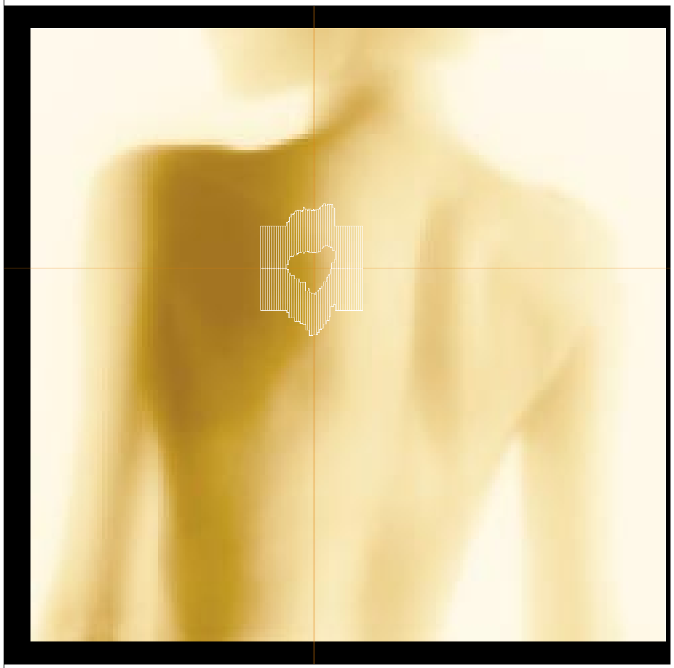


Targeting Cancer

IMRT

The situation reads like the scenario for a science fiction movie. The enemy is an alien intruder that invades the human body, with deadly consequences. This enemy comes in many different forms and assumes a bewildering assortment of odd shapes, which can change when it is under attack. In their search for weapons with which to fight back, humans have developed an amazing technology — one that can seek out and identify the enemy as it hides within its intended victim; track and target its location, adjusting to any changes of shape or position; and destroy the invader with an intense beam of radiation that does minimal harm to the host body. The bad news about this scenario is that the enemy described is an all too real disease — cancer — the second-leading cause of death in the United States (after heart disease) and the slayer of millions worldwide every year. The good news is that the weapon described is real, too. It is a technology called Intensity Modulated Radiation Therapy (IMRT) and it is offering many cancer patients perhaps their best hope ever for successful treatment.

The Millennium multileaf collimator shapes radiation beams with 120 computer-controlled "leaves" or "fingers."

With SmartBeam™ IMRT, Sarah's oncology team will put her tumor in a crossfire, targeting it with precisely shaped beams. They will envelop the tumor in a sculpted radiation cloud where the beams intersect.

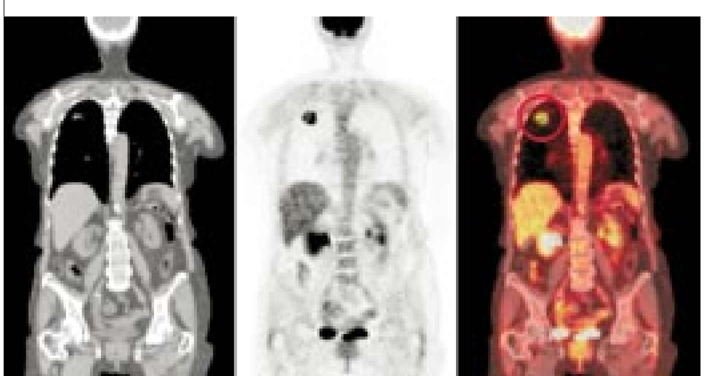
A WOMAN NAMED SARAH

Take a look at what happens in the hypothetical case of a woman whose name, let's say, is Sarah. She is 42 years old, is married, and has two daughters, ages 12 and 10. She has gone to her primary care physician complaining of a nagging cough and occasional shortness of breath. She appears to be in good health otherwise, exercises regularly, watches her weight, and has never smoked. Nonetheless, chest X rays and follow-up tests confirm that she has lung cancer, the leading cause of death among the known forms of cancer, claiming more victims in the U.S. than breast, prostate, ovarian, and colon cancer combined. She is among the nearly one out of every five victims of lung cancer who neither smoke nor live with a smoker. What's worse, the tumor has been classified as a type that, because of its size and general location, is inoperable using conventional pulmonary surgery.

Other medical conditions make chemotherapy problematic. Like more than half of all the other cancer patients who are treated in the United States, Sarah is advised to undergo radiation therapy, also known as radiotherapy. As recently as five years ago, Sarah's lung cancer would probably have been untreatable with radiotherapy because large doses of high-energy X rays, much like the chemicals used in chemotherapy, inflicted extensive collateral damage to surrounding healthy tissue. To minimize the effects of collateral damage, oncologists often had to limit the treatment dosages, which in turn cut down on the effectiveness of the therapy. This drawback would have been particularly acute in Sarah's case, because lung tissue is especially sensitive to radiation damage and lung tumors are highly resistant to radiation treatment.

Fortunately, Sarah has a new treatment option that has only recently become available. She can be treated at one of about 200 radiation oncology clinics around the world now using new SmartBeam™ IMRT technology developed by Varian Medical Systems. SmartBeam IMRT has been compared to shooting at a target with the precision of a high-powered laser. With IMRT, the target area covered by the X-ray beam is narrowed and matched to the shape of the tumor. This enables the oncology team to direct and narrowly concentrate potent doses of high-energy X rays at Sarah's tumor while minimizing complications from hitting surrounding healthy tissue.

With SmartBeam IMRT, Sarah's oncology team will put her tumor in a crossfire, targeting it with precisely shaped beams delivered from several directions or angles. This will envelop the tumor in a finely sculpted radiation cloud within the area where the beams intersect.



These diagnostic images of a lung cancer case were created using a Discovery™ LS scanner from GE Medical Systems, which combines PET and CT scanning in a single machine. On the left, a CT image shows anatomical detail, but the cancer is hard to see. In the central PET image, cancer shows up distinctly as a spot on the upper portion of the patient's lung, but anatomical details are hard to see. On the right, a fused PET/CT image can help doctors precisely localize the cancerous tumor.

THE PREPARATION

Before beginning Sarah's treatment, doctors will need digital high-resolution 3D images of her tumor and the surrounding anatomy. With sophisticated diagnostic imaging, the oncology team can establish the exact location and shape of Sarah's tumor. This will make it possible to develop the treatment plan needed to deliver a high enough dose to eradicate the tumor without harming the surrounding tissue.

To obtain the needed images, Sarah's doctors may choose to use Computed Tomography (CT) in combination with Positron-Emission Tomography (PET). With CT scans, thin, low-energy X-ray beams are swept across a tumor-harboring area to generate a number of detailed cross-sectional images, or "slices." For PET scans, patients are injected with glucose marked with a radiotracer such as fluorine-18, which emits positively charged electrons, or "positrons." These positrons interact with surrounding tissues, producing photons that can be detected by the PET scanner. Since rapidly growing cancer cells metabolize glucose up to 20 times faster than healthy cells, the glucose concentrates at tumor sites. Cancer cells that have taken up the marked glucose appear on a PET image as a clearly visible bright spot.

Before imaging commences, Sarah's team has to deal with the problem of tumor motion during imaging. This is especially critical in cases of lung cancer, where oncologists have tumors moving 1.5 to 2 centimeters (nearly an inch) during respiration.

To cope with this, Sarah's oncology team will use Varian's RPM™ Respiratory Gating System to synchronize the acquisition of CT and PET images with Sarah's breathing cycle. While setting Sarah up for imaging, the team will place a small plastic cube with reflective markers on Sarah's chest. A video camera will track the up-and-down movement of the cube. The X-ray beam from the scanner will be synchronized with Sarah's breathing, so that images are taken only when the lung is in the proper position. Varian's respiratory gating system will come into play again when Sarah is treated so that beam delivery can also be synchronized with her respiratory cycle.

Once Sarah's oncology team has the images needed to begin planning her treatment, they will use Varian's SomaVision™ image processing software to generate three-dimensional views of Sarah's tumor and the surrounding anatomy. The medical team will use the software to mark, or "contour," the 3D images, indicating the area to be treated as well as the organs to be protected.

The next step for Sarah's team will be to prepare her treatment plan. At this point, the radiation oncologist will prescribe the ideal radiation dose for the tumor, as well as maximum dose limits for the surrounding healthy tissue. To determine how the dose will be delivered, Sarah's oncology team uses Varian's Helios™ inverse treatment planning software. Once the dose levels have been entered, Helios goes to work, using its unique algorithms to calculate and devise a detailed treatment plan just as a computer mapping program determines the best route to a destination. The plan includes beam shapes and exposure times as well as electronic instructions that will automate and control the delivery system through 30 to 40 treatment sessions. The next destination for Sarah will be post-planning simulation.

SIMULATION

Prior to actually treating Sarah, her oncology team will first conduct a dry run using Varian's new Acuity™ imaging system. This enables the oncology team to properly position Sarah on the table and run through a simulated treatment session.

Proper patient positioning is critical to ensure that the tightly focused X-ray beams are targeted accurately. Sarah, like most radiotherapy patients, will be tattooed with small marks that will be aligned with lasers in the treatment room, to ensure that she is in precisely the right spot in relationship to the radiotherapy machine. The Acuity system, which mimics the treatment machine, will enable the medical team to take X-ray images of Sarah in her treatment position, and compare them with reference images from the treatment plan. This will enable the team to fine-tune the plan and verify that it will work as intended.

THE TREATMENT

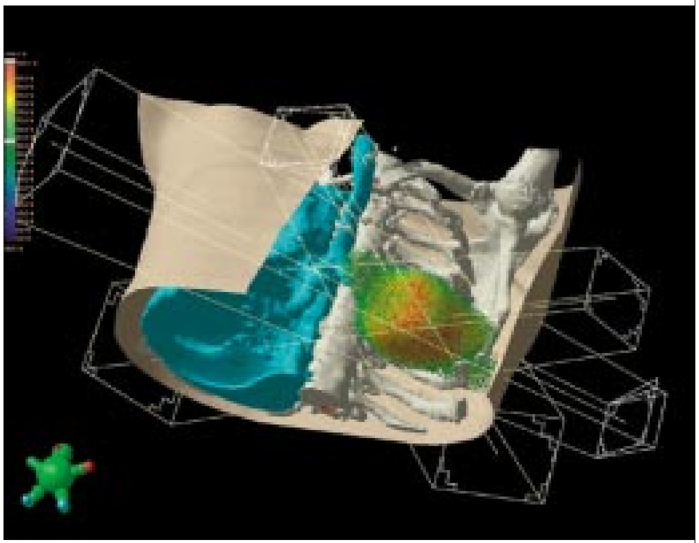
Before Sarah begins the next phase of the IMRT process, let's look at the room in which she will receive her treatment. It measures about 19 feet by 16 feet. In this room is an imposing machine hovering over a futuristic treatment table or couch that might have come from the set of a science fiction film. The machine is a Clinac® medical linear accelerator (linac) manufactured by Varian.

> The radiation oncologist will prescribe the ideal radiation dose for the tumor as well as maximum dose limits for the surrounding healthy tissue.

Linacs are critical to the success of IMRT and all other radiotherapy treatments based on X rays. Reaching tumors deep within the body requires intense penetration power with X rays at energies ranging from 4 to 25 million volts (MV). X-ray tubes, such as those in an X-ray machine being used for diagnostic purposes, typically generate X rays at energies between 60 thousand and 150 thousand volts, far short of what is needed. Linacs, on the other hand, originally developed as a tool for smashing atoms and first adapted to medical applications by Varian in 1960, have no problem meeting the energy requirement.

When the power and intensity of linac X-ray beams are applied to tumors over a number of treatment sessions, the accumulated radiation dosage is enough to fatally damage cancerous cells.

To concentrate a dose of radiation on the tumor, Varian outfits its Clinac with a beam-shaping device called a Millennium™ multi-leaf collimator (MLC). An MLC consists of a computer-controlled array of up to 120 parallel and individually adjustable tungsten bars, or "leaves," that move to shape the aperture through which the radiation passes. It will enable Sarah's



A treatment plan for treating lung cancer. By delivering radiation from a number of different angles, the beams converge on the tumor, seen here enveloped in a "dose cloud." The radiation dose is concentrated in the tumor (red) and falls off toward the outside margins (green).

VARIAN MEDICAL SYSTEMS ILLUSTRATION

oncology team to precisely and automatically conform their beams to the shape of the tumor in her lung.

With IMRT, Sarah's doctors can divide the area being treated into thousands of segments as small as 2.5 mm by 5 mm and give each one a specified dose. The adjustable leaves of the MLC are used to control not only the shape of the beam, but also the exposure duration for each segment of the tumor, effectively "modulating" the dose within the treatment area. This way, higher doses can be concentrated in some parts of the tumor while lower doses can be used in other areas where sensitive tissue may need protection.

Now it is time for Sarah's first treatment session. She enters the treatment room, which is softly lit and quiet. Her radiation therapist positions her on the treatment table. A small plastic cube is again placed on her chest so the respiratory gating system can again compensate for breathing motion. During treatment, the system will turn the Clinac's X-ray beam on and off as the tumor on her lung moves in and out of position. If Sarah coughs or moves, the beam switches off, further protecting her healthy tissues.

Sarah is ready. The therapist leaves the room, closes the door, and moves to a computer workstation to administer the treatment.

Inside the room, the Clinac rotates and locks into a fixed position at the first of the planned beam angles. The beam goes on and the leaves of the MLC begin moving the aperture across the treatment field, changing its size and shape in order to deliver the prescribed dose. This "sliding window" approach to IMRT puts the leaves of the MLC in continuous motion while the beam is on and yet maintains a pattern that conforms to the 3D shape and size of the tumor.

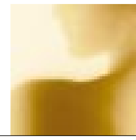
Sarah hears a low humming noise but feels nothing. The Clinac rotates and delivers beams from several angles until the treatment is completed.

During treatment, Sarah's medical team uses Varian's PortalVision™ device on the linac to instantly capture X-ray images of Sarah's anatomy as viewed through the beam aperture. By using Varian's image-processing software to compare the PortalVision views on a computer monitor with diagnostic images and the treatment plan, the team is able to verify treatment accuracy and make any adjustments that might be needed in her position or the plan for future sessions.

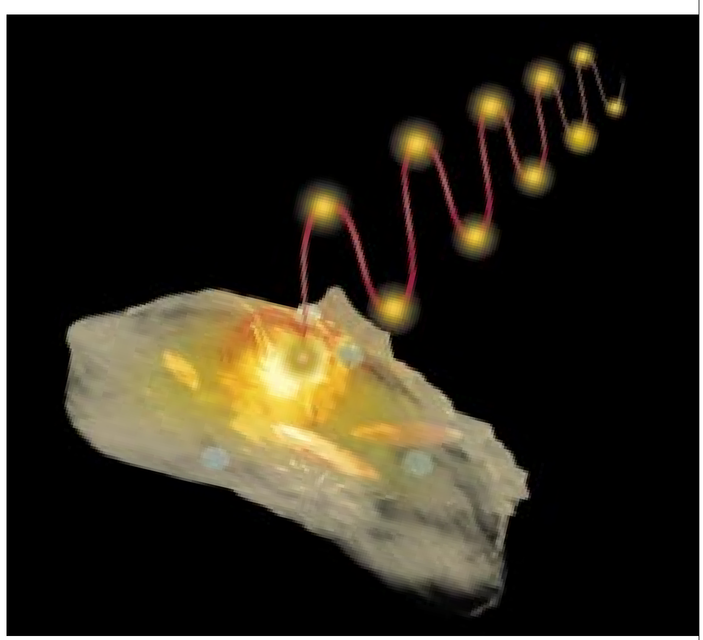
It is 10:00 a.m. when Sarah enters the IMRT treatment room. Ten minutes later, her placement and immobilization on the positioning couch are completed and her treatment begins. Five minutes later, the session is complete. Sarah is free to return home to her family and resume her daily activities.

Sarah will have to undergo multiple treatment sessions, on a Monday through Friday schedule, over a period of weeks. Otherwise her life should not be disrupted. What is the outcome of her IMRT treatment? Hopefully, follow-up tests will show that Sarah's tumor has been functionally eliminated. She will have to be re-scanned, perhaps six months after treatment has been completed, for the possible appearance of new lesions and to be sure that all of the original tumor was destroyed. If either situation should prove to be the case, she will have to undergo another round of treatment and the process will continue until all the lesions are gone. In the end, however, the likelihood is good that she will be cured of her lung cancer.

Sarah's doctors can divide the area being treated into thousands of small segments. Higher doses can be concentrated in some parts of the tumor while lower doses can be used in areas where sensitive tissue may need protection.



Is this too rosy a scenario to project for Sarah? No, nor would it have been had our patient been George, 57, diagnosed with prostate cancer, or Robin, 54, diagnosed with breast cancer, or Bill, 63, who had cancer of the head and neck. IMRT is being used to treat all of these major cancers. According to the early clinical results and the testimony of oncologists who are at the forefront in the fight against cancer, it can be highly effective. For example, in a study conducted by researchers at Memorial



A beam of high-energy photons strikes a cancer cell. In radiotherapy, the aim is to bombard cancer cells with highly energetic photons (X rays), which interact with water molecules in the cells to create ions or "free radicals" that damage DNA. Healthy cells can repair themselves to a degree and continue to metabolize. However, cancer cells often have faulty repair mechanisms and thus lose the ability to replicate. Repeated exposure to high energy X rays eventually impairs or kills all cancer cells, eradicating the tumor.

ILLUSTRATION BY BRIAN SPATOLA, GEORGE RETSECK AND BRYAN CHRISTIE

> Already in the works is a Dynamic Targeting™ initiative that will provide real-time high-resolution images for tumor localization and motion tracking during treatment.

Sloan-Kettering Cancer Center in New York between April 1996 and January 2001, 772 patients with prostate cancer were treated with IMRT at fairly high doses made possible by IMRT's precision. The 3-year relapse-free survival rates for favorable, intermediate, and unfavorable risk group patients were 92 percent, 86 percent, and 81 percent, respectively. Compare that success rate with comparable rates of only 75 percent, 55 percent, and 35 percent in an earlier study in which prostate cancer patients were given a more conventional treatment at a lower dose.

Sloan-Kettering's chief of radiation oncology, Steven Leibel, MD, has said, "IMRT is revolutionary in its ability to modulate the radiation beam. It can do what standard conformal therapy can't. IMRT has become the standard mode of conformal treatment delivery for localized prostate cancer treatment at our institution."

Leibel says the Sloan-Kettering Cancer Center, which treated its first patient with IMRT in 1995, now treats roughly a quarter of their patients with the technology, approximately 1,000 patients a year. George T.Y. Chen, Ph.D., head of radiation physics, Department of Radiation Oncology at Massachusetts General Hospital, and professor at Harvard Medical School, says his department, which began using IMRT a couple of years ago, is now using IMRT to treat between 10 and 15 percent of their patients.

"IMRT is in its infancy and so we don't know, for example, what the 10-year success rate will be," Chen has said. "In some cases, such as cancer of the head and neck, the impact is obvious. It provides the opportunity to spare critical structures such as the parotid gland and this enables us to reduce the side effects of radiation. It's a technological revolution that's really changing radiotherapy. The oncology community is very excited about it."

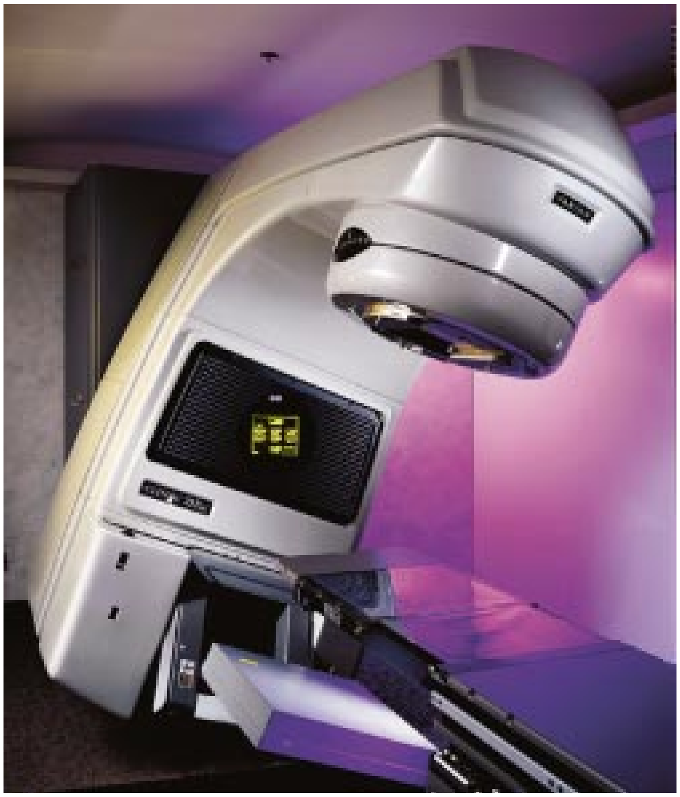
The opinions of Leibel and Chen have been echoed by other leading oncologists across the nation (see "What They're Saying from the Front").

Although less than ten percent of the world's nearly 5,500 radiotherapy centers for cancer treatment are currently offering IMRT to their patients, the numbers using Varian's SmartBeam IMRT climbed from one in 1995, to 40 in 2000, to 98 in 2001, to an estimated 200 by the end of 2002. Expectations are for continued expansion around the world.

The IMRT procedures being implemented at radiotherapy centers now are a first-generation technology. Already in the works as a next evolutionary step is a Dynamic Targeting™ initiative that will eventually equip Clinac linear accelerators with an X-ray-based on-board imaging system. The aim of this research initiative is to attach Varian's latest amorphous-silicon flat-panel image detector directly to the Clinac on a pair of robotic arms that move relative to one another. The goal is to provide oncology teams with images and motion tracking capabilities that can help them guide the beam during a treatment session.

Varian unveiled a research prototype of this next step in Dynamic Targeting at the 2002 American Society of Therapeutic Radiology and Oncology (ASTRO) meeting.

As we move into the new millennium, humans for the first time ever have the technology at hand with which they can confront their ancient enemy and bring it under manageable control. The idea of cancer being transformed from a life-threatening condition to a manageable disease is no longer wildly speculative science fiction but is tantalizingly close to becoming scientific fact. ■



The Clinac® digital medical linear accelerator delivers the most advanced forms of radiotherapy, including IMRT, to eradicate tumors.

An Ancient and Persistent Foe

Cancer is the term commonly used to describe what is actually not a single disease but more than 200 individual disorders, each characterized by the presence of mutant cells that proliferate through uncontrolled growth and division. This uncontrolled proliferation leads to the formation of tumors that can invade and take over surrounding healthy tissue. Eventually, cancerous cells can metastasize – that is, break away from the primary tumor and, traveling through the circulatory and lymphatic systems, establish new cancer sites in other areas of the body.

Cancer in its various forms has plagued humanity dating back almost to the beginning of recorded history. Incidents of breast cancer, for example, were reported on papyrus manuscripts by the physicians of ancient Egypt, who at around 1600 B.C. recommended that diseased tissue be cauterized. Hieroglyphic inscriptions nearly a thousand years earlier report cancers of the stomach and uterus, which were treated by compounds of barley, pig ears, and other ingredients. Last year, cancer claimed in excess of six million lives throughout the world. In the United States, about 1.3 million Americans are diagnosed with cancer each year, and about 500,000 Americans die annually from one or more forms of the disease, which is an average of about 1,500 people a day. According to the National Cancer Institute, about one in three Americans will be diagnosed with cancer during their lifetime. In the U.S., one of every four deaths is from cancer, according to the American Cancer Society.

About 80 percent of the cancer-related deaths in the United States are caused by only a dozen types of cancer. In descending order, they are lung, colon, breast, prostate, melanoma, uterine, kidney, pancreatic, ovarian, stomach, and cervical. Some forms of cancer can strike even the very young, but cancer primarily affects adults past age 55, which is why the rate of cancer incidence, particularly that of the four major types – lung, colon, breast, and prostate – can be expected to rise as the "baby-boomer" population ages.

Major advances have been made in identifying oncogenes – genetic mutations that can promote the development of specific forms of cancer. With the deciphering of the human genome, the pathway to understanding the genetic roots of cancer development is now open. This has led to speculation about the potential for discovering "cures" through gene therapy (the deactivation of oncogenes or the activation of genes that suppress oncogenes) or through immunotherapy (the harnessing of the human immune system to genetically engineer unique cancer-fighting antibodies). Advances along this front in the war against cancer surely await, but recent findings by cancer researchers and molecular biologists sound a cautionary note. Genetics is only one of several risk factors in the development of cancer. Diet and environmental elements can also play important roles. For example, epidemiological studies consistently show that American and Western European women are five to six times more likely to develop breast cancer than Asian or African women. And while the mutation of a gene called BRCA1 has been identified as a source of inherited breast cancer, women with a family history of breast cancer account for no more than six percent of all new cases. Such findings point to cancer as being caused by a complex interaction of events. This indicates that the prospects for discovering a genetic "magic bullet" capable of curing any one of the major forms of cancer are unlikely anytime soon.

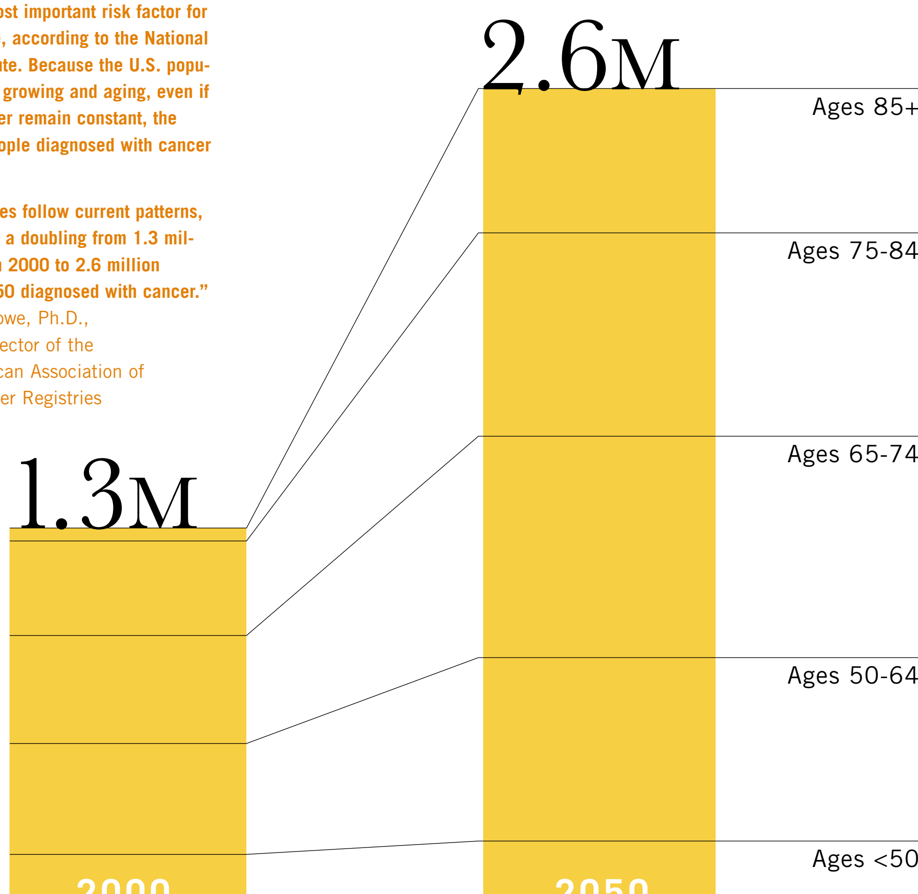
Nonetheless, cancer patients today have more reason than ever before to take heart, as oncologists have at their disposal an increasingly sophisticated arsenal of therapeutic weapons. Through the combined firepower of new and improved radiation and chemical therapies, and increased genetic knowledge, this ancient and persistent enemy of humankind may finally be tamed. ■

PROJECTIONS OF CANCER CASES IN THE U.S. BETWEEN 2000 AND 2050 BY AGE

Chart data derives from NCI's SEER program (The Surveillance, Epidemiology, and End Results (http://seer.cancer.gov), NCI (http://www.nci.nih.gov/) and population projections from the U.S. Census Bureau (http://www.census.gov).

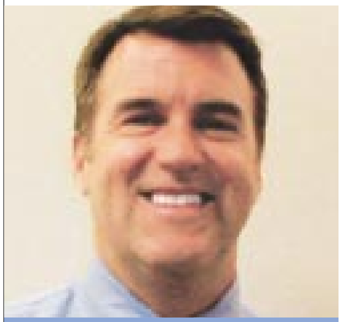
The single most important risk factor for cancer is age, according to the National Cancer Institute. Because the U.S. population is both growing and aging, even if rates of cancer remain constant, the number of people diagnosed with cancer will increase.

"If cancer rates follow current patterns, we anticipate a doubling from 1.3 million people in 2000 to 2.6 million people in 2050 diagnosed with cancer."
– Holly L. Howe, Ph.D., executive director of the North American Association of Central Cancer Registries



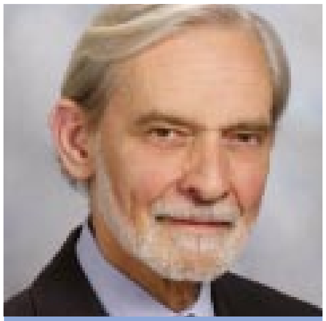
PHOTOGRAPH BY KENNETH GARRETT, NATIONAL GEOGRAPHIC

What They're Saying from the Front



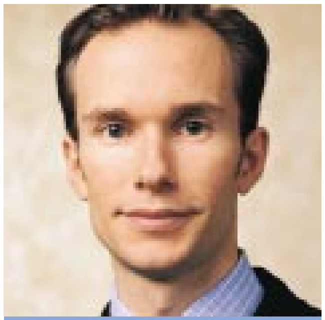
"A safe estimate is that a quarter or possibly a third of our cancer patient population will soon be undergoing IMRT."

Patrick Swift, MD



"IMRT is a more sophisticated way of achieving our goals and it is very much a part of our future."

James Cox, MD



"IMRT lets us treat irregularly shaped tumors with high conformality, thereby improving the therapeutic ratio."

Richard Emery, MS

"IMRT permits us to have dose distributions that were previously impossible. It has opened up some extraordinary possibilities."

Ted Lawrence, MD

To learn about the effectiveness of a weapon, who better to ask than those who have actually used it in battle? In the war against cancer, oncologists who have used Intensity Modulated Radiation Therapy (IMRT), the latest technology in radiation treatments, have been enthusiastic and strongly supportive in what they have to say.

Patrick Swift, MD, medical director for Radiation Oncology at the Alta Bates Comprehensive Cancer Center in Berkeley, California, says he is "hard-pressed" to find any downsides to IMRT.

"We treated our first patient with IMRT on October 1, 2001, and now all of our prostate cancer patients are on it," Swift says. "A safe estimate is that a quarter or possibly a third of our cancer patient population will soon be undergoing IMRT and we've been moving carefully and methodically because we want to make sure we're doing it right."

Swift says his center is focusing its IMRT efforts on prostate, head and neck cancers, and a simplified variation on breast cancers. He thinks, however, that IMRT has excellent potential for the treatment of brain tumors, particularly brain tumors in children.

"The clear thing you're trying to do for the kids is control a deadly disease right now, so you want the dose escalation that IMRT makes possible," he says. "Plus, you want to prevent side effects, which are tremendously deleterious. So many of these kids with posterior fossa tumors go deaf now from conventional radiation therapy. Treating certain pediatric brain tumors with IMRT lowers the risk of deafness."

Professor James D. Cox, MD, heads the Division of Radiation Oncology at The University of Texas M. D. Anderson Cancer Center. He says his staff began using IMRT about three years ago and now treats nearly 1,000 patients with the technology every year.

"The demand has been out there," he says, "but we haven't had the resources in terms of physicists to work with us, so we had a slower ramp-up phase than we would have liked. We'd seen the progress with 3D conformal therapy and how it had improved our ability to give higher doses and decrease side effects in normal tissue. IMRT is a more sophisticated way of achieving both those goals and it is very much a part of our future."

Richard Emery, chief medical physicist and director of radiation services at St. Vincent's Comprehensive Cancer Center in New York, says their first patient was treated with IMRT in the spring of 2001 and the number has since grown to 200, most with cancer of the prostate.

"IMRT's number one upside is that it lets us treat irregularly shaped targets with high conformality, thereby improving the therapeutic ratio. In other words, more dose to the target and less to the normal tissue," Emery says. "IMRT has taken us to another level of care for our patients. It's deeply satisfying to have a technology that can be curative without the side effects associated with conventional therapy."

The downside to IMRT most often cited is the added demands on staff in terms of training and preparation. Ted Lawrence, MD, Isadore Lampe Professor of Radiation Oncology at the University of Michigan, who has been involved with IMRT since the technology's inception, says, "If you're going to deliver a very conformal dose of radiation, you have to have a very high level of knowledge as to where the tumor is. Setup and planning are critical."

However, the added demands on staff can deliver a substantial payoff to the patient, as Lawrence acknowledges.

"IMRT permits us to have dose distributions that were previously impossible," he says. "It has opened up some extraordinary possibilities and will let us test whether it will achieve a revolution in cancer treatment." ■

How a Linac Works

A linear accelerator, or "linac," generates X-ray radiation via the acceleration of electrons that are extracted off the surface of a heated metal disk. The electrons are accelerated through a vacuum chamber by microwaves to nearly the speed of light, an action that greatly boosts their energy levels. These speeding electrons bombard a metal target, usually tungsten, causing it to emit X rays, which are collimated into pencil-thin beams that can be adjusted to cover the 4- to 25-million-volt spread of energies needed to penetrate tumors. The beams are intense, meaning they contain a large number of X-ray photons.

Varian's Clinac EX linac can deliver a dose rate of X rays up to 600 centigray per minute and concentrate them on an area 2 millimeters in diameter, which is about the size of this spot.

1

Radiation therapy begins with a linear accelerator, which speeds electrons toward a target to generate a radiation beam aimed at the patient's tumor.

2

The multileaf collimator shapes the radiation beams and varies their intensity. This enables physicians to target higher radiation doses to the tumor while sparing healthy tissue.

3

The radiation beam is precisely tailored to the shape of a patient's tumor. This shape changes as radiation is delivered from different angles, so that the tumor is always targeted and healthy tissues are protected.

4

A computer system uses three-dimensional images of the tumor and surrounding anatomy to optimize a treatment plan for delivering radiation according to the oncologist's specifications.

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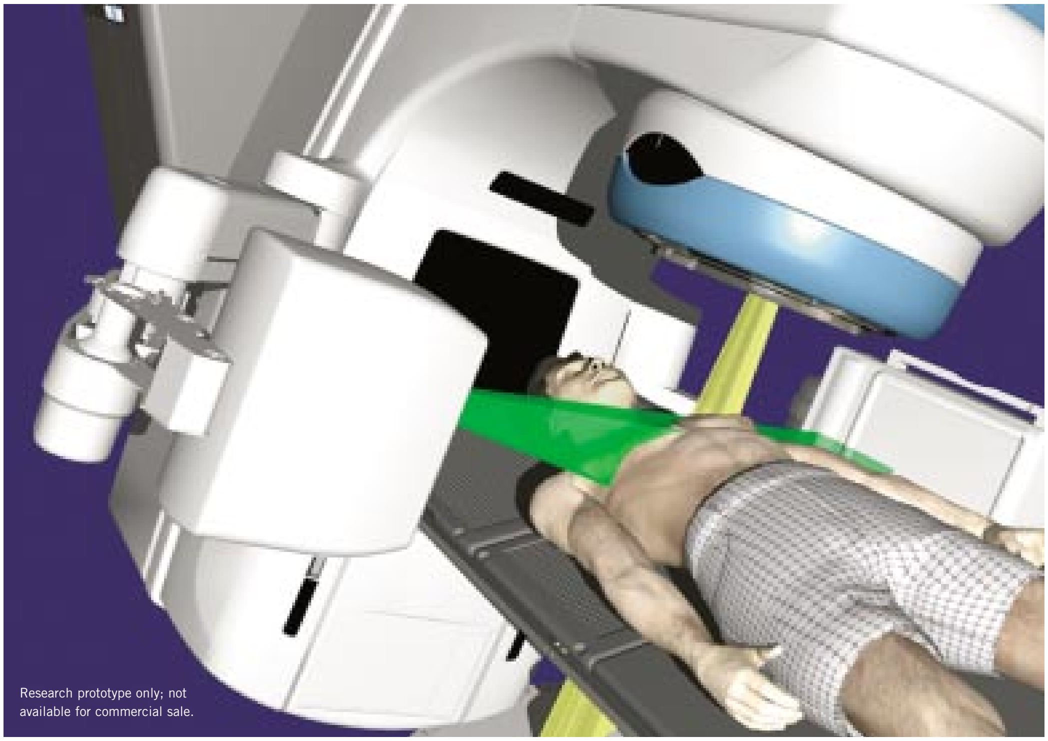
VIEWPOINT

The Radiation Oncology Department of the Future



"Image-guided radiotherapy will make it possible to treat a broader range of cancer cases."

Timothy E. Guertin

An artist's rendition of a medical linear accelerator with an on-board imaging system consisting of an X-ray tube and an amorphous silicon flat-panel image detector on a pair of robotic arms. Clinicians envision using on-board imaging to verify tumor position and adjust for movement during treatment.

With the advent of IMRT and other advanced forms of radiotherapy, imaging has moved to center stage in the field of radiation oncology. These new treatment approaches make it possible for doctors to plan and deliver radiation doses that are precisely tailored to each patient's anatomy and tumor. Consequently, clinicians need much more detailed information about the tumors being treated – information that we can get with the latest advances in imaging technology. Without images that can give doctors three-dimensional views of the tumor and the surrounding healthy tissues, these treatment approaches would not be possible.

DIAGNOSTIC IMAGING

Imaging plays a role at every step in the radiation oncology process, from earliest diagnosis to treatment verification. The radiation oncology department of the future will depend on diverse imaging modalities even more than it does today. Currently, for example, Computed Tomography (CT) and sometimes Magnetic Resonance (MR) imaging show the structure of a patient's internal anatomy and help the oncologist to determine the boundaries of a tumor. Very recently, however, doctors have begun to augment what they know about tumors using imaging techniques like Positron Emission Tomography (PET). PET imaging provides them with metabolic information about the location, size, and aggressiveness of the tumors they are treating. Better diagnostic imaging improves the utility of techniques like IMRT for delivering escalated doses of radiation to the most active parts of a tumor, as well as to any areas of early spread. In the future, we may see doctors using additional biological imaging techniques like Single Photon Emission Computer Tomography (SPECT) and Magnetic Resonance Spectroscopy (MRS) to learn even more about the nature of the tumors they are treating.

ON-BOARD IMAGING

Imaging is also increasingly playing a role in treatment delivery. Radiation oncologists use several forms of imaging to help them accurately target the tumor during treatment. Present-day tools include electronic portal imaging, a technology that uses the treatment beam to capture images of irradiated areas to make sure that beams are being delivered as planned. In the radiation oncology department of the future, medical linear accelerators will be equipped with on-board imaging — special X-ray systems that provide high-resolution images for verifying tumor position and tracking their motion during treatment. These new machines will use high-energy megavoltage beams to treat and kill tumors, and low-energy kilovoltage beams to acquire clear images that can be used to guide the treatment beam. In this scenario, doctors will need software that adjusts radiation therapy in a real-time response to tumor motion caused by a patient's breathing. This software will interpret the images coming from the on-board imaging system and coordinate the treatment delivery device so that it follows the tumor as it moves.

These developments, taken together, have the potential to simultaneously achieve unparalleled tumor control and spare the maximum amount of healthy tissue, opening the possibility of using higher doses within fewer treatment sessions. At Varian Medical Systems, we are actively developing an integrated suite of products that transform the radiation oncology department into an image-guided treatment center. Image-guided radiotherapy will offer us improved precision, and that will make it possible for radiation oncologists to treat a broader range of cancer cases. ■

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