

Ok, so I want to list the clinical vascular problems and tasks where high and really spatial is more my interest than contrast resolution that may be important. And those, kind of, I've grouped into two groups. So diagnostic and IGI, which is image guided interventions. So in..in diagnostic imaging one may need high resolution for detection tasks, especially looking at small objects to determine size, shape and to look at flow characteristics, and of course I..I'm sure there are many, many others but I just list these to whet your appetite. In image guided interventions, one needs to evaluate the image, the intervention, and this may require very high resolution. One ma..may need to see details of the devices if one is using endovascular devices, for example, and that is devices that go through blood vessels. One may need to find the orientation and location of these devices. And what we've found recently is that high spatial resolution has actually enabled us to come up with designs for new devices and I'll show you some of that

in a little bit.I'm going to restrict my examples to neurovascular subjects because that's what we are most familiar with. And in that case you're dealing with vessels in the brain, pathologies such as stenoses or constrictions, that is narrowings of the vessels as you see here, bulges in the vessels, aneurysms. What I'm showing you here is the so-called Circle of Willis which are the major vessels in the brain, in the inside of the brain, so the vessels leading to the brain are the carotids which end up here going into the middle cerebrals, and in the posterior the vertebrals going into the basilar artery. And around this Circle of Willis they're all connected like this, hanging in and around this there can be aneurysms. A lot of people are carrying aneurysms and never know about it, something like 2 to 4% of the population so they're very common. Also it may be important to image these little vessels that stick out of the..of these important larger vessels and these are perforator vessels and they have no redundancy so neurosurgeons are very

careful about not hurting these vessels when they're doing invasive surgical procedures, and similarly interventionalists have to be careful. But the problem is you can't see them except the largest ones during standard imaging procedures. We'll talk about that a little bit more later as well. It might be important to evaluate flow characteristics, for example whether there's a stenosis or a narrowing or whether there's a hemorrhage, whether there's stasis or stoppage of flow or lots of turbulence, and some of the effects on wall, wall shear stress, is determined or determinable by the flow characteristics. So today we'll be dealing with these standard, now standard modalities. I just put this up to indicate that we're not going to be talking about these others. Nuclear, for example, which is generally a low spatial resolution modality better at function than at morphology. And we're not going to talk about optical which although it is ultrahigh or has the capability of ultrahigh spatial and temporal resolution is not generally

available and I..I really don't want at this point want to talk about the plus and minuses of them. But I will just review briefly this handout that I left for you as a basis for dis..discussion later. So we have radiological ultrasound and MRA, and I think..I think most people would agree that radiological is the gold standard and probably because it has high or very high spatial and temporal resolution including the possibility of..of 3D. But there are some negatives. You have to use contrast media to see the vessels. We can't really measure flow directly, it's an indirect flow measurement. And the real negative, of course, is unlike these other two we use ionizing radiation. So the pluses of ultrasound and these, of course, are going to be a source of debate. Medium to high spatial and temporal resolution is a plus, it's inherently tomographic is a plus.

You can measure direct flow with Doppler and the problems, however, are the higher the resolution the shorter the range because of the attenuation characteristics. And the real

negative being, I believe, that you have to really be in contact to get the sound. And in MRA again, the positives are a medium and probably all the way up to very high spatial resolution, depending upon the system that you have, direct flow measurements are possible, depending upon the pulse sequence. It's minimally invasive except if you use contrast media, of course. And loads..but..but the negatives I..I suppose are a low to medium spatial resolution, and then real negative would be the limited access to the patient and some possibilities of severe artifacts. So keep that in mind, there's a list in front of you and we'll talk about that at the end. So now let's get to the first talk on radiological imaging. I just list for you some of my co-authors who were indispensable in..in much of the work that I'm presenting here. And I want to start right off by showing you some of the advances in imaging techniques in radiological imaging. So here's an image intensifier picture which is standard, and this is our micro-angiographic detector

picture, and we're..we're taking a picture of a Neuroform stent. These are unique stents that are probably one of the only endovascular devices used for cerebral interventions and we've used one, we..we try to simulate a head with a skull and 4" of acrylic and I thank **Chip Ionita** for some of this work. You can see that you really can't see the stent struts. And if we magnify you still can't see them. You can see the..the markers but that's about it. Whereas with the micro-angio you now can see the stent struts. These are 60 micron nitinol wire stents, and if you blow it up even more I think you begin to see the actual detail. There seems to be doublets here and that's the..the strut behind and..and the one in front. So going on to make this comparison of other cases. Here's a canine maxillary artery. There was a vasospasm which is a constriction on this one, but one didn't know it until one saw the micro-angiographic picture and you can see the edges of the vessels so much sharper and actually where the stent, this was caused by the

putting in of the stent. We go to another example in a rabbit. This is a 2 millimeter vessel and so we're able to see vessels down to 100 microns. This is perforator-size vessels and even smaller, maybe 80 microns we were able to see. Final example is an undeployed coronary stent so the whole thing across is less than a millimeter and this is with the highest mag mode of an image intensifier. This is with our micro-angiographic camera so you can see the detailed struts crimped onto the balloon catheter, and this is where we would like to be going with a direct flat panel amorphous selenium detector that can see in more detail in addition. And let me go over these one by one. Well, this is an old slide and the more I look at it the more I dislike it because this is supposed to be curved shaped for an input phosphor and the CCD camera here, all of them are now 12 bit at least, but it just gives you the general idea of the pixel size of over 100 microns for..for the mag highest mag mod of the image intensifier. And it's those set of

optics and a camera for looking at it. And that's the best you can do with..with the best and most modern of these camer..these image intensifiers. With a..with our ROI micro-angiographic detector we have a small field of view because we're only interested in the catheter tip and that is..it's designed for guidance of interventions. We can go five frames per second with this one and..and our pixel sizes are 43 microns. We use also an indirect phosphorus cesium iodide. The light goes through a fiber optic..fiber optic taper to a large CCD camera which is cooled, and that's the picture we get. If we were to..we took this one picture with an experimental

mammographic selenium direct flat panel and you can do even better with that. These are unavailable for us unfortunately at the higher images and frame rates that we need. But just to compare the different principles of how each of these detectors work. Well, we're not using this at all but the first two are cesium iodide grown in a column and this green place is where the x-rays come in

and are converted into light so that's the source of the simulation. If we had used the regular screen they'd go bouncing around and you'd get a full-width..you'd get a point spread function that's wider than if you use the columnar grown crystals which most people use for indirect phosphors and that's what's used in the image intensifiers and that's what we use in our micro-angio detector. But if we had the capability of using a direct, amorphous selenium detector, here the amorphous selenium converts the x-rays into whole electron pairs directly, no light to spread and you get a very sharp high resol..high spatial resolution capability. And I won't go into this but you've all seen, I'm sure, flat panels. This is particular one that was given to or that I took from a paper by Hologic people and you have the ca..gate lines that control the source readouts for each of the pixels and here's the selenium layer. So this is a..an MTF and this is line pairs per millimeters, sorry about that. So if you'll look at the standard image intensifier maybe you just

get past three line pairs per millimeter. For the micro-angiographic camera that we have built and used, we can go out to mammographic resolutions, ten line pairs per millimeter, and the..for the selenium detectors they're really limited by the pixel size so this is really limited by the 70 micron pixel size but if we could find somebody to make a smaller one it would go out further. So the spatial resolution characteristics are quite good and one can get very high resolution, higher than one presently uses commonly for imaging. The DQE is a good measure of..of the use..usefulness of absorbed photons. I won't go into defining it in detail, you..you..you all can find references to it. And again, three line pairs per millimeter for the image intensified compared to way out there for the micro-angiographic and even better at the high frequencies if we could get a direct flat panel. Well, there's more to it than the detector. And here we have our detector in the neurograph, neurological imaging suite, biplane system with standard IIs

to do most of the procedure, and then we move in this high resolution micro-angiographic detector. When we need high resolution images there's the phantom. Here's an extra monitor for the clinicians to see the results of that and the computer's stuck way back there and this is the computer so it's coming in from the other direction. And here's a close-up of the micro-angio. So the detector is not the only part of the system affecting the visualization. We have to include scatter from the patient and geometric and sharpness due to focal spot, finite size and the geometry. Even though these terms like MTF have been mostly for detectors we have in our group started to generalize the MTF by including scatter, a scatter MTF and a focal spot MTF, and I refer you to the poster which has probably been taken down now, but there was a paper by Jake Kyrianiou had SPIE earlier this year. So if this is the scatter fraction and M is

the magnification, if we have a magnification of 1 we just have a scatter term. If we have a scatter zero then we just have a term related to the focal spot which is modified by the detector. And you can see we've taken some of the work of some of these people and put it together. And

just to get back to the original, if you have no magnification or, that is, if you have magnification of 1 and no focal spot on sharpness and no scatter, then this generalized MTF goes back to the detector MTF. But I think it's important to realize that a total system includes more than just the detector so we hope that people start using this kind of formulation to include these things because they're both important. And as you can see, we have the NEQ generalized here. This is the ratio of the square, the generalized MTF square and the normalized noise power generalized again. Without going into details, you can look at some of our detailed definitions of some of these terms. But just look at what happens to

the NEQ when you add magnification. So just even a small amount this is with magnification 1.1, 1.2, you see we really begin to lose it due to geometric on sharpness in the high frequency details. And that's important for us. So similarly you may not be aware and it somewhat surprised us that even with a small field that is 4 x 4 centimeters, and this is 10 x 10 centimeters, the whole NEQ drops. And so scatter and focal spot are really important in evaluating even these small field of view systems. And this is the same sort of thing only with the normalized NEQ which is the DQE but the same discussion. But even the GDQE is not the only characterization of system performance in interventional image guided imaging. We are interested in a task. We have to do a task so we may have the greatest imaging system but if we can't do the task we're not successful. So the question became how do we evaluate the task? And we tried to break up the complicated tasks into at least some elemental tasks. And here's the

first one that was done by now Dr. Wang of our group. What she did was to put a tip of a guidewire at the on a stage that you can turn here, a linear stage, and tried to get it so it just tips a marker wire, a thin marker wire, and look at objective truth through this microscope and then take radiographs as well with the different imaging systems to compare the x-ray image intensifier and the micro-angio for localization task. And we took pictures every 25 microns and you get sort of something like this. So this is a micro-angio, this is the image intensifier. If it's aligned, this is overshoot. And you can see I think you can see this slight gap for undershoot. Very difficult to see these sorts of things with the image intensifier but we had people rate these. In other words, we gave them a set of pictures every 25 microns or so and asked them to tell us what the distance was between the tip of the point and the marker wire, and this was the results. So for the image intensifier it was over 100 microns, and for the micro-angio it is

about 40 microns. Now we figured that maybe the fact that just the pixels along were smaller in the micro-angio might have an effect and so we just interpolated the pixels with the image intensifier data and we did slightly better. But still by improved image resolution you're able to get, at least objectively we can show the task improvement by doing better by a factor of 2 at least. The fluctuation in each of the observers was also smaller, and without going into this in too much detail we had intra-observer, inter-observer, all observers with a particular frame, but the fluctuation for the II was much greater than for the higher resolution system. So we need to have not only a static imaging high resolution system but a system that can do dynamic imaging and fluoroscopy as well. So we've recently reported on a micro-angiographic fluoroscope or what we call the MAF or M A F. And what it is is a slight modification of our system, we still have a cesium iodide indirect phosphor taper, fiber optic taper, but here's where we

pu..insert a light image intensifier which is a flat device right here, and has a micro-channel plate for

amplification. And then there's plenty of light that comes out. We throw away most of it with this mirror-optics and then focus the image into a CCD camera. We have more modern components now that YeWu reported on earlier in this meeting. Here's an example of what he showed. At 20 micro-R per frame, we can do better but this is an example, because it's adjustable, because you have the adjustment of the light image intensifier. At 30 frames a second we binned 2 to 1. So we got for this particular case 60 micron pixels. Here's an image of a stent coming in and being deployed. You can see the saline blowing up the balloon. Saline has contrast in it, and then the saline is removed and then the balloon is collapsed and pulled out, leaving the stent in..into the..in front of the aneurysm. So these cu..this new capability, that is the high resolution capability, has got us..got us thinking about actually redesigning or designing new devices. So this is an aneurysm. There's a complex vortex flow that usually goes on in an aneurysm. So we figured well, what if put in a low porosity patch-like region among..in amongst the high

porosity region. We have to protect those perforators so we have to keep this very high porosity in most of the places but we..so we..we welded on a patch with a micro welder onto a standard stent. And this is the image..x-ray image with no stent. And this is the image with the patch. So the..the..the flow is totally changed and we still don't know exactly how much change we need to have an effect, that is to be able to thrombose the aneurysm without en..enabling new endothelial cells that cover up the neck and to form a treatment. But this is in process. We wouldn't have thought of this if we didn't have this high resolution capability. This is now the same kind of experiment just reviewed directly optically with light and you can see how quickly the flow is in and out with the unstented and how strange the kind of slow the flow is in with this mesh. OK. So what we need with these new devices we believe is accurate localization, both angularly as well as longitudinally. And that's where the high resolution will be needed. We will probably

also need 3D. Now Dr. Hoffman will be talking more about 3D but we will be needing 3D ultimately for treatment plans and guidance, and right now we use it to evaluate our custom, our new devices with custom designed micro CT system that we actually built with the micro-angio detector. So this is our object, this is the source. We have the rotary stage. We have a micro-angio detector. And this is the kinds of images we get. There's a projection image. You can probably see the mesh here. This is an older picture of an older stent. Not quite in position here. This is cone beam CT with an II. This is our micro-angio with contrast in the vessel as well as mesh, and there's the mesh and these are the stent struts. This is a slice that we've done. The summary then is we can do 10-line pairs per millimeter. We can do real time and we have good enough resolution to motivate us to have new endovascular devices. So the gauntlet is down and for those of you old enough to remember this, this is the challenge we have

now of the gold standard to the other modalities. So I thank you for listening and those are the acknowledgements.