Melanie Cole (Host): Welcome to the podcast series from the specialists at Penn Medicine. I'm Melanie Cole. And today we're highlighting diaphragm pacer implantation. I have a panel for you today with Dr. Daniel Hashimoto. He's an Assistant Professor of Surgery at Penn Medicine and Dr. Jeremy Cannon. He's the Trauma Program Medical Director and Section Chief of Trauma and a Professor of Surgery at Penn Medicine. Doctors Cannon and Hashimoto, thank you so much for joining us. Today we're discussing diaphragm pacing, a device that offers an alternative to mechanical ventilation for individuals with ventilator-dependent spinal cord injury and central hypoventilation syndrome.

As we begin, Dr. Cannon, can you briefly describe what's happened to impair breathing in people with ventilator-dependent spinal cord injury and why it's so beneficial or necessary in these populations to offer an alternative to mechanical ventilation?

Dr. Jeremy Cannon: Well, in the patients that I take care of in trauma, we see that patients who have a cervical spinal cord fracture and a spinal cord injury, have severe respiratory failure, so they no longer have the ability to inspire, to take breaths and as a result they end up dependent upon mechanical ventilation, as you mentioned.

This all relates to the innervation of the chest wall and the innervation of the diaphragm. So in the setting of a severe complete spinal cord injury in the cervical spinal cord, these patients have really no other option. ~~Until very recently~~, the device that we'll be talking about today has been FDA approved or cleared for this application to really help patients who have this severe injury pattern eventually liberate from the ventilator.

Host: This is a fascinating topic we're discussing and Dr. Hashimoto, diaphragm pacing involves artificial innervation of the diaphragm to bring about breathing. Give us a little history of the concept of this. Tell us how it works. And while you're telling us that, I'd like you to speak about the benefits or risks for patients with respiratory muscle weakness. Is this considered a first line therapy for patients with ventilatory failure due to bilateral paralysis or severe paresis of the diaphragm?

Dr. Daniel Hashimoto: Absolutely, Melanie. That's a great question. You know, as interesting as this type of technology seems, and maybe as modern as it seems, people may be surprised to know that it's been around for quite some time. In fact, the first time that diaphragm pacing was demonstrated was in the 1960s, and the first device that was developed for diaphragm pacing that was

FDA approved, well, that came out in the 1970s. So, the concept of diaphragm pacing has been around for quite some time, but it has certainly taken some time for it to grow and sort of spread in terms of usage. Now, this question around whether it's first line or not, it kind of depends on the individual patient situation.

And that's where it becomes so critical to have a multidisciplinary team of surgeons, pulmonologists that can really think about what is underlying the diaphragm dysfunction? Is it bilateral? Is it unilateral? Because actually we're now seeing that there's some benefits in unilateral diaphragm dysfunction as well.

And how does that come together and impact the patient's quality of life and their goals for how they want to live with any potential respiratory issues? And when you think about sort of the risk profile for undergoing this type of procedure, well, it kind of depends on what else is going on.

The type of diaphragm pacing device that Dr. Cannon and I use, is actually placed through the abdomen, directly onto what's called the motor endpoint of the phrenic nerve, which innervates the diaphragm and drives breathing. And as far as procedures go, it's pretty low risk. And it comes with the upside of helping to condition the diaphragm, which, like any other muscle, needs to be stimulated to grow and stay strong.

And so that's one of the benefits of taking this approach is really thinking about how can you think about sort of the underlying pathophysiology of the disease? Can you sort of make an impact there at the point where it's going to best influence the patient?

Dr. Jeremy Cannon: Dan, you raised some really interesting historic points there. As we were leading up to performing this procedure and then even after the procedure, I've been looking back at some of the historic events in the development of diaphragm pacing and many of our listeners will probably remember Christopher Reeve, and his terrible spinal cord injury in the late 1990s, in the setting of an equestrian accident.

He was one of the very first patients to undergo this type of diaphragm pacing, almost 20 years to the day, before we performed our diaphragm pacer implantation. So, I know that, you had a chance to train with the inventor of this device, and that surgeon had implanted Christopher Reeve's device.

This is all in the public domain. And so, it's readily available. There are stories in the New York Times and even a story in the New Yorker by Jerome Groopman that I very much enjoyed reading, talking about this innovation. Did you have a chance to speak with Dr. Onders, the inventor about the procedure and sort of his experiences with developing this device?

Dr. Daniel Hashimoto: Yeah, it was a great privilege to get to train with Dr. Onders. He was very personally motivated In terms of thinking about to develop a device that could treat these kind of problems. And, it's really interesting the amount of work that was put into making sure that the scientific premises underlying this was met.

A lot of, for example, cadaver studies to fully map out the diaphragm and understand where are the possible places where the phrenic nerve inserts under the diaphragm. And that's what led him to think about diaphragm pacing in a manner that had been a little bit different than the historical devices that I mentioned from the 60s and 70s.

Those devices took the approach of trying to stimulate the phrenic nerve, as it goes down toward the diaphragm, whereas this device specifically implants into the diaphragm right at the motor endpoint. And so it's decades worth of data, as you mentioned, in terms of ensuring sort of the safety and efficacy of doing these types of procedures.

Host: Dr. Cannon, tell us a little bit about the procedure itself. How long does it take? Any technical considerations you'd like to share with other providers and speak about the outcomes and success rates that you've witnessed.

Dr. Jeremy Cannon: Well, you know, this is the great innovation of Dr. Onders is that he converted it from either a procedure in the neck or a procedure in the chest to actually being an approach that's very familiar to most, if not all general surgeons, and that's transabdominal laparoscopy. So, quite literally, we entered the abdominal cavity just as we would for removing the gallbladder or removing the appendix.

And, you know, there are some important subtleties and nuances there, but we really sort of moved along through the procedure. And I'll let Dan talk a little bit about his perspective on this. But, we were able to identify the optimal placement of the pacing wires, pretty readily and then I implanted the wires just as they were meant to be implanted.

And the cool thing about the procedure for me, was all the device assembly at the end of the procedure. So you literally are creating a socket that the pacemaker plugs into, and you protect that in a small pocket on the patient's abdominal wall. So, it really speaks to my engineering interest and my sort of techie bent.

And it sort of combines the best of surgery with the best of engineering and, makes for a marvelous and wonderfully elegant procedure. As far as the outcomes, we've got an N of one here at Penn Medicine. We looked at the literature for the historic outcomes and saw that patients in many cases, even with high cervical spinal cord injuries, are eventually able to wean down if not entirely come off the ventilator.

I'm very pleased to say that for our patient, she has come off the ventilator within a month of the operation. She's been working very hard at one of our local rehabilitation centers, to achieve the success and through their efforts and her drive, they've just achieved a wonderful result of ventilator liberation, which is very satisfying.

But Dan, I'm curious about your thoughts on just some of the technical aspects of the procedure and the successes you had seen, out in Ohio when you were there with Dr. Onders.

Dr. Daniel Hashimoto: Oh, absolutely. No, I think it's really great because as a minimally invasive GI surgeon, obviously I love laparoscopy and to be able to do a procedure through basically three, five millimeter incisions, and then a one centimeter incision where you actually pass the wires through; it's sort of a huge benefit in terms of avoiding a larger incision, for example, in the neck or potentially in the chest to do this thoracoscopically when you want to stimulate the phrenic nerve directly.

You know, in terms of historically, there have been over 2000 patients that have been implanted with this device directly on the diaphragm. And when you're doing the procedure, the nice thing is you actually get to see how much does the diaphragm actually move, how much atrophy has the diaphragm undergone.

And then in addition, we're able to also measure the changes in the pressure of the abdomen when we deliver a pulse to the diaphragm. So because we're insufflating with carbon dioxide in the abdomen, we're measuring the pressure of the abdomen, and then when we deliver the pulse, obviously, the diaphragm contracts, it drops, it increases the pressure in the abdomen.

And so we can find the point along the diaphragm that leads to the best response. So I like that kind of quantitative element of knowing that the electrode position is optimized for that individual patient. And in terms of the recovery, it's great that they come off the ventilator as quickly as they do.

You know, you mentioned our patient, in a month. Some are even sooner than that. And it's that kind of diaphragm conditioning that becomes so important. A lot of these studies on ventilator-induced diaphragm dysfunctions show that even within the first 18 hours of being mechanically ventilated, you start to see some dysfunction of the diaphragm.

And then by 72 hours, that can be quite severe. And so the benefit of having these types of electrodes is one, yes, you're conditioning the diaphragm, but you can also use these electrodes as an EMG to actually measure the electrical activity of the diaphragm. So it gives you an additional measure to see how the diaphragm is progressing and rehabilitating.

Host: Dr. Hashimoto, a glimpse of PubMed for diaphragm pacing makes it clear there's no set algorithm for the collaboration of specialties involved in these surgeries. How did your collaboration come about and how does it define what's happening today at Penn Trauma and GI Surgery?

Dr. Daniel Hashimoto: Well, I have to give a lot of credit to Dr. Cannon because he is not only a leader, obviously, in our health system, but just a thought leader in general. You look at his PubMed, I can't even count, I think, the number of publications he's got. But, he was very kind, and when he called me, he knew I trained with Dr. Onders, and he said, you know, Dan, I think I've got a patient that would benefit from diaphragm pacing. We haven't done one of these here at Penn before. You trained with the person who invented this. You want to work together on making sure that this goes as well as it could possibly go? And so that's a place where obviously we collaborate a lot between divisions anyway, but to have that kind of expertise all housed within Penn Medicine and within the Department of Surgery, it allows us to collaborate quite easily and figure out if we want to take the best care of a patient, let's tap all of the experts that are available to us at Penn Medicine and ensure that they're all involved to make sure the patient gets the best possible outcome.

Dr. Jeremy Cannon: I'll just echo that. I think it is absolutely a wonderful collaboration, and we're so fortunate to have recruited Dr. Hashimoto to Penn Medicine and Penn Surgery. It's just a great addition to our team, and I look forward to many future collaborations.

Host: I'd like to give you each a chance for a final thought, Dr. Cannon, are there any factors that could affect the longevity or functionality of the diaphragm pacer device and how does it integrate with other treatments or therapies a patient may be receiving?

Dr. Jeremy Cannon: I'll tackle the second part first. We've had a lot of questions from the rehab facility about can the patient move in certain positions, can the patient undergo various therapies such as electrical stimulation? And the answer is that it's a very robust and resilient system.

So I think that speaks to the quality of the engineering that went into this device. And, to your first question, this is a very robust device. In a pinch, it can run on actually batteries that you buy from the store. Of course, they offer long life batteries so that you don't have to worry about switching the battery pack out very frequently.

But, as a military surgeon, I am always interested in sort of the ruggedness of various devices, and this one definitely passes the rugged test.

Host: Well, thank you for telling us that. And Dr. Hashimoto, last word to you. I'd like you to speak to other providers about when you feel it's important that they refer their patients to you and Dr. Cannon, and also speak a little bit about the ongoing care and monitoring that is required for patients for whom diaphragm pacer implant has taken place.

Dr. Daniel Hashimoto: As with many conditions, especially complex ones such as diaphragm dysfunction or spinal cord injury, it's never too early to reach out for collaboration. As I mentioned before, we often see ventilator-induced diaphragm dysfunction as early as 18 hours from the initiation of mechanical ventilation.

So, for anybody in whom prolonged mechanical ventilation is anticipated, particularly with a diagnosis of spinal cord injury, or if on imaging there's a notice of an elevated diaphragm on either side, that might be the time to reach out and ask, would it be appropriate to get further workup to determine whether or not this patient could be a candidate for diaphragm pacing.

Now, in terms of long term, there's a lot of collaboration, as I mentioned, between us as the surgeons and the pulmonologists who are sort of managing the overall pulmonary rehabilitation. We obviously keep an eye, for example, on the EMG activity from the electrodes to see how the diaphragm is recovering.

In spinal cord injury patients, oftentimes these patients will obviously have to continue to use the pacemaker long term. There are patients that have had pacemaker for 15, 20 years at this point. But in other types of indications, like idiopathic diaphragm dysfunction, sometimes after the recovery of the diaphragm, the electrodes can actually be removed.

And so again, this is very much tailored to the individual patient, which actually is what I think makes it so great that we can ensure that each individual patient gets the care and the outcome that they hope for.

Host: Thank you both so much for joining us and really explaining this fascinating topic to us today. To refer your patient to Dr. Hashimoto and Dr. Cannon at Penn Medicine, please call our 24/7 provider only line at 877-937-PENN. Or you can submit your referral via our secure online referral form by visiting our website at pennmedicine.org/referyourpatient. That concludes this episode from the specialists at Penn Medicine. I'm Melanie Cole. Thanks so much for joining us today.