[MUSIC PLAYING]

JOHANNES BONATTI: Hello, and welcome. My name is Johannes Bonatti. I'm a cardiac surgeon at the UPMC Heart and Vascular Institute. And today I will discuss with you robotically assisted coronary artery bypass grafting.

As heart surgeons, we have for a long time dreamed about being able to offer procedures like our colleagues in general surgery and other disciplines, who developed laparoscopic, endoscopic techniques. And in heart surgery, we also moved into that direction.

And what we really want to achieve is a totally endoscopic version of coronary artery bypass grafting, like you see here on the right side with these portholes, only instead of a standard sternontive, midline incision of the chest.

The first attempts to go less invasive were a little cumbersome. Surgeons, heart surgeons, including myself, we tried to do bypass surgery through small incisions, as you see here, with these special spreaders that you see on these photos. The internal mammary artery, the most important bypass in heart bypass surgery, was harvested, as we call it, through this mini incision with a tangential view. And that was rather cumbersome.

So that's why robotics come in-- robotic techniques come in. The first procedure I want to introduce is robotically assisted MIDCAB. MIDCAB standing for Minimally Invasive Direct Coronary Artery Bypass grafting. That's the procedure I just showed through the mini thoracotomy, but with the aid of a surgical robot.

Here you have a look into our operating room. This is the surgical robot that we are using. It's the da Vinci XI system. That has a patient cart with four arms mounted on that cart. And the robot is controlled by the robotic surgeon from a console. We have two consoles in the room in order to be able to teach and to share these procedures with other colleagues. Other than that, the operating room is essentially the same as in open bypass surgery.

You see the robotic arms, which are covered with sterile drapes, docked to the patient, three of them for the first part of the procedure. Let me just explain here, the robotic arms are docked to these metal tubes, ports as we call them, each of them 8 millimeters. And robotic instruments are inserted in through those ports into the chest.

The mid arm here carries the robotic 3D and HD camera. We are on the patient's left side. And with this port and robotic arm arrangement, we start harvesting the internal mammary artery, which we will use as a bypass.

The patient is intubated with a double lumen endotracheal tube or a standard endotracheal tube. And into that one the anesthesiologist puts a bronchial blocker, as you see here. Because we need to be able to isolate the left lung, that we have enough space inside the chest. We use TEE throughout the procedure. Very important to put defibrillator patch-- patches.

We work from the patient's left side, as I mentioned. The chest is pumped up a little bit. And the patient is prepped and draped as for a regular bypass surgery operation. The portholes go in like this. You see here a triangle is formed with the hands. And where the thumbs meet I put in the first port, which is the camera port. You see that here, a small incision.

Again, these ports are 8 millimeters in diameter. And the left lung is isolated, is dropped, so that I can do that safely. And the first port goes in. And then we insufflate CO_2 at a pressure of 8 millimeters of mercury. And now we have the first view into the chest with the robotic camera.

The robotic patient cart is moved in and the arms are docked to the port, as you see here. There's a special docking mechanism. This docking maneuver takes about three or four minutes with experience. And we insert our instruments under robotic view, which you see on the right side here.

Now, the surgeon sits behind the console, looks into a 3D-HD binocular and controls the robotic instruments, which we have inside the chest here. We see the aortic arch, the phrenic nerve, also the anterior left-sided pericardium, and the pericardial fat pad.

And we start our operation by taking down some fat that is covering the internal mammary artery. And we already see it pulsating here in the back. And before we can take it down, we have to detach the endothoracic fascia from the IMA, which we see here.

We go further, caudally, and split the transverse thoracic muscle, just above the vessel. Then on the sternal side, the connective tissue is removed with electrocautery. And we can then harvest or take down the internal mammary artery in what we call skeletonized fashion, without the concomitant veins.

Smaller branches, as you have seen, can be just burned with the electrocautery, whereas larger branches require clipping, as you see here, the robotic endoscopic clips coming in. And we clip the side branch on the IMA side. And on the thoracic wall side, we again use electrocautery.

The patient-side team has to be very proficient with changing these instruments and also loading the robotic clips. A port protector is used here so that the clips don't suffer any damage during insertion. Sometimes we have small bleedings that can be stopped by compression only, with the electrocautery spatula. And again, larger bleeding sites need to be clipped and then the connective tissue is further cauterized.

The internal mammary artery is a vessel of 3 millimeter in diameter. We give heparin and clip the vessel distally once the harvesting is finished, and divide the internal mammary artery as you see here, and drop it into the chest for auto dilatation. So that's the robotic part of the robotic assisted MIDCAB operation.

We then take out the ports, remove the robotic arms, push the machine back, and work through a mini thoracotomy, as you see here, which is placed on the left-sided chest. A special spreader is also used and a soft tissue retractor. And additionally, this, what you see here, octopus device, a suction device, that helps us stabilize the target vessel during the anastomosis on the beating heart.

You see us here, working through the mini thoracotomy. Again, this is a soft tissue retractor. We work with regular standard microsurgical instrumentation and use a CO_2 blower to clear the operative field. How does that look in a video? You will see here the target vessel is immobilized with the suction stabilizer. And I place a stitch here on the beating heart.

The CO_2 blower clears the operative field. This technique requires training first in open surgery before you can do that in the mini thoracotomy version.

So again, this procedure is called robotically assisted MIDCAB, Minimally Invasive Direct Coronary Artery Bypass grafting. But we don't want to stop here. As I mentioned at the beginning, we want to go to a completely endoscopic version of the procedure here, the last picture on the completed bypass in robotically assisted MIDCAB.

Robotically assisted MIDCAB is done-- can be done for single vessel and multivessel coronary artery disease. Important, the target vessels have to be suited for beating heart anastomosis. Not all of them are suited. And specifically in patients with contraindications for cardioplegia, when they have big hearts that have a very low ejection fraction, we wouldn't use cardioplegia or go for a totally endoscopic procedure, but use that MIDCAB approach.

Caveats, small and diffusely diseased, calcified coronary targets we don't want to tackle on the beating heart. Also, if there is severe aorta iliac atherosclerosis, in those cases, we have a risk of retrograde embolization or dissection if we connect the heart lung machine in the groin, if that is necessary. Those patients are not suited. And patients with morbid obesity. In those, it's just hard to place a small incision and work through that keyhole view.

Robotic TECAB stands for robotically assisted Totally Endoscopic Coronary Artery Bypass, meaning we work through the ports only, and also do the anastomosis robotically. That's the next version of the procedure that I'm introducing.

You can do this procedure on the beating or on the stopped heart. The patient is cannulated in the groin. You see here with a venous drainage cannula and a arterial return cannula, with a side arm. That side arm is important. And I will show that in the minute. And we also use a distal perfusion line to ensure that the leg is perfused during that procedure.

In order to induce cardioplegia, we use this balloon catheter, which instead of a clamp occludes the ascending aorta during application of cardioplegia. You see me here clamping the side arm of the arterial perfusion cannula. The balloon catheter is brought into that sidearm.

Important to turn that screw, that it's not bleeding from there. And then that clamp is removed. And we advance the catheter all the way up to the descending thoracic aorta and then into the ascending aorta.

We connect all our lines, as you see here, the cardioplegia line and the vent line. We then go on hard lung machine and finally position the catheter and inflate the balloon. Adenosine shots are used to induce asystole once the balloon is in place.

You see here that shot of adenosine coming into the aorta root, up here on the right. That snowstorm-like picture shows you that the adenosine is going into the coronary artery-- in arteries. And that leads to immediate asystole, as you see here on the EKG monitor.

Carioplegia is running and the heart is stopped. The next step is we expose the LAD in epicardium and incise it with this lancet here. That's our landing zone for the endoscopically placed bypass. We also use an additional holding forceps here so that we have good exposure.

The LIMA, the left internal mammary artery is incised, then checked for free flow. And then we suture that vessel to the LAD. It's a 7 centimeter, 7-0 polypropylene suture that we are using. First, the back wall is done. And it's very important to apply proper suture tension here, that you have no slings or leaks afterwards.

And what you can appreciate, that we have nice magnification. Again, the coronary artery and the IMA are 2 and 1/2, 3 centimeters in diameter. And we have up to 10 times magnification. We see here how the two threads are pulled so that there is adequate suture tension on the back wall.

You may appreciate that this work is completely tremor free. And you get insights into the anastomosis that you just don't have with your standard loop magnification of 2 and 1/2 or 3 and 1/2 that we use in open surgery. So the surgical robot is also an operating microscope, if you wish.

Ergonomically, this is very attractive. And you see here, also left-handed stitches can be done with the robotic device in a very comfortable, elegant fashion.

The additional joints here on the robotic end effectors make the work so nice. You see how nicely these sutures can be tied. It is very important now to hand everything over to the patient-side surgeon through the assistance port. We open the bulldog, the endo bulldog and see there is no major bleeding.

We can, with the same bypass, by the way, also land on other vessels. So that one bypass supplies two coronary targets. In this case, a diagonal branch. And, as we call side-to-side anastomosis between the LIMA and the diagonal branch is done in the same fashion as you have seen earlier for the LIMA to LAD. Again, magnification and ergonomically very, very comfortable work that you can do on these small vessels.

So a completed LIMA to LAD and diagonal sequential or Chomp graft as we call it. Once we open the flow into that bypass, the heart usually starts to beat. And we deflate the endo balloon. And after a resting phase on heart lung machine, the patient is weaned off cardiopulmonary bypass.

Completely endoscopic-- you see here, ports only, instead of a mini thoracotomy and instead of a sternotomy. TECAB, Totally Endoscopic Coronary Artery Bypass, robotically assisted.

Now the same procedure can be done on the beating heart. I also have good experience with that version of the procedure. Technically more difficult than the last one that I have shown, at least on the sewing of the anastomosis side. But doable, as you see here, with a robotic stabilizer.

So it's similar to the one you have seen in robotically assisted MIDCAB, but that one is a robotic instrument. Unfortunately, that one is currently on hold. And we have to wait until it is back. So currently, the beating heart totally endoscopic version of the procedure cannot be offered. The other one, yes, the one with cardioplegia and the endo balloon. This is a close-up of this endostabilizer, which is currently on hold.

But look at this. A TECAB patient. Two years post-operatively, you can hardly appreciate the scars here of these small portholes.

Indications, we can offer robotic TECAB for single vessel and multivessel coronary artery disease. We can do beating heart. If the stabilizer is available, in the rested heart also at this-- in this current time.

Contraindications, we don't do these procedures in patients with thoracic deformities, such as pectus excavatum, because the anatomy is distorted. When there is dense adhesions, we may need to convert to an open procedure. It's hard to diagnose these pre-operatively. But that explains why reduce are also more challenging.

Severe lung disease is a contraindication because we need to deflate-- isolate the left lung in this procedure. And some patients may not tolerate this. I mentioned before that patients with severe left ventricular dysfunction are not so well suited because they wouldn't tolerate the cardioplegia. And multi morbid patients, we probably do not tackle because it's a longer procedure than the open one, because it's more delicate. And those patients may not tolerate a longer heart lung machine run or longer operation overall.

For the arrested heart, cardioplegia version of the procedure, there are patients who have a dilated ascending aorta, where the balloon would not sit properly. Or patients with aortic iliac atherosclerosis, in those patients, we don't want to connect a heart lung machine in the groin and risk retrograde embolization and dissection. For the beating heart version, again, small, diffusely deceased, calcified coronary arteries we do not do because that-- may need to local dissection of the vessel or even occlusion of the bypass.

So in my own experience, we have pushed this operation in a way that we ended up doing a few cases of even quadruple coronary artery bypass grafting. I just explain here it was bypasses to the diagonal branch and the LAD with a right-sided IMA of that vessel, a RIMA-- sorry, the other one was the LIMA. And the RIMA going from the LIMA down to the PDA, and also vein graft from the left axillary artery to an OM branch, which you see here.

Highly complex, long, tedious procedures. Most of the times when we do multivessel, it's a double vessel bypass with a Chomp graft of the LIMA to the diagonal and the LAD. And also, RIMA to the LAD and LIMA to OM. That is a very doable version of the procedure.

And multivessel disease can also, instead of doing long, tedious, complex multivessel totally endoscopic CABG, you can do hybrid interventions. An example here, a patient who underwent robotically placed LIMA to LAD placement. You see here the patient on post-op day number three. Endo cath lab, nicely patent LIMA to the LAD, filling the distal and proximal target vessel.

You see the chest tube, by the way, and no sternal wires. And this patient with left main disease underwent, under the protection of LIMA, a PCI balloon angioplasty and stenting of the left main coronary artery with a perfect result, as you see here. You also see the stump of the LAD, which is now filled by the bypass.

Doing this hybrid intervention leads to a reduction of complexity. This would be a-- would have been a bifurcation stenting procedure with the endoscopic replaced LIMA in place. The PCI to the left main was relatively straightforward, as my colleague in the interventional cardiology regime told me.

We have also experience with simultaneous hybrid coronary interventions in hybrid operating rooms, where you have a cath lab and a robotic OR in the same setting. And you can, in this setting, check on the patency of your LIMA right away. And also, do PCI in the same setting. We did that in less complex cases, usually where we placed one IMA graft and stented the rest.

Now we can also, if we do it staged, a nicely combined double vessel IMA grafting with PCI. You see here a patient with a RIMA to the LAD, and a LIMA to an OM branch, and a stent to the circumflex coronary artery, an advanced version of hybrid coronary interventions, which can treat complex multivessel disease. And these two IMAs, again, were placed in a completely endoscopic fashion, without cutting the sternum.

We have looked, at my former workplaces, into long-term results of hybrid coronary intervention. The survival at five years was 92.9%. Complex patients included here, and the freedom from major adverse cardiac and cerebral events was slightly above 70%.

That was absolutely in line, both survival and freedom from [INAUDIBLE] with, at that times, published Arts and Syntax trials, the surgical arms of the same, and also very similar to what other groups that did hybrids found. So we can state that this procedure has good long-term outcome.

Also, the one thing to remember is we had 97% freedom from re-intervention on the arterial grafts, where the-- whereas, the re-intervention rate, freedom from re-intervention rate on the PCI part of the procedure was 85%. So some patients who undergo hybrid coronary intervention, robotically assisted, will undergo repeat PCI. That needs to be accepted if you go for that concept.

The long-term patency rate of the LIMA to the LAD was recently investigated by one of my former colleagues, Dr. [INAUDIBLE] and we he noted that was CT-- coronary CT follow up, that at five years, the patency rate was still 95%, and a little less than 90% at 10 years. So absolutely acceptable results.

We were one of the first groups in Innsbruck in Austria, and at that time at the University of Maryland. We published one of the first larger series on robotic TECAB, 500 patients, published in the *Annals of Thoracic Surgery* in 2013.

Now, we did these procedures with an observed to expected mortality lower than predicted and a stroke rate of 1.8%. About one third of these TECABs were new iterations of the procedure. So when we went from single to double pass, then from double pass to triple pass, then to quadruple, and when we introduced complex hybrids. The procedures were relatively safe.

95% of them free from death, myocardial infarction, stroke, vascular complications, and long-term ventilation, requiring even tracheostomy. If we speak about other factors, like re-operation for bleeding, conversion to large incisions due to a technical problem, 80% were free from all these events.

What was interesting for us to see was that the factors predicting success were if you did an arrested heart, single LIMA to the LAD, that's a very safe and successfully performed procedure. Arrested heart TECABs did better than the beating heart ones thoracic assistance, meaning once we introduced new ports to help us get the material in and out, that helped. And non-learning curve cases, of course, where no procedure development was involved.

Safety, however, was purely predicted by the-- at that time used EuroScore, meaning safety of that procedure is predicted by the patient's comorbidities, rather than by technical aspects.

We have recently looked into 25 years of minimally invasive CABG. And there are several versions of minimally invasive CABG. The vast majority of these procedures are MIDCAB operations, the classic one that I showed in the beginning. And one third of the procedures have been done robotically assisted. Again, this is 74 papers analyzed with more than 10,000 patients in the international literature.

So about one third internationally of these procedures, of the less invasive ones, done with robotic assistance. And where were these procedures done or published? Started out in Europe, and also on the US, East and West Coast. There was also one very active center in China.

Robotically assisted MIDCAB, those are the blue triangles-- US, East Coast and South, and also European centers, and some centers in East Asia. Those are the epicenters of development, if you wish.

Now, interestingly, 81% of all these less invasive procedures were done as single LIMA to LAD cases only. So less invasive CABG internationally is mostly a LIMA to LAD placement. The same is true for-- for the robotically assisted MIDCAB. Around 85% done as a LIMA to LAD. The TECAB procedure, however, 72% are single vessels. So meaning almost one third of the procedures in TECAB were done as a multi vessel CABG.

The less invasive procedures take a little longer than open surgery. So overall, 3 hours, 42 minutes. And the robotically assisted MIDCAB is done in a little shorter time frame than the TECAB operation, which takes roughly five hours in the published literature. That's also our experience. It has to do with more technology involved, and due to the fact that more multivessel was done.

Conversion rates in robotically assisted TECAB have come down nicely over the phase of development. Started in 1998. And my colleague Dr. [INAUDIBLE] has published that paper. You see here that the conversion rates came down from almost half of the patients to less than 5% within a 20-year time frame. So that's very encouraging and shows all the technological and procedure development that has happened.

The mortality in less invasive CABG overall, published in the literature, 0.9%. For robotically assisted MIDCAB, 0.4%. For robotic TECAB, again a more complex procedure with more multivessel, 1.3%. Stroke rates overall, 0.6%. For robotic MIDCAB, 0.4%. And for robotic TECAB, 1%.

How is that procedure or robotically assisted CABG distributed, spread over the US? The STS, the Society of Thoracic Surgeons database was analyzed-- or this was published in 2016, after an analysis in this big database.

Essentially, in roughly 100,000 CABG procedures a year, only slightly more than 1,000 are done robotically assisted, meaning 1% only. So slow adoption overall, even though there was an increase over 10 years prior.

It's interesting to see that it's not spreading more, because the results are good. Also, in this analysis here, we see that the bleeding was slightly more in the robotic cases, whereas stroke was 0.5%, as compared to 1.1% in open procedures. Prolonged ventilation, 5.6% in the robotically assisted, 8.6% in the non-robotics sternotomy cases. Renal failure, 2.2%, versus 2.9%. And hospital stay was four days only for robotically assisted cases and five days for non-robotic cases.

To keep in mind that only one graft was placed in the robotically assisted cases on average, whereas it was 3%-- three grafts in the non-robotic cases. A little more complex patients in this group of patients that were done through sternotomy, but overall the results are very satisfactory with a robotic approach

I'm also part of a European working group on robotic cardiac surgery. And let's see what is done across the Atlantic. Over there it started earlier. In fact, in 1998, the first robotic TECAB procedure was done in Paris, the first one worldwide.

After that, we saw a bit of a hype, but then a decrease in procedures again. Had to do with also slow adoption, expensive technology, long learning curves, et cetera. But since 2013, we saw an exponential rise in procedures again, a renewed interest, with the new fourth generation version of the robot and surgeons becoming interested again.

Also, over there in Europe, out of 2,563 cases done over-- sorry-- over four years, half of them were robotically assisted CABGs. A little more than one third was mitral valve and tricuspid valve surgery. You can also do ASD closures, and myxomas, and some arrhythmia procedures. But those are a smaller segment. The vast majority were robotically assisted CABGs, specifically MIDCAB procedures.

Let's look into the results in that group of patients. Skin-to-skin operative time, a little more than three hours. Remember, most of them were robotically assisted MIDCABs, LIMA to the LAD. Those take a little less time. But a very small conversion rate of only 2.6%. Revision for bleeding, very favorable, 2.1%. Overall in CABG, in open CABG, the revision for bleeding rate is usually in the 2.5% range.

Stroke-- no stroke whatsoever in this group of more than 1,000 robotically assisted CABGs. Hospital mortality, 0.6% only. And you can see that here also, on this graph, in the whole group, and specifically in the CABGs, the blue line is the predicted mortality.

The observed mortality was significantly less than what was predicted by the Euro score risk assessment tool. The observed to expected mortality was 0.4 only. So very satisfactory. And we can state that the procedure is safe, as all these data have shown.

The advantage, even more than reducing hospital stay, is that patients are back to normal activities much earlier. We can state that around three weeks post-op, these patients really are back to normal activities. You see here a patient after robotically assisted TECAB lifting weight in the gym as early as three weeks post-operative. The patient kindly sent me this picture.

The sternum is not cut. We only have ports on the patient's left side. That's the reason why he can do that. And these small wounds have just healed faster than a midline sternotomy, which is done at most places in the world.

We look into this very carefully, and in our own patients now, they state that they start household activities nine days post-operatively, and driving, and doing essentially everything around the house within a little more than two weeks. We are also getting quality of life scores according to the EQ-5D in these patients.

And you see here that pre-operatively, the overall score is 0.83. And the highest score that can be achieved is 1. And you see here that after four weeks, the patients already reach 0.92, a score of 0.92. And after three months, the score is 0.94. So within four weeks, they jump almost to what they can achieve after three months.

There's interesting times coming up for us as robotic heart surgeons. Until now, it was one type of surgical robot that was used. But there are several-- in fact, nine new companies coming up that offer robotic devices, as you see here.

Most of the new ones are modular devices, where you don't have robotic arms mounted on a patient cart, but several columns standing around the patient. And each one of them carrying a single robotic arm. They are also new console technologies, console versions. Most of them have flat screens now, with the surgeons, as you see here, wearing goggles. And these robotic devices, new robotic devices will be tested. And we are very curious how they will function.

Also, robotic surgery has the advantage that it includes computer chips that can function as carriers for integration of artificial intelligence. And also, big data, et cetera, is something that can be applied in the field of robotic surgery. And that, I think, is the feature that will eventually lead to the breakthrough of these devices.

I am a very enthusiastic robotic surgeon. And I just believe that this is the future of surgery. It has helped us to offer patients a much less invasive completely endoscopic coronary artery bypass grafting procedure. The future is bright. And it was a pleasure discussing this topic with you. Thank you very much for your attention.