

Thank you very much and, you know, I wanna remind you that after...after the meeting these images and slides will be on the...on the web, so that I can feel free to go relatively quickly. But I wanna try and survey a very large area and, basically, many of us are gonna be talking about computer aided surgery and in particular, some of the image guided interventions, which might be properly classified as one aspect of computer aided surgery. The purpose for this talk is really to survey a lot of these technologies, so I borrowed heavily on the work of many outstanding groups and they're acknowledged at the end. And I would like to leave you with some idea of the applications of these kinds of interventions. The motivations for this are many. We would like to improve on current practice and then, open the opportunity to develop therapies which couldn't be done

without this and to do it in a minimally, or less invasive, fashion. So, this is the outline of my talk and I'll get through as much of this as I can in the few minutes that are available. Talk a little bit about the general topic, then to show you a vertebroplasty, say a few words on CT fluoro, and then, some other types of biopsy procedures and robotic procedures that are done under image guidance. First of all, I think it's worthwhile to have a definition and the definition is, of course, for a GI would be that you use images and these, typically, would be real time, although, not necessarily. There has to be some sort of a target and that you use the images in guiding, navigating, orienting to the field of view and that there's some kind of an operator involved; some human in the loop. Computer aided surgery, now, ties very closely to imaging and it's hard to find a surgical

specialty that doesn't use imaging and, also, use them in conjunction with computational tools and each one of these different areas is advancing independently, and then, also, together. This is a concept of...from this; Johns Hopkins Center, about how computer integrated surgery is done; where of, centrally, their computers and networks with specialized interface devices, both to the surgeon and to the patient. And there are numerous examples of this, including robot-assisted surgery and you'll hear about this from the speakers that follow me, particularly Ron Kikinis. Now, there're several aspects of information flow that we should attend to. One of them is gathering information preoperatively and then using that information and augmenting it, modifying it, applying it intraoperatively and then, perhaps, using it, also, postoperatively; making the

experience that's gained and the outcome, reusable, to improve future procedures. Minimally invasive surgery just, in general, is an enormous potential market, estimated to be over three billion dollars, even though a minority of surgical procedures may be performed using this and the opportunities exist in trying to expand the applications to areas of surgery not always served by the minimally invasive techniques and this is continuing to evolve, but remains as a major challenge. In the operating room, in a modern operating room today, you'll see the introduction of work stations, visualization devices and other accessories that...that I'll discuss independently. From a practical standpoint, in order to be able to use this, it's necessary to be able to do it in a time frame, where the information can actually be applied. So, going from a CT or MR scan, through

the network, to develop a model and a surgical plan using various tools to bring it into an

operating environment where instruments are calibrated to patient's reference frame and then to, actually, use it in the midst of a procedure; all of this has to be done efficiently and rapidly for it to have any practical use and this is one of the great achievements now, from improvements in computers and networking technology. There's several other prerequisites. It's been necessary to develop imaging techniques that produce very high quality images and produce them in three dimensions. And then, there are tools, which are not strictly imaging tools, but tools that go into a set of images and do some useful function, like this, to remove the bones from a three dimensional image and leaving the vessels themselves, is an important added information that can be used. And then, going into a three dimensional volume and being able to track a vessel, for example and using that tracked information, in order to guide a procedure in a quantitative way. We see,

also, the emergence of...of new instrumentation; the multi-slice CT's, that are built for cardiac applications, where gating is taking place during the CT scans, is one element of a comprehensive examination; where one instrument can, potentially, solve a multitude of different problems. It could be, in a sense, a one-stop shop. With a single instrument and multiple tools, software tools, in general, for solving the specific problems that occur in tailoring the examination to the needs of a specific patient. Doing this, with current technology shows you images with astoundingly high quality, and more and more, we can produce these kinds of images routinely in clinic. Inextricable from all of this, is a post-processing capability; post-processing capability based on work stations, which use high speed computing, in order to add additional value to the acquired images

themselves. And on these workstations, there are, also, a multitude of tools and these individual tools are applied, depending on the specific requirements in a specific case. But, in general, we seek to have a whole constellation of tools available and tailor the examination and the post-processing to a specific needs. So, let me give you a simple example; a vertebroplasty, in case...in case you're not familiar and this vertebroplasty is something, which is applied in the back. So, here we have an MR slice through a vertebral body. This is the spinal canal with the nerve roots in it and several other salient points of anatomy pointed out here. In some instances, and this...these are CT scans of the spine, you can see that there are changes in the vertebral bodies and these changes in the vertebral bodies may impinge on the spinal nerves and spinal canal. Among these,

and this is an example of a spine, you can see that there are deformities within the spine at specific levels and these deformities often contribute to pain and the patient experiences pain. We would like to have some way to treat that pain and it's done with an image guided intervention and you can see one of the steps of the procedure here. Again, during the procedure, itself. So, this is a post-procedure examination, showing a vertebral body, where some radio dense material has been added to the vertebral body, itself. The addition of this material is added by passing a needle through the pedicle, under local anesthesia, perhaps, as an outpatient and then, with biplane fluoroscopy, for example, treating the results of osteoporosis, or of a metastasis, which caused exquisite pain and may be very debilitating to a particular patient. So, let's take an example. This

is an 85-year-old man, who has severe, chronic back pain, that couldn't be... was unable to be treated with conventional therapies. And if you take a radiograph, or part of a radiograph of the spine, you see normal vertebral segments above and below and then a single level, where the vertebral body has collapsed and this is the source of the pain. This is another image of the pain, and you can see the spinal canal and the spinal cord within it. So, under biplane fluoroscopy, you know, we have the patient lying on his stomach here and you can, basically, put a probe onto the back and you can see the probe adjacent to the vertebral body and we'll align that with the pedicle. And then, basically, advance that into the vertebral body itself with an 11-gauge biopsy needle and then, adjacent to the table, we're preparing methyl methacrylate. The methyl methacrylate

solution is prepared. It's drawn up into syringes and it's injected through this biopsy needle into the vertebral segment itself. And if you look through the other plane of the fluoroscopy instrument, you can see that the vertebral body is beginning to fill with this radio dense material, and over a period of time, this will tend to harden. So, now we've completed this on one side and we move to the opposite side and repeat the procedure. So, now the vertebral body is filled with this material. The procedure is completed and the patient experiences almost immediate elimination of pain. Sometimes, patients will get up and walk off the table, when they came in bedridden. So, for vertebroplasty is just an example of recent introduction of therapy, where patient's who were... had pain, unresponsive to medical therapy, get tremendous relief and has, relatively, few

complications. I want to say a few words just about x-ray fluoroscopy and CT fluoroscopy. This is the basis for most interventions, traditionally; using it for biopsy, for drainages, for a variety of other types of procedures. In fact, we can use fluoroscopy in conjunction with other techniques, including CT. And here, you can see the vertebral body and lining an intended path with a pedicle and, actually, the needle placement during a particular procedure, shown here. So, now we've see instruments, where CT scanners are combined with the fluoroscopy units in a operating-type environment. You see the fluoroscopy unit, and the patient lying on the CT table, in this example. And there are many examples of using fluoroscopy in conjunction with localization devices, on order to manipulate the spine, or to do orthopedic-type procedures. This shows an

example, where fiducial points are produced by anchoring to a vertebral segment and then placing a probe and being able to visualize on the computer work station screen, the location of the probe, in order to avoid critical structures and to improve the precision of the procedure in an operating room environment, with a fluoroscopic navigation system. CT fluoroscopy is another enhancement to this. CT fluoroscopy, basically, allows continuous CT imaging. So, in real time, for example, 12 frames a second, you could begin scanning and watch the slices, as they appear, on the screen. In a single slice scanner, you get a fluoroscopic display that shows you an example of trying to reach a nodule in the lung with a probe. In a multi-slice scanner... Whoops, how did we get to the end? (Inaudible discussion.) Is there an end button? Sorry about that. Okay. So, on the multi-slice version, you see that there are actually multiple frames and you can watch the

needle as it's approaching obliquely in one or an adjacent frame and see the target in two of the frames and not in another, so that you can triangulate and locate your target. Another use of this is for CT angiography; to, basically, start monitoring after the injection of contrast material and you follow the timed activity curve of the contrast material, as it percolates through the vasculature, in order to optimize the capture of the vessels at the peak of enhancement, in a particular procedure. CT fluoroscopy is not as frequently used as you might think and the principle concern is dosimetry. The dose to the patient and the dose to the operator are of great concern in CT fluoroscopy. So, more efficient systems to do CT fluoroscopy are needed, in order to reduce the dose problems. It has a number of potential applications, but only a relative minority of CT scanners are supplied with this particular type of accessory. There are some enhancements to CT

reconstruction algorithms that have been developed for CT fluoroscopy. This is an example, which shows a CT slice of the abdomen, and then, trying to place a needle into a mass in the abdomen. This is filtered back projection, with the metallic streaks that come from metallic objects, that show you what the reconstruction would be and then this is a specialized algorithm that reduces the metal artifact and allows you to see much better detail. Similarly, there are other algorithms, which have been developed, in order to try and do noise suppression, because these are dose limited studies and using filtered back projection, you get a certain amount of noise and with the irradiative type of reconstruction methods, you can do this with less noise. So, this is an important tool. Let me show you another example of a clinical-type study, very routinely done on patients;

inpatients and outpatients. Kidney biopsies have been around a long time; since the 1930's. We do em, perhaps, a little bit differently but, one of the things that's used is this accessory, a spring-loaded biopsy gun. The spring-loaded biopsy gun is inserted after guidance with a transducer; the transducer on the ultrasound machine. And you can see that...that you, basically, have to look...turn your head to see the results of the ultrasound machine while you're operating on the patient in a different direction. This is a more ideal way of depicting the results, as you visualize the results, in multiple different contexts, from image processing, with a much superior display. In general, you would use an ultrasound transducer and, perhaps, a guide, or a needle holder, to puncture the skin at a particular point of triangulation in real time. And sometimes, the needle tracks, in order

to reach the kidney; this is showing the patient lying prone. This is his back and the kidney embedded in fat and you're trying to localize this with ultrasound and then come up with a needle track, in order to sample the kidney itself. And this is an example of the type of sample that you would receive. Just a small amount of tissue, which is inspected, histologically, to look at the glomeruli, to look at the stroma and be able to diagnose the patient's kidney disease. There are some complications from these types of procedures. The commonest one is to develop a subcapsular hematoma; such is shown here, by introducing this type of needle. The patient develops hematuria and, in some patients, the bleed may be quite large. So. Current practice also uses, sometimes, CT to do this. This has a long track record and, often times, percutaneous biopsy is done when you can't

really see the kidney very well with ultrasound guided biopsy because of the patient's body habitus. Here's an example. The patient's lying prone. The needle is placed into the kidney, in order to sample this in a different patient; to sample a mass in the kidney from a different orientation and to...here, you have another patient and the kind of biopsy apparatus that's introduced into the CT scanner, in order to actually carry out the biopsy. In the future, the hope is that better instruments, particularly robotic instruments, would be under the control of the CT scanner or the other...any other type of scanner, so the patient could undergo this and there are a number of accessories attached to the CT scanner, in order to facilitate this and take the operator out of the room. Let me look at a few issues in computer aided surgery. In the past, we, you know, operated on patients by

opening them and finding out what's inside and, at the present, we have great visualization tools and we often see that and then do an open procedure in a majority of cases. In the future, more and more integration of information, both from this patient and from previous patients, to reuse the experience and to do this with multiple modalities simultaneously, and present that, at the time and the place when the decisions and interventions are being made. So, this is clearly the future, but technically intense and much more complex. To do this, there are a number of devices, including real time tracking devices, such as this with the camera and the various instrument; either with passive markers or with active markers, in order to do the localization in real time, and also, there's been a long history of the use of robots. And the robots take many different

forms, but share some general principles. In general, they are task and procedure dependent and they have tremendous opportunities for augmenting human skill and also, for being able to do things, which we couldn't consider doing in the past. And doing that in an minimally invasive fashion. They come under various classifications. Some robots are passive. Some are semi-active and some are active. And all of these have examples in clinical practice. There's one that has a long history and this one, I'll show you an example, in total hip replacement, called the Robodoc. The Robodoc was intended to improve on human capabilities for deploying artificial hip joints; basically, these types of joints, which are usually done by manual techniques and placing this hip prosthesis in the femoral canal. In order to do this, you, basically, have to remove the old femoral head

and then, use these tools to mill out a position to put the stem in the existing femoral canal. If you do this manually, you end up with a rough surface. If you do it with a robot, you can end up with a very clean surface. So, there was a planeing computer, integrated with a robot, in order to carry this out on the patients themselves. And the planeing computer has visualization tools and you can model the intervention and choose exactly how you would like to do the procedure. And then, in the operating room, was the specialized robots, such as the one shown here. You can see the robot, actually cutting into the femoral canal, basically replacing what the human operator would be doing. The history was, as I mentioned, this had been gone...had been developed over a number of years. A number of human cases have been done, primarily outside the United States, but

it was never approved by the FDA and basically, served, just as an example, of a

technical instrument that never made it into real clinical practice. There are other types of robots that have been far more successful. One, in particular, a laparoscopic assistant; you know, laparoscopy, which is used for, for example, for cholecystectomy, as an example. Laparoscopy is the commonest example of minimally invasive surgery and, in general, you know, the problem is that there are multiple probes placed through the body wall and the surgeon needs an assistant to hold these, but the assistant may daydream, may not hold it steady and so, by having a robot assistant, that responds to voice commands, the surgeon can use his time much more effectively. So, that there are actually, many hundreds of these types of robots already in use in the United States and other types of robots, such as this one, that have come into use, which basically, the surgeon sits at a work station and the patient is under the control of multiple robots

simultaneously, which has completely changed the operating environment and this is the, kind of the, state of surgical practice for now. So, with that, I think I'd like to close my presentation and look forward to hearing from our other speakers. Thank you.