Left Ventricular Assist Device

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Objectives

The reader will:

1. Explain the function of an LVAD.
2. Describe the daily care involved with the LVAD.
3. Recognize the risks associated with implantation.
4. Identify the imaging used during the process of implantation and follow up care with the LVAD.

Outline

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Introduction

Organ transplants are a widely known and used method for recipients to live a longer and more active life. Even with this life-saving foundation, there are many limitations to transplants including long-term medication, therapy, current health of the recipients, and the limited number of organs available due to their biological nature. Because organs are biological, there are limits on who can be donors and what organs a recipient can receive and from whom. For some organs the donor could not survive the removal, so the organ must come from a donor with major brain or heart damage. Thus, heart transplants are performed less often than other transplants, such as liver or kidney because the donor can survive and live a normal life without the donated organ. Transplant recipients are screened continuously to ensure that they will be an appropriate recipient. Any of the patients on the transplant list could be ineligible for a small amount of time, or completely ineligible, due to other diseases. These complications range from a common cold to a chronic illness. To bridge that gap, hardware for the heart, like the LVAD, can work for patients waiting to receive a transplant or for patients who want to extend their life without going through a transplant.

Background

The LVAD, or left ventricular assist device, helps pump blood to the rest of the body from the left ventricle. This implant is usually indicated due to the heart weakening and/or having decreased performance. LVADs are considered “long-term mechanical circulatory support (MCS)” according to *The Ochsner Journal*.[1] LVADS are designed to assist the body for an extended amount of time, usually for years. This can be helpful to extend the life of patients and to keep the body in better shape for everyday life. This can be an option on its own or because the patient is not responding to medication anymore. It can be used to elongate his/her life or to increase the amount of time before the patient receive a more permanent option and to keep the patient as active as possible in that amount of time.

LVADs have components inside and outside of the body. The components inside the body include the pump, cannulas, and half the driveline. The components outside the body include the second half of the driveline, batteries, and control unit.[1] Figure 1 clearly shows all the basic components of the LVAD.[1] The pump is the main functional part of the LVAD that takes on the work of the heart to increase blood flow to the body. The inflow cannula diverts the blood from the left ventricle to the pump and the outflow cannula attaches to the aorta to direct the blood flow to the rest of the body. To supply power to and control the pump, the driveline attaches from the pump inside the body and crosses to the outside of the body where it attaches to the control unit. The control unit displays and stores data about the pump's function. It also stores the history of the pump so that providers can view activity at appointments to check for complications. Lastly, there are batteries that attach to the control unit which provide power to the unit to allow the patient to travel with the pump and to resume normal activities.

The design of the LVAD varies slightly between different brands and generations. Generational differences are mostly seen by the LVAD becoming increasingly smaller with newer generations, as can be seen in Figures 2 and 3 in the patient's chest x-rays.[2,3] The new, smaller generations are especially beneficial for younger and smaller patients. It is also beneficial to adult patients because it takes up less room in the body. Because of its smaller size, the Heartmate is one of the most commonly implanted LVADs.[4] There are currently three generations of LVADs; the first generation's pump is pulsable while the second and third generation's pumps uses centrifugal force.[5] The first-generation LVAD functions more like the natural force of the heart; however, there are generally more mechanical issues than using centrifugal force. With centrifugal force, since the mechanics are not mimicking the body's pulse, it can be a much more difficult to feel for a pulse. At times, the pulse is subtle and hard enough to feel that a Doppler is sometimes needed; the patient still has a pulse it is just not palpable at the time because of the difference in waveforms.

With any procedure, there are risks associated and LVADs are no different; however, it is important to weigh the risks versus the benefits. LVADs are normally recommended at stage D heart failure. At this point, the patient is likely on the transplant list and the heart has diminished function. The LVAD can help the patient's body and mindset become stronger to better handle the transplant because the body is able to get enough blood to ensure that the patient can stay healthy and strong. It is preferred to do LVAD procedure sooner rather than later to increase the survival rate.[1] Similar to transplants, where it is preferred to perform surgery when the body is healthier, LVADs are preferred to be implanted before the patient's body gets too run down to properly heal after the procedure. This can be especially important for transplant candidates since it can be a long wait for a transplant due to the amount of patients needing transplants versus the amount of viable donor hearts.

Major Reasons for Implantation

LVADs are normally implanted for three reasons: heart recovery, destination therapy, and bridge to transplantation. Heart recovery can sometimes be possible when the patient's heart will get close to resuming normal function after decreasing the ventricle's workload function and giving it the time to heal.[6] LVADs can be helpful in this regard because patients may be able to save their own heart and not have to go through with transplantation and its permanent effects.[6] This is especially important in pediatric patients because these patients would be required to take medication for the rest of their lives, and they would have a compromised immune system due to the anti-rejection medications needed.

Destination therapy is for patients who use LVADs as a treatment for the rest of their lives. This is also called bridge to treatment. Patients in this category are unable to receive a heart transplant or have personal reasons to not want a heart transplant. Heart transplant eligibility can be affected by age, other pathology, active infection, history of cancer, or unwillingness to change lifestyle habits.[7] Elderly patients can have a harder time recovering from surgery, which can affect eligibility. The overall health of the patient is also an important factor. Pre-existing pathology or disease that may shorten a person's lifespan, even if it is not affected by the heart, can deter a patient from receiving a donor heart. An active infection or a history of cancer in a patient can also deter the process due to the risks of infection and metastasis to the heart due to the increased risk of cancer associated with immunosuppressants. Since the immune system does not work as well, there is an increased risk of cancer reoccurrence or an infection spreading faster and doing more damage. Lastly, if a patient is unwilling to follow instructions to keep the donor heart in good health, the patient will likely be denied the chance to receive a heart transplant. This includes giving up harmful habits such as smoking or excessive alcohol intake.

Bridge-to-transplant is a significant reason for implantation of LVADs. Heart transplantation is the gold standard of care even preferred over LVAD implantation.[1] This is because LVADs have a higher risk of infection due to the fact that parts of the LVAD components are outside of the body, and transplantation is a longer and more permanent option. However, there are a limited number of transplants that can be performed due to the biological nature. There is an average of 2,200 heart transplants per year and 2,500 LVAD implantations per year.[8] LVADs more than double the number of patients with a weakened left ventricle that can be treated. LVAD patients also have the option of receiving most of their care outside of the hospital. Patients have appointments to follow up on the LVAD and disease progression instead of the patient having to stay in the hospital or have multiple emergent visits due to symptoms from decreased functioning of the heart. LVADs do require more constant care while patients have them compared to receiving a transplant, but it is a more flexible treatment than hospitalization if symptoms from their disease are critical.

Surgery Implantation

The patient has a large, collaborative team when determining if he/she is a candidate for an LVAD and if he/she are able to go through the surgery process. The team consists of "the patient, family, cardiologist, cardiothoracic surgeon, LVAD coordinator, social worker, and palliative care provider."[9] The cardiothoracic surgeon is the ultimate decider on whether the patient is approved for surgery.[9] Many factors are taken into account when looking at who is recommended. Patients with life-threatening conditions, active renal failure, serious brain injuries, severe infections, and serious health conditions are not normally candidates for LVADS.[10] The team determines if the patient is a good candidate by evaluating medical history and lifestyle. Medical workers and non-medical workers coordinate together to determine if the patient is physically and mentally fit for the LVAD due to the daily, proper care needed after implantation and dependency on the device.

The LVAD surgery typically takes four to eight hours depending on the patient.[11,12] This is similar in length to a heart transplant.[13] LVAD surgery usually requires the use of a heart lung bypass machine so that the prosthetic can be implanted into the heart without the heart moving during surgery. It is also possible to perform the surgery without the bypass machine; however, a mechanical device is used to hold the heart steady to allow the surgeon to work on it.[14] The heart bypass machine is common in cardiac surgeries because of the ability to temporarily divert the blood flow of the heart to a machine so that the heart can be easily be assessable to work on.

To implant the LVAD, there are two main methods of insertion including lateral thoracotomy and medial sternotomy. With medial sternotomy, access is gained to the heart by creating an incision down the middle of the chest and cutting the sternum into two or three pieces. This allows the sternum to be moved away from the heart. The lateral thoracotomy involves a small incision to the lateral side of the chest with an additional one or two small incisions to help guide instruments. The medial sternotomy is the typical surgical strategy used during cardiac surgery. The incision down the middle of the chest and moving the sternum creates an easy view of the heart and surrounding structures. Instruments are able to get close to the heart and bigger instuments are able to be utilized. Imaging does not play a vital role due to the surgeon being able to view the heart himself/herself during surgery. After the surgery, the sternum would be wired closed to protect the heart.

The lateral thoracotomy is a newer technique for cardiac surgeries and especially for LVAD implantation. There are only a limited number of surgeons experienced enough in this technique to implant LVADS by lateral thoracotomy.[12] This is because the procedure is much more complicated. Since the incision is on the lateral side of the patient, the heart is not as visible as it would be for a sternotomy. This can get more complicated with any atypical anatomy, especially larger or rotated hearts.[15] However, in multiple studies, it is shown that this procedure has many beneficial outcomes after surgery. The *Journal of Heart and Lung Transplantation* has two articles that studied the difference between minithoracotomy and minimally invasive surgeries versus the medial sternotomy surgeries. One study showed differences in decreased mortality, ICU stay, operative time, total ventilation time, decreased blood products used, and a faster recovery in lateral thoracotomy.[16] The journal also showed shorter intubation length and a smaller chance of right ventricular failure.[17] A decrease in trauma, bleeding, hospital stays, and costs were also seen as well as a shorter post op time.[15,12] There are many benefits to creating a smaller, lateral incision into the patient, mostly to do with recovery and decreased complications as can be seen through many studies.

The lateral thoracotomy is possible due to the decreasing size of the LVADs implanted. Older versions of the LVAD would be too large to fit through the incision made during this procedure. To combat the limited view during surgery, there are many different imaging tests that are done before and during surgery to better visualize the heart and, most importantly, the apex of the heart for the insertion of the inflow cannula. In addition, the lateral thoracotomy preserves the sternum for patients who are waiting to receive a donor heart. The sternum is the optimal insertion location when receiving a transplant. Preserving the sternum is beneficial because the additional trauma of scarring can lengthen the transplant surgery time and increase its complexity.

After surgery, the patient stays in the intensive care unit for a couple days. The patient will wake up with multiple wires and tubes in the chest to monitor and help with recovery after surgery. This can include a ventilator, chest tube(s), and a catheter in the heart in addition to the wires from the newly inserted LVAD. The patient remains intubated until waking up from the anesthesia used during surgery. A chest tube is normally used after heart surgery to collect and drain blood from the surgery.[18] The pulmonary artery catheter (PAC) is placed intra operative.[19] The wire is inside of the heart and constantly and more accurately monitors the function of the heart to collect data for recovery and any problems that may arise.

The patient receiving the LVAD is put on anticoagulation therapy and antiplatelet therapy. While there is not a standard for therapy, one source states that their hospital prescribes 81mg aspirin daily, but it can also depend on the individual's history of diseases, stents, and prior strokes.[1] The patient is screened for possible strokes; however, with the additional hardware, there is a chance of a clot developing within the pump or from the pump forming pump thrombosis, which can be a serious complication that can only best be solved by drastic measures such as replacing the pump or a heart transplant transplantation as soon as possible.

Recovery in the hospital typically takes 14-21 days with regular monitoring through blood draws, chest x-rays, and many other tests to ensure the new implant is functioning properly and the patient's body is recovering from surgery well.[11] The patient starts in the ICU immediately after surgery, but within a couple days, the patient is moved to a regular unit for recovery if the patient is tolerating the surgery well. During those couple weeks in the hospital, the patient and caregiver will learn and understand the function of the LVAD and the daily care required for the implant.

Taking Care of the LVAD

Caring for an LVAD includes daily tasks by the patient and appointments with healthcare professionals to monitor the function, infection, and health of the patient. Taking care of the LVAD requires some work to understand the implant and how to maintain it for as long as possible. One requirement for getting an LVAD is relying on a caregiver after surgery. Depending on the source, caregivers are needed for three to six months or up to 12 weeks.[9,20] This can depend on the hospital and the condition of the patient. The caregiver can be a spouse, child, or friend that will be living with the patient during the time of recovery. The patient is still learning about his/her LVAD and recovering from cardiac surgery, so he/she will be limited on the activity that they can do. The caregiver can help the patient with daily tasks in addition to helping the patient monitor the LVAD and give emotional support. The caregiver will also need to help the patient get to and from doctor's appointments. The caregiver receives all of the same information about the function of the LVAD including warning signs and alarms that come from the LVAD. At some hospitals the caregiver and patient must show understanding of the routine care of the LVAD before the patient is discharged.[1]

A patient must make small adjustments to his/her life to accommodate the LVAD. There are daily tasks and warning signs of complications that need to be monitored for the rest of the time with an LVAD, but it can be a small price to pay to have a chance to be more active and decrease symptoms of heart problems. Since the LVAD has a line that goes inside of the body from the control unit, there is a high chance of infection. To help prevent infections, a daily sterile dressing change is needed.[1,9] The dressing change needs to be done with sterile gloves and is taught in the hospital during recovery. As seen in Figure 4, there is a sterile dressing around the incision the driveline passes through and a dressing, called a driveline anchor, to hold the line in place as much as possible.[20] A stabilization belt can also be used, depending on the hospital, to help hold the driveline in place since the driveline connects the pump and control device/batteries together.[1] If a patient has a stabilization belt, it is meant to be worn continuously because body movement is normally constant and it will decrease the risk of the driveline bending and kinking inside or outside of the body.

Another daily task is to chart vitals including weight, blood pressure, and temperature, along with the LVAD numbers.[11] A daily assessment is also done to check the batteries, driveline, and back up controller.[9] It is important to keep a consistent weight to ensure the patient is kept well hydrated. Hydration is related to blood pressure, which is critical to keep a consistent gradient from which the pump works from. Keeping track of temperature is used to monitor any symptoms of complications and infections. Checking the equipment daily is a good habit to make sure all the LVAD components are functioning properly and if not, the patient should get it checked and fixed as soon as possible. The batteries, when not worn, should be kept charging. The batteries are designed to last 12-14 hours.[9] Two batteries are able to be attached to the LVAD at all times in order to make sure constant power is supplied the LVAD. There is a specific order to change the batteries, and only one at a time is replaced to keep constant charge to the pump.[9] The batteries are a very significant part of the LVAD because they allow the patient to be able to move around and not confined to a hospital bed. The equipment needs to be taken care of to make sure it is always functioning properly.

A daily self-test is conducted to check that all the alarms are working on the LVAD so that if there is a problem, the patient knows immediately.[9] Along with alarms, the control unit displays key parameters. The *American Nurse Today* considers these key parameters as the pump flow, pump speed, pulse index, and power, also known as the four P's.[9] The pump flow is the estimate of the cardiac output, typically 4 – 6 liters per minute. The pump speed is the rate the rotors are spinning in the LVAD, typically around 8,600 to 9,800 revolutions per minute. The pulse index is the flow of blood through the pump, typically from 3 to 7 with a scale of 10. Greater values than these indicates that the patient's heart is doing more of the work than the pump. The power is the voltage used by the batteries to work the pump, typically 4 to 7W.[9] The four Ps are a quick way for the provider and patient to check the functioning of the pump and how the patient's heart is functioning compared to the LVAD. These numbers can be read either from the controller or when the device is plugged in.

When the patient is leaving the hospital, he/she has an understanding of the tasks needed to keep himself/herself and the LVAD healthy. The patient is sent home with batteries, a charging station for the batteries, and a shower bag.[9] Showering is a slightly more complicated task with the LVAD because the LVAD should not get wet, nor the site where the driveline exits the body, due to the increased risk of infection. The LVAD also cannot be submerged in water, so bathing and swimming are not feasible for the patient. However, other physical activities, as long as they are non-contact sports, are still able to be played and even encouraged to increase the health of the patient. The patient is encouraged to keep his/her heart and body healthy by exercising as long as the patient does not overdo it.

Appointments with the doctor are vital in the follow up care after an LVAD implantation. During these appointments, the provider checks for device and non-device issues.[1] The device can potentially malfunction, but the patient's overall wellness is also important. For this reason, patient screening is important to evaluate the patient's mental health in addition to physical health. If the patient is not able to handle the emotional strain, the device will not be beneficial. This is also why it is important for the patient to keep up on general wellness practices.[1] Keeping healthy by exercising and routine care like dental work and vaccines are important in fighting preventable infections. Because of the LVAD implantation, the patient's provider will check the patient for nutrition, organ function, and screen for psychological problems.[9] The right ventricle can be particularly vulnerable due the extra pressure around the left ventricle from the LVAD.

Mental health problems, such as depression, can arise due to the loss of control and dependency on the LVAD and caretaker. Mental health problems can also from in the caregiver due to the increased pressure and worry associated with taking care of the patient and LVAD.

At appointments, the provider will check the device for the alarm history and obtain labs to check how the anti-coagulation medication is functioning in the body.[1] A white blood count is taken to check for infection along with other lab tests. Other tests can be done including an ultrasound doppler to measure blood pressure, an EKG, and echocardiogram.[20,1] *The Ochsner Journal* also states that the frequency of doctors appoints depends on the stability of the patient.[1] Regular doctor appointments are still needed; however, the frequency of the doctor appointments will decrease once the patient is recovered and stable. If complications arise, appointments with the doctor can increase to monitor the patient and the LVAD more closely.

Complications/Risks

With every surgery, there are risks and complications. There are risks due to anesthesia and nosocomial infection because of a hospital stay. There are also risks specifically associated with the LVAD components and medication required to keep the LVAD. Common complications after implanting an LVAD include bleeding, infection, device thrombosis, GI bleeding, right heart failure, and aortic hemodynamic changes.[8] The two main complications are infection and changes in the patient’s clotting factors.

Infection is a huge risk with any implant, but the LVAD is particularly vulnerable due to the driveline connecting components inside and outside of the body. The driveline travels up the patient’s abdomen and is very close to the heart. Even though the dressing is changed daily and checked for any infection or skin breakdown, infection can still occur. In fact, the incidence of infection is 17-22% of recipients of the LVAD.[21] These infections are mostly bacterial but can also be fungal.[1] Chances of infections can be decreased with daily dressing changes, but infections can still occur. If an infection is caught early enough, it can be treated relatively simply; however, if it is untreated major complications like sepsis can arise.

Bleeding is also a major adverse complication within 9% of patients. This is because of the change in pulse pressure due to the LVAD.[1] Also contributing to this can be from the anticoagulation therapy reducing the patient’s ability to clot and stop the internal bleeding. The treatment for this is to stop receiving anticoagulated therapy for a certain amount of time and to receive endoscopic evaluations and treatment to the part of the body bleeding.[1] Patients also have an increase in GI bleeding in modern LVADs, which could be due to the change in pulse pressure from the continuous flow mechanism rather than the pulsable nature of previous generations.[5] The bleeding can be solved with proper treatment; however, the patient should be restarting his/her anticoagulation therapy as soon as it is safe due to the risk of device thrombosis. Signs and symptoms are important to monitor on patient's daily care tasks because a bleed is a serious complication, but it can be taken care of with endoscopy or by interventional radiology. It is possible to stop a GI bleed as long as symptoms are noticed as soon as possible.

Device thrombosis is a common risk, and it is monitored clinically.[8] Device thrombosis is monitored closely because "suboptimal positioning has been associated with pump thrombosis, inotrope dependence, and mortality."[15] This is also why it is so important to get good positioning during surgery. Pump thrombosis can cause device malfunction and lead to a stroke or myocardial infarction, all of which are life threatening.[22] Laboratory tests are the main defense to screen and diagnosis pump thrombosis by detecting many factors including lactate dehydrogenase levels and indirect bilirubin. In addition, echocardiography is used in limited forms to see inflow cannula occlusion or to measure blood flow.[22] Once the patient has device thrombosis, the most effective treatment is heart transplant or pump replacement. This keeps mortality at the same rate as a patient without pump thrombosis which is twice as high within months after diagnosis.[22] "Symptoms of pump thrombosis include increased heart rate, shortness of breath, increased pulse pressure, and steady increase in pump power over several days" and if bad enough, the pump flow rate decreases.[9] Daily monitoring by taking vital signs can help determine if there is an increase in heart rate and pulse pressure because values many not be the same from patient to patient. However, by the patient tracking his/her own data and being familiar with his/her own numbers, symptoms can be noticed in daily checks rather than waiting weeks between regularly scheduled doctor appointments specifically checking for complications.

A kinked or broken driveline can cause complications. Since the driveline serves to pass information from the pump to the control unit and the power from the batteries to the pump, it is important to keep the driveline in good condition. The driveline spands through the abdomen where there is a lot of movement, which can be problematic because it can cause kinking. The part of the driveline that is external can also be damaged because of excess movement. This is where the stabilization belt or a driveline anchor can help reduce the potential damage. The driveline can be kinked, twisted, or broken. On the outside of the body, the driveline can be visually inspected, but if the damage to the driveline is from the portion inside the body, imaging modalities may be needed.

Radiology Role

Many tests and imaging procedures are performed on a patient during the process of receiving an LVAD. It follows the patient from deciding if he/she is a viable candidate, planning for the LVAD implantation, through recovery from the surgery, and follow up appointments. Major radiology components guiding the LVAD process are echocardiograms and x-rays. Other imaging modalities used include CT and the PET scan. MRI is not typically used on the LVAD post procedure due to the most sources stating the LVAD is not MRI compatible.[23,8]

Two different types of x-rays are mostly used for the LVAD: Chest x-rays and abdominal x-rays. Chest x-rays are used commonly after any cardiac surgery to monitor recovery. They are also used to check placement of the LVAD and how surrounding structure, like the lungs, are functioning. Abdominal x-rays are used mostly after the implantation to “aid in diagnosis of LVAD driveline damage.”[4,23] The driveline is a very important part of the LVAD and can be susceptible to a lot of complications due to its length and exposure to inside and outside the body. Abdominal x-rays are routinely done; they are usually used to diagnosis a kink or damage because a problem is shown on the LVAD controller. Figure 5 shows an abdominal x-ray of the driveline and the kink in it.[24] Mandible x-rays can also be used when looking at potential candidates to check the patient’s dental health.[25] Dental health is important because abscesses and infections in the mouth can easily spread to the brain and body, causing major damage.

Ultrasound is one of the main modalities used during the LVAD process with transesophageal echocardiography (TEE) and echocardiograms. Echo is considered the “first line” modality because of the portability and decreased cost when evaluating the device and complications.[8] While CT is also a main imaging modality, the patient has to travel to the CT scanner, which can be a disadvantage. Another source states “transthoracic echocardiography is the primary imaging modality used to monitor patients supported by LVADS” followed by stating it is used to monitor the speed and shift of the septum.[8] *The International Journal of Cardiac Imaging* states that TEE monitors the outflow cannula for malfunction, kinking, thrombosis, angulation, and to measure peak velocity to check for obstruction or narrowing.[8]

Echocardiography is consistently used throughout the follow up after the LVAD is implanted. Surveillance echocardiography is performed at two weeks and 1, 3, 6, and 12 months follow up appointments.[1] Echocardiography is ideal for follow up doctor appointments because clinic sites are more likely to have ultrasound rather than a CT machine. Ultrasound also uses sound waves rather than the radiation that the patient would be exposed to multiple times for regular, follow up CT scans. These routine echocardiographs are used to check for myocardial recovery and monitor for optimal pump parameters in addition to checking for any complications.[1,8] Echo can also be used to guide thoracotomy implants, for preoperational evaluation, and during surgery to check cannula position.[15,19] As sources show, echocardiography is key throughout the process and can be compared to previous exams to check for infections or position. It can also be beneficial when using the more complicated insertion method of thoracotomy to visualize the LVAD components.

PET scans are not used as often as CT and Echo, but they can still be helpful. A PET scan can be used to have a baseline for comparison to diagnosis any potential complications or infections.[21] When the patient has a large infection, the PET-CT scan can highlight gas or fluid pockets.[8] Since there is such a high chance of driveline infection, diagnosing these infections are very important in order to treat the patient before the infection spreads throughout the body. This can shorten length of a hospital stay and increase the chance of survival.

Computed Tomography is used for preoperational and post operation imaging. Unlike Echo, CT cannot be used during the LVAD surgery; however, it can offer different options that ultrasound cannot. CT and Echocardiograms can offer similar results and images for the LVAD process. For example, CT can be used to visualize internal parts of the LVAD to ensure the components and angles of the components in the correct place.[23] Similar to Echo, "routine post-operative CT imaging may help guide clinical management"[8] and check for internal bleeding.[8] In these ways, CT and Echo can be interchangeable as modalities to monitor the LVAD. However, in some incidences, ultrasound can be better for the patient because of the addition of radiation and risk of nephrotoxicity from CT scans with contrast, in addition to the increased cost and hard artifacts from the LVAD.[1,5] Most patients receiving an LVAD have heart failure, and a common side effect is decreased renal function. This can limit the amount of contrast that can be used during CT scans, if it can be used at all. Even with these negative effects, CT may be more efficient than ultrasound when the apex is superimposed on the lung or if the patient has a thick chest wall.[15] This can be caused by patient anatomy or if the patient is overweight. While it is not always the case, CT can be used as an additional modality to get better images and accurate placement for the inflow cannula where it connects to the apex.

Computed Tomography is being used for a new technique to mark the position of the patient's heart apex by using a CT biopsy grid.[15] As seen in Figure 6, a radiopaque grid is used to mark the place of the patient's apex so that surgeons can premark the skin where the apex lies to have a more accurate measurement.[15] The axial reconstruction in particular can show the orientation of the left ventricle's apex, its angle, and the distance from the chest wall.[15] In some patients finding the apex can be simple; however, on overweight patients, physically feeling along the ribs can become a challenge, which is not the best scenario for patients who are having cardiac surgery. Pre operative CT's can be incredibly helpful in visualization during surgery. Even though surgeons cannot physically use CT's during surgery, they can use the scans to aid in the process of finding the patient's apex if the anatomy is atypical and difficult to locate. It can also be helpful in patients with abnormalities in anatomy due to radiation, prior surgery, skeletal deformities, chronic lung diseases, or cardiac abnormalities.[15]

Cannula position is very important for LVAD patients. One study showed a CT scan that was performed to measure for the optimal position of the cannula in relation to the patient's apex. In surgery, the surgeon changed the cannula position to what he/she visually saw, which was deceptive due to the patient's abnormally large heart which was hard to visualize from the thoractomy view. A post op CT showed that the cannula inflow position was more than 50 degrees from what was recommend in the preoperative CT scan as can be seen in Figure 7.[15] During follow up, the patient had many complications including mitral regurgitation, right ventricular failure, renal failure, and pump thrombosis.[15] With increased use of the lateral thorcatomy, imaging modalities have become more important to visualize hearts, and especially abnormally large and rotated hearts. A CT scan shows a more uniform view of the patient's anatomy rather than the deceptive view from a smaller incision for a 'safer,' but more complex surgery. It is important to get optimal positioning for the inflow cannula because of the many problems that can arise if it is out of the optimal position.

Conclusion

Left Ventricular Assist Devices are little-known outside of the cardiac community. The LVAD does an excellent job at supporting the heart for patients who are unable to receive heart transplants, waiting for a heart transplant, and for myocardial recovery. These patients have to take care of and monitor the device daily. With any surgery, the hardware and patient can develop complications, but with new surgery techniques and by using imaging modalities to assist in surgery and in diagnosis complications, the risks a patient may face can decrease. While the LVAD is not a permanent solution to heart diseases, it is a start to bridge the gap between treatments or to extend the patient's life. This allows the patient a more active life since the patient has less symptoms of heart disease that are stopping them from activities with symptoms or hospital visits.

Images

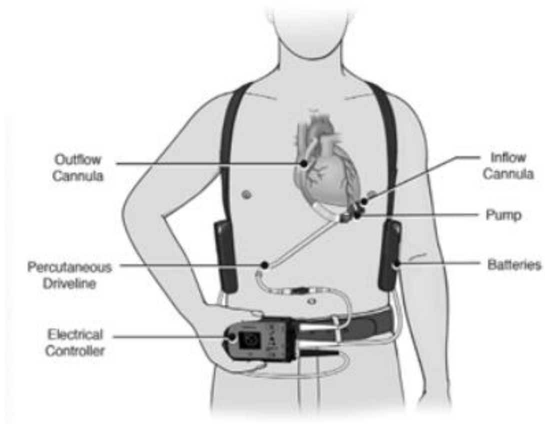

Image 1: Major components of the LVAD inside and outside of the body.

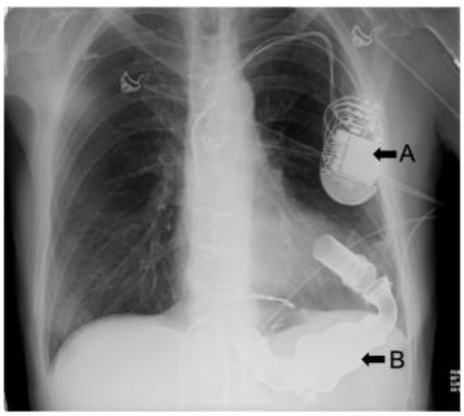

Image 2: The device labeled as B shows an older, larger generation of the LVAD in a patient chest x-ray.

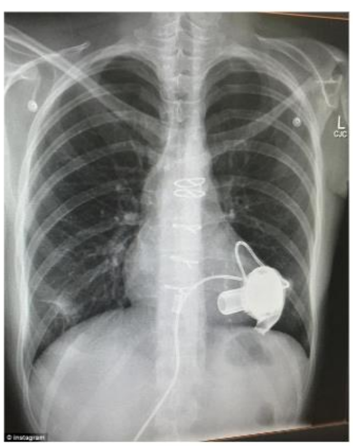

Image 3: Newer generation of LVAD implanted from a patient chest x-ray.

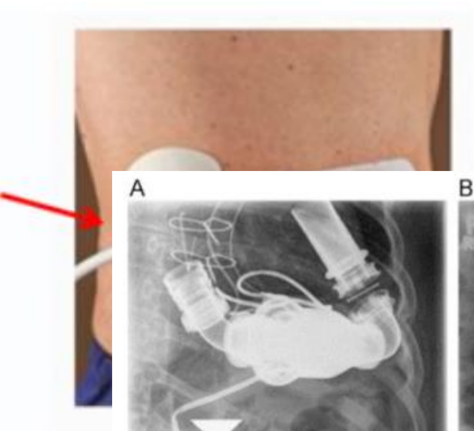

Image 4: The dressing for the driveline include a sterile dressing and an anchor to help hold the driveline in place outside of the body to reduce the chance of it kinking.

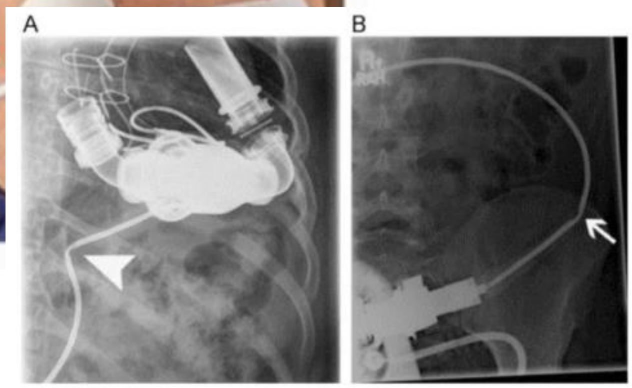

Image 5: Abdominal x-rays from a patient showing kinking in the driveline.

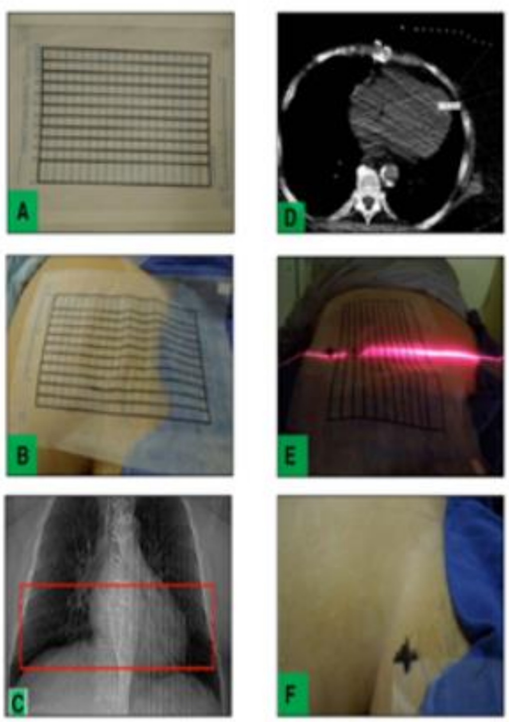

Image 6: Images from a CT biopsy grid to mark where the apex of the left ventricle of the heart sits from outside of the body.

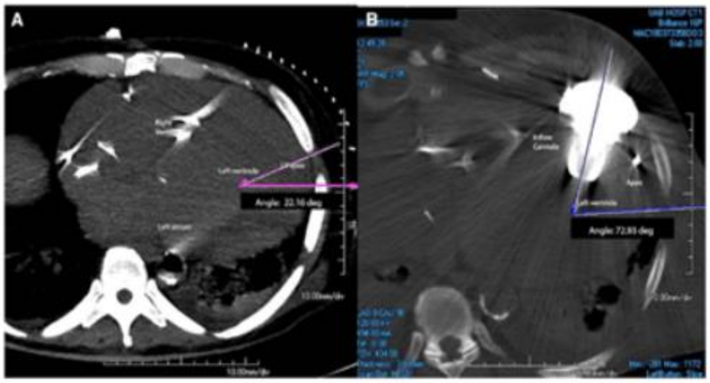

Image 7: Image on the left shows what the CT recommend the angle of the inflow, image on the right shows how the inflow cannula was implanted during surgery which shows more than a 50-degree difference.

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