Hello.

I'm Brian Houston.

I'm a cardiologist at MUSC.

And I am a heart failure doctor, and I specialize in the care and selection of LVAD patients, or patients that have Left Ventricular Assist Devices.

I want to thank you for joining me for this lecture.

Specifically, we're going to be focusing on the devices currently available at MUSC, and that's the HeartMate 2 and 3 LVADs and the HeartWare HVAD devices.

And these are the current devices available both at MUSC and that are FDA-approved in the United States for use.

I want to preface this by saying there's going to be a lot more information on the slides than I may present.

The slides will be available for your reference going forward.

If I slide past some information, feel free to pause and go back and read.

We are always available also to answer questions, and we welcome that interaction.

I'd also like to say thank you in advance for the care of our LVAD patients.

This is a complex and vulnerable population, and we appreciate all you do for them.

So I want to give you some background on why we would ever give a patient a Left Ventricular Assist Device or an LVAD.

It's something that seems kind of like science fiction, that may seem more so as I go through this talk.

But the reality is that heart failure can be a very severe disease.

There are thousands of people in the United States that have some type of heart failure, and many need a heart transplant, which we all agree is the best therapy for advanced end-stage heart failure.

The problem is, there are not enough to go around.

We only have about 2,000 heart transplants per year in the United States, and we may have as many as hundreds of thousands of patients that are sick enough to qualify.

And so that's where left ventricular assist devices step in to fill the gap.

These patients that can't right now get a heart transplant but are sick enough will get a ventricular assist device, potentially.

These devices will support the patient until they can get a transplant.

And that philosophically is called a bridge-to-transplant device.

Or some patients may use the LVAD for the rest of their life, and we call that destination therapy.

There are shades of gray in between, of course.

But philosophically, you'll hear people refer to BTT or DT, and that's what we're talking about.

There are a lot of long term MCS devices we talked about in the beginning.

We're going to talk about HeartMate 2 and 3 and the HeartWare HVAD.

The objectives are listed here.

You can read those if you want.

I'm going to skip through that.

I said earlier that there are a lot of different types of mechanical support devices.

Some are just designed to support the failing heart for a short amount of time until we can either help the heart with medications, the heart can recover from an insult, such as a heart attack or myocarditis, and you'll see those listed here-- the CentriMag, the Impella, the TandemHeart, et cetera.

The long term devices-- the Berlin Heart is available for pediatrics, not for adults.

The Total Artificial Heart is not available at MUSC, and is only available at a couple of centers in the United States at this point.

We're going to focus on HeartMate 2 and 3 and the HVAD.

What is nice is that these pumps share a lot of features.

They're both continuous flow pumps, which means that the blood is flowing through these pumps at a continuous rate.

Which seems a little strange, because what it means is the patients often don't have a pulse.

The blood is just being continuously pumped around by a rotor.

Because of this, we're not able to measure traditional blood pressures with a cuff often, and we have to calculate or measure with called a mean pressure via a Doppler.

Blow up a blood pressure cuff, and as the cuff deflates, you'll hear just a continuous rumble of noise.

And that's the patient's mean opening or mean arterial pressure.

Because the blood is coming into contact with metal services, all these patients require blood thinners or anticoagulation.

The pumps, because they function at a continuous speed, they require enough fluid to be able to suck out of the heart.

And that's what we call preload dependent.

If the patient is dehydrated, the pump won't work well.

And then we'll talk more about this later, but CPR, defibrillation, and/or cardioversion are all OK with the patient currently hooked to the LVAD.

And we'll go and do some basics about when you should or should not consider things like CPR and defibrillation.

Here's a picture of two of the pumps.

The HeartMate 2 has largely been supplanted by the HeartMate 3.

But that's only happened in the last couple of years, and so many of our patients still have a HeartMate 2.

You'll see here on the left hand side of the screen, the HeartMate 2 has an inflow cannula, which goes into the left ventricle.

The blood then goes through a bend and into the motor, where the rotor is that drives the blood, then through the outflow cannula up to the aorta.

The pump itself sits below the diaphragm.

And so the surgeons have to create a pocket for the pump to sit in.

The HeartWare HVAD is a smaller device.

It's completely intrapericardially.

The inflow cannula is not visualized in this picture, but it's a tube that goes into the left ventricle.

The blood then goes into the pump and out the outflow cannula up into the aorta.

And we'll kind of dissect these pumps a little more when we get to each of them in the talk.

So you get to see kind of the insides of them.

This is the HeartMate 3 device.

And you may notice that the device itself looks a lot like an HVAD, and that's because it is.

It shares a lot of similarities.

The controller looks like the HeartMate 2.

And we'll go into that a little bit later.

You can see from the configuration of these devices, they are pulling blood out of the left ventricle, and then pumping it to the body, essentially doing the work of the failing left ventricle.

And that's how they work.

They help supply perfusion.

They reduce congestion.

And overall, they help patients live longer and feel better for the patients that have end-stage heart failure.

So let's dive in.

We'll go through our first device, the HeartMate 2.

I said earlier that this device was being supplanted a little bit by the HeartMate 3.

These are like iPhones-- there's 1, 2, 3, et cetera.

But because this device was implanted for over 10 years here at MUSC, many of our patients still have this device.

And so it's good to know about it.

It's also a good platform that's an introduction to LVADs.

It's a little larger pump, and it can help you get used to thinking about what an LVAD is and how it works.

You can see here on the figure that it's kind of cut away.

The inflow cannula goes into the left ventricle.

And then there's an impeller there that spins at a constant rate, driving blood flow for the body.

The impeller spins in this pump on blood-lubricated ceramic bearings.

So it's actually the patient's blood that reduces friction.

And the spinning is created by magnets with opposite polarity.

Because this is not a constant motion machine, it requires electricity to work.

And all the motor driving control electronics are actually outside of the implanted pump.

They're outside of the body.

I told you that this pump spins at a constant RPM.

Typically for the HeartMate 2, you'll see speeds 8,000 to about 10,000 to 11,000.

Above 11,000 would be highly unusual.

The lifespan is listed at 10 to 12 years.

I've seen patients go longer.

One of the advantages of this pump, it is highly durable.

The pump itself rarely breaks.

We'll sometimes have driveline faults or controller problems.

But the actual pump, the bearings, the rotor, and the cannulas actually do a great job of holding up.

This pump is currently approved for both BTT and DT indications.

Here's a closer view of the rotor.

And this shows that you've got two stators on the ends of the rotor that help make the flow laminar.

And then there's your pump rotor there.

Of course, there's more to the pump than just the pump and the tubes and the rotor.

The patient interacts with the controller, the driveline, and these other things-- batteries and power sources, listed here.

The top right, the system monitor, is really only needed for in-hospital evaluation and setting changes.

This is the power module.

The patient will have one of these at home.

And this applies power to the pump when the patient is not mobile.

So if they're sitting in a chair or they're sleeping at night, they will hook their pump up to this power module.

The supplies AC power.

And in case the patient's electricity goes out, for example, there's a battery in this power module that supplies 30 minutes of backup power.

So at that time, the clock's ticking.

The patient has to get to a supply of AC power.

Fortunately, the power model does come with an automobile port, so the patient can plug into their car.

It allows them to take long road trips, as long as they've thought ahead.

And if the system controller is showing alarms-- which we'll go through later-- the power module will repeat those alarms.

The patient is supposed to do a daily alarm self-check, if they ever talk about that.

That just make's sure that the power module will actually supply an alarm if the pump detects one.

And these are the batteries for the HeartMate 2.

These are 14 volt lithium ion batteries.

Each last 10 to 18 hours, depending on the power consumption of the pump at the time.

And they take about four hours to recharge.

When the batteries aren't holding a charge, they'll recalibrate, which means when you recharge them, they'll make sure they know how much charge there is.

And every three years, we supply new batteries to the patient.

One mistake the patients can make is falling asleep when only hooked to battery power.

You can imagine if you sleep for a long time and the battery starts out partially depleted, the battery might run out while they're sleeping.

Now, the pump is supposed to supply them with an alarm, but some patients sleep really soundly, and we have had patients sleep through low and depleted battery alarms and have serious complications.

The system controller itself is smart enough to tell the patient when it's time to change the batteries.

And I've shown a picture of the battery charger down here that you'll see in the patient's house as well.

Just briefly, this is the system monitor that we use in the hospital.

And we're going to go through this pretty quickly, because you won't see this in the patient's home.

But it helps give you a sense of what we're thinking of as providers whenever we're taking care of a VAD patient.

There are six main kind of home screens that system monitor can show us.

And those are listed there.

We'll be dealing with the Clinical Parameters screen.

So this is the screen that we interact with, and it shows a calculated pump flow, the set pump speed, something called a pulse index-- which is a measure of how pulsatile the flow of the blood is going through the LVAD.

The pump power, which is measured precisely the amount of watts that the pump is taking to turn at that set speed.

The operating mode, which is always fixed.

These pumps operate at a fixed speed.

And then if there are any alarms, it will tell you on the Clinical Parameters screen what the alarms are.

You can see that in this Clinical Parameters screen, the pump is set at 9,600 RPMs and the patient has a pulsatility index of 3.6.

Totally normal.

You may hear the patients tell you I had some PI events.

PI stands for Pulsatility Index, so PI event.

And that's when the PI changes by 45% either up or down from the PI measured in the previous 15 seconds on average.

So what most commonly we'll see is that the Pulsatility Index drops.

The machine then records an alarm called a PI event.

This often means that the patient is dehydrated-- that the left ventricle is empty, and so the pulsatility of the blood going through the pump is lower.

You can see some causes may be dehydration, bleeding, too much diuretics.

Sometimes if the patients have arrhythmias, like atrial fibrillation, ventricular tachycardia, we'll get PI events.

Vasovagal fainting can cause a PI event.

And occasionally, failure of the right ventricle, if it's not pumping blood to fill the left ventricle, can also cause PI events.

A special type of PI event can occur called a suction event.

And that's when the actual inflow cannula is obstructed, usually by the wall of the left ventricle.

So the patient's so dehydrated that the pump has sucked the left ventricle around the inflow cannula.

And that's called a suction event.

And those can be pretty serious.

If the pump detects a PI event, it will slow down to what we have set as the low speed limit, and then gradually ramp back up by 100 RPMs per second, detecting the pulsatility index the whole time to make sure it doesn't suck down again, to the original fixed speed.

This is what you will see the controller.

So this is hooked to the driveline, and then to the power sources-- whether they be batteries or the power module.

And this is kind of the brain of the HeartMate LVAD.

This is where, when we set a speed, it's set in the controller.

When there's an alarm, it's recorded in the controller.

And we just use the system monitor to interrogate that controller.

You can see all the buttons here.

Important to note the alarm silence button.

So if an alarm's going off, you can silence it with that alarm silence button.

And then the alarm status symbol-- so that heart with kind of the jagged line through it.

We'll go through some of what that can indicate.

But if that's red, that's a serious problem for an LVAD patient, and they're instructed to come straight to the hospital when they have a red heart alarm there.

The pocket controller can also display data to you.

So if you just press that square-- that button there-- it will scroll through different screens there, showing you the speed, the flow, the pulsatility index, the power, and if the backup battery in the controller itself is charged.

The HeartMate 2 is unique in that the controller has about 15 minutes of backup power in it.

So if it's unhooked from all power, batteries, and power modules, the patient has about 15 minutes-- presuming that the backup battery's charged, has about 15 minutes of power to keep their pump going and stay alive.

So these are those heart alarms that I talked about.

Yellow is not that serious.

Maybe a pulsatility index event, low flows, things like that.

A hazard alarm is more serious, and it will prompt the patient to call the hospital contact.

For our patients, that's our LVAD coordinator.

And they all have that number they should know to call if they get a red heart alarm.

These are other symbols you may get on the pocket controller.

I'm going to leave this here for your reference.

The patient and their caregiver themselves should be well educated on what all of these symbols mean.

Importantly, if there's a low battery symbol, that's important.

The patient needs to know to hook up to an alternative power source.

This is what the pocket controller hooked to the different types of power sources look like.

Here it is hooked to batteries, and then the cables for the power module on the right.

At all times, we like redundancy in our systems.

Of one battery goes down, the other battery's there.

So the patient must be hooked to two power sources at all times.

When they're unhooking, there's one always hooked up, meaning they don't unhook both and then hook back to power.

All right, so that was the HeartMate 2.

Kind of a whirlwind tour.

And now we'll go into the HeartWare HVAD.

So we showed you this picture earlier, although this is a little bit different.

You can now see the inflow cannula in the left ventricle.

And you can notice that the HeartWare HVAD is a smaller pump.

Again, it sits completely intrapericardially.

And so let's dive in.

So here you can see a cutaway of the HeartWare HVAD and some important differences between it and the HeartMate 2.

Similarly, the HVAD is a continuous flow pump.

But as a difference, it's centrifugal difficult flow as opposed to axial flow with the HeartMate 2.

And what that means is with the HVAD, blood flows in at one angle and flows out at a 90 degree angle.

And that's driven by this wide blade impeller.

And that's the only moving part for the HVAD.

Another difference is that the impeller itself or the rotor-- what we call the rotor in the HeartMate 2-- is magnetically levitated.

And we'll go through some caveats for that.

But that is different than the HeartMate 2.

So there's a cushion of blood between the impeller and the pump housing.

And in theory, that reduces stress and strain on the blood and the blood cells.

It's also supposed to be a wearless or frictionless system, although of course, every system has some friction at it.

And there are dual motors designed to provide power efficiency and redundancy within the HeartWare HVAD.

This is a view of the real pump from the outside.

You can see the sewing ring is actually sewn onto the left ventricle, and then the strain relief, which helps that outflow graft from twisting or getting kinked when we put the pump in.

This is also FDA-approved for both bridge-to-transplant and destination therapy patients.

The batteries in the controller are slightly different than the HeartMate 2.

And we'll take a look at those.

And drastically different is the RPMs.

So if you recall, the HeartMate 2 revolved somewhere between 8,000 and 11,000 RPMs.

The HVAD typically you'll see somewhere between 2,400 and 3,200 RPMs.

So that's drastically different.

Also, the HVAD has incorporated hematocrit as we try and make flow calculations, because blood viscosity changes the calculation of flow based on the power that the pump is consuming.

Also different is because of this pump's small size, there are cases where we can place this pump on the right ventricle as well.

So the patient has a BiVAD-- a left ventricular assist device and a right ventricular assist device.

Some patients not only is their left ventricle sick, but their right ventricle is sick as well, and they may require by BiVAD support.

These are rare and complex cases, but just know that you may see a patient with two independent HVAD setups out there.

And the RVAD configuration is not FDA-approved, but is used fairly widely across the United States.

This is the setup that's kind of outside the patient's body, including the monitor, the HVAD pump, the AC adapter, the controller, and the battery.

This is the controller.

In the HeartMate 2, we call it the pocket controller.

And it serves a very similar function.

It's the brain of the pump.

When we set the speed, it's set in the controller.

You can interrogate it for data.

It provides you alerts if the pump is malfunctioning.

And we'll go through all of those as well.

I've listed all the connections here that you'll see on the controller.

You don't have to memorize.

These the patients should know what they are themselves.

But just know that in general, the power sources come into the controller, and then go out to the pump through what's called the driveline.

This controller operates on just one power source, and then utilizes the second as backup.

But it needs to be connected to two power sources at all times for redundancy.

And that can either be two batteries or one battery and the AC adapter-- so what we call the power module for the HeartMate 2.

This is also a difference between the HVAD and the HeartMate 2.

If you recall, the HeartMate 2 could be hooked only to the power module.

The HVAD will require a battery connection at all times.

Similarly, the system drains power consecutively.

So if you're hooked to two batteries, it'll drain one battery down to 25%, and then switch over to the other battery.

Here are some things you can see on the pump controller.

It'll give you the speed, the power, and the calculated blood flow.

Importantly for all these pumps-- and I don't think I've mentioned this yet-- but all the blood flow is calculated.

It's not measured.

There's no flow meter inside the pump.

So what the pump does, it has an algorithm where it measures how much power the pump is using.

In the cases of the HVAD and the HeartMate 3, it knows the blood viscosity.

And then it can predict what flow you should be getting.

There are times when this will be false, when the flow will be lying to you.

The power should always be accurate, though.

If there is an alarm, the pump information-- so speed, power flow-- is replaced by the alarm information.

Just like the HeartMate 2, there are various priorities of alarms-- yellow, flashing yellow, and flashing red.

The important take-home message, flashing red is important.

Get to the hospital.

These can be things like pump failure, controller fault.

And these are important.

These are the HeartWare HVAD batteries.

You can see they're a little bit smaller, and they provide about four to six hours of support.

If you hit the little battery button on the battery, you can see its real-time capacity at the time.

And the charger can also charge up to four batteries.

We said this earlier, but when the controller is hooked to two batteries, it'll deplete one battery to 25%, then switch to the other battery.

I leave this in here for a reference, because if the patient ever has to do what's called a controller exchange.

So if their controller is malfunctioning and they have a backup controller they want to switch, for the HVAD, they have to put this little red button on there called a pacifier.

If you just unhook the HVAD controller, it'll scream at you like a banshee.

If you have the pacifier in there, that quiets that down.

It won't scream at you.

And so the patients all know if they're doing a controller exchange that they've got to put the pacifier in first.

Similar to the HeartMate 2, there's a system monitor.

The patients don't have this at home, but we do have it in the hospital.

And I've included a couple of slides here again to kind of give you some background on what we're thinking about and what we're looking at when we take care of an HVAD patient.

This monitor does not provide power.

So the patient always has to be hooked to two batteries or a battery and the power module.

And it's not needed for daily patient management.

We can use it to interrogate alarms, to look at waveforms-- which are uniquely available on the HVAD-- and make changes in the settings.

This is what the monitor looks like in real-time when we're using it in the hospital.

Similar to the HeartMate 2, you get a flow estimation.

I put the word accurate there in quotes, because we discussed how that's a calculation, and can sometimes be misleading.

It displays a set speed and the power consumption.

What's different with the HVAD and the HeartMate 2 is instead of a numerical pulsatility index, you get a visual representation of how pulsatile the flow is going through that pump.

And these are both the power and the flow waveforms.

And we can use this to guide our decisions, telling us if the patient is dehydrated, the patient is in RV failure or tamponade, if the patient is in heart failure, arrhythmias.

So these are an excellent tool that we can use for clinical management in the hospital.

Again, the patient's hematocrit is used in the HVAD to help provide a more accurate flow estimation.

The more viscous the blood is, the more power it's requiring to move that blood, and the lower the flow will be for any power consumption.

These are what the waveforms look like kind of blown up.

You can see a clear systolic and diastolic flow.

And we like to see an excursion of about 2 liters from the top of the flow waveform to the bottom.

That tells us that the pump has got enough fluid, enough blood to be functioning normally.

This goes into that in a little more depth.

Again, you see the pulsatility should be greater than 2 liters per minute.

And we'd like to see the trough or the bottom of that flow waveform to be above the 2 liter mark on flow.

This gives a visual representation of what the flow waveforms look like at varying speeds, all the way from zerp to absolute maximal speed of the HVAD pump.

You can see at zero flow, you have humongous waveforms.

There's a lot of excursion all the way on the left, and that the nadir of the flow is dipping below zero.

Importantly, all LVADs are valveless systems.

There are no valves in the outflow graft, the inflow graft, or the rotor itself.

And so if I turn the pump off, blood will be regurgitating from the aorta back into the left ventricle.

And that's what that flow going below zero means.

That's not something we like to see.

As we speed the VAD up, we start to increase the flow rate, and decrease the pulsatility as we empty out that left ventricle.

Ultimately, when our flow rate kind of plateaus off, we start to see suction events, where the flow suddenly dips down.

This can be partial suction there on the brown, or continuous suction there in the gray.

And ultimately, if I crank the HVAD all the way up and suck the LV all the way around the inflow cannula, flow will go to zero.

There's no blood flowing to the pump.

It's just spinning in a vacuum.

We talked about this a good deal.

Our waveforms look a lot like an arterial waveform tracing.

It's important to note, this is not an A-line.

It doesn't provide you a blood pressure.

And remember that the flow is calculated.

It says here we're going to review some waveforms.

We're not actually going to do that.

I'm going to spare you the multiple choice test.

But this is something that our fellows and our nurse practitioners go through to better learn how to manage LVADs.

So we're going to dive forward into the HeartMate 3 device now.

So this device orientation looks surprisingly similar to the HVAD.

But the interface is very similar to the HeartMate 2.

We'll get to see pictures of those a little bit later.

The differences.

So unique to the HeartMate 3, we talked earlier about how the brain of the HVAD and the HeartMate 2 is in the controller.

In the HeartMate 3, some of the brain is actually in the pump itself.

Meaning when I set the speed, that's housed in a chip inside of the pump.

There is also a modular driveline, which means if the patient has a problem with their driveline-- let's say they accidentally cut it with a pair of scissors, which has happened-- you can then just unhook the driveline and hook a new one in-- hook to a power source and get the pump going again.

Also unique to the HeartMate 3 is that there's speed modulation throughout the cycle.

What this means is that the pump cycles at a continuous speed, but every few seconds, it drops by 2,000 RPMs for 200 milliseconds, then increases above baseline by 2,000 RPMs for 200 milliseconds, and then goes back down to its baseline speed.

The theory for this is it's supposed to kind of prevent eddies and pockets of blood stagnation from occurring, or it's supposed to wash the pump.

There is controversy over whether this actually happens, although there are some improved outcomes with the HeartMate 3, meaning we see less thrombotic complications than we previously saw with the HeartMate 2.

And it may be that the speed modulation has something to do with it.

This is kind of a cutaway cross section of the HeartMate 3 to highlight a couple of other differences.

Importantly, if you look down at the rotor down at the bottom, there are very large gaps between the pump and the housing.

They're about a millimeter, which doesn't seem large.

But for a blood cell, it's humongous.

And so that further prevents wear and tear on the blood cells that are flying through this pump.

The rotor itself is also fully magnetically levitating.

So remember in the HeartMate 2, the rotor spins on blood cushioned housings.

In the HVAD, there's some magnetic levitation.

But the rotor itself floats on the blood.

Here, there's full magnetic levitation, and so there's no stress or strain on the blood theoretically.

I mentioned before there may be some outcome differences.

The MOMENTUM trial, which was the large clinical trial looking at HeartMate 2 and HeartMate 3, largely showed improved hemocompatibility driven by reduced pump thrombosis.

And it may be that these larger gaps, the full magnetic levitation, and the pump speed modulation provided that.

All right, so that's the HeartMate 3.

The rest of it's going to look very similar.

I'm going to spend a few slides talking about patient management.

Your knowledge on this, of course, does not have to be comprehensive.

But I do want to give you some insight into the problems that can occur with VAD patients so then when you meet face-to-face with one, you can be thinking, I wonder if this could be a stroke or a bleed or an infection.

After initial implant, there's a lot of stuff we're thinking about at the ICU.

We want to make sure that the pump isn't pushing against high afterload or blood pressure.

We want to make sure that the pump has enough preload, has enough volume to function.

We want to make sure the patient's not bleeding, that they're not hemolyzing blood, because blood's flying through a blender in there.

We want to make sure the patient doesn't have right ventricular failure.

But by the time the patient goes home, all these problems should be under control.

All patients will remain on anticoagulation.

There is a very rare patient that's had multiple bleeding complications, where we will eventually just stop the anticoagulation.

But to prevent pump thrombosis and strokes, the patients are managed on warfarin, with an INR between 2.0 and 3.0 usually, and aspirin at varying doses.

Sometimes our patients have arrhythmias, such as atrial fibrillation or ventricular arrhythmias.

It is OK to defibrillate patients, provided the usual precautions.

We use antiarrhythmic drugs, pacemakers, and defibrillators the same way we do with other patients.

If you do have to give a patient CPR, we'll need to confirm pump position, because there are cases where CPR can dislodge the pump housing.

And we'll go a little bit more into detail about the decision algorithm for when or when not to give an LVAD patient CPR.

When a patient comes in to see us in the hospital, we are wary of strokes.

We are looking for signs that the patient could be in heart failure.

Sometimes, they need diuretics.

And before they go home, we're going to be looking for right ventricular failure.

Patients always ask us, can I shower?

What sorts of things can I do?

Showering is possible once the patient's healed from surgery.

They use this shower bag-- kind of a big Saran wrap bag-- to wrap up their controller and their power source, and then get in the shower.

They cannot get in a pool or in the ocean.

We've had some patients question about that before.

That's not possible.

This table outlines some differences and similarities between the HeartMate 2, the HVAD, and the HeartMate 3.

I've bolded the places where there are differences.

You can see the HeartMate 3 rotates between 4,400 and 6,000 RPMs.

That's unique compared to the HeartMate 2 in the HVAD.

The HVAD typically requires a higher dose of aspirin.

And the HeartMate 2 does not include viscosity or hematocrit in its power calculations.

Other than that, these pumps are very similar.

Driveline care.

So this is important we tell patients that their driveline is their lifeline.

This is what carries the electrical power from the controller, which is hooked to either batteries or power module, to the pump itself.

It will enter through a hole in the skin, and run subcutaneously, and then go to the pump, whether that's sub-diaphragmatic with the HeartMate 2 or intrapericardially with the HVAD or HeartMate 3.

We are religious about telling our patients to take care of their driveline.

And that means good handwashing technique.

They need to be sterile when they change the dressing.

They need to always be looking at their driveline to make sure there are no tears, kinks, or trauma to the driveline itself.

They're taping down their dressing to make sure that there's no contamination.

And the driveline needs to be immobilized.

Here we've used this immobilizer.

And what that does is keep the driveline from tugging over and over again on that entry side into the skin, which is a setup for infection.

So these are some pictures of driveline infections that we can see these can see.

These can be as simple as something kind of superficial like a cellulitis, to something very serious like a whole pump pocket bacterial infection.

And that can be life threatening.

So a patient comes in with an LVAD problem, and we don't know what it is.

We tell our fellows we're going to get an echo.

And we want to make sure that the LVAD is unloading the left ventricle, that the right ventricle is not under duress.

We want to look at the valves.

It's a good initial test when an LVAD patient is having problems.

We're going to look at hemolysis labs.

One thing a patient may tell you when you're interacting with them is that their urine has suddenly turned dark.

This is a bad sign.

It's a sign of hemoglobinuria or hemolysis.

And what that means is there is extra drag or friction on the rotor.

We are often concerned about pump thrombosis in that case.

So if a patient tells you, all of a sudden my urine turned Coca-Cola or dark tea colored, that can be a serious sign of a pump thrombosis.

If there's a concern about driveline fracture, we'll get x-rays of the driveline as well.

Just in general, we are constantly looking at power consumption of the pump as a clue of what's happening.

So if there is increased power, that can be something that is just increasing flow through the rotor.

It's asking the rotor to do more of that constant speed.

Sometimes, it's volume overload.

But it can be clot on the rotor, or something that the pump has ingested, like a fibrin product.

And that increases drag on the rotor.

This is a scenario where the pump flow will lie to us.

It'll tell us that the flow is higher, because the power consumption is higher.

But in reality, the flow through the pump is lower.

If I speed up the pump, power consumption will go up.

If I give a patient a vasodilator, there's more flow through the pump, and so power will rise.

And when patients exercise, they'll notice that their power goes up.

On the flipside, if they see power going down, that could be dehydration.

And that can also be signaled by those PI events that we talked about earlier.

Sometimes, we can get clots not on the rotor, but on the inflow or the outflow cannula.

And that can involve decreased power, though it doesn't have to.

The flipside of vasodilation is hypertension.

That will caused decreased power.

And arrhythmias like rapid atrial fibrillation, ventricular tachycardia, or ventricular fibrillation can cause decreased power.

So we've talked some about how LVADs work, about the different types of LVADs, and why they can be good for many of our patients.

These are not complication-free devices.

You can imagine that putting a metal pump in a patient with a driveline going outside can carry its risk of complications.

And that's absolutely true.

The most common complication we see is bleeding.

Patients are on blood thinners.

They're on aspirin.

But beyond that, something about that continuous flow sets our patients up for bleeding in the GI tract and elsewhere.

About half our patients will suffer at some point during their LVAD support time with an infection, usually driveline related.

And depending on your definition of RV failure, up to a quarter or more of our patients can suffer from failure of the right ventricle.

If you think about the LVAD, it's supporting the LV, and it's increasing the flow.

But you're also asking the right ventricle to keep up.

And for myriad reasons, after an LVAD, sometimes it can't.

And this can be a serious complication.

In extreme circumstances, the patient needs an RVAD that we talked about earlier.

Oftentimes, we can manage this with diuretics and medications.

Stroke is rare, but not rare enough.

Pump thrombosis is also rare.

The HeartMate 3 looks like it may have a lower pump thrombosis rate, although we're still in the infancy of this device.

And device malfunction is actually really rare, meaning the device just itself breaks.

These devices are well-made.

They're made to be there for the long term, and support patients through their life.

It is rare that we see a device itself break.

So I promised we would talk some about CPR in LVAD patients.

The thinking on CPR for LVAD patients has probably evolved over the last decade.

When we first started implanting these continuous flow devices, there was concern that CPR would dislodge the pump.

There was also concern that in a patient who usually walks around without a pulse, just finding them unconscious without a pulse was not significant enough to start chest compressions.

That thinking has changed due to studies showing that in patients that have gotten CPR, pump dislodgement is very rare.

We now recommend CPR if the patient is unresponsive and you can't get a blood pressure.

And recall that blood pressure is best obtained with a Doppler device and a blood pressure cuff.

So if the patient is unresponsive and no blood pressure, then CPR is OK.

If the pump is irrevocably malfunctioning-- meaning the pump is off and the patient is unconscious without a pulse-- that is not an LVAD patient at that time, and CPR is also OK.

Similarly, you can defibrillate the patient and provide cardioversion if that is appropriate.

You don't need to disconnect the pump or the controller.

You can defibrillate them just like you normally would. These reminders we give to patients, but I think it's important for providers as well.

CT scans are OK, MRIs are not.

This is a big hunk of metal in there, and so putting the patient in a big magnet is a no no.

This device is compatible with defibrillators and pacemakers.

We tell patients no contact sports.

So they're not going and doing jujitsu and playing football.

And absolutely no swimming.

They cannot submerse themselves in water.

No water or fluids can get into the controller.

We mentioned the shower precautions, like the shower bag that patients take.

One important thing is don't drop the controllers.

We tell the patients, don't drop them.

So when you're interacting with a patient and maybe transferring them from their chair to the gurney, make sure that you've bundled up all of the gear, including the controller, and are keeping care of it.

We have had cases where the patient or provider drops a controller, the controller breaks, and the pump suddenly stops.

And that can be life threatening.

We also want to keep that driveline secure.

The patients should have it secured as well.

But we want to avoid jerking or tugging that driveline, because that's a setup for either driveline malfunction or an infection.

So do's and don'ts we give to patients.

They can resume daily activities, drive.

They can go back to work or school.

We have patients with LVADs that travel the world.

They can do sports, but no contact sports.

They can take showers, they can resume intimate relations, and they can travel.

They don't are the flipside of that.

Of course, contact sports.

They can't submerge in water.

No excessive jumping.

So their skydiving and bungee jumping days are over.

Activities that may produce electric shocks.

So if a patient's an electrician, we tell him they're going to have to do something else, because high doses of electricity are bad for the LVAD patient beyond what's normally bad for humans.

It says they can't go through metal detectors.

That's just because they have metal in them.

They'll set off the metal detector.

And they can't become pregnant.

This is an important one for our female patients, of course.

And we require that they all be on reliable birth control.

In the hospital, our LVAD patients travel with a trained LVAD provider, and they're gathering all their gear-- their controllers, their batteries, they make sure they have their emergency numbers.

Because you never know when an LVAD patient can suddenly have a pump dysfunction or complication.

I put this on here because the same holds true with EMS transport.

We want to make sure when we bring the patient to a hospital that they're coming with all of their ancillary gear-- their controllers, their extra batteries, et cetera.

The patient and their caregivers should know what those are.

But it helps to remind them, make sure you get all your stuff.

So in summary, one of the most important points is that the controller is the brain, the driveline is the lifeline.

So the controller itself-- and I've included both the HeartMate and the HeartWare controllers here.

For the HeartMate 2, these are the brains of the pump.

They tell the pump how fast to go.

They will tell you what alarms the patient's having.

And they can give you some sense of the history of the pump.

Remember in the HeartMate 3, some of the brain is housed in the pump itself.

The speed is housed in the pump.

Key points and summary.

The HeartMate and HeartWare HVAD devices are common and becoming more common.

mechanical circulatory support devices, these can provide a bridge to transplant or lifelong therapy for destination therapy patients.

To check a blood pressure, you usually need a manual cuff and a Doppler to find that opening or mean arterial pressure.

Patients will be on blood thinners and antiplatelets with aspirin and warfarin.

We have yet to start patients on novel oral anticoagulants, like Xarelto or apixaban or dabigatran.

Early trials show that these are not safe for LVAD patients.

Complications that we're monitoring for-- bleeding, infection, thrombosis, right ventricular failure, stroke, or rarely device malfunction.

Before you start CPR on a patient, make sure the patient is truly unresponsive, has no blood pressure or mean Doppler pulse, remembering that these patients will often not have a palpable pulse, even when the pump and the heart is functioning normally.

And when the patients travel, they always need to travel with extra batteries, clips for the HeartMate 2, extra controllers, and all the emergency number and contact information.

So that wraps up the presentation.

Again, I want to say thank you for the care you provide for these complex patients.

We are always available to answer questions.

If you call MUSC and ask to speak to an LVAD provider, we will be more than willing to talk with you or set up conversations.

We appreciate your care of our LVAD patients.