Thank you for having me today to speak about a topic that's near and dear to my heart which is pediatric dialysis. So I tried to get a provocative title to get people to show up, everything you wanted to know about pediatric dialysis but were afraid to ask. So since none of you will really be dialyzing anybody it's not everything that you need to know or everything there is to know, but everything you would want to know. So we're going to talk about the pathophysiology of dialysis, we are going to spend a good bit of time about the history of dialysis because dialysis is a field that has a lot of honorific titles and dialysis has probably affected the practice of medicine probably more than anything else, and you'll see why. We'll talk about vascular access with dialysis which is so important which is really critical to dialysis, the different modalities we have, the indications for dialysis, the complications associated with it, the epidemiology and the ethics of dialysis.

So the father of dialysis was Thomas Graham from Scotland and he realized that you could remove particles through a dialysis membrane, so dialysis basically is the transport of solutes across a semipermeable membrane, primarily across a concentration gradient but not only. There is two ways of removing particles, one is dialysis which is diffusive clearance and hemofiltration which is convective clearance, and some people are going to be coming in late, we are going to be going over this again and again in the talk. So to do dialysis you need three things, you need a membrane, you need dialysate and you need access to the blood stream. So with dialysis you have a dialysate which is a low concentration gradient and particles diffuse across the membrane. Smaller particles will diffuse better than larger particles. Now there is convective clearance. With convective clearance there is no dialysate but with a negative pressure particles and water move across the membrane. Larger particles can move that way.

How does the kidney do it? So it's good to have an idea of how the kidney filtrates to see how a dialysis membrane filtrates. So you have the afferent arterial and the efferent arterial and that regulates the glomerular pressure and with the transcapillary pressure you get ultrafiltrate, and this ultrafiltrate is essentially isotonic with the plasma and is how we have GFR. The kidney has probably the highest blood flow per size, it has a blood flow of approximately a liter per minute. The renal plasma flow is 650 ml per minute because a normal hematocrit is 45% and the glomerular filtration rate is 125 ml per minute normally. So that's a filtration fraction of about 20%. This is very similar to the way dialysis will work.

So it's good to have a perspective of how much the kidney works when we try to figure out how much clearance do we actually get with dialysis. So a normal GFR is about 125 ml per minute, it varies, and that translates into about 180 liters per day of filtration. Just keep that in mind. Now we have different ways of estimating the GFR. One way is to a creatinine clearance. We won't spend a lot of time on this but it's your urine creatinine times the 24 hour volume divided by the plasma creatinine and there is estimation equations we can use based on creatinine or Cystatin C. We have a Schwartz formula which we commonly use in pediatrics and then there is adult formulas, the one that's the most widely used is the CKD-EPI.

So there is stages of chronic kidney disease, so this is the kidney disease and outcome quality initiatives and kidney disease is graded based on stages based on the GFR and kidney failure is defined as a GFR less than 15 ml per minute per 1.73 meters squared which is less – approximately

less than 15% of normal. That doesn't mean you need to start dialysis at that point, but that's when it becomes a consideration.

So dialysis was first described by John Abel in Maryland and I want you to take a look at his dialysis membrane because it looks remarkably similar to the membrane which we use today. He needed a membrane and he figured out that cellulose is a dialyzable membrane. He had Collodion but you need something else, you need an anticoagulant. And they used Hirudin which was not very good and had reactions. He dialyzed animals primarily. The first person to dialyze humans was George Hass in Germany in 1924, he dialyzed 16 humans and they all died. But he had quite a few challenges though.

The first successful dialysis was going to be done by Willem Kolff from the Netherlands in 1945. He was working for the resistance and he had had some patients with renal failure that died and he figured out that he could come up with a way to help these people. Now he is the father of artificial organs and you see here that he's holding an artificial heart. He did not become a nephrologist, he started the Journal of Artificial Organs and he actually developed the artificial heart that Barney Clark got in Utah. So Willem Kolff realized that sausage casings would make a great dialysis membrane and that's what he used, cellophane sausage casings. And Heparan had been invented and he realized that that would be a great anticoagulant and he came up with the Kolff rotating drum kidney. So he took the sausage casings, wrapped it around the drum, had that sit in dialysate fluid and the blood was pumped through there and I'm pretty sure it was just done through the patient's cardiac output, there was no actual blood pump.

He came to America and he worked with William Merrill at the Brigham and they came up with the Kolff Brigham rotating drum kidney, but the biggest problem they had was dialysis access. How are you going to access the vessels? The vessels had to be accessed each time through a cutdown. And after about 4 or 5 dialysis treatments the patient would have lost all vascular access and would have died. So it could only be used for acute dialysis. The problem with this is you don't have ultrafiltration which is so important, you need to remove fluid from the patient to correct pulmonary edema and to replace the urine output.

So Nils Alwall modified the machine and figured that if you had it standing up and you had it in water you could make – you could lower the pressure gradient through the sausage casings and you could have a hydrostatic negative pressure that could remove fluid. So who was going to try this on the first child? Who was going to dialyze children successfully? A big problem with this system is the priming volume, blood has to go through this system and the priming volume was about 1400 ml, which is about a third of a person's blood volume. So blood would need to be used.

So again you have dialysis, blood going across the membrane, dialysate going in the opposite direction which gives solute removal and then you have hemofiltration, transmembrane pressure leading fluid to have net fluid removal. So the indications for acute dialysis are fluid removal, pulmonary edema, ARDS, making room for nutrition, clearance for uremic symptoms with acute kidney injury, acute metabolic control, hyperkalemia, lactic acidosis, hyperammonemia, rhabdomyolysis and poisoning. So a good question is when do you need to start dialysis? There are

no clearcut indications, you have to weigh the risks of the dialysis access and the procedure with the benefits and there is no clearcut numbers for any of these.

The molecular weight of the dialyzable substances affects what molecules you are going to remove, so smaller molecules will be removed more efficiently than larger molecules. And urea is not a uremic toxin, it just approximates the size of what we believe to be the uremic toxins so we use that of a guide of when someone might be uremic. So these are the agents which represent the size of different uremic toxins and basically smaller molecules are cleared better than larger molecules.

So who is going to come to the rescue of the children? It's going to be a Pitt graduate, Frank Mateer. And I want to thank Penny Mateer, his daughter, very much for helping me with this talk and Penny is in the audience today. Through researching the talk I got to meet Penny. So Frank Mateer graduated from the University of Pittsburgh in 1944 and he went in to the military as a psychiatrist and when he came back he couldn't get a residency position even though he graduated AOA it was very difficult at the time, so he went into the lab of Dunkowski, this is Dr. Mateer, and it was in a physiology lab and Dunkowski says you know what they are doing dialysis, see if you can get a hold of one of these machines and figure out what you can do with it. So Westinghouse made an Alwall dialyzer. And Frank had the crazy idea that he would build a pediatric dialysis machine and he would be the first person to successfully dialyze children with hemodialysis. And it hadn't really been attempted after him for a long time and this is a letter from Frank Mateer, Children's Hospital of Pittsburgh, Desoto Street to a transmission company about purchasing motors to pump this. Blood pumps were not used. And Dr. Mateer had the first successful report of a large series of

dialysis published in 1955, keep in mind the first successful transplant wasn't until December 23, 1954 in identical twins. Transplantation wouldn't really begin as a field until 1964.

So this is what he developed. And this machine looks almost identical to what we do today, you have arterial access, venous return, a blood pump going through a dialysis membrane, dialysate solution, transmembrane pressure to remove fluid, an air clot chamber and Heparinization. And the dialysis solution they used was Pittsburgh tap water. Now he knew that was going to be a problem, so he primed the system, well he needed blood but he ran antibiotics through the system. The first time he used it was with Penicillin. Problem, Penicillin VK, the patient arrested and died. He decided next time I'll use Tetracycline. So that's how they got away with infections.

And I just want you to look at his system and look at our system today. Principles of dialysis are the same. If you read his paper from 1955 you would understand the principles of dialysis. You have blood going through the dialysate, dialysis dialyzer, dialysate going countercurrent, pressure monitors, air trap chamber, blood returns to the patient and you need to anticoagulate the patient. That is the principles of all extracorporeal therapies. CVVH, ECMO, phoresis, all extracorporeal therapies have the same principles, you need access, you need a filter, you need dialysate or ultrafiltration and you need to return it, you have to keep the system from clotting and you have to keep air out of the system. That is how dialysis works, nothing has changed.

So he dialyzed 5 patients, 2 had HUS, 2 had chronic GN, one had polyarteritis nodosa, he dialyzed them a total of 7 times and look how long he dialyzed them. He dialyzed them for about 12 or 13

hours. It was essentially what we do now in the ICU CVVH. They were quite uremic at the time, BUNs 200 to 300. And this is one of the patients who he dialyzed who lived. Most of the patients succumbed to other illnesses. And this is a nice example of what happens. Look what happens, he puts in dialysis access, he dialyzes them once, the patient starts peeing. I can't tell you how many times the patient starts peeing once you put in the dialysis catheter. It's frequent. You do one dialysis and they get better.

Then came the Kill dialyzer by Frederick Kill and the big advance is this is a flat plate dialyzer where now you have dialysate going through the system, you don't have it sitting in a bath. And then in the 1960s came the Hollow Fiber Dialyzers which we use today, you can see they are in different sizes. Why they are in different sizes, the surface are of the dialysis membrane approximates the body surface area of the patient. And that's frequently how they are numbered so the CA50 pediatric dialyzer has a body surface area of .5 meters squared. CA110, 1.1 meters squared. So you calculate the body surface area of your patient and that's the size dialyzer you use. The smaller the dialyzer the smaller the blood prime and that's very important because if the blood prime is more than 8% of the plasma volume, 8 ml/kg you need to prime with blood. So we have neonatal dialyzers, adult dialyzers and again the principles are the same. You have dialysate, blood going in one direction, dialysate the other direction which removes the molecules across the concentration gradient and you have ultrafiltration, transmembrane pressure removing fluids and larger molecules. We have different size lines based on the size of the patients. And this is a patient who is getting hemodialysis in our Dialysis Unit and this is the dialysis machine.

The only one big advance that's happened recently is we have online monitoring of how much fluid we are removing. The amount of fluid we can remove is really remarkable. In a 3 hour period you can remove about 5% of the patient's plasma volume, in a 4 hour period – I mean their total body weight, in a 4 hour period about 7% of someone's total body weight. So we are removing about a liter an hour on a patient of fluid. And we don't use Pittsburgh tap water anymore per se, but we run it through, we have a water treatment chamber where we get our water for dialysis in the Dialysis Unit.

So our dialysate is basically isotonic to the plasma in many respects, sodium is 139, potassium is a little bit lower too because we want to remove potassium, calcium is physiologic, bicarb is a little bit higher than physiologic because we want to give bicarbonate back to the patient. Again it goes across a concentration gradient with magnesium and glucose.

So something that's important is so that's acute dialysis. Now how are we going to do chronic dialysis? It's important to remember kidney failure is a systemic disease that essentially affects every organ in the body and much of what we know in different areas of medicine came from renal failure patients. Patients with renal failure have anorexia, nausea, hypercatabolism, failure to thrive and malnutrition. They have neurological symptoms with severe uremia, they have seizures, coma, decreased mental acuity, fatigue; hematologic, they have anemia, they have erythropoietin deficiency, iron deficiency, decreased red cell survival, platelet dysfunction, immune dysfunction; cardiovascular problems with hypertension, fluid overload, pericarditis, LVH, vascular calcifications; endocrinological problems with renal osteodystrophy, secondary hyperparathyroidism, hyperphosphatemia, vitamin D deficiency, insulin resistance, amenorrhea and

sexual dysfunction, short stature and metabolic problems with hyperkalemia, acidosis, hyperuricemia, oxidative stress. Dialysis does not fix all of these problems.

ESRD is not common in children, the incidence is at about 12 per year per patient million compared to leukemia and congenital heart disease it is quite uncommon. Pediatric nephrology other than adult nephrology is a field of rare diseases. We have no common disease that children are dialyzed for. This is from the most recent USRDS data, I only show diseases that have – that are more than 2%, so focal segmental glomerulosclerosis, hypodysplasia, obstruction uropathy, lupus; this is sort of a grab bag diagnosis of hypertension, I assume this is probably patients who have other solid organ transplants; reflux nephropathy, polycystic kidney disease, HUS and IgA. So it's a field of rare diseases. Most of the diseases are less than 1% of our patients.

So one of the big hurdles to doing chronic dialysis is access, how are you going to access the vessels? And the answer was going to come from Wayne Quinton. Now Quinton didn't have formal engineering training, he was basically – he worked for Boeing, and he was hired at Seattle to have a small instrument room, anything that a doctor couldn't get he would have to figure out how to make it. Belding Scribner was the head of Nephrology at the University of Washington in Seattle and he was frustrated that he would lose access in his patients after 4 treatments and then they would die, so he went to Quinton and said can you come up with something that we can use repeatedly for dialysis? And he came up with a Quinton-Scribner shunt. This is something that they would access the vessels, it was still used when I was in medical school, they would de-access it and they'd be able to access the arterial and the venous side to do repeated dialysis. And that was the dawn of

chronic dialysis as a field. Now what was so innovative about this, why not just access both sides and cap it off? Because it would clot; Quinton realized that if you could shunt it then the blood would go around continuously through the shunt it wouldn't clot. And that was his big innovation. And the first person to get dialysis was Clyde Shields at the University of Washington. Immediately now you have ethics problems, who are you going to dialyze, which we are going to talk about later.

Soon thereafter they started a home hemodialysis program and they would – patients would set this up at home and do dialysis through the Scribner shunt at home. The problem is that the Scribner shunt didn't last that long. Now one of the most – one of the most famous people to get dialysis was not John F. Kennedy, we'll get to that. But on November 22, 1963 in Dallas, Texas John F. Kennedy is assassinated, that day Liberace was to perform in concert and the concert was cancelled. And he couldn't get his outlandish outfits dry-cleaned. So he got a bottle of dry-cleaning solution and he dry-cleaned his outfit himself in a room that had no ventilation and he got carbon tetrachloride poisoning and he went into hepatorenal failure. He had hepatorenal syndrome, he went into renal failure. And they said there is no chance that you are going to live. And this happened at St. Francis Hospital right here in this building. And who was going to come to his rescue? Frank Mateer. He dialyzed him and Liberace lived. The next day Liberace says a very young and lovely nun wearing a white habit came to see me late one night when I was very near death, she said she was going to pray to St. Anthony for me and he would make me well. The very next day I began to get well. I described the nun to the Mother Superior at the hospital and I asked who she was. Mother Superior said there are no nuns in the hospital who wear white habits. I'm going to assume Frank Mateer had a black suit on that day. When the new St. Francis Hospital was built the lobby

was called the Liberace Library and if you went to the Liberace Museum there was a wall of St. Francis Hospital and his first dialysis and every time he performed a concert in Pittsburgh he would give tickets for all the nuns in the hospital. And they loved Liberace.

The big breakthrough with dialysis was going to come with the Brescia-Cemino Fistula. The Scribner shunts would clot, they would not last long, the patients could maybe get a couple of months of therapy. So James Cemino was – had worked as a phlebotomist at Bellevue and he realized that he could get pretty high flows when he drew blood with a tourniquet on. So he thought you know what I think we can dialyze people through venovenous access and we can bypass the arterial circulation. So he would tourniquet the arms and he would access the veins and it did work and he published in the New England Journal. The problem is to do that you had to hydrate the patient and part of dialysis is removing fluid. So he had an idea, he knew that for polio they were making shunts in the kids' legs to try to increase the blood supply, he said maybe if we shunt the vein we can get a big enough blood flow. This was Bronx VA Hospital. She went to Kenneth Appell, a vascular surgeon, he says hey can you create me a shunt? And that's what they did, they connected the arterial, the artery to the vein in a side to side fashion and low and behold the vein got large enough that you could stick it, and this revolutionized dialysis. Now you had a permanent way of doing chronic dialysis the arteriovenous fistula, which until today is the gold standard. And this is one of our pediatric patients who has an AV fistula in the upper arm and she has these buttonholes, this is where it is accessed. This is still the gold standard for dialysis for hemodialysis. There's been no innovation since then in terms of dialysis access. The problem is not everybody can get a fistula. Until this day it requires great expertise, we are very blessed that Pittsburgh has one outstanding

vascular surgeon, Dr. Dillavou who does beautiful work, but this requires an incredible amount of skill, there is a lot of variation between the specialists. So not everybody can get an AV fistula and especially small children.

Come Robert Hickman. Robert Hickman was a pediatric nephrologist who did his fellowship at the University of Washington. Now Scribner wanted to do intestinal dialysis so he had a resident Jack Broviac work with Quinton and they came up with a Broviac catheter to give TPN, again invented by a nephrologist. Very soon afterwards there was a very wealthy woman with cancer who was dying and they used this Broviac catheter for TPN for hematology for access for chemo and that was huge. But no one tried it for dialysis and Robert Hickman in the 1970s with Quinton, with Wayne Quinton came up with a double lumen hemodialysis catheter. It was until 1987 they put a Dacron cuff on it, so until that time hemodialysis was not practical for a lot of people. These cuffs were a blessing, these catheters were a blessing and a curse because they were so easy to put in they were widely used and to this day they are the cause of a significant if not the most morbidity in dialysis patients. They get infected, they cause thrombosis, but they are cheap and they are easy to put in and they don't require that much relatively speaking that much skill in relationship to a fistula.

Now I want you to look – here are the pediatric catheter that we have the 8 French and here is the adult catheter the 14 French. But I want you to look at the two tips, one is to withdraw blood and one is to return blood so you don't have recirculation. These tips are pretty far apart so you try to fit that in a little pediatric heart without it sticking up against the wall without one being too deep and one being too high and you realize you have very little room for error. So when we complain about

our interventional radiologist about them not being able to give us a catheter that works, realize that this is not – these things are not easy to put in. And they are fraught with complications.

So what kind of clearance do we get with these dialyzers? It's not 100% efficient. The blood flow that you can get with a catheter is about 250 to 350, the blood flow you can get with a fistula is about 400. The actual clearance that you get is based on the coefficient of the dialyzer and how fast can particles move across that membrane. The dialysate flow rate is about 500, so if you have a blood flow of 350 you are going to be getting a clearance of about 200 ml/minute. Now in the early days of dialysis when they had to access the vessels they would only do dialysis like once or twice a week, the patients were on very strict diets. Now we dialyze patients 3 days a week about 3 hours, and where did that number come from? When you get below that mortality starts to increase. So this is the minimum amount of dialysis you can give someone to get an acceptable outcome. It is by no means optimal. So if you are dialyzing someone with a 350 ml blood flow for 3 hours 3 days a week you just do the math, take the urea clearance, multiple it by all the time, you get about 108 liters of clearance a week. You take a normal GFR multiply it by 7 days a week you get 1,260 liters per week, dialysis only provides about 9% of normal GFR. Your dialysis patient when they show up to the dialysis unit they have creatines around 12. It does not provide a lot of clearance. The residual renal function 1 ml/minute of GFR provides about 10 liters of clearance, that's about 1 hour of dialysis, 1/10 of what you get on dialysis. So if you have a patient who has renal failure don't just so oh, they are on dialysis let's give Ibuprofen, let's give Gentamicin, every bit of residual renal function you have is extremely precious because dialysis does not deliver a lot of clearance.

Complication of hemodialysis, vascular thrombosis, vascular stenosis, these catheters used to be put in in the subclavian, patients would get 50% incidence of subclavian stenosis. The arm could no longer be used for a fistula if you have subclavian stenosis, bacteremia which has a number of morbidities on dialysis and dysequilibrium syndrome. When you do rapid dialysis and when you drop urea very quickly there is a solvent drag, it takes time for urea to cross the membrane so urea is higher in the brain, lower outside of the brain and water can shift from the extracellular space into the brain and you can get cerebral edema. So you have to be very careful if you have a patient who has a high BUN and you are dialyzing them quickly. You have blood loss, hypotension, cramping.

So this is one of our patients who had a hemodialysis catheter, you can see where the catheter goes, two different ports of it. Now there is something unusual about this, this is a catheter in the heart and what's unusual about it, where is the rest going? She had a dialysis catheter changed, the catheter cracked off in her heart. These catheters get fibrous sheets around them so in order to get this out she would need open heart surgery. So we just decided we would just leave the catheter in her heart, but these catheters are dangerous and they have a lot of complications so they are best avoided.

Peritoneal dialysis was well known as a therapy and it seemed very simple but the obstacles were in fact greater than hemodialysis because you need to have a way of accessing the peritoneum. So you would put a catheter in, you would put fluid in the peritoneum, fluid would diffuse off around a concentration gradient and ultrafiltration would be done by having a higher dextrose concentration in the peritoneum. Now water would move across by a concentration gradient, you could remove

particles and you could remove water, you could move ultrafiltration. Interestingly enough we said that a dialysis membrane, a hemodialysis membrane should have the same body surface area as the patient, it turns out your peritoneum has a body surface area which is the same as the patient. So it's perfect for removing toxins, so you'd need a catheter, you would need to put fluid in and you knew it would drain the fluid. The problem with peritoneal dialysis is they did not have a good way of accessing the peritoneum. Every time you would access it you would get leaks, they would do intermittent peritoneal dialysis once a week for 60 hours and then take the catheter out. Every time someone needed peritoneal dialysis they'd have to re-puncture the peritoneum, it would leak, they would get peritonitis.

Henry Tenckhoff did his Fellowship at University of Washington with Belding Scribner and his job and his job was to go around to people's homes, place a peritoneal dialysis catheter every week, hookup the dialysis machine, go back to their house at the end of the weekend and pull the catheter out. He really did not like doing that. So he went to Wayne Quinton and said hey, can we come up with something better? And they came up with the Tenckhoff Catheter in 1968 which we use today. It's a silastic catheter, it's a silicone catheter with a silastic cuff and he – and they invented the trocar to access the peritoneum. Now we have different size Tenckhoff Catheters, infant, pediatric, adult, it's a pigtail catheter and you have one silastic cuff deep in the abdominal wall, one superficial and this prevents bacteria from getting into the peritoneum and you have multiple holes so fluid can go in and fluid can go out. So if one holds clots you haven't lost the catheter. The catheter goes in the pelvis so fluid can drain in the pelvis, you can put fluid in and you can put fluid out. And this is one of our patients who we recently put in a peritoneal dialysis catheter.

So that only solved part of the problem. The other problem is how are you going to make this a convenient home therapy? And that problem was solved by Moncrief and Popovich. They started a dialysis unit in Austin, Texas and they had a man who could not get hemodialysis. The fistula clotted and he was going to die. And they – and he lived too far away to get in-center peritoneal dialysis, so they figured out that you left the peritoneal fluid in the abdomen all day and you did intermittent exchanges you could probably get enough clearance. And what they reasoned was they knew when you did peritoneal dialysis you would lose a lot of protein so they figured the molecules they would remove were bigger and that was CAPD. So they submitted abstracts to the Journal of Artificial Organs and it was promptly rejected. And no one thought it would work, but it did work. So that's CAPD. You put 2 liters in the abdomen 4 times a day and you get adequate clearance.

The problem is where are you going to get the fluid? They were using 40 liter glass bottles. The answer was going to Demetrious Oreopoulos, and this actually changed medicine permanently. He was a Greek physician at the University of Toronto, he said we need a better way of doing this, he went to his Backstra representative and he realized there is a plastic drain bag that they were using for an osmosis machine and he said I think we can use that for dialysis and that became the Dianeal bag which now we use for all IV fluids. Prior to 1978 they were all glass bottles and they realized you can put it in a plastic bag. Now you have home dialysis. And he also came up with the spikes, having multiple spikes. They had a spike every time the peritonitis rate was very high, and this is what we have now, we have Dianeal, we have bags that are conveniently shaped on a dialysis machine which warms it with multiple spike bags, you can spike multiple bags and decrease the risk

of infection and you only have to access the patient once and de-access the patient once and all the fluid is drained into a bag and now you have portable peritoneal dialysis. And for the small babies we have a manual setup where we can deliver very small volumes of dialysate. And this is what we call Continuous Cyclical Peritoneal Dialysis. You have a dialysis machine which delivers frequent exchanges throughout the evening and during the day you have a long dwell volume. This is our training room.

And so what's the efficiency of peritoneal dialysis? So if someone had 2 liters put in 5 times a day and there was 100% efficiency which there isn't, that would give you about 70 liters a week. We said that the normal kidney does 1,260 liters, that's about 6% of normal GFR. Again not a lot of clearance but it's happening continuously. One milliliter per minute of GFR is 10 liters per week, so that's basically one day of dialysis. So every bit of GFR you have is important. Complications of dialysis, infection, peritonitis, exit site tunnel infection, leaks, hypertension, hypotension, electrolyte imbalance, hernias.

So which renal replacement therapy is best? Well it depends, renal transplantation is the preferred modality for sure. Peritoneal dialysis usually CCPD is preferred for small children, the access is easier, there is improved nutrition, better socialization, more independence, kids can go to school during the day, get dialysis at night. Hemodialysis may be better if a transplant is imminent since you don't have to train the family which takes about a week, preserves body image in adolescents and if there is a poor social situation where a family cannot do home dialysis reliably.

Now but one of the huge hurdles to dialysis was going to be money. Who is going to pay for this? And this is the Life or Death Committee. This was published in Life Magazine in 1962, Seattle had to decide who they were going to dialyze, cities only had a few dialysis machines, the therapy was expensive, so they had a committee of a lawyer, a minister, a homemaker, a banker, a state official and a surgeon and they basically decide who is going to live or die. They only had – Seattle only was able to dialyze 13 patients at a time, and they would decide who got that. That sort of caused an uproar because they were deciding it based on social worth and one group which they would absolutely exclude is for children, no one under 18 was going to get dialysis.

So in 1965 Medicare was established, but it did not cover ESRD. In 1967 there was a Gottschalk report chaired by a famous nephrologist and he said it should be covered, it wouldn't cost a lot, it's primarily going to be a home therapy and it's only going to be a bridge towards transplantation. In 1972 was the social security amendment where Medicare was extended for patients less than 65 who qualified for social security. Dialysis exploded in America. In 1983 home peritoneal dialysis was covered, now peritoneal dialysis lagged so far behind hemodialysis that it never caught up in the United States, only 10% of patients get peritoneal dialysis. It's different in children though, peritoneal dialysis is very common. Erythropoietin is covered, that ballooned the expenses of dialysis and in 2008 there was a major reform, the Medicare Improvement for Patients and Provider Act, which was a bundled payment. You get one amount of money, Erythropoietin is not billed separately.

So the incidence of ESRD in children in the United States is very low. So this is by age, so the incidence is not high, this was per million. There is only about 2000 children in the United States on dialysis, about 1000 are on hemo, about 1000 are on peritoneal dialysis. And again this is the prevalence by age. As you note it is not really increasing very much. That is very different than in adult patients where it has been skyrocketing. This is the prevalence by modality, transplant, hemodialysis, peritoneal dialysis. It's about a 50/50 split, most children are transplanted, about 30% of children are transplanted within the first year of starting dialysis. And this it the one year adjusted all cause mortality. You notice that the youngest children have the highest mortality. And transplant patients have a much lower mortality than either hemodialysis or peritoneal dialysis.

And this is the adjusted 5 year survival in pediatric patients between 2001 and 2005. This is very, very low in comparison to adults where the 5 year survival is about 30%. But infants have the highest mortality of about .8. These numbers seem really high to me because our mortality is about 0. We hardly have anyone who dies. There is many reasons for that, but if you have good access, god dialysis access and you have a great nursing staff and you dialyze the patients adequately they can do well.

So the ethics of infant dialysis. I have about 4 minutes so I think we're going to end right on time. I do want to talk about this because this is very important. I remember when I was a Resident in the NICU we had a baby on dialysis and the doctor, the nephrologists weren't too crazy about dialyzing this baby. And I remember on my first day of Fellowship we had a baby who was end stage, and the nephrologist did not offer dialysis and told the family it's in their best interest to take the kid home

to die, which they chose to do and a week later the baby didn't die and showed up at the emergency room. Now he thought the baby was going to die, the child ended up dying and I remember during my Fellowship we had another child, prune belly syndrome, who was on an oscillator, had pulmonary hypoplasia and was on ECMO and the mom wanted to do dialysis and the nephrologists were basically screaming at her that it was unethical to do it. She said I don't care we are doing dialysis. And the child did fine. He had developmental delay but he lived. And this was an ongoing issue, the nephrologists not wanting to do dialysis.

When I came to this institution that all changed, that crazy Greek doctor in Pittsburgh was not crazy, okay. Dr. Ellis opened my eyes to a whole different world of taking care of children, and it was a huge paradigm shift for me. I mean what you see here, we are saving kids every day. Those kids to this day are dying in other centers, okay, and I just cannot tell you the impression Dr. Ellis has made on me. And what he was doing when I came here was just a whole paradigm shift, I mean back in the early '90s he had a baby who had cortical necrosis and short gut who could not have peritoneal dialysis, and they had the worst social situation possible, and he was bringing him to the NICU 3 times a week and doing hemodialysis. And that girl is now 18 and had a successful transplant.

So this was an article, this is 2013, Ethics of Infant Dialysis. ESRD is rare in newborns and very few centers have extensive experience with dialysis of neonates. This may lead to a feeling that the treatment is always a bit experimental, a bit extraordinary and not something that would ever be forced upon an unwilling family. This was a survey of pediatric nephrologists who would offer dialysis to all infants with renal failure. In 1998 41% would, 2011 30% would, it was less.

This was when I got here we had a family who had a beautiful little baby with PKD, they had lost a previous infant to PKD, polycystic kidney disease. The baby had severe pulmonary hypoplasia and on day one of life could not be ventilated and died. They tried again, the second child had PKD, the mother found an OB who would do amino-infusions. As soon as the baby would be big enough to be born at 32 weeks the baby was delivered. I went to Magee to see the baby, he looked pretty good. He wasn't on any oxygen, he was breathing well, the belly wasn't so big. I said you know what I think we are going to be fine, this is really not going to be a problem. Man, was I wrong. This is just in a few days later. I called the world expert on PKD, I'm not going to mention the person's name, I called the world expert on PKD and asked him how we should manage this baby, that I was going to take the kidneys out, put him on dialysis and try to get her advice. She yelled at me and said that is unethical to take this baby's kidneys out and put him on dialysis. Ventilate the baby, see what happens, the risks of dialysis were too large. Well I thought she was crazy.

We took the kidneys out, they were about a third of his body weight. We put in a peritoneal dialysis catheter, we put in a hemodialysis catheter. We started in center peritoneal dialysis. And it worked. And they took home a baby.

Next we had twins who had a twin to twin transfusion, one twin is called Jesse James, the other twin is called Butch Cassidy. Now these were term babies, but there is a twin to twin transfusion and Jesse James has cortical necrosis and he had bloody urine on day one of life and no urine on day tow. And we put him on peritoneal dialysis, now this was a term baby, it was a lot easier and you can

notice the tremendous amount of growth retardation, Jesse James compared to Butch Cassidy. But we got him big enough to do a living related transplant and you can see that now they look like twins. And the bottom line is never give up.

And dialysis is really not something that physicians do, we just write the orders and walk away. This is a nursing procedure and we are so blessed that we have the best dialysis nurses, certainly in the city, if not the world and it's all due to our nurse manager Elaine Lander. She is unbelievable. Her standards are so high and she is so meticulous that the good outcomes we get are due to these incredible nurses and it is a huge team to dialyze patients. I think we have a great team, I think we have the best team. We have a great administer Amy Cashdollar who is assisted by Dawn Burke and without support, without resources, without the support of the administration we could not do what we do. We have a great nurse manager, outstanding dialysis nurses. Susan Carter is no longer here but she will always be here in my heart, she helped start this unit with Elaine. We have great nephrologists with Yo and Christina, clinical nutrition with Neelam Katyal, social work, dialysis technicians and our surgeons. We are so blessed that we have dedicated surgeons who are committed to good access. We try to keep our PD catheters only done by Aviva Katz and Barb Gaines. These are not simple procedures, even if the surgeons think it's simple and they can all do it, it is not the case. This is their lifeline. If one of these catheters doesn't work, if they get peritonitis they lose their peritoneal membrane. They may never be able to go back on peritoneal dialysis. That peritoneum is 10 or 20 years of their life, if you lose the peritoneum you are cutting 10 or 20 years off the life of a patient. And our interventional radiologists who put in these catheters, this is a thankless job, these catheters are terrible, they clot, they are hard to put in, they have fibrin sheaths

and every time we have a problem we call them and they come to our aid and our vascular surgeon Ellen Dillavou. It's a long story how I heard about Ellen Dillavou, she's at Presby and Magee, she is amazing, she has saved so many children. Our kids have terrible access, all the lines and blood draws that they have their access is terrible, she has done amazing things to get fistulas in kids. We have a great team. And we have 5 minutes for questions.