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BRANDON YUAN: My name is Brandon Yuan. I'm one of the OTS trauma consultants. And so I'm going to talk about something relatively specific, more than the title of the talk would suggest. Basically, something that I tell the residents-- why the femur is a special bone, or-- as one of my mentors told me-- why the femur is a magic bone, and what that has to do with taking care of orthopedic injuries in a polytrauma patient.

So a little bit of history. We'll describe the history of management of lower extremity long bone injuries in a trauma patient, understand the relationship of long bone fracture, specifically femur fractures, to the overall physiology of the multiply injured patient, and what is the rationale for using early versus delayed definitive fixation of a femur fracture in 2019?

So in the 1960s-- actually, before the 1960s, even-- nailing or incrementally nailing of long bone fractures was done initially over in Europe. And then this guy, who was still doing cases occasionally when I was doing my fellowship in Seattle, Dr. Hansen, was one of the first people in North America to put a nail or rod inside someone's femur. And he did it in a patient that-- he tell still tells a story. He was a third-year resident at the time, had just been to Europe and watch Küntscher and those guys put nails in over there, came back, was in Seattle, and had an 18-year-old female patient who was sitting in the ICU in traction with a femur fracture, and said, hey, I think this would benefit this patient. And the staff who was with him at the time said, if you do it, don't tell me about it, because I don't want to be responsible. So he took the patient to the OR himself, put a rod in, and she luckily got better, and healed her femur fracture.

And since then, from the late '60s into the '70s and the '80s, Seattle, specifically, or Harborview Medical Center, became the place where they did the most femoral nails for four fractures, and then ultimately from there changed the entire practice of taking care of femur fractures in North America.

So before that, people thought that early nailing of femur fractures was something that was dangerous to do, and that the patients were basically too sick to go to the operating room-- these multiply injured patients that had femur fractures-- and you would make them worse by taking them to the operating room and putting a rod inside their femur. The thought was that the femur fracture-- of course, the femur is full of all this marrow, which has a high concentration of fat in it. You put a rod inside the bone-- which, at that time, the rods weren't even reamed-- and you just put this wood hammer-- you cut it to length and just [INAUDIBLE] the thing into the bone-- would cause a massive amount of fat emboli, which was dangerous for the patient and would kill them. And so patients were frequently treated, then, in traction, in something like this, for their femur fracture, for fear of causing more damage with surgery.

It wasn't until like the 1980s when Dr. border said that the traction was actually probably the thing that was causing the most harm. And a quote from him was that "traction produces an obtunded patient in the enforced supine position," which was only making all these sick, multiply injured patients worse, and not better, as they sat in bed in traction to heal their femur fracture.

Now, the thought at that time changed slightly, from that fat emboli was happening only when you put the rod inside the femur to that maybe fat emboli was an ongoing phenomenon, and that as the patient sat him bed in traction and the broken femur moved around, more and more of this marrow contents was being forced into the venous circulation and causing ongoing embolization of marrow contents, which was causing ongoing damage to the patient as they sat there in traction.

And so this guy, Larry Bone, did a prospective randomized trial back in the '80s about whether or not we should fix femur fractures early or later. Should you go ahead and take them to the operating room, going against what the dogma was in the early '80s saying that we should not fix them early, and go ahead and fix them before 24 hours, or they would randomize into fixing them after 48 hours. The story I was told about this study is that Dr. bone himself actually went by and drew all of the blood samples that were done for these patients by himself, individually, every single time a patient was enrolled in the study.

At the time, of course, femur fractures in general were considered to be a bad deal. So basically, in the '80s, if you had bilateral femoral shaft fractures, your in-hospital mortality was about one third. So almost 30% of those patients died. And unilateral femur fractures-- this, to me, is even more surprising. Unilateral femur fractures, more than 1 in 10 of those people were dying in the hospital.

So what did you find when you did this? Basically, through some statistical methods that probably wouldn't get past most peer review at this time, but in 1989 showed that patients that got early fixation compared to delayed fixation had less pulmonary complications, less fat emboli syndrome, less pulmonary embolis, less pneumonia, less days in the ICU, and less days in the hospital, which changed the practice of nailing femur fractures in the United States entirely. The focus shifted from delayed fixation at that time to doing early fixation of femur fractures, including early definitive fixations-- so placing rods inside femur fractures the night the patients come into the hospital, and stabilizing them as quickly as possible. Because the thought was that you would reduce their actual ongoing fat emboli and reduce the days they would spend in the ICU, and then reduce their pulmonary complications.

So the question then became, is an early intramedullary nail the right answer for every single patient? And it came clear as they were putting more nails in patients earlier that certain patients, particularly patients that had chest injury with pulmonary injury and patients with head injury, were maybe not benefiting from getting their femur rodded immediately. A couple of studies came out after that-- this is into the '90s now-- showing that the risk of ARDS and multiple organ failure, not just pulmonary complications, actually increased with early intramedullary nailing. And when they say early, this is like within 12 hours of getting to the hospital. Basically, the patient's coming into the emergency department. They're going to the ER very quickly afterwards to get their intramedullary nail for their femur fracture.

The other thing people notice about that is that potentially, patients with head injury were also doing worse. There's a couple of studies from back in the '90s about this, none of which had great measurements long-term of how a patient functioned neurologically. But certainly by discharge Glasgow Coma Scale, patients were doing worse, potentially, with early definitive fixation of their femur fracture.

So then the question becomes this-- is there something about nailing a femur fracture that causes or it makes worse a lung injury and predisposes a patient to a significant problem with their lungs or getting ARDS? And what is the relationship between putting a rod in someone's femur and head injury, or potentially making a head injury worse? And why is the femur, then, such a special bone?

So if we back up a little bit, this is going to be stuff that you guys know better than I do, mostly. But if we talk about just multiply injured patients in general, trauma with or without a femur fracture leading to hemorrhage, eventually leading to hypoperfusion of end organs or shock, initiates the inflammatory cascade. So this was the initial thought that people had of why these patients that are getting their femur fractures nailed early were potentially doing so poorly-- is that they had this initial hit from the trauma itself, which could be with a femur fracture, it might be without a femur fracture-- but resulted in this large inflammatory response around the body. And that inflammatory response is exaggerated. It's too much, and can actually lead to end-organ damage in and of itself.

So looking at it graphically, this is something showing that if there's a potential patient that has a severe injury right off the bat, and they have a very large inflammatory response from the injury itself, bypassing this supposed threshold for developing things like ARDS, it seems to be that the lungs are some of the first affected things by the inflammatory cascade after trauma, multiple organ dysfunction, and bad complications and even death.

So what about this patient, though, that has a much less exaggerated but still present inflammatory response after trauma? Potentially, if this patient gets a rod inside their femur at just the wrong time-- they have this first hit, which is the purple line of inflammatory cascade, and then they have a second hit, which represents the marrow emboli and the potential hypotension and blood loss associated with the surgery of having the rod placed inside their femur, which causes what was going to be a curve that looked like this to spike up here and end up beyond this threshold, and end up getting ARDS or multiple organ dysfunction.

This potential thought at the time was the first time people thought that the nail itself may be the cause, in a particular patient, of pushing them over the edge of getting ARDS or multiple organ dysfunction. And so some studies have been done looking at that, measuring inflammatory markers such as elastase, IL-6, and showing that after intramedullary nailing, they definitely do go up compared to controls. And so there's no doubt that the process of-- just something about placing a rod inside the femur does actually cause a systemic inflammatory response. It's probably through embolization of bone marrow contents when the rod is placed. It's also from other inflammatory mediators that are within the marrow that get pressed into the venous circulation. And then, additionally, the triglycerides that are present, obviously, in the marrow fat may be directly harmful to the alveolar architecture.

So at that time, then, this guy at-- Tom Scalea at Shock Trauma, who I'm sure some of you know, thought of this process of doing something he called damage control orthopedics, which-- the term "damage control" came from, I think, from World War II, actually-- from how the Navy would handle ships, warships, that had been damaged to basically contain a fire or a partial flood of the ship and allow the boat to stay afloat-- and applied that term, "damage control," to do damage control orthopedics. It was basically using external fixation as a bridge to later intramedullary nailing of a femur fracture in a patient with multiple injuries in order to avoid that second inflammatory hit and potentially keep a patient that might have otherwise gone into ARDS or multiple organ dysfunction from doing that. And they've found in their experience in the late '90s at Shock Trauma that this was very efficacious and didn't seem to have too many other side effects, aside from the extra operation from needing the external fixator and then the intramedullary nail later.

So the advantages that they proposed at that time were that you got early fracture stabilization, because you placed the external fixator, which improved patient positioning in the ICU. The patients could be turned side-to-side. It also decreased their pain. It avoided the major surgery early on, which was associated with intraoperative hypothermia and blood loss, hypotension, in addition to that second hit or that second inflammatory response, which could potentially push an at-risk patient over the edge to getting ARDS. They basically, then, planned the intramedullary nail for after this initial inflammatory cascade had abated, which was usually several days later.

The disadvantage, of course, is the second operation. There's an increased cost associated with it. The external fixator, believe it or not, is actually more expensive in some cases than the nail is. And there's potentially a risk for infection, because now you have these open wounds around the pin sites, where bacteria could potentially crawl down there next to the femur itself. And then you place a rod inside the femur. Now it's colonized with bacteria and potentially could get an infection. They did do a study on that, as well, at Shock Trauma, and showed that as long as the ex fix on it was on for less than three weeks or so, it did not seem to increase the risk of infection at the time when the rod was placed.

So when should we utilize damage-control orthopedics? Or which patients are those ones in the purple line here, that are potentially susceptible to the second hit from a rod being placed too early inside their femur?

So in the summary statement, basically, is that you've got to take into account all factors which would influence end-organ injury, with a particular focus on the respiratory system, because it's at such risk. So those include things like direct pulmonary or aortic injury, visceral injury, or TBI or head injury. So although I rarely, these days, look at much more than, like, the clavicles and the shoulder joint of what I can see on a chest X-ray, I do pay very close attention to what you guys, as the [INAUDIBLE] team, are saying about the patient's pulmonary status in a patient that has a femur fracture that we're about to take to the operating room for a nail.

So the unstabilized femur fracture itself represents an ongoing systemic injury if it's not treated, not placed in traction, not placed in an external fixator, or not fixed with a rod. Ongoing fat emboli, ongoing hemorrhage from the fracture not being stabilized, and difficulty with mobilization.

So what should we do? Should every single patient get damage-control orthopedics? Actually, the answer to that question is not entirely fleshed out in the literature. There are places like in Denver where they use it over half the time for patients that are multiply injured with femur fractures, get an external fixator right off the bat, and then later replace it with a femoral nail, and places like in Baltimore where they tend to use damage-control orthopedics very rarely, or the external fixator very rarely, as long as they pay close attention to what's going on with the patient before they select someone that gets a nail.

This study from, again, out of Shock Trauma, showed that they had great results with low rates of ARDS with early stabilization, meaning early intramedullary nailing of femur fractures, as long as the patients were appropriately resuscitated before surgery and they were appropriately resuscitated or supported during the operation. Those two things happened, then patients could get their femur nailed very early with minimal risk of complications to their lungs.

So I think it's helpful, probably, to go through a couple of examples of when, as an orthopedic surgery team, we would choose to do ETC, which is short for early total care, meaning placing the rod inside the femur on day one, or DCO or damage-control orthopedics and placing the patient in traction or an external fixator.

So this patient's a 33-year-old male. He was involved in a high-speed motor vehicle collision. He has this isolated right-lower extremity injury. He has a couple of rib fractures, which are minimally displaced. No flail segment. He has no head injury on his initial CT. And he's not even intubated, he's just on nasal cannula and satting 95% on 2 liters. His lactate, initially, was 5.5, which is the biggest lab value that I use to look at to see if a patient is well-resuscitated or not. And then after he's been in the hospital for a few hours, he's gone down to 3.5.

So should this patient get early total care, like with a rod, or should they get damage-control orthopedics? The way I look at this is they have no primary significant chest or head injury, meaning no direct damage to the head, no direct damage to the lungs other than a couple of small rib fractures. Resuscitation is ongoing, but the likelihood that their resuscitation status will improve over the next 12 hours is very high. His lactate's already gone from 5.5 down to 3.5. We can get another lactate in the morning before taking the patient to the operating room. Now it's 2.0. And so for that patient, for sure, I would go ahead and place the rod inside their femur early, meaning within the first 24 hours. And because they've been appropriately resuscitated-- that's the key part-- then the risk of ARDS or pulmonary complications is low.

So what about this patient? This is a patient that came in like, actually, six days after I started on staff here. He's a 45-year-old male, high-speed motor vehicle collision. He's got bilateral femur fractures. It's hard to tell here, but he also has a femoral neck fracture up on the right side here. He also has bilateral rib fractures. No head injury.

He's initially stabilized in traction. And this is actually very important. It has been shown in some studies that traction can be almost as efficacious as external fixation as a means for stabilizing a femur fracture and preventing ongoing fat emboli and ongoing problems with hemorrhage from a femur fracture. So he's stabilized in traction immediately in the emergency department. He's intubated. His peak airway pressures, though, are about 15. His lactate was initially 5.2. He's received blood, and now his lactate is coming down to 2.5. And so it seems like his resuscitation is going pretty well.

So for this patient, even though he's got rib fractures and he's intubated, the pliability of his lungs seems to be pretty good. His peak airway pressures are not that high. He's being resuscitated well. His lactate is coming down. And so this patient, even though he has direct thoracic trauma, is appropriate resuscitated. So I would go ahead and do early total care, and take this patient to the operating room with a plan to place a rod in their femur.

Now, the one caveat to that is, you have to ensure the patient maintains appropriate perfusion, and that the resuscitation is not falling behind while they're in the operating room. Because there's no doubt that the level of hemorrhage from the femur fracture is actually going to increase partially while we open up the femur and ream it and place the rod. So this type of case, after we fix one side, for sure, asking anesthesiology to recheck labs, recheck that patient's lactate in the middle the case. And if it's going up or rising, I will stop that case after fixing one side, place the patient in an external fixator or traction on the other side, and come back to do the other side another day.

So what about this one? This is a 23-year-old male, high-speed motorcycle crash. He's got a right-lower extremity injury, bilateral pneumothoraces, multiple visceral injuries, but no head injury. He's got significantly less-- or worse, rather-- lung compliance, peak airway pressures that are approaching 30. His lactate, initially, was 5. It's going up. Actually, now it's 7.5 from after he came in. So again, this patient has direct thoracic traumas. They're at risk, not appropriately resuscitated, as evidenced by the lactate, so I would consider this patient not OK for early total care, placing a rod inside their femur. They're definitely at high risk for inducing a second hit, because they're under-resuscitated, if you place a rod inside their femur at this time. And so the plan would be for early damage-control orthopedics, or placing an external fixator, to prevent ongoing fat embolization and hemorrhage. We certainly wouldn't want to just leave the patient with a femur fracture that's not stabilized either with traction or an external fixator in the ICU while this is going on, because that can actually make them worse.

So this patient gets placed in an external fixator in a delayed fashion. And the question is, of course, when? How long do you wait? Usually, for me, that would be at least four to five days, minimum. And that's based on, mainly, studies measuring their levels of inflammatory markers like IL-6 in the bloodstream after a trauma like this, and showing that they tend to decrease after day five or so. So usually after four or five days, then you would convert the-- at the earliest-- convert the external fixator to a rod.

The one last one-- this is a 26-year-old male, high-speed motorcycle crash. He's got a left femur fracture. No chest injury, but has a closed head injury, and has a bolt in. The patient is sitting in the ICU, intubated, upright from neurosurgery, because they're trying to reduce their intracranial pressure. Lactate, though, is getting better. It's really just the head injury that they're worried about. This is not this patient's CT, but as an example-- what about the head injury? And what is it about a head injury that's connected to the femur fracture?

Neurosurgery, frequently in this type of patient, would say the patient is not clear to go to the OR. They can't even lay them supine completely in the ICU. But the main thing that you have to think about is what is it that, actually, neurosurgery is worried about? And I usually tell at least the residents in orthopedics this, that they have to actually understand what it is neurosurgery is worried about. Because neurosurgery, they're concerned about their one thing, which is the brain, which is very important, obviously. But they don't know exactly how everything-- without input from us, they don't know how everything fits in with this patient with a femur fracture and a closed head injury.

So they're really worried about cerebral perfusion pressure. So they've got to make sure the mean arterial pressure remains high, the intracranial pressure remains low-- that's why the patient is sitting bolt upright-- and avoid situations in which there might be hypotension or the intracranial pressure would rise. So that's why they don't want the patient go in the operating room. Certainly, if you take that patient to the OR and you bleed them out through their femur fracture as you're placing the rod, their mean arterial pressure will go down. Their cerebral perfusion pressure will thus go down. And that certainly has a deleterious effect on their overall neurologic outcome.

So the main thing, though, is they want to avoid bleeding in the operating room, hypotension and hemorrhage from the prolonged surgery. They also want to avoid supine positioning. So I usually tell the neurosurgery resident-- usually it's the chief resident this time. Then I give him the same talk, that the femur is a magic bone, OK? We can't let the patient sit in the ICU with their femur fracture unstabilized. It's magically connected to the lungs. And if I don't do anything about it, it will actually be worse for the patient. They'll have ongoing fat embolization and hemorrhage.

Additionally, you can make the argument that pain and catecholamine response from the unstabilized femur fracture could reduce their cerebral perfusion pressure by increasing their intracranial pressure. So, because the femur is a magic bone, then I say I can even put the external fixator on the patient with patient sitting upright. And there will be minimal blood loss. You don't have to lay them back. The intracranial pressure doesn't have to rise then. And then the next line is, after they say no to that, you say, if the patient is cleared for an IV to be put in, then they should be cleared for an external fixator. Because all we're doing is making holes in the skin, placing a drill inside there, and placing pins across there to stabilize the patient's femur. And that's really not a whole lot more that can be done in the ICU. We don't really do that very commonly here, but can be done even in the ICU. And so if the patient is cleared for an IV, they should be cleared for an external fixator.

Now, the other concern, though, is what about the patient that is not as severely head-injured and is cleared by neurosurgery, but has a closed head injury? Can they go to the OR and get their femur nailed? The main question there has to do with, is it possible to continue to monitor that patient's neurologic status while they're under anesthesia in the OR? If it's a patient that neurosurgery is worried they're going to need to get repeat CTs of the head, and they're worried that something might happen soon, and they want to be able to examine that patient serially, then certainly, that's probably not the best situation to put him under anesthesia for a prolonged period of time, which will prevent them from getting an examination, or prevent them from going to CT, or cause ongoing blood loss and reduce their cerebral perfusion pressure. So that one, typically, is if we're thinking about nailing the femur, is a discussion I would have with the neurosurgery team to see how tenuous is this head injury, and can this patient actually tolerate a major operation, which will involve hemorrhage and blood loss? And is that going to be a problem for them? But an external fixator is a much different deal.

So in summary, long bone fractures are often associated with other direct visceral injury. The unstabilized femur fracture-- it's not in an external fixator, is not in traction-- is actually worse for ongoing pulmonary injury. Early definitive stabilization leads to better outcomes. But you must ensure that there is appropriate resuscitation before and during surgery if you're going to place a rod. And for me, that's making sure that they're appropriately resuscitated. It has to do not just with the absolute level of the lactate, although I usually look at that-- if it's less than 2 and 1/2, I feel better-- but the overall trend. Is it going up? Is it going down? What's the patient's overall status? Normalizing pH in the absence of severely elevated peak airway pressures.

In at-risk patients-- patients with direct thoracic trauma, large anticipated embolic load, like bilateral femur fractures that are going to get nailed-- I would consider damage-control orthopedics to reduce the risk of ARDS. And you must prioritize the injuries. If the patient cannot tolerate major surgery because they have a head injury, aortic injury, or something like that, then that's another good reason to do damage-control orthopedics. But you still have to stabilize the femur fracture.

But remember, almost everybody is cleared for putting them in traction or in an external fixator. All right. Any questions?

SPEAKER 1: Thank you to both of our presenters. We have about 10 minutes for questions or comments.

AUDIENCE: Great talk. Thanks. I'm happy to hear that you're so aggressive about early definitive treatment of fractures. We looked at this literature in fellowship in Houston, in a high-volume center, and we really pushed hard to have early fixation. And our review of the literature was that unless they're like ASA class 5, completely moribund, multiple [INAUDIBLE] then they have better outcomes if they are given an early fixation. So [INAUDIBLE] hear that you're very aggressive as well. It's way better for the patients.

AUDIENCE: This question more so for Dr. Shaughnessy. Has there been, or do you follow, any sort of MESS score for the mangled extremities in the pediatric population? Because the ones that you've demonstrated, you had some clear indications for amputation in the one, but the use of flaps is clearly a part of salvage.

SPEAKER 2: Yeah. The need for an amputation in a child as a result of trauma is always something that's difficult. And for the most part we will avoid an amputation if there's any way to avoid it. So while there's a lot of scoring systems that are used in the adult population, especially the dysvascular amputations, for the kids in trauma, about the only absolute indication for an amputation is the Gustilo 3C, which is the amputation that completely devascularizes the limb and cannot be revascularized. And we have even violated those rules in several circumstances where we will shorten the limb, revascularize, either through the thigh, the leg, or even the foot, and reattach it. So if there is a way to keep a limb in a child, we will do it.

And we'll even do that to the extent where we might have to deal with a late amputation down the road rather than doing an emergent amputation early on. The kids are remarkably able to withstand the traumatic event, as I showed you in some of those pictures, and so it's rare that they won't survive the injury. So we can wait 2, 3, 4 weeks before we have to make a decision about an amputation. And that also gives the family time to realize what's happening before we have to make that a reality.

The hard ones are the ones that, like I showed you, the farm injuries where the part comes in-- it's completely detached, obviously, and there's no way for us to put it back on. And that always leads to a lot of, well, guilt in the parts of the parents, especially if they were involved with the accident In any way, shape, or form. But we don't have an easy way to deal with that.

So I have a question for Brandon. What about the tibia? Do all these rules still-- do they apply to the tibia as well?

BRANDON YUAN: That's a good question. It seems like the tibia is probably not as magic of a bone as the femur is. Because the patients even with bilateral tibia fractures that are sitting and that aren't stabilized don't have the same predisposition to develop fat emboli syndrome or have the same direct pulmonary complications as frequently as femur fractures.

Now, that being said, there have been cases of fat emboli syndrome, of course, described in patients with clavicle fractures and weird stuff like that. But I consider those, for the most part, one-offs-- that the main thing that we need to focus on is femur fractures. All long bone injuries are a potential problem. And certainly if you had a patient that had femur fractures and tibia fractures, or even ipsilateral femur and tibia, then I think you should take that into consideration, because their embolic load from nailing both of them is going to be higher than if you just did one of them. But only in the patient that would be truly at risk for developing bad pulmonary problems would that be an issue.

Thanks, everybody.

AUDIENCE: What is the current practice if you are out on a farm and there is an amputation? What are you supposed to do with that limb?

SPEAKER 2: The current recommendations are to take the limb and wrap it up in some sort of dressing. If you have something sterile, that's great, but it's contaminated, so it often doesn't matter. But a towel, some sort of rag, something to protect the skin so that the next step, which is the ice, doesn't come in direct contact with the skin. And then to put it in a plastic bag and get it to us as soon as possible.

Usually if there's muscle in the limb that's amputated, which is leg or thigh, that has about a six-hour time frame. If it's a foot or a hand, where there isn't that much muscle, the time frame gets extended a little bit longer. But the trick is to get it here quickly. And if we know it's coming, in that circumstance, we'll put two surgical teams on it-- one to start working on the limb itself, and one to debride the patient. And then we get the vascular team or the microvascular teams involved to start doing it.

The trouble is it requires a clean amputation. Almost no farm implement causes a clean amputation, as you saw there. They're usually dirty and comminuted and contaminated, to say nothing of what the residual part-- the lawnmower, for example, never leaves a part that can be reattached. But yeah. It's wash it off, cover it, ice, so to cool it down, plastic bag, and then transport as soon as possible.