

Helical tomotherapy in the community setting: a personal account

James S. Welsh, MD, MS

Departments of Human Oncology and Medical Physics, University of Wisconsin School of Medicine, Madison

Helical tomotherapy is a unique modality of image-guided intensity (IMRT) modulated radiation therapy that was conceived by investigators at the University of Wisconsin. It can be thought of as a hybrid between a linear accelerator (linac) and a helical CT unit. As such, it has intrinsic capabilities of image guidance through its megavoltage CT component. The miniaturized 6 mV linac is mounted on a slip-ring gantry allowing continuous 360-degree rotation while the patient is translated through the bore, thereby providing a helical radiation-delivery pattern. The unit is designed to administer IMRT, and this continuous helical radiation-delivery method appears well suited for generating highly conformal, complicated radiation dose distributions. Although initially created and tested in a large academic institution, helical tomotherapy demonstrated impressive versatility early on, and swiftly became a valuable new cancer-fighting technology in community oncology.

In the mid-1990s, Thomas Rockwell Mackie, PhD, and Paul Reckwerdt of the University of Wisconsin (UW) conceived the idea of a radiation treatment machine that would combine desirable features from a helical CT scanner and a linear accelerator (linac) capable of intensity-modulated radiation therapy (IMRT). The hypothetical device would deliver IMRT in a helical fashion through continuous rotation of the miniature 6 mV linac as the patient was moved through the bore. Because of its design, it would have the potential to provide megavoltage CT (MVCT) images as well as highly conformal radiation treatment. It would permit true 3D image guidance, which in turn would engender confidence that the extraordinary radiation dose distributions generated by the treatment planning/dosimetry software would, in fact, be administered to patients with precision and accuracy.

This promised to be a significant step forward in image-guided radiotherapy (IGRT), which at that time was only in its infancy. Most early IMRT investigators agreed that to capitalize on the true potential of IMRT, image guidance as well as precise patient immobilization would be necessary. Thus, helical tomotherapy, appearing at the dawn of the IGRT era, offered tremendous potential as an integrated IG-IMRT treatment machine, which some believed might revolutionize radiation therapy.

Eventually, a prototype unit was built and moved into the radiation therapy clinic at UW in 2001 (Figure 1). Initial preclinical dosimetric studies yielded rather astounding radiation dose distribu-

tions, which emboldened researchers to conceive of novel clinical applications—applications that were previously considered impractical if not frankly impossible. Among the early dosimetric studies performed at UW were total-scalp irradiation (with minimal dose to the brain); total-marrow irradiation (without unnecessarily irradiating the total body); an improved version of mantle-field irradiation (to address the nodal regions at risk without administering unwanted dose to the lungs, heart, spinal cord, larynx, etc); and noninvasive accelerated partial-breast irradiation.

The fact that such exotic, highly conformal radiation dose distributions now looked attainable encouraged UW radiobiologists and clinicians to envisage improvement in the outcome of cancer patients through novel, biologically designed dose-fractionation schemes. As part of a National Cancer Institute-funded program project grant headed by Minesh Mehta, MD, several UW investigators created novel dose-fractionation approaches. One example was an accelerated, dose-per-fraction escalation scheme for non-small cell lung cancer to avoid

Manuscript received August 18, 2009; accepted September 11, 2009.

This article is based on a talk given at the 21st Annual Meeting of the Japanese Society for Therapeutic Radiology and Oncology (JASTRO); October 16–18, 2008; Sapporo, Japan.

Correspondence to: James S. Welsh, MD, MS, UW Cancer Center–Riverview, 410 Dewey Street, Wisconsin Rapids, WI 54494; telephone: 715-422-9208; fax: 715-421-7408; e-mail: welsh@humonc.wisc.edu.

Commun Oncol 2009;6:463–467 © 2009 Elsevier Inc. All rights reserved.

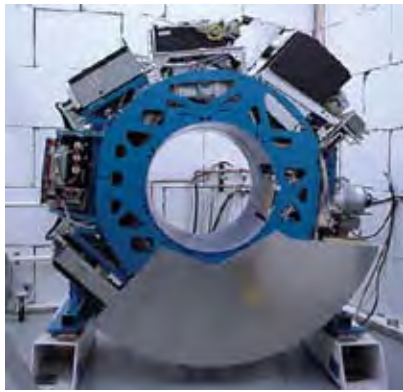


FIGURE 1 The original University of Wisconsin (UW) helical tomotherapy prototype after construction but before installation at the UW Hospital in 2001.

the treatment-defeating problem of accelerated tumor cell repopulation. Another was a hypofractionation approach to prostate radiotherapy to capitalize on the recently discovered low alpha-beta ratio of prostate cancer.

Thanks to the ability of helical tomotherapy to avoid high doses to sensitive normal structures, the concept of “conformal avoidance radiotherapy” (as a complement to conformal radiotherapy) appeared to be clinically attainable. This tactic was proposed for head and neck cancer as one of the core clinical projects.

First trials of helical tomotherapy

As part of the pathway to full clearance for definitive human treatments, the US Food and Drug Administration (FDA) insisted that the Wisconsin re-

searchers address veterinary patients first. In our first actual clinical trial, canine patients with nasopharyngeal carcinomas or sarcomas were treated with image-guided intensity-modulated helical tomotherapy. This study tested both the conformal avoidance capabilities of helical tomotherapy as well as hypofractionation (since veterinary patients require general anesthesia for each fraction and thus the number of fractions was limited to 10).

As hoped for, the MVCT images proved more than adequate for patient setup and tumor localization. The fact that some of these animals had relatively huge tumors, yet experienced a complete response, intimated that large doses per fraction might offer a clinical advantage for human patients in the near future.

Following our veterinary experience, the FDA asked for further proof of principle with human palliative treatments. Thus, during my fellowship under Dr. Mehta, Dr. Mackie, and Dr. Fowler, I treated the first human patients with helical tomotherapy in the summer of 2002 on a clinical trial for bone metastases designed by Mark Ritter, MD, PhD. Shortly afterward, the UW team began its formal clinical investigations of definitive human cancer treatments with helical tomotherapy. In parallel, the company TomoTherapy, Inc was growing and began manufacturing commercial machines. Within a short period, the company expanded and

began distributing units throughout the United States as well as overseas.

Community applications

A serious question remained about the practicality of helical tomotherapy in the community setting. In Madison, Wisconsin, where it was conceived, there was no doubt of its success, given that the team included physicist and co-inventor Dr. Mackie, along with Dr. Fowler, a world-renowned radiobiologist, and the stellar physician-scientist team in place. But there were doubts about the general applicability of helical tomotherapy outside a large research hospital.

Fortunately, we had the perfect opportunity to test the versatility of helical tomotherapy through one of our outreach community oncology programs, UW Cancer Center-Riverview. This program is located in Wisconsin Rapids, about 100 miles north of Madison. Wisconsin Rapids has a modest population of around 17,000 and therefore presented a tough test for this exotic radiotherapy technology. At the time, the Riverview Hospital (which had an average census of around 25 patients) did not have many specialty services, such as pulmonology, cardiology, neurology, endocrinology, dermatology, or neurosurgery, but it did have a cancer center, and I was appointed the medical director.

I had to weigh very seriously the pros and cons of upgrading to helical tomotherapy, knowing that moving into such uncharted territory could cause the program to go down in flames—and I would be largely responsible for the disaster. With input from our home faculty in Madison, as well as encouragement and optimism from the Riverview Hospital administration, we proceeded, removing the relatively young and fully operational linear accelerator and replacing it with a TomoTherapy Hi-Art unit (Figure 2). To further compound the challenge, the UW Cancer Center-

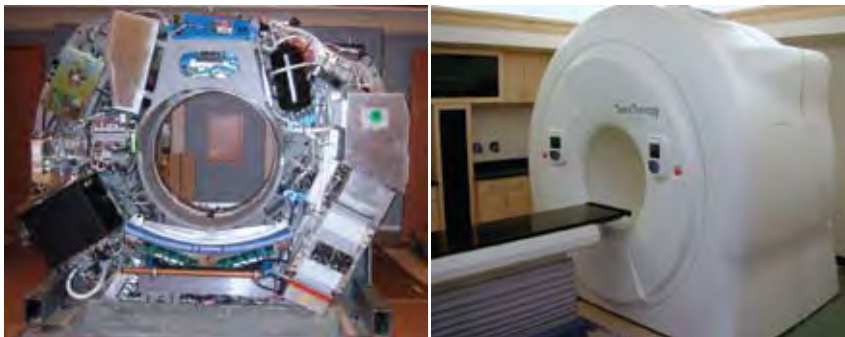


FIGURE 2 TomoTherapy Hi-Art unit without cover (left) and installed with cover (right) at the UW Cancer Center-Riverview in Wisconsin Rapids, Wisconsin.

Riverview did not have onsite medical physics or dosimetry services, so there were additional obstacles to overcome; our physics/dosimetry was done remotely in Wausau, Wisconsin, about 50 miles away.

Skin and breast cancer challenge

Among the immediate clinical challenges were nonmelanoma skin cancer treatment (a common diagnosis in central Wisconsin) and breast radiation therapy. Would I have to send these patients to another facility now that we had only a fancy helical tomotherapy unit? At that time, many believed that simple clinical cases such as skin cancer and breast cancer could not be dealt with efficiently using helical tomotherapy. Through a lot of thoughtful input from our former chief physicist Jeff Limmer, we devised methods to treat skin cancers efficiently, easily, and effectively using the helical tomotherapy unit.

We also came up with techniques of treating breast cancer with helical tomotherapy that were not only just as convenient as the conventional “tangent fields” but also, in many ways, far superior in dose distribution. Given the expanding use of potentially cardiotoxic trastuzumab (Herceptin) for breast cancer patients around that time, it appeared prudent to devise means of avoiding unwanted high doses to cardiac structures. Helical tomotherapy proved to be well suited for this task, given its conformal avoidance capabilities.

The key to successful breast IMRT hinges on the ability to immobilize the breast and use image guidance to assure that the computer-generated dose distributions will truly be administered with accuracy and precision. Just as our initial studies in Madison predicted, the MVCT image guidance instilled confidence that we were indeed accurately and precisely hitting our target, and our clinical breast tomotherapy program was launched successfully.

An immediately perceived advan-

tage of helical tomotherapy was the possibility of a simultaneous in-field boost technique. For example, the whole breast might receive conventional fraction sizes of 1.8–2.0 Gy per day, but the lumpectomy region might receive a higher dose of 2.12–2.25 Gy per day, allowing the whole course to be done in about 5 weeks rather than the customary 6–7 weeks. In recent years, we have further refined our technique and published our methods. Physicians and physicists from the United States and other countries have come to UW Cancer Center-Riverview to observe and learn our approach.

Prostate cancer

For prostate cancer, helical tomotherapy is capable of exquisite dose distributions that minimize doses to the rectum, bladder, and femoral head. Thus, hypofractionation seemed possible in a community setting. Although image guidance with the MVCT of tomotherapy is acceptable, it can be difficult to visualize the prostate apex with MVCT (or conventional CT for that matter). Since we traded in our ultrasound guidance equipment when the TomoTherapy deal was made, we had to either cope with the MVCT capabilities or purchase new ultrasound equipment—or come up with something innovative.

Following up on investigations I did in the 1990s, in conjunction with our urologist Roy Brandell, MD, we developed an approach in which gold marker seeds are placed near the apex and base to provide clearly visible markers for the prostate target. In this fashion, the MVCT of TomoTherapy is capable of the image guidance so critically needed for dose escalation in prostate radiotherapy. This, coupled with a rectal balloon catheter for improved prostate immobilization and targeting, has allowed a successful community prostate cancer treatment program.

Intracranial disease

The addition of helical tomotherapy to our community cancer center (or more accurately, the replacement of our old linac with a helical tomotherapy unit) opened several new doors and opportunities. For one, we began treating patients with more complicated intracranial disease in the community rather than sending them to specialty centers many miles away. Helical tomotherapy proved well suited for IG-IMRT for commonly encountered brain tumors as well as acoustic schwannomas, craniopharyngiomas, chordomas, pituitary adenomas, and other less common lesions, thereby strengthening our community neuro-oncology program. We observed that helical tomotherapy may be used for fractionated stereotactic radiotherapy or perhaps even for single-fraction stereotactic radiosurgery.

One pleasant surprise was the ease with which helical tomotherapy can be used for palliative whole-brain radiotherapy. It proved less complicated than feared, and we have been able to capitalize on TomoTherapy’s strong points and routinely administer whole-brain radiotherapy with a reduced dose to the scalp and ears (which is obviously appreciated by our patients). We may soon be participating in a clinical investigation of hippocampal sparing as a possible means of reducing cognitive loss.

SBRT for lung cancer

Another program created shortly after the acquisition of helical tomotherapy in Wisconsin Rapids was stereotactic body radiotherapy (SBRT). There were legitimate concerns about attempting such a sophisticated approach in the absence of image guidance, but once we had the IG-IMRT capabilities of helical tomotherapy, we began our endeavors.

Over the years, our SBRT program for non-small-cell lung cancer has flourished, and we currently have data

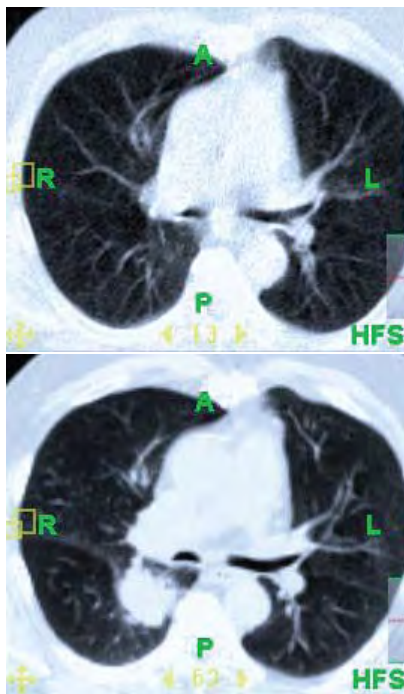


FIGURE 3 Top: Megavoltage CT (MVCT) image obtained with the helical tomotherapy unit after 4 weeks of treatment for lung cancer. Bottom: Original appearance during conventional CT imaging done for simulation (treatment planning). Note the obvious tumor regression on the MVCT scan.

on nearly 100 patients—when pooled with that of fellow community oncologist Lane Rosen, MD, in Shreveport, Louisiana. All patients were treated using a similar dose-fractionation scheme with a BodyFIX immobilizer (made by Medical Intelligence, Germany) and helical tomotherapy.

At about 3 years' median follow-up, local tumor control rates are 93%. Since its inception, none of the SBRT patients has had any significant complications. These results rival anything in the published literature, from either academic facilities or community practices. The dose fractionation schedule I presently favor is 60 Gy in 5 fractions of 12 Gy, each spread over 10 days. This scheme is partially based on radiobiologic modeling performed at our main facility in Madison. Given the excellent clinical results, this is what I plan to continue with for now.

Emergencies

When UW Cancer Center-Riverview became a community oncology center with only a helical tomotherapy unit, our referring physicians (and the radiation oncology staff) began to wonder whether we would be able to effectively handle the occasional emergency or if these patients would have to travel 50 miles to the nearest all-purpose radiation oncology facility. The latter would not be acceptable in a community practice.

Given this dilemma, I acquired TomoTherapy's StatRT option, which enables me to simulate a patient right on the tomotherapy unit using MVCT imaging and to generate a plan in a matter of minutes while the patient remains in place. In many cases, within a half hour, the simulation and entire treatment can be completed, again proving that helical tomotherapy is a practical technology, in the community setting. Fortunately, we have not had to manage many patients emergently, but it is comforting to realize the ability is

there should we need it.

Adaptive radiotherapy

A machine capable of image guidance opens the doors to "adaptive radiotherapy" (Figures 3 and 4). With the MVCT ability of helical tomotherapy, one can monitor the patient's overall size and the tumor volume on a daily basis. With these data, one can determine whether there has been a significant change since the simulation (which is, of course, what the IMRT plan is based on).

If there is a drastic and obvious anatomic change, one can use the MVCT images to quantify the dosimetric difference; if the difference is significant, one can re-plan based on the MVCT images. In this way, one can ascertain whether the dose distribution generated on the original CT simulation is going to be delivered to the targets (and *not* to nontarget tissues) throughout the entire course or if tumor shrinkage/patient weight loss has led to dosimetric differences that could be corrected (or compensated

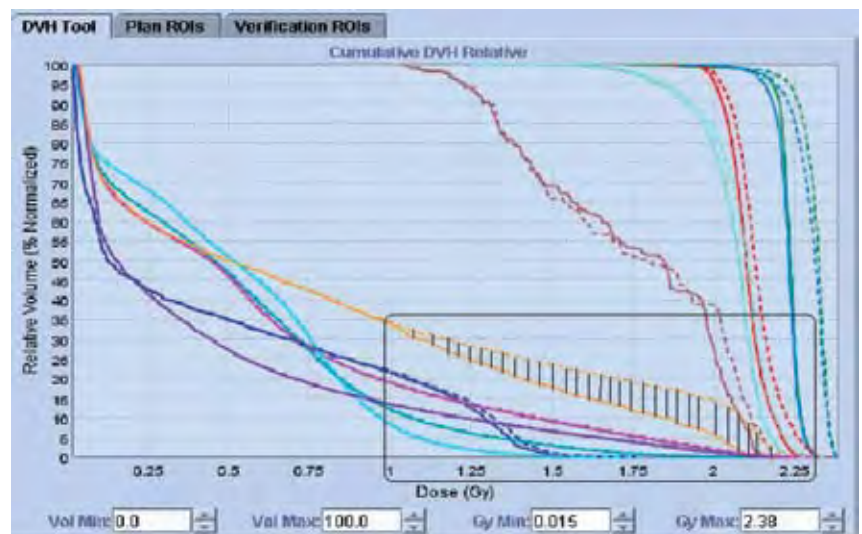


FIGURE 4 Dose-volume histogram showing the effect of lung tumor regression on the esophagus. Within the rectangle in the bottom right, the upper dashed curve represents the actual radiation dose being administered to the esophagus as determined by the megavoltage CT scan shown in Figure 3; the lower solid curve represents the desired dose planned during the simulation. With the lung mass regression, there is less solid tissue to attenuate the radiation beams, which then wind up dumping dose onto the esophagus. "Adaptive radiotherapy" is possible with this information, allowing adjustments in the dosimetric plan to keep the dose delivered to the esophagus acceptably low.

for). Detecting such dosimetric discrepancies and adapting the course for them are now easy and routine both in academia and in the community.

Pulsed reduced-dose-rate RT

Community cancer centers can remain at the cutting edge in many ways. One example from our clinic stems from the creation of pulsed reduced-dose-rate radiotherapy as a means of re-treatment. This technique of turning the linac beam on and off periodically over 35-minute radiotherapy fractions effectively reduces the biologic effect of the radiation, but more so on normal tissues than on malignant tissues.

Created in our mother ship in Madison by Steve Howard, MD, PhD, and Wolfgang Tome, PhD, pulsed reduced-dose-rate radiotherapy is a practical means of exploiting tumor radiobiology and allowing re-treatments in cases where repeat radiotherapy might otherwise be ill advised. Initially, this approach was

thought to be impossible on a helical tomotherapy unit, but further investigation by our team in Wisconsin Rapids with physicist Yi Rong, PhD, has led to a new method of using helical tomotherapy for pulsed reduced-dose-rate radiotherapy. Thus, with exciting technology, even in the community setting, new and innovative ideas and techniques can spring forth.

Remote dosimetry

The remote dosimetry challenge proved to be no major hurdle, although there were several “hiccups” along the way. After a few years of trial and error, we now have a unique setup in which my dosimetrist lives about 500 miles away in another state and generates the plans at home at her own pace. This process has worked out very well for all parties involved. And it again demonstrates that community oncology is the place where such innovative ideas originate and become reality. We would never have needed even to conceive of this

approach at our well-staffed facility at the university!

All in all, we have found helical tomotherapy to be a valuable and practical addition to our community-based cancer center. With this distinctive and novel technology, there has certainly been no shortage of new ideas to explore and test, and most of these investigations have proved fruitful. Although initially designed at the University of Wisconsin for research and specialized cancer care, the real test of the practicality and versatility of helical tomotherapy came in the community setting. It appears to have passed with flying colors.

ABOUT THE AUTHOR

Affiliations: Dr. Welsh is Clinical Professor of Human Oncology and Medical Physics, University of Wisconsin School of Medicine, Madison, and Medical Director of the University of Wisconsin Cancer Center-Riverview, Wisconsin Rapids, Wisconsin.

Conflicts of interest: Dr. Welsh is a speaker for TomoTherapy, Inc.