Medical Image Analysis
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Lecture 23
Computer Vision & DL in the Operating Room

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Hello guys, I am Doctor Vinayak. I am a surgeon. I am General laparoscopic surgeon and I am doing my advanced fellowship in pediatric and neonatal surgery which is basically operating on small humans. And I also run a deep tech startup called Curium life where we try to solve real time problems in surgery using machine learning and deep learning. And we work closely with IIT Madras and Professor G K at the MIRL. So, I am just going to be talking about how to solve certain problems in the operating room using computer vision and deep learning.

So, my series of lectures is going to be just an analysis of it is going to be a series of case studies basically, where we are going to look at successful examples of how certain startups have leveraged the power of deep learning to solve problems in surgery, and how deep learning has actually made a direct impact on patients lives and improving the quality of outcomes in surgery.

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So, before that, you will need a little bit of an idea about what actually goes on in the operating room. The operating room, as a lot of you might think is not some sort of steely grey chamber, as you see on a web series such as Grey's Anatomy or MASH. So, it is a place where humans are there, the surgeons, the anesthetist the nurses, they are all humans, they all have limitations and biases, which all humans possess. And using terms such as surgical precision or all a little bit of an oxymoron because surgeons are also not as precise as you think they also have their own bias, they also have their own error rates and each surgeon is very different.

To assume that you are going to have an excellent outcomes just because you are going in with a very experienced or a name surgeon is also a little bit of too much to ask too much of an expectation because complications and problems do catch up with every surgeon statistics. Ultimately, statistics do catch up with everyone. You must have also heard of the famous joke where the surgeon says 99 percent of patients do well after the surgery, just 1 percent suffered a major complication. And he says, I finished 99 cases successfully. So, you might be the case with the complication.

So, that is what so I mean, it is that is not how things work in real life. But the fact is that at some point of time, statistics catch up with most people. And more or less, they also do catch up with surgeons. So, the fact is that right now, for the past 100 years, we have been told to accept that complications are inevitable. The last 10 years have been very different because there are been a group of surgeons, a group of scientists, experts in deep learning, machine

learning and with the advent of AI, these people have started challenging that popular notion that complications are inevitable.

They are trying to change things using deep learning and one of the ways they are changing is to leverage the experience of thousands of surgeons using the power of deep learning. So, at Curium life, we are also trying to develop a model in to make surgery safer for surgeons without much experience. This is including in the developed nations, such as the US or the UK, where due to lack of volumes of cases, surgeons do not have access to enough clinical material. So, the sad fact is that the surgeon who is going to operate on you might not have seen enough complications or enough variations or changes in the surgical anatomy before he gets to operate on you.

So, using the power of deep learning, we are trying to leverage the experience of thousand surgeons who have operated thousands of cases before this particular surgeon and use that makes surgery safer. At the same time, we are also developing models to evaluate surgical performance objectively in terms of how good the surgeon actually is. And using this we are not doing just to judge surgeons or give you say that the surgeon is bad. This serves as a means of training as a means to improve the levels of surgical training all over the world. With the mushrooming of numerous training centers all over the world, access to healthcare has become as real the last mile in most parts of the world.

That is a good thing from a very public health point of view. But to understand that from a training point of view, the training loads of surgeons, surgeons these days are operating much fewer cases in their training period than surgeons 50 years ago. Technically this results in less technically sound surgeons and that is a fact which you have to be afraid of and the last 10 years has been revolutionary because using the power of deep learning we are trying to change the scenario again. So, going back to the operating room, so there is a surgeon and a surgeon has a team.

There is one person who is the chief operating surgeon he has an assistant, sometimes two or even three who assist him with during the surgery and then there are the surgical nurses. The surgical nurses help around a assisting a surgeon giving him the instruments and they are asking to the surgery as a surgeon themselves because they are the people who are very intuitive and they know what steps to do next and what instrument to give next. This is the seizure team, anesthesia, the anesthetist is actually the leader of the surgical table because he controls the entire theatre process.

The surgeon he or she takes care of the headend, we call the headend as place where the anesthetist sits around he intubate the patient or if he is doing spinal anesthesia, he gives the spinal anesthesia and make sure that the patient is pain free, his vital parameters are controlled and there are the anesthesia nurses who help around with anesthesia and then the circulation nurse who basically tries to give things whatever you need to the surgical team or the anesthesia team.

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One of the major problems in surgery is hemorrhage. In common man terms, hemorrhage is nothing but blood loss. And when you are talking about blood loss, blood loss can be due to a variety of reasons which we will be discussing later. But the major means of dealing with blood loss is blood transfusion or fluids infusion, why does blood loss affect us so much? So, we have to understand what is blood? Blood is essentially in the form of RBC red blood cells. So, what do these carry, they carry hemoglobin. And in these hemoglobin, we have oxygen attached. And basically, this RBC travels in the blood vessels and deliver oxygen to the tissues. When a patient loses blood. When there is an injury, when you actually cut open a person with a knife, he loses blood, there are major blood vessels running all over the body.

And when these blood vessels are injured or when there is bleeding, what happens is the oxygen carrying capacity of the human body decreases to a certain extent. When there is no oxygen to vital organs, such as the brain, the brain can actually shut down. When there is no oxygen going to the kidneys, the kidneys actually shut down. And the patient coming out or

recovering out of the surgery might have survived the surgery from a technical point of view, you might have actually treated his cancer condition by operating on him.

But if the blood loss has been significant and the blood loss has been consistent over a period of time, if he has lost enough blood, it also means that he may never be able to recover from the loss of blood to certain key vital organs. So, an essential part of the surgeon and the anesthetist is to make sure that blood does not keep flowing and that the blood loss is arrested. There are many ways to arrest blood loss.

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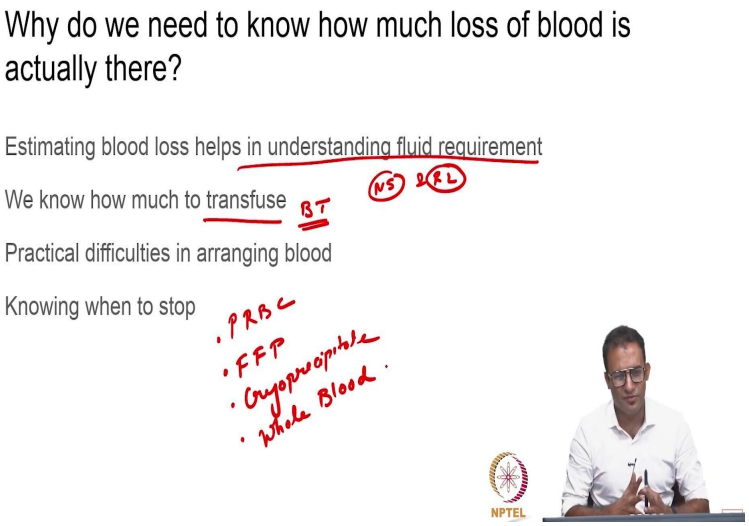

So, before that, we will have to evaluate how much of blood loss has actually happened. So, estimating blood loss helps us in understanding the fluid requirements. The fluids can be of various types, we call them as normal saline or ringer lactate. These are all technical stuff, all of them have their own certain uses, what kind of fluid to use in what situation but the best way of making sure you do not transfuse blood with minimal amounts of blood loss you try to compensate them with fluids. But if a significant amount of blood loss has happened, the best way to do it is through blood transfusion.

Which in layman terms or even in surgical terms is called as BT. When you say blood, it does not just mean whole blood, you just do not take a blood from a donor, keep it in the fridge and bring it out to transfuse, blood undergoes a variety of processing techniques. So, what we actually transfused today when somebody even your relative or your friend who needs a surgery or has undergone trauma, undergo something known as a blood transfusion, what he is actually undergoing is a blood competent transfusion. So, when they say blood transfusion,

it is a very generic term. There are many types of blood products such as packed RBC, which we call as PRBC.

Fresh frozen plasma FFP. There is something called as Cryoprecipitate. Sometimes in major trauma we might need to transfuse whole blood. Blood transmission also takes time. It is not just that the patient needs blood immediately and you can actually transfuse into blood. Sometimes you do not go into surgery anticipating blood loss. But as I told statistics do catch up and if there is a 0.1 percent of chance of a major hemorrhage happening. Sometimes it does happen. It is not always Murphy's Law, but it sometimes does strike you and hit you and blood transition needs to be done.

And at that point of time, in smaller hospitals, you have to understand India is a big country 95 percent of operations 95 not 99 percent of operations happen in smaller hospitals in smallest parts of the country. Operations happen in Dindigul, operations happen in Gorakhpur, operations happen in Dharwad. In small villages also have operating theater small villages also have advanced equipment such as laparoscopic but most small hospitals do not have ready access to a blood bank. So, understanding the amount so, at this point of time, you have to understand that blood is expensive to procure blood is not an easy task.

Also, we have realized the fact that you should not keep your threshold to transfuse blood very low because blood is a precious commodity, we generally Indians do not have an habit of donating blood on a regular basis, blood banks all over this country, let me tell you all over the country, especially in underserved part of the country, blood is in huge shortage. So, we have to be very rational about when to transfuse because blood transfusion is also not a magic bullet, it is not a server of Nivaran it does not solve all sorts of problems. So, because blood also has its own set of complications.

So, we also have to know if the bleeding is too much. There have been times even I have taken the decision, when the patient is bleeding too much and I am not able to control it, we just I do a lot of abdomen surgery. So, I open the abdomen and I actually operate on patients sometimes a patient suffers from a clotting or bleeding disorder intraoperative you might not have injured any blood vessel, but even one small injury it just stops it does not know how to clot and at that point of time, you have to know when to stop, you cannot keep on operating like a madman if the patient is bleeding continuously.

So, it also tells us surgeons when to stop. So, on a lighter note when surgeons discuss what is the grade of bleeding? they divided into various grade, the first grade is when will this bleeding stop? The second grade is why did I operate on this patient? The third grade is why did I become a surgeon? And the fourth grade is why I was ever born? So, bleeding. For to you it might look like I am some sort of a very confident surgeon who operates on major cases on just one cases. But the fact is that every surgeon at some point of his time has encountered a bleeding, a major hemorrhage which he has not been able to stop and every surgeon if he has operated reasonably enough in his life has to go through all these four stages because that is a part of life and that is something which you have to accept.

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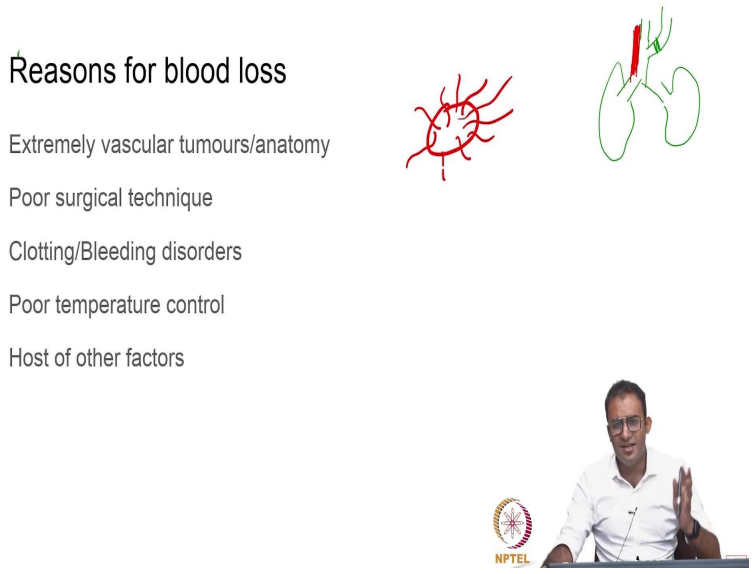

So, what are the reasons for blood loss? We have to understand there are multitude of reasons for blood loss it is not just that the surgeon is an incompetent surgeon or the anesthetist does not know how to control the blood pressure. You just cannot blame this thing or you can say you can just cannot say that the patient has a bleeding tendency there are multiple reasons. So, when we are operating surgeon certain surgeries are prone for high blood loss if you are operating uncertain vascular tumours.

I mean in many, many of the brain tumours are extremely vascular. So, if there is a tumour it is supplied by a multitude of blood vessels and these blood vessels arise from major sources or may arise from the bed of the tissue. These extremely vascular tumours which have an extremely vascular anatomy, when I mean vascular I mean that it is supplied by a lot of blood vessels. So, these tumours these vascular tumours are when you are operating on these, they

are extremely prone to blood loss. So, the moment you start cutting open, you will see that the entire abdomen or the entire chest is filled with a pool of blood and that is extremely disheartening.

Next is the anatomy. Certain regions generally are prone for bleeding if you operate on the face, especially if you are doing a tumour on the parotid region. Parotid region is a cheek region, there is a gland called the protein it is prone for tumours or apps this area is supplied by a lot of blood vessels. So, if you are operating on these particular areas, you are prone to encounter a lot of blood vessels. And if you are operating, saying you are operating doing a tech use of tracheal fistula, so, just a thing, I am going to talk about tracheal fistula because that is a significant part of what I actually do in my in my practice.

I tracheal fistula is a connection in the newborn between the trachea and esophagus. If this is the trachea, the trachea goes to the lungs as bronchi so, sometimes what happens is that the esophagus, esophagus is the food pipe it ends up joining the trachea. So, when you have this particular condition, you have to disconnect the esophagus and join it to the lower end of the esophagus or else whatever milk the newborn kid is having it might go into the lungs and basically it causes the child to aspirate and die or very painful and very early death in life. And even if the baby survives is going to suffer from lung problems and infections throughout its life, throughout its short life.

So, it is a very complex surgery, which we perform in neonates born one in the first day or second day of life, and when you are operating on this region, there are certain major vessels as a gas vein, small blood vessels in the neonate. These are major blood vessels, but these appear to be very small. And if you actually induce these blood vessels, you run the risk of major bleeding. And the fact is that the most important blood vessel in the body, what we call as the arterial blood, the Aorta, the Aorta also passes very near to all these regions. So, if you end up injuring the Aorta or if you end up cutting the Aorta, instead of cutting the esophagus, you have literally signed the death warrant for the patient or for the child.

So, it is very important to understand the anatomy to proceed with caution when approaching these tumours post-surgical technique. Training, like in any other field is a major issue. A poor surgeon will struggle to understand anatomy will struggle with a surgical technique. Surgery is as much as an art as it is a science and you need a solid amount of technique to execute a surgery well. A lot of surgeons suffer from clotting and bleeding disorders,

whereby the physiology itself is not amenable for clotting and bleeding. Poor temperature control.

In many parts of the country, during winters or in the western world, patients go in for hypothermia. Hypothermia is basically the body temperature becomes too low. It can also be because of the IV fluids which you are putting if these fluids are not warmed, it can result in hypothermia. It is very well understood that the hypothermia is a major problem affecting surgical patients. And it also means that it also affects the clotting factors and it can lead to a lot of bleeding. There is a host of other factors including very high BP. That is very simple to understand. If the BP is high, the pressure in the pipe is high, the pipe is going to leak. So, it is going to cause excessive bleeding, and the bleeding does not stop.

So, there is a whole host of factors. But the fact is that bleeding is a major problem. And at this stage, I think that is more than enough to understand the operating room is a constant conflict zone.

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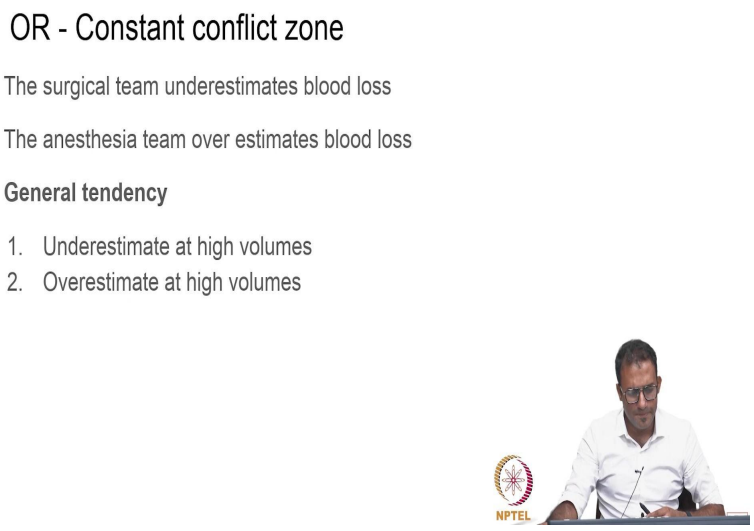

So, the surgical team constantly underestimates the blood loss because they are operating and they are going to be blamed, they take responsibility for the patient, they are going to be blamed for the bleeding and they also do not want anyone to undermine the technique. So, you might see an entire lot of blood 100 ml blood loss and the surgeon will say operation completed with minimal blood loss 25 ml blood only and if the surgeon is very senior, nobody is actually going to have the guts to even disagree with him.

The hierarchy in surgery is pretty high let me tell you. The anesthesia team tends to overestimate the blood loss because they want to constantly put down the surgery team they want to tell the surgeon, boss you are not doing a job well, we are doing a very great job at making the patient all right. So, the patient is doing well despite your incompetence so, the anesthesia the OR is a very constant conflict zone where both of us are trying to distinct. So, the general tendency this is through many scientific papers is that blood loss is underestimated at high volumes and over.

So, the general tendency is to underestimate high volumes and overestimate the blood loss at low volumes.

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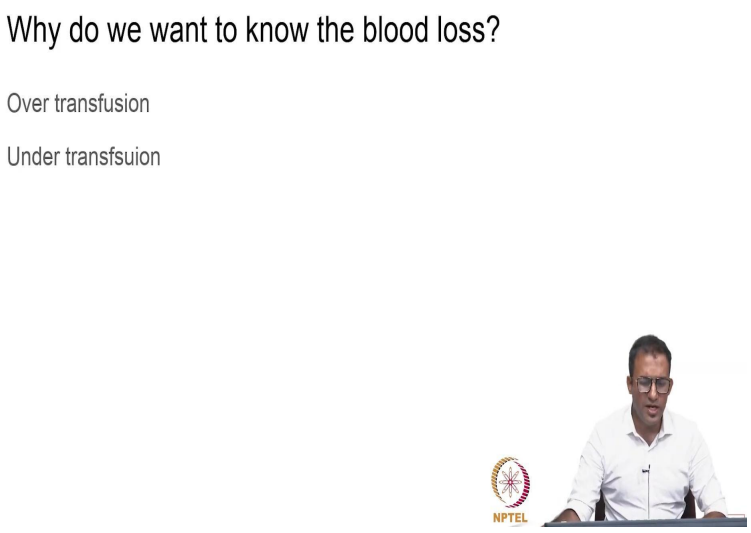

So, why do we want to do the blood loss? I think we have spoken about it. We do not want to over transfuse blood transfusion has a significant amount of side effects. And we do not want under transfuse because we want the transmission to be optimal.

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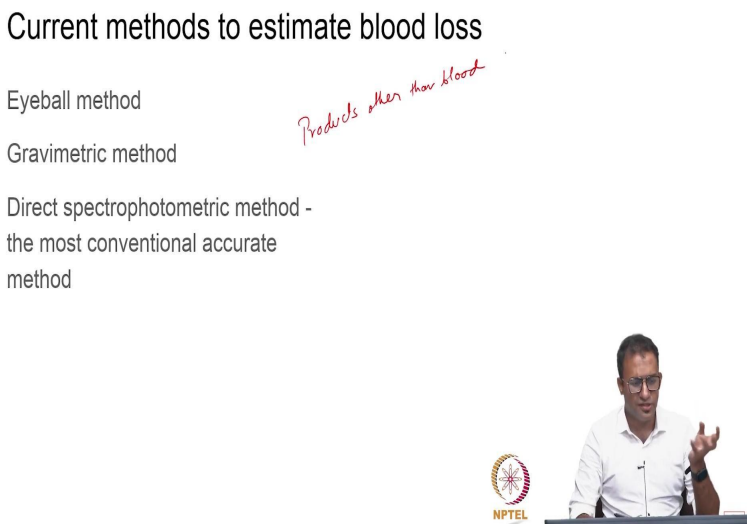

So, what are the current mystery methods to estimate blood loss? The most common method is the eyeball method, where we look at it and just to make an approximation, one part is gone 30 ml, 50 ml blood loss. So, this is the most common method followed in India, including in the biggest hospitals in the country. What is the gravimetric method? Gravimetric method is measuring the amount of blood loss using measurement of the sponges. So, before the so what do we to address blood loss? We use sponges, abdomen sponges, basically cotton sponges, we keep them in the abdomen or in the chest or wherever we are operating. And we that absorbs the blood and we then we throw that away. And then what we do is we measure the amount of the weight of these sponges.

So, we have measured them before we put them in the abdomen and then we measure them after we get them out. So, it gives us an amount about how much of blood loss is the same. But the problem is that inside the abdomen there are extra sanguineous fluids where I mean extra segments fluid, sanguine is just a complex Latin term to talk about blood when I mean extra sanguineous fluids, it means products other than blood.

What it could be? It could be acidic fluid, acidic fluid is just fluid in the inside the abdomen. It could be just plain water we use saline to wash a lot of things during the surgery for a lot of others stuff. So, it could be certain medications which are putting inside the abdomen or to clean certain tissues. So, it could be a lot of stuff. So, the major problem with the gravimetric method in many developed parts of the world they use a gravimetric method, but the fact is that the gravimetric method itself is inaccurate. The most accurate among the conventional method is the direct spectroscopic method.

So, when you are talking when as we go through it, I will be explaining the direct spectroscopic method also, but it is through visual analysis using spectrophotometry where we analyze the blood products basically using spectrophotometry and tell us the hemoglobin content of this.

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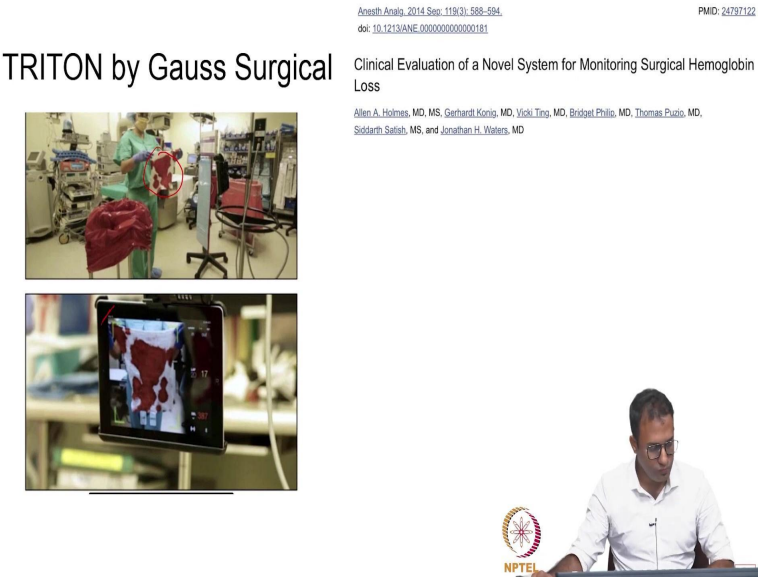

So, today's case study is of a successful surgical startup called Gauss surgical. It was founded by Siddharth Satish he is an engineer, a deep learning expert, and the product was called TRITON. Now, Gauss surgical recently has been acquired by Stryker as of July 2021 and Siddharth has become vice president at Stryker. Gauss surgical use a very simple technique, it uses techniques of computer vision and deep learning to analyze the sponges which are coming out as you can see, in this particular image, you can see that these are the surgical sponges, which the operating nurse is holding.

So, she is holding it in front of an iPad. This particular device is an iPad 2, they use an iPad and they also won the Apple design award in 2018. So, usual, using just plain visual analysis using computer vision techniques and applying deep learning algorithms, they have been reasonably accurately able to estimate the amount of blood loss in each sponge and overall gives us an idea about the total blood loss.

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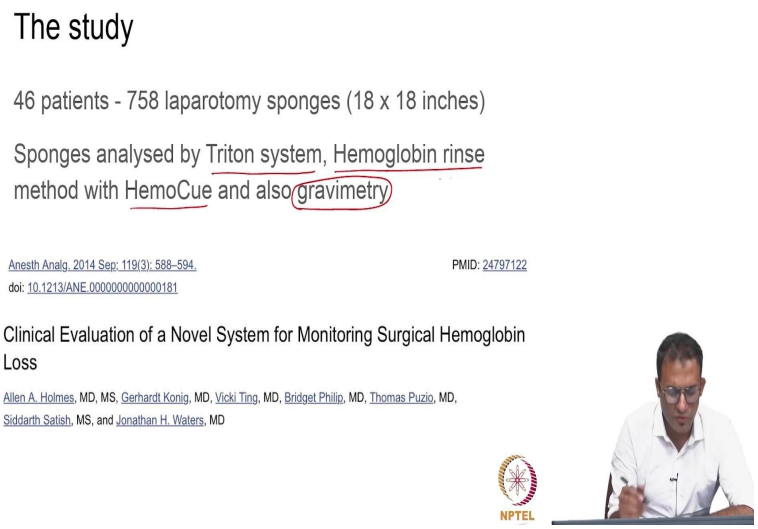

So, this was one of the early studies in 2014. It was published in anesthesia and analgesia, one of the leading journals in the anesthesia and medical space. So, it is performed in around two centers in California, two leading surgical centers and there were 46 patients who underwent laparotomies. Laparotomy is opening the abdomen for various for surgeries. And there were 758 laparotomy sponges each of them 18 cross 18 inches.

And these sponges were analyzed by three different systems. So, one was the product, the Triton system, the second was gravimetry, which is the conventional weighing method. The other one was the current gold standard, the hemoglobin rinse with HemoCue. The gold standard method definitely is a very time staking method. And that is the problem which Triton is trying to solve.

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Because time is of essence here, when a patient is losing blood, you do not want to take 2, 3 hours to try to estimate the amount of blood loss. So, we will be looking at all the methods one by one. So, as I told you about Triton, the nurse collects all the operating sponges and shows them in front of a camera system powered by an Apple iPad 2 using computer vision and deep learning algorithms.

Of course, I am not going to be delving too much into the specifics of the deep learning algorithms and the computer vision tools they have used. So, using these particular images of these sponge they have been able to identify the amount of hemoglobin loss. The second method is gravimetry basically, where you measure this sponge before it encounters blood and then you measure this sponge after it encounters blood and then you try to estimate the hemoglobin loss.

The third method, the gold standard method is using the HemoCue system, which is a spectrophotometric analysis of the hemoglobin loss. So, basically what you do is they crush the sponges using a mechanical technique and using the effluent which comes out this is analyzed by a Swedish system which called the HemoCue plasma or low hemoglobin analysis system. So, the formula is that measure hemoglobin using certain content, the formula is measured hemoglobin is equal to hemoglobin of the effluent into the volume of the effluent. So, this gives us the gold standard. So, when comparing the results of the Triton and the gravimetric analysis to the gold standard.

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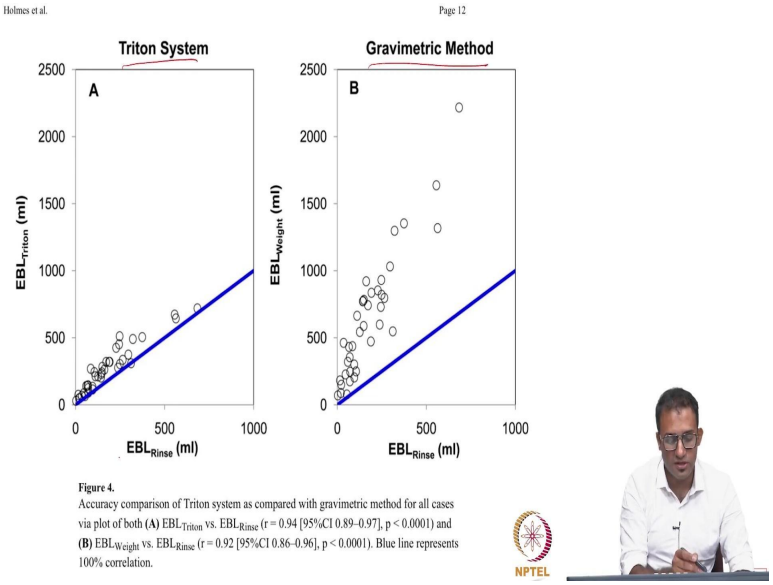

They found that this blue line indicates 100 percent correlation. So, this is the Triton system. And this is the gravimetric analysis. They found that accuracy of the Triton system correlates much more in this particular plot compared to the gravimetric as you can see here.

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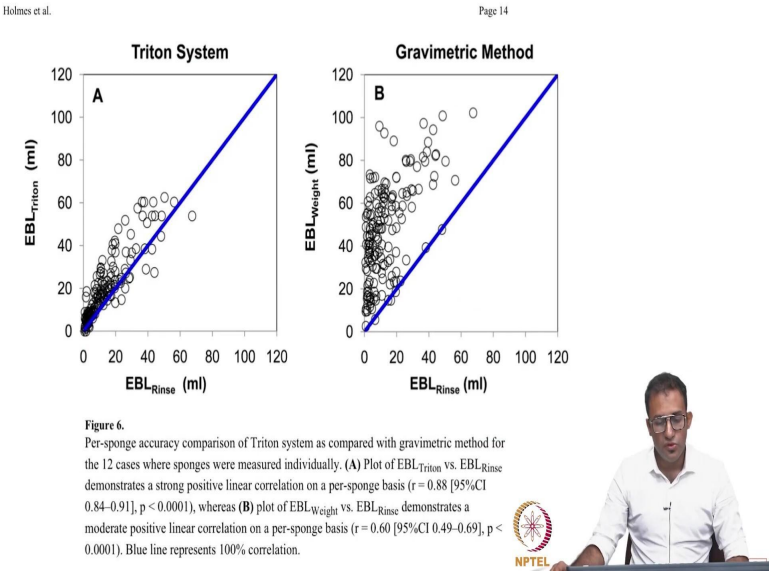

So, this is another similar plot where they compared these first sponge accuracy of Triton along with the graph gravimetry and again, Triton seems to be much more accurate.

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So, Gauss surgical won the Apple design award at 2018 and a few years later in 2021. During the peak of the pandemic, Stryker also applied Gauss surgical for a significant amount of money. So, the learning here is that Gauss surgical tackled a problem, which was a burning problem in surgery, patients have been losing blood for the past 200, 300 years. This is a 300 year old, 400 year old problem. From the advent of modern surgery, since the time surgeons actually started operating on patients hemorrhage and bleeding has been a major issue. And these guys had Gauss have actually ever leveraged the power of deep learning to make sure that a system and accurate system to analyze the amount of blood loss has been discovered.

So, the real challenge which deep learning investigators have been founding startups are trying to create or trying to find solutions to problems is that they often do not end up trying to analyze problems which are actually burning in the industry. A good correlation and a good repo with the clinical team is a must because we want to find out what actually is the problem plaguing surgeons. The other thing is that most of researchers, they go into areas which have been already analyzed, dusted and done. If you are looking into pathology majors for a lot of stuff, it is a very interesting area where a lot of research already has been done.

But the fact is that a significant amount of the research has already been commercialized. One of the final frontiers which we have in computer vision and medical image analysis is the analysis of intraoperative imaging, intraoperative videos. And I think using these images and using these systems to analyze surgical performance to improve surgical outcomes is a frontier which is yet to be explored. And I hope you guys learn from these sessions to create

your own ideas and discuss with surgeons and physicians to try to understand what sort of problems they are facing and come up with solutions to help you solve these issues.