now for the listeners to this podcast who are perhaps not familiar with the numbers, it's important to state that not all inhaled anesthetics are equal. For example, desflurane has global warming potential that is very large; it's 2,540 and the atmospheric lifetime is 14 years. For sevoflurane, that global warming potential is 130; that's much less with an atmospheric lifetime of 1.1 year. And, as already stated by Dr. McGain, nitrous oxide is also a potential greenhouse gas with a very high global warming potential and the long-lasting atmospheric lifetime of 140 years.

So, the choice of anesthetic agent is already important. So, desflurane and nitrous oxide have the biggest CO_2 footprint, nevertheless sevoflurane is still a significant contribution.

Now, earlier studies have shown that the direct emissions from these halogenated ethers in nitrous oxide are responsible for an estimated 3% of the climate footprint by national healthcare services in industrialized countries and can account for more than 50% of the greenhouse gas emissions from the entire perioperative chain.

However in the study from Dr. McGain, when used during general anesthesia, sevoflurane contributed for around 35% of the total anesthetic carbon footprint and in a combined group it contributed for sevoflurane around 20% on average. So, as already stated by Dr. McGain, there is more than only inhaled anesthetics, but inhaled anesthetics certainly play an important role here in the entire story.

Dr. James P. Rathmell: So, one of the big surprises we've already talked about is the lack of a big difference between the carbon footprint when spinal versus general anesthesia was used. Can you expand a little bit on what Dr. McGain's already told us and discuss why weren't there any differences and why was there so much variability from case to case from your read?

Dr. Michel Struys: Yes, that's an interesting observation that Dr. McGain (inaudible) big differences in the carbon footprint between different anesthetic techniques and as a clinician myself it surprised me also that spinal anesthesia is still a significant footprint which was equal to the other groups.

But first we should, I think, be careful when interpreting the results and the study was not powered to detect differences between anesthetic techniques. The authors only used a convenient sample of 10 patients per group and on top of it within each group there was a large variation in results stemming from case-by-case differences in our anesthetics where administered; this is just clinical practice in reality.

So, the result of it was a large overlap in confidence intervals between groups and so it's too simplistic to say that stopping using inhaled anesthetics will do the job; it's much more important to examine the relative contribution of a possible CO_2 footprint generating products and the local situation as clearly stated also in this article.

Dr. James P. Rathmell: So tell me how you're going to translate this into your own clinical practice.

Dr. Michel Struys: I think the study doesn't offer a different answer which anesthetic method is the most detrimental to the climate, but I think what this study offers is an interesting example, I'd say, kind of a theoretical framework of how clinical or cohort studies can be used for sustainability analyses in your own clinical practice and what are the important data in such an analyses. And because of the large variation and results from each group, the investigators were able to note practices that led to lower impact as already stated by Dr. McGain.

So, some were specific to the anesthetic technique applied, such as using low-flow anesthesia or total intravenous anesthesia and general anesthesia or reducing oxygen flows when possible for spinal anesthesia and other recommendations cut across all techniques such as reducing single-use plastics or improving energy efficiency of patient warmers.

So, I think as a clinician taking multiple actions to reduce emission, it was fine to be beneficial than simply shifting to a different anesthetic technique and that's certainly something that I will adopt in my clinical practice and in my department.

Dr. James P. Rathmell: Well, again, Dr. McGain's hinted at this, but can you tell us why the carbon footprint of the same technique might vary so much from one country to another? Are there things that Dr. McGain didn't describe?

Dr. Michel Struys: I think it's a very valuable lesson that the authors highlighted recommendations for sustainable clinical care must consider local conditions. Some of the aspects of carbon footprints are location-dependent and I think we cannot assume a priority that actions to reduce emission in one clinical setting or country will have exactly the same effect somewhere else.

So, the life cycle assessment is flexible being able to test the different assumptions about where different products originate or where certain processes take place and authors use this flexibility in their article very well to estimate how the results would change for clinical settings in Europe, the UK, the US, or Australia. So that's very interesting to observe in their article.

Dr. James P. Rathmell: Dr. McGain, any final comments? And maybe you can tell us what comes next for your research group.

Dr. Forbes McGain: I think there's enormous opportunities within sustainability and anesthesia. Working with a team and others looking at a bit more detail about the surgical and engineering components to the story beyond anesthesia because I think that's really important needs to be explored. That's going to be an important one.

I think looking at COVID-19 is one I can't miss and just see the enormous waste that goes with PPE and particularly gowns and N95s and ways to gradually explore how we can pay back the amount, the

extraordinary amount of waste that we generate working in (inaudible) care as well and it's quite, I guess, recognitive dissonance dealing with it.

And I think that advocacy as well with groups such as Doctors for the Environment Australia and I know there's other groups in the US certainly that's important as well.

And further research with Jodi Sherman and Andrew MacNeill and the rest based in the US, Canada and otherwise I think is going to be important. I think there's a real community now of people who are involved in this process and anesthesiologists are really leading the way. It seems quite exciting.

Dr. James P. Rathmell: Terrific. I hope today's discussion will lead many of you listening to read this new article and the accompanying editorial that appear in the December 2021 issue of *ANESTHESIOLOGY* where you can learn more about the environmental impact of anesthesia.

One of my other duties for the journal is helping to create each cover illustration and for the cover of the December 2021 issue, Dr. Struys connected me with one of his patients, Maria Koijck. She's a Dutch artist who had surgery for breast cancer. Maria asked all of her caregivers to collect the waste that was generated from her care and she created a spectacular video that dramatically demonstrates the enormous waste. An image from her video is featured on the cover.

Jon Wanderer from Vanderbilt University and I also create an infographic and it's titled, "Anesthetic Carbon Footprints: Weighing the Options and Impact" that summarizes the findings of the study.

Drs. McGain and Struys, thank you for joining me today and for the terrific explanations.

Host: You've been listening to the *ANESTHESIOLOGY* Journal podcast, the official peer-reviewed journal of the American Society of Anesthesiologists. Check anesthesiology.org for an archive of this podcast and other related content.