Beaming with confidence

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The London Regional Cancer Program leads the way in radiotherapy with cutting-edge treatment technology

BY STEPHEN GIBSON, C.E.T.

When it comes to providing radiation treatment technology, the London Regional Cancer Program (LRCP) has a long, distinguished history of being on the cutting edge. The first treatment in the world with Cobalt-60 radiation took place on October 27, 1951 at the then Ontario Institute of Radiotherapy, Victoria Hospital in London, Ontario. In 2001 the last Cobalt-60 machine was removed from LRCP and replaced with a Tomotherapy unit making LRCP one of only three treatment centres in the world to have this new technology at the time.

Radiation therapy

Radiation is well known to be highly disruptive to cancerous cells, often to the point of killing the tumour. Without great care, it can also be dangerous to healthy cells. Radiation therapy (also called radiotherapy) has two equally important goals: to eradicate a patient's cancer cells and to do so while minimizing exposure to the surrounding normal, healthy tissue. Depending on the type of cancer, the radiation oncologist may prescribe radiation, either alone or in conjunction with surgery, and/or chemotherapy. Radiation therapy uses controlled high-energy radiation beams, usually x-rays, to damage cancer cells and treat tumours in the breast, prostate, head and neck, lung and anywhere in the body where radiation treatment is indicated. Advances in radiation therapy, especially in the past decade, have been significant. Improvements in treatment planning, real-time tumour imaging, beam shaping modalities and delivery methods have converged in routine clinical practice.

The linear accelerator

Unlike Cobalt-60 machines, today's modern radiation treatment machines (Figure 1), known as linear accelerators, do not use live radioactive sources at all. These machines generate radiation with nothing more than high voltage, high power radio frequency waves, high vacuum, and a supply of electrons.

Generating radiation without a radioactive source

The first step is to generate a source of high-voltage DC. Figure 2 represents a simplified model of the modulator, a separate enclosure whose main purpose is to generate and supply high-voltage DC pulses to the treatment machine. A power conditioner provides 208 VAC 3-phase voltage to the modulator. A large step-up transformer bumps this voltage up to 11,000 VAC or 13,000 VAC, depending on the power mode required. The AC voltage is rectified to DC (B1). When switch S1 is closed, current flows from B1 through a charge choke and charges the capacitor (C1–C4) in the pulse-forming network (PFN). The initial inrush current through the choke generates a large electro-magnetic field (EMF) around the inductor. Diodes (CR1) in the charging path prevent current from returning from the capacitor back to B1. As the PFN capacitor nears maximum voltage, the charging current flow decreases until the EMF developed by the charge choke collapses causing an equivalent amount of current to once again flow into the capacitor, doubling its charge up to either 22,000 VDC or 26,000 VDC. In reality, the voltage is regulated to somewhat lower values.

To regulate the exact amount of voltage on the PFN capacitor, we simply short-circuit the charging choke at the appropriate time. This is done using a special switch, a deuterium-filled glass tube called a thyratron (S2) capable of handling high pulse repetition rates and high power. At this point we have the high voltage necessary to provide the desired level of x-ray beam energy. Now we need to transfer this potential energy to the machine.

The control system provides triggered pulses to the grid of a main thyratron (S3) which acts as a high-voltage, high-speed switch to discharge the high voltage. The high-voltage pulses are sent from the PFN capacitor via four triax cables impedance matched to a pulse transformer load inside the treatment machine (simplified as resistive load R2).

Generating high-power microwave radio frequency (RF)

The high voltage DC pulses from the modulator are converted into microwave RF by a klystron amplifier which resides in the back of the treatment machine. The 2.856 GHz RF waves travel through a waveguide directly coupled to a standing wave accelerator that is under high vacuum. An electron gun injects electrons into the back of the accelerator in much the same way a CRT television gun injects electrons into the picture tube. Powerful magnets around the accelerator squeeze and compress the electrons into a pencil beam approximately 1mm in diameter as they are accelerated by the RF wave up to 99.97 per cent of the speed of light. As the electrons exit the accelerator section, still under vacuum, they are redirected through a 270° bend by more intense electromagnets. This has the advantage of permitting only electrons of the desired energy to exit the machine. As the electrons exit the bending magnets they impact a tungsten button called a target. Due to the extreme energy of the electron beam (up to 20 million electron volts), the sudden deceleration causes photons of energy (x-rays) to be emitted in a phenomenon known in physics as Bremsstrahlung or "braking radiation." Figure 3 depicts the electron beam travelling from the gun end through the bending magnets and emerging out of the machine as x-rays.

Shaping the radiation beam

Ideally, we want the x-ray beam coming out of the machine to conform to the shape of tumour. In early days the beam was limited to square or rectangular shapes of the primary definer jaws. Beyond this, additional shaping required labour-intensive manufacturing of lead or cerrobend alloy molded blocks.

Modern treatment machines use a device called a mutileaf collimator (MLC) attached directly to the machine where the beam exits (Figure 4). The MLC uses 120 motor-driven tungsten leaves which can move into an infinite variety of shapes with sub millimeter accuracy.

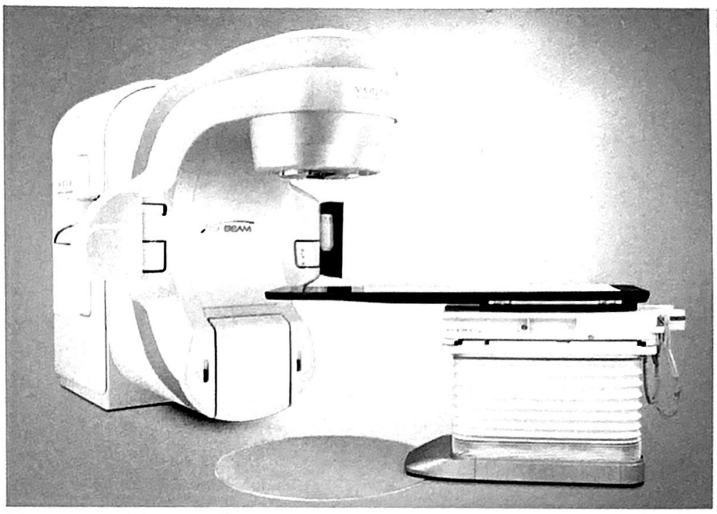

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Figure 1. Varian Medical Systems TrueBeam™ Radiotherapy System

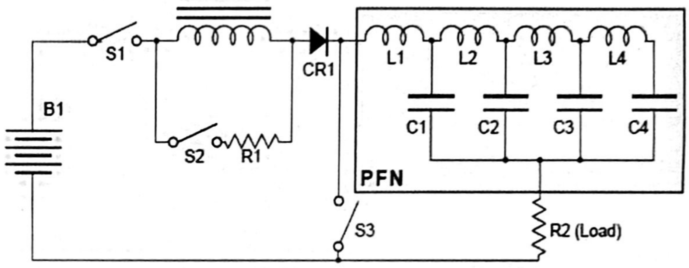

Figure 2. Simplified equivalent model of modulator

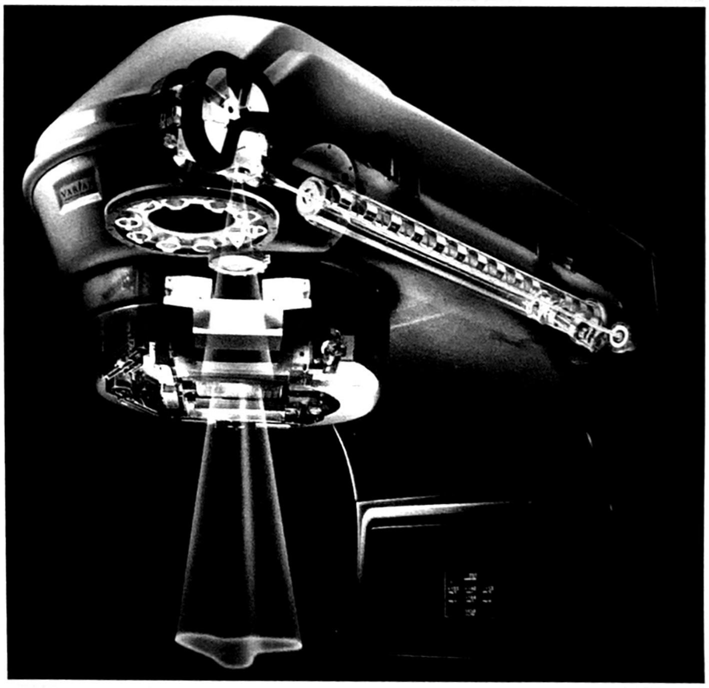

Figure 3. Inside the accelerator

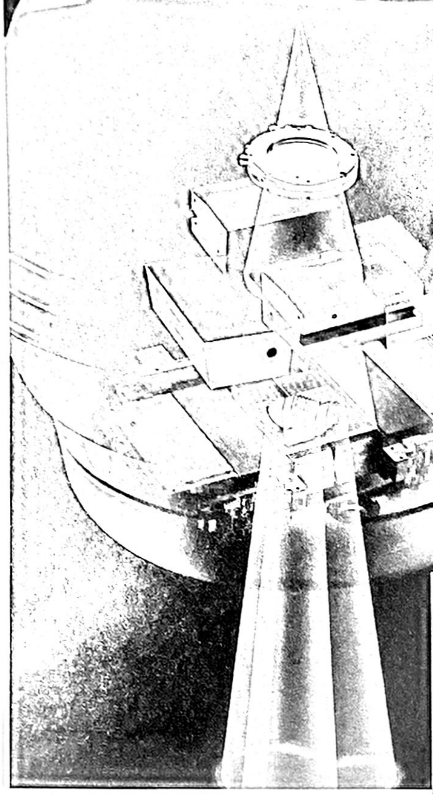

Figure 4. Varian multileaf collimator

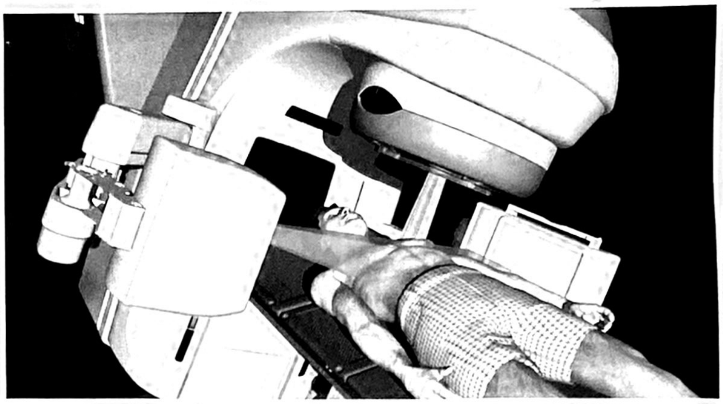

Figure 5. On-board imaging

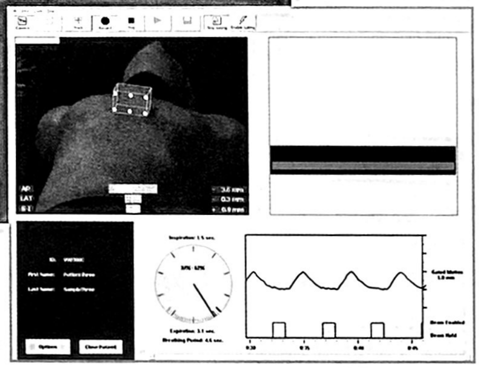

Figure 6. Varian Respiratory Gating Motion Tracking

On-board imaging

Of course, we need to know exactly where the tumour is located. Historically, after setting a patient into position on the treatment couch, the radiation therapist would set up an x-ray film, take a limited beam exposure, then take the exposed film to be processed in a dark room. The x-ray film would later be reviewed with a lightbox to QA the accuracy of the delivered treatment.

Today treatment machines are equipped with on-board imaging (OBI). OBI provides high-quality images of soft tissue, boney anatomy or other markers for optimal patient positioning. Two robotic arms orthogonal to the treatment beam provide kilovoltage (kV) imaging, one holds a kV imaging source and the other holds a kV imaging detector (Figure 5). Not only can single images be acquired from any gantry angle, the machine can be rotated around the patient while acquiring a continuous series of images in a mode known as cone beam CT. These acquired images are then reconstructed to yield high-resolution 3D CT slices.

Real-time motion

What happens if the tumour moves as with the case of a lung tumour moving with the breathing cycle? Respiratory Gating is a technology used to compensate for large movements of the lungs. Using an infrared tracking camera and a reflective marker, the system measures the patient's respiratory pattern and range of motion and displays them as a waveform (Figure 6). Gating thresholds are set when the tumour is in the desired portion of the respiratory cycle. These thresholds determine when the gating system turns the treatment beam on and off.

Advanced treatment planning and delivery modalities

Many other advanced techniques are available in routine clinical practice, a few of which include:

Treatment Planning. LRCP has recently purchased RayStation, the next generation of treatment planning systems with groundbreaking features like multi-criteria optimization, ultrafast parallel GPU computation speed and 4D adaptive radiation therapy.

Image Guided Radiation Therapy (IGRT) provides high-resolution, three-dimensional images to pinpoint tumour sites and adjust patient positioning when necessary prior to each treatment.

Intensity-Modulated Radiation Therapy (IMRT) uses 3D scans of the body to guide the beams of radiation to the tumour from many different angles. At each of these angles, the intensity of the radiation is varied (modulated) and the shape of the beam is changed to match the shape of the tumour.

Volumetric Arc Therapy (VMAT) is an advanced form of IMRT that delivers a precisely sculpted 3D dose distribution with a 360-degree rotation of the gantry in a single or multi-arc treatment.

Hybrid Linac-MRI. The world's first hybrid merging the imaging capabilities of a Magnetic Resonance Imaging (MRI) system with the radiation treatment capabilities of a linear accelerator was recently designed and developed by Cross Cancer Institute of Edmonton.

Certainly we have come a long way since the early days of Cobalt-60, yet cancer still proves to be a difficult disease to treat. Last year, the London Regional Cancer Program alone treated more than 7,300 cancer patients with radiation therapy. This does not take into account the number of patients treated by other methods such as surgery or chemotherapy. It is a scenario repeated across the province at other cancer centres. Thankfully, technology in radiation therapy is advancing at a rapid pace giving doctors ever more effective tools to achieve the ultimate goal for their patients, a cure.

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