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CYBERKNIFE STEREOTACTIC RADIOSURGERY
UNIVERSITY HOSPITALS CASE MEDICAL CENTER
CLEVELAND, OH,
DECEMBER 3, 2007

00:00:12
ANNOUNCER: Welcome to University Hospitals Case Medical Center in Cleveland, Ohio. In just moments, you'll see how the revolutionary CyberKnife system expands detection and treatment of tumors inside and outside the brain. Unlike other sterotactic radiosurgery systems, CyberKnife uses a combination of robotics and image guidance to deliver concentrated and accurate beams of radiation to specific targets throughout the body. There is no incision for the patient and the treatment benefits those who are poor candidates for conventional surgery. OR-Live makes it easy for you to learn more. Just click on the "request information" button on your webcast screen and open the door to informed medical care. Now let's go to the doctors.
00:00:57
ROBERT MACIUNAS, MD, MPH, FACS: Hello, I'm Robert Maciunas.
00:00:59
DOUGLAS EINSTEIN, MD, PhD: I'm Doug Einstein.
00:01:01
ROBERT MACIUNAS, MD, MPH, FACS: As directors of the University Hospitals CyberKnife Radiosurgery Center, we welcome you today. We're going to be speaking today about the use of this remarkable technology of CyberKnife Radiosurgery for treatment of tumors and other lesions throughout the body that previously could not be treated or could be treated less optimally than they can be with radiosurgery. Today we're going to be treating a patient who is 71 years of age with recurrent squamous cell carcinoma of the cranial base and upper cervical spine. She has previously undergone extensive surgical resection of this tumor and radiation therapy. Despite those treatments, progressive growth of her tumor has resulted in pain, disability, and the need for further treatment. After extensive discussion and consultation, we elected to undergo CyberKnife radiosurgery with this patient. And speaking with the patient, she was amenable to receive this treatment.
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DOUGLAS EINSTEIN, MD, PhD: This treatment allows her to have more focused radiation, even within the previous conformal radiotherapy fields because the radiation is very pinpoint and precise, as we'll show you later in the CyberKnife suite and through the planning that we do preoperatively for this patient.
00:02:21
ROBERT MACIUNAS, MD, MPH, FACS: To begin with, the patient underwent volumetric stereotactic MR and CT scanning. That data was transmitted into a treatment planning computer, and the treatment was arrived at sequentially and iteratively by a

collaboration of neurosurgery, radiation oncology, radiation physics, and the technicians involved in this care. We'll take you now to the treatment-planning area, where we can demonstrate some of that treatment planning and the results of that effort. Our patient today has a squamous cell carcinoma at the base of the skull that was first noticed because of drainage from her right ear. She underwent as extensive an operation as was possible to do of this tumor and then subsequently underwent external beam radiation therapy. Despite the radiation therapy and despite the extensive surgery, her tumor has continued to progress. And as it progresses, she's having more and more pain in her neck. The pain is not due to mechanical instability of the neck but rather because of tumor growth. So it's the primary tumor growth that is causing her pain in this circumstance. Because of that, she was selected as a candidate for CyberKnife radiosurgery for this cranial based tumor that extends from the base of the skull down into the upper cervical spine. The first step in CyberKnife radiosurgery is for the surgeon, radiation oncologist, and radiation physicists all to work together in a collaborative fashion for several days to several weeks using CT and MR scans to guide us in our definition of what the critical structures are, what our target is, and then for all of us to work with the computer that provides an artificial intelligence-based software package to enable us to come up with a treatment plan that gives an enormous dose of x-rays just to the tumor itself while sparing the critical structures. So we have a very rapid drop-off of the radiation dose at the edges of the tumor, especially at the areas where a critical structure such as brain stem or cervical spine is. And that's what we were able to achieve in this particular patient's case. What we see on the screen here is that we have the tumor volume conservatively mapped out as this red contour. Surrounding that, we have the fine orange line that very closely hugs the tumor contour, delivering the treatment dose, which in this case is 2,000 centigrade to the 60% isodose line. The other colors are different isodose curves that show the spill of radiation in various directions. Here, this orange structure, is the cervico medullary junction, so the lower brain stem and the upper cervical spine are defined by this. And it was important for us to be able to keep this dose below 800 to 1,000 centigrade at all points for the cervical spine and for the brain stem while making sure that the tumor received more than 2,000 centigrade in a single fraction at the 60% isodose. We were able to achieve that. We also were able to protect various other structures in the nasopharynx and in the eyes up above as well as the optic nerves. As we leaf through these sequences of images, you see the contouring that occurs over the dose, around -- we see the contouring of the dose that appears around the tumor while sparing the critical structures that we would find, such as the brain stem and the cervical spine. At all areas in the spine, we have good coverage of the tumor all the way down to the cervical spine and C-2 in this particular case. So that we had a very conformal treatment plan that also gave us good coverage of what we wanted to treat in terms of the tumors. We can see the CT, we also see the treatment plan on MR scanning as we come into the lesion itself and the dose that we selected around the tumor. Again, sparing the lower brain stem and the upper cervical spine. In this view here, we have a coronal view of the tumor that is encompassed by the treatment isodose line while sparing the brain stem and upper cervical spine.
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In this coronal view, we can see again the conformal treatment plan that treats the entire target tumor volume while keeping the high dose off of critical structures both within the

brain stem and cervical spine and other critical structures within the cranium and within the nasopharynx. In order to achieve this treatment plan, we went through multiple iterations of plans, saving each one until we had a plan that satisfied all of our constraints and provided us with a dose that was satisfactory both to the tumor and to the critical structures such as the brain stem. In this dose volume histogram, you can see that all of our tumor is covered by the 60% isodose line at 2,000 centigrade, whereas the brain stem receives less, actually, than 850 centigrade in this case. The spinal cord receives less. And in fact, receives less than 556 centigrade in this circumstance, well within tolerance ranges for what we wanted to achieve. The next step in the treatment of this patient is to take this treatment plan that we've come up with, double check it, triple check it with our physics colleagues, and then transmit it to the CyberKnife room, where the robot will then do its work of carrying out this treatment plan in a patient who is breathing and moving. So the robot will deliver this plan without the need of stereotactic frame, without the need of any significant restraints. There will be a gentle restraint of the head in order to optimize the accuracy of this, but other than that, the patient will be free to move during the operation in order to deliver this dose of radiosurgery in a single day.
00:10:04
DOUGLAS EINSTEIN, MD, PhD: Now you've seen the treatment planning. We want to now bring you over to the CyberKnife suite to show you some of the details involved with the actual hardware of this treatment.
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ROBERT MACIUNAS, MD, MPH, FACS: We've brought you into the CyberKnife vault now. This is where the actual radiosurgery will be performed on our patient today. We want you to see the components of the system so that you can have a sense of what is going on as the patient undergoes her CyberKnife radiosurgery. Doug?
00:10:37
DOUGLAS EINSTEIN, MD, PhD: This is the main CyberKnife radiosurgery unit. As you can see, we have a linear accelerator that focuses the radiation beams on the patient. This is attached to a robotic arm that enables the linear accelerator to be moved into a variety of different angles to treat the tumor very precisely. We usually treat a tumor between -- with between 150 and 300 different angles, and the robotic arm moves around the patient during those angles to deliver the treatment. To make sure that we're tracking the tumor continuously during the treatment, we actually have several camera systems in the room that follow both the tumor and the patient. First we have mounted in the ceiling camera systems over here and over there that are focused in on the tumor and actually adjust the robotic accelerator to any change in the tumor movement and so we can continuously achieve precise treatment. Also, we have a third camera system over here we call Synchrony that tracks the patient's chest-wall movement when they breathe and also adjusts the linear accelerator to their chest-wall movements to again ensure for very precise targeting of the patient's tumor.
00:11:56
ROBERT MACIUNAS, MD, MPH, FACS: The beam itself that will be delivering the radiation to the patient is collimated, or tightly focused. And you can see one collimator here that narrows this beam down to nearly a pinpoint. We have a variety of different size collimators all the way from six millimeters up to sixty millimeters. Today we're going to

be using a fifteen-millimeter collimator in order to treat this patient's tumor while sparing the surrounding critical structures.
00:12:25
DOUGLAS EINSTEIN, MD, PhD: We have started the pa-- the treatment for our patient today here in CyberKnife. Where we right now is the CyberKnife control center. CyberKnife treatment requires the coordinated efforts of several professionals that I wanted to introduce you to here on our CyberKnife team. We have our radiation therapist, Brenda Meyers. We have radiation physicists, Barry Wessels and Jim Brindle. And we have our CyberKnife nurse, Mark Anderson. The -- what is going on right now, I wanted to show you a few things that we're doing simultaneously during this treatment. One, the patient is being monitored, and we see a four-panel screen that you may have on your video right now, where the patient's vital signs are being monitored. The patient, as you can see there in the right lower panel, has a -- what we call an aquaplast mask, essentially a molded plastic mask to make sure that she doesn't move her head back and forth during the treatment. On the top left panel of the screen, you can see the CyberKnife machine moving to a different angle, as you can see a movement there right now. You can also see that same movement in another angle view on the left lower screen. And those screens are continuously monitored by our CyberKnife team here. If the patient at all gets concerned about anything, they can talk, and she actually has a microphone that she's wired with and we can stop treatment at any time. And what those camera systems that we have talked about before that are mounted to the ceiling are actually right now monitoring the patient's skull. So even though the patient is in that aquaplast mask I told you, it really helps prevent any movement of her head, there might be slight millimeter or sub-millimeter movements that are going on that we're actually tracking with a different camera system. And that camera system is over here on our other monitor, where we have digitally reconstructed radiographs of what we expect the patient's skull images to be, bony anatomy to be, from those two camera systems. And those are the synthetic images A and B. And then, continuously, as you see the camera image A and B are updated as the CyberKnife unit moves to a different angle, another set of pictures are taken. You'll see that happen in a few seconds. What happ-- what then the computer system does is it compares those camera images to the synthetic images, overlays them, and determines any degree of differences between the bony anatomy. You see another camera image was being taken right now, or acquired, and now it's displayed, digitally fused with the reconstruct-- with the reconstructed images, and the overlays are analyzed by the computing system. What that then presents to us are a list of what we call couch corrections for the patient. That is slight millimeter or sub-millimeter movements of the patient's position that will maintain the precise position of the tumor for the CyberKnife treatment. You can see that those couch corrections listed there are really less than one millimeter for the left anterior and superior. And we also have degrees of freedom of rotation, which were showing degrees below the millimeters of movement. Here we're having another set of couch corrections being lowered in right now. As the robot is moving to a different angle, another set of images is being taken and another set of couch corrections is being fed into the computer. And a patient's -- you can't -- it's very difficult for you to tell on those, on the four-panel screen how slight the patient is moving, but that couch is actually moving .5 millimeters in one direction, .6 millimeters in another direction, .7 degrees, .5 degrees and 1.5 degrees for rotational adjustments. We also on

that screen allows us to determine how often a patient is moving during a treatment. The positional movement is being tracked and shown on the left lower screen, and you can see that the average positional movement there is about -- right now it's registering .63 millimeters. That's how much movement the patient has and that's how much we're adjusting for in every treatment. And you can see by the graph that the patient really hasn't moved a heck of a lot during the treatment, but each of those movements we're adjusting for.
00:17:33
And on the right lower panel, you can see not only the positional movements and corrections that are being made through the movement of the couch in the X, Y, and Z direction but also the degrees of freedom, or rotational movements, are also being tracked. And if we saw big spikes in those orientation changes, we would say that well, maybe the patient has a big position move and maybe they coughed, maybe we should pause the treatment temporarily and readjust. But right now we're not seeing that at all. You can see that the lines are relatively flat, indicating minimal patient movement during the treatment. The patient does not have to participate in this at all. The cameras track the patient movement, the computer systems analyze that, compare it to where we want the patient to be, and adjust the patient into exact position, whether that means a millimeter of movement or .5 millimeters of movement of the patient to make sure we have precision that's sub-millimetric during this treatment. The patient is quite comfortable. She could talk with us if she wanted to fairly -- just -- she's listening to music and kind of sleeping a little bit, or resting. There's no need for general anesthesia during the procedure and the patient doesn't feel a darn thing as this robot is moving around them. And that's pretty beneficial to the treatment. It indicates that we can, just by showing you how the patient is treated during a CyberKnife radiosurgery procedure, it gives you an idea of what patients may or may not be candidates for CyberKnife radiosurgery. These are -- by the virtue of the fact that we do not need general anesthesia, many patients who are medically inoperable would be candidates for CyberKnife radiosurgery. Patients even who, you know, may move around a little bit during the treatment, we can track that movement and then continuously refocus in on the tumor, as you saw on the image tracking that we're doing continuously during her treatment. Did you have anything you wanted to add, Bob, to this?
00:20:11
ROBERT MACIUNAS, MD, MPH, FACS: No, I think that's beautifully explicated. You know, it's important to remember that the sum of all these individual shots of the robot delivers a distribution of x-rays to the patient, and that distribution is a single very high dose to the tumor itself, but surrounding that tumor, the dose drops off very rapidly because of the sculpted manner in which these shots come at the patient from these hundreds of different orientations and hundreds of different angles at which they're delivered. So as a result, although the tumor receives a lethal dose of radiation, really, literally a few millimeters away, the brain stem, the spinal cord is receiving a dose of radiation that is easily tolerated in the circumstances, something that previously was not able to be done by traditional methodologies. And we can do that despite patient breathing, despite patient movement without the need for a stereotactic frame in this situation.
00:21:18

DOUGLAS EINSTEIN, MD, PhD: All right, so this differs from -- a little bit from our gamma knife radiosurgery within the brain. With gamma knife, a frame is attached to the patient's head. The patient has nothing attached to them right now. It does require the continuous image tracking to -- to assure us that we have the precision that we need for intracranial and extracranial stereotactic radiosurgery, that is the delivery in what we're doing here is delivering extremely high doses of radiation in one treatment. Normally when we deliver radiotherapy, we deliver a small amount of radiation over a fractionated course of several weeks of treatment. The goal of doing -- of performing fractionated radiotherapy is to treat larger volumes of tumor but also there might be normal tissue that's between tumor that we might also be hitting with that fractionated radiotherapy. We allow a time period between fractions of treatment to allow for the normal tissues to repair the DNA damage that is made, and then we hit the tumor again. We're lucky in radiation therapy that there -- we achieve a therapeutic ratio of treatment that is hitting the tumor more selectively than the normal tissue because tumor cells just don't stop to repair the DNA damage very effectively, whereas normal tissue, if allowed the time interval to do it, will repair the DNA damage. Now, the concept of radiosurgery is very different than the fractionated radiotherapy in that we don't have that inner fraction interval to allow for repair of any DNA damage to normal tissue that we want to treat, so the goal of radiosurgery is actually not to treat anything that we think is normal and to treat -- and to exclude all normal tissue and just treat tumor we have to be, obviously, very precise on where we're focusing these beams to achieve that precise tumor treatment and no radiation to non-tumor structures. And the way we do that here with CyberKnife radiosurgery is coming in with 150-300 different beam angles and where all the beams essentially converge on the tumor, the tumor gets a very high dose of radiation but those normal structures that are sitting right around the tumor get essentially 1/150th or 1/300th the dose that the tumor gets, depending on how many beams that we're utilizing. And again, it comes back to precision. We obviously have to be very precise when we're focusing the beams, and that's why we have all the camera and computer equipment to be able to do that. And it allows us to deliver these very eloquent treatments that we just couldn't do previously, giving a patient a very high radiobiologically effective dose to their tumor but yet the normal structures receive essentially nothing or a very small proportion of that. And allowing us to treat tumors in eloquent areas, that is tumors right next to normal structures that we really do not want to deliver any significant radiation to. This device allows us to do that very well and very accurately. Right now we're essentially getting into a more autopilot situation here, in that this is what we're going to be doing for the next maybe couple hours. And if a patient wanted to take a break during this treatment, they could. Let's say patient had to go to the bathroom, they could do that during this treatment. We could stop it, we could bring the patient back. The computer system knows exactly what was treated, what wasn't treated, what beams were treated, which beams were not. We can line the patient up again, achieve the same precision even with breaks continuously throughout the treatment if we needed to. If the patient said, "I've got to take a break, I've got to go to the bathroom," we can stop the treatment, restart it again without any necessity for replanning or anything like that, the patient could just continue on where they started. And as you can see on the four-panel screen again, the robot's moving to a different angle and that's what's going to -- that's what's going to

happen continuously throughout this treatment. Bob, did you have anything else that you wanted to add?
00:25:48
ROBERT MACIUNAS, MD, MPH, FACS: I think that it's truly a remarkable device that gives you sub-millimetric accuracy of beam on target and allows us to treat tumors not only at the base of the skull and the cervical spine and the entire spine, but really throughout the body, anywhere within the body, whether it's liver, pancreas, spleen, colon, prostate, you name it. All of these tumor locations, whether they move with respiration or not, are now amenable to the similar levels of stereotactic accuracy for radiosurgery. I think it's a remarkable device. At the same time, what we have here I think really -- and I think you've gotten a sense from our time together today is that radiosurgery really is a treatment that involves people, all the professionals that you see around you, each person monitoring what they need to monitor to make sure that this is safe, effective, and successful for the patient today.
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DOUGLAS EINSTEIN, MD, PhD: I just wanted to know if our physicist, Dr. Wessels, wanted to add anything to this.
00:27:02
BARRY WESSELS, MD: Yeah, physically, the CyberKnife is what we call a very high-duty cycle. There is lots of radiation MU delivered for a relatively small amount of centigrade that comes onto target. For instance, this patient's receiving near 20,000 MU and the dose on target, again, is about 20 gray. So the aperture that's being used is a 15-millimeter aperture, so much of the radiation is actually being stopped in the collimator and this causes quite a bit of radiation potentially to be scattered, so we have to do the proper shielding calculations and door modifications to make sure that the room is entirely safe for the patient. So now in treatment, we like to node number 58, you say, 59, out of -- how many, Brenda, do we have total? 173 positions that the robot goes through.
00:28:06
DOUGLAS EINSTEIN, MD, PhD: So essentially, we're just about a third of the way done with treatment right now that you've seen, so we only have two-thirds left to go. Again, the patient's quite comfortable. Our -- you can see on the, again, the position data -- how do I know the patient's comfortable? We can talk to the patient. But also you can see the patient's not moving a heck of a lot from our position data that we see. Again, moving under a millimeter per camera verification, through acquisition of the images. Each time we acquire a new image, the patient really isn't moving much. And we're able to deliver this very accurate treatment.
00:28:49
BARRY WESSELS, MD: Yeah, everyone wants to know what kind of problems you can have. If the patient were to breathe or fidget a little bit or let's say they wanted to scratch their nose, that machine or the therapist can generate an e-stop. And this e-stop is a sequence by which we can stop the machine entirely, as Dr. Einstein just said, can put them back in the same position. If we have fiducials and they're in, let's say, not as solid a mass at the base of the skull, these things do tend to move with breathing artifact and other artifact that might be introduced by body functions. And so the machine will tolerate movement in the order of one to two centimeters. If it goes out of that range, then the machine will generate what they call an e-stop and stop the treatment, as Jim Brindle,

our physicist, always says, if we're having trouble treating a patient and the patient's fidgeting, again, the machine is working fine when it generates an e-stop. Because the machine stops if the patient's out of position. So this is, again, for a high-precision target.
00:30:04
DOUGLAS EINSTEIN, MD, PhD: Again, we're on node 63 right now. Anything you wanted to add? Okay. I think that the rest of -- well, we've had a nice opportunity, actually, to show you a lot of the details that go on during a CyberKnife radiosurgery treatment. It's certainly been our pleasure and -- and our privilege to have technology like this here at University Hospitals to allow us to treat patients like our patient today where no other treatment really realistically was available to her, and now there is a treatment that can allow for control of her tumor which was previously uncontrollable. What we're going to be doing for the rest of the treatment is similar to what we just showed you and continuously tracking the patient, continuously making sure that the radiation beams go exactly where we want them to go with accuracy less than one millimeter continuously during the patient's treatment with the patient not feeling anything during the treatment, quite comfortable, not requiring any anesthesia whatsoever, with efficacies of this treatment similar to that as if she had the tumor taken out surgically. And that's just, to me, quite remarkable that we have this technology to do this. I want to -- on behalf of our CyberKnife team here, I want to thank you for logging on and looking here -- and sharing with us the treatment of this patient during OR-Live. And it's been my pleasure to speak with you. Bob, is there anything else you want to add?
00:31:51
ROBERT MACIUNAS, MD, MPH, FACS: No. Thank you for your attention. We welcome your questions, and good day.
00:31:58
ANNOUNCER: This has been a demonstration of stereotactic radiosurgery using the CyberKnife system from University Hospitals Case Medical Center in Cleveland, Ohio. OR-Live makes it easy for you to learn more. Just click on the "request information" button on your webcast screen and open the door to informed medical care.
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