Medical Dosimetry, Vol. 27, No. 2, pp. 161–169, 2002
Copyright © 2002 American Association of Medical Dosimetrists
Printed in the USA. All rights reserved
0958-3947/02/$–see front matter

PII: S0958-3947(02)00099-7

# CLINICAL IMPLEMENTATION OF INTENSITY-MODULATED RADIATION THERAPY

CHENG B. SAW, PH.D., KOMANDURI M. AYYANGAR, PH.D., WEINING ZHEN, M.D., MAUNG YOE-SEIN, M.S., SUSHA PILLAI, M.S., and CHARLES A. ENKE, M.D.
Department of Radiation Oncology, University of Nebraska Medical Center, Omaha, NE

(*Accepted* 26 *February* 2002)

**Abstract—The clinical implementation of intensity-modulated radiation therapy (IMRT) is a complex process because of the introduction of new treatment planning algorithms and beam delivery systems compared to conventional 3-dimensional conformal radiation therapy (3D-CRT) and the lack of established national performance protocols. IMRT uses an inverse-planning algorithm to create nonuniform fields that are only deliverable through a newly designed beam-modulating delivery system. The intent of this paper is to describe our experience and to elucidate the new clinical procedures that must be executed to have a successful IMRT program. Patients who undergo IMRT at our institution are immobilized and simulated before proceeding to computed tomography scan for patient data acquisition. Treatment planning involves the use of different prescription dose formats and different planning techniques compared to 3D-CRT. The desired dose goals for the target and sensitive structures must be specified before initiating the planning process, which is computer intensive. After the plan is completed, the delivery instructions are transferred to the delivery system via either a floppy disk for MIMiC-based IMRT or through the network for MLC-based IMRT. Target localizations are carried out using orthogonal radiographs. Ultrasound imaging system (BAT) is used to localize the prostate. Dose validation is performed using films, ion chambers or dose-calculation-based techniques. © 2002 American Association of Medical Dosimetrists.**

*Key Words:* **Quality assurance; Treatment planning; Radiation therapy; Intensity-modulation radiation therapy.**

## INTRODUCTION

Advances in computer technology have dramatically changed the practice of radiotherapy toward intensity-modulated radiation therapy (IMRT).[1–4] IMRT is considered an extension or an advanced form of 3-dimensional conformal radiation therapy (3D-CRT). Instead of using uniform fields as in 3D-CRT, IMRT uses nonuniform fields to generate dose distributions that are more conformal to the targets. This technique is possible because of advances in medical imaging modalities that have greatly improved the ability to delineate targets in 3 dimensions. High-speed computers with large data storage disk capacity are now available to handle sophisticated software, such as inverse-planning algorithm, that seeks optimized solutions based on objective function. Another contributor to the emergence of IMRT is the improvement in beam delivery system, which allows the automated modulation of radiation therapy beams. The overall requirement for IMRT is the need to generate optimized and deliverable nonuniform fields. Different delivery techniques have been proposed, 2 of which, tomotherapy and MLC-based IMRT, are commercially available.

Reprint requests to: Cheng B. Saw, Ph.D., Department of Radiation Oncology/UNMC, 987521 Nebraska Medical Center, Omaha, NE 68198-7521.
E-mail: csaw@nhsnet.org

IMRT requires a higher level of precision compared to 3D-CRT. This is because the generation of nonuniform fields by the inverse-planning algorithm is directly based on the CT patient data set.[5,6] Any movement of target and/or sensitive structure location relative to the patient data CT set would result in the delivery of doses to a different region. Clearly, before the clinical implementation of IMRT, the patient setup technique must be evaluated for higher level of precision and reproducibility. The intent of this paper is to describe the clinical procedures implemented for patients undergoing IMRT at our institution.

## PATIENT SETUP PROCEDURE

Patients who will be undergoing IMRT are first simulated for treatment. During the simulation procedure, the patient treatment position is specified. To achieve precise and reproducible patient positioning, treatment aids and immobilization devices are used. These devices are fixed to the treatment couch for better reproducibility.[7] Thermoplastics are used for the treatment of the head and neck, while alpha cradle is used for the treatment of the abdominal and pelvic regions.[8]

Preparation for the treatment of the head and neck is briefly described here. Initially, a head baseplate is placed on the simulator table. The head baseplate is fixed to the simulator table via 4 pins fitted to drilled holes on

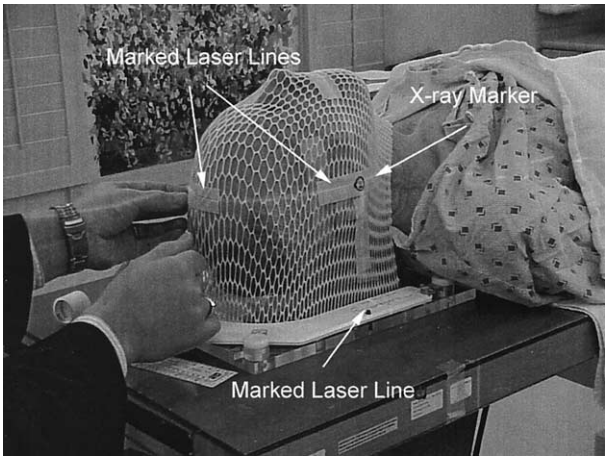


Fig 1. Fixation of immobilization device and establishment of marks for reproducible patient setup.

the simulator table. The patient is placed with the head positioned onto the headrest, which is placed over the baseplate. A cushion is placed underneath the patient's knee for comfort. The patient is then aligned under fluoroscopy. Once aligned, a thermoplastic mask is made. After the thermoplastics harden, the patient alignment is checked and the patient is moved so that the isocenter is in a neighborhood of bony landmarks for convenient portal review of patient setup; it is generally no more that 10 cm from the tumor or region to be treated. Once this task is completed, laser lines are marked on the thermoplastic mask, as depicted in Fig. 1. In addition, x-ray markers are placed on the intersection of laser lines at the lateral and anterior of the patient. Orthogonal radiographs are then taken and examined to validate patient setup. After the validation, the mask is removed and the patient is brought to a designated GE high-speed helical CT scanner for the acquisition of patient data CT set.

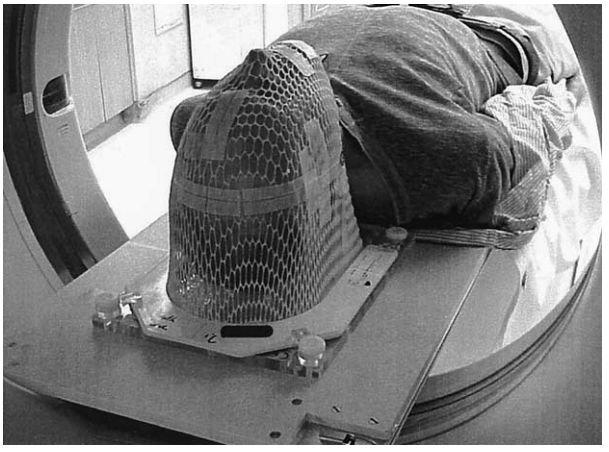

Fig 3. Alignment of patient during CT scan procedure using lasers.

## CT SCANNING PROCEDURE

To replicate patient setup on the CT table, a flat table board with matched drilled holes to accommodate the head baseplate pins, as depicted in Fig. 2, is used. After the baseplate is set on the flat board, the headrest is placed over it, followed by positioning the patient's head and neck on top of the headrest. Next, the thermoplastic mask is placed over the patient's head and aligned with the internal lasers of the CT scanner, as depicted in Fig. 3. Once the patient is aligned, the table position is set to zero, with the lasers passing through the x-ray markers. After the setup, the patient is scanned with contrast or per directives prescribed by the radiation oncologist. The typical scanning format is 3-mm slice thickness through the target and 5-mm slice thickness for 5 cm above and 5 cm below the target. For those patients who require irradiation of the supraclavicular region, the scan extends down to the chest, as marked on the simulation radiograph by the radiation oncologist.

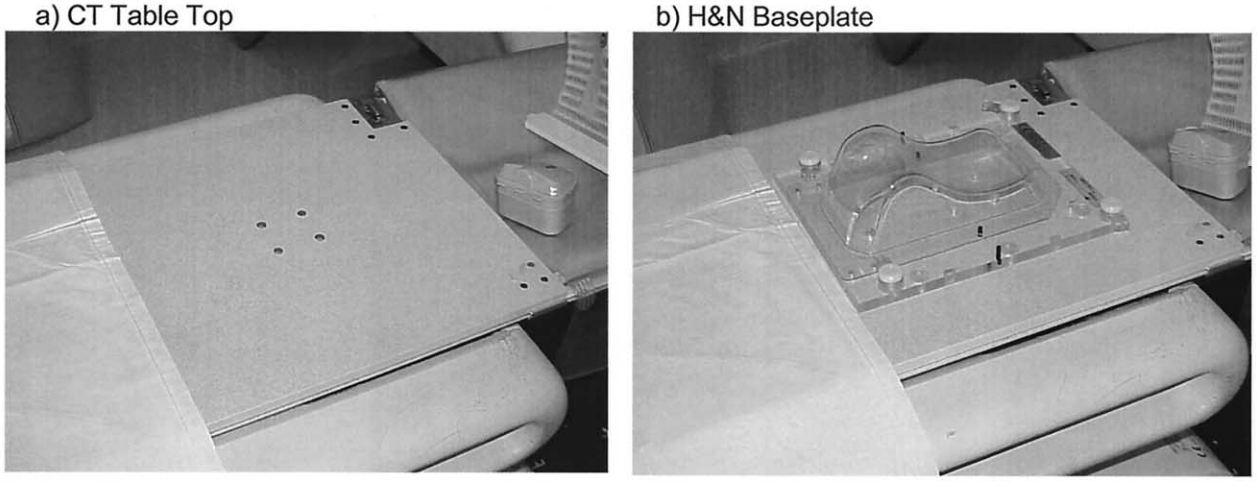


Fig 2. Fixation technique based on the peg system with pins from the head-and-neck baseplate fitted onto the CT table top.

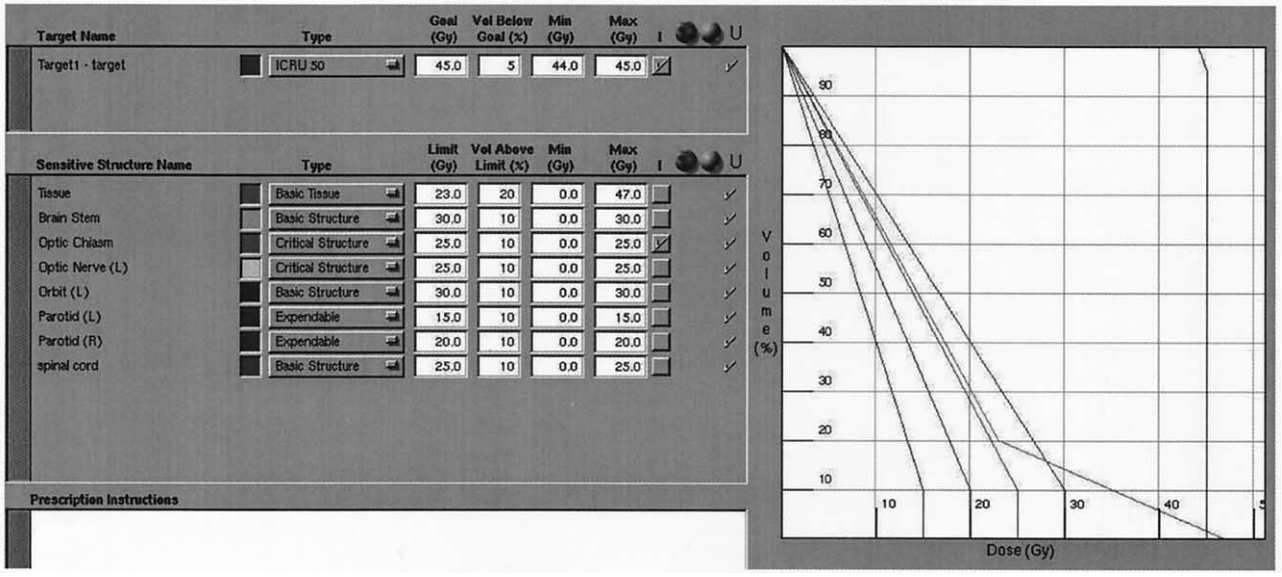


Fig 4. Prescription page for IMRT that requires not only dose level to the target but also allowable volume below the prescribed dose, minimum dose, and maximum dose, plus sensitive structures.

After the scanning is completed, the CT image set is pushed through our hospital network system to the CORVUS and ADAC treatment planning systems for further action. We use the ADAC treatment planning system to generate digital reconstructed radiographs (DRRs) to verify patient setup and fiducial markers. All CT and MRI scanners are connected to the network in our institution; hence, making the transfer of patient data from these medical imaging modalities to the treatment planning systems convenient.

## TREATMENT PLANNING PROCESS

Our CORVUS planning system is designed as an integrated system for use with either the MIMiC or the MLC as its beam-modulating device to perform IMRT. IMRT is a true example of image-based guided radiotherapy because it requires patient data derived from CT images. The fusion of functional images from imaging modalities, in particular magnetic resonance imaging (MRI), single-photon computed tomography (SPECT), or positron emission tomography (PET), to CT image is feasible to allow for a better definition of the target volume. The planning system uses an inverse planning algorithm instead of forward planning algorithm. Here, the desired goals for the target(s) and sensitive structures are initially specified, as illustrated in Fig. 4. Familiarity with acceptable dose limits and definition of structure types are important before completing the prescription page. Based on this prescription, the algorithm performs a trial-and-error procedure based on an objective function to arrive at an optimized treatment plan. The optimization procedure is based on simulated annealing criteria. As described, the CORVUS treatment plan is therefore a computer-intensive process compared to the forward planning algorithm. After the planning is completed and reviewed, the planning system creates treatment delivery instructions that have to be transferred to the beam delivery system. For the MIMiC-based delivery system, the instructions are stored on a floppy disk, which is physically carried over for downloading into the MIMiC controller. On the other hand, the instructions are stored in an RTP (radiation therapy prescription) file format for the MLC-based delivery system. These instructions are then pulled through the network to the IMPAC record & verification system to be downloaded into the linear accelerator.

The patient planning section is divided into modular forms in the CORVUS system. These are patient information, image registration, image fusion, anatomy, prescription, and display results. Initially, the CT data set is converted into a planning patient data set. Once the conversion is complete, the planning patient data set is retrieved and evaluated.

The first modular section of CORVUS is the patient information section. Here, patient name, ID number, and referring physician's name should be checked for correctness. In addition, the plan type should be identified as "patient." After the change, the module must be approved before proceeding to the image registration module.

At the image registration module, the grayscale is adjusted for clear visualization of the anatomical structures. The CT image set, patient orientation, and coordinate system to be used are also defined. Care should be taken to properly define patient orientation, especially in those cases where a CT scan is performed with the patient's feet in first. Fiducial markers are routinely used at our institution. In addition, the external body contour

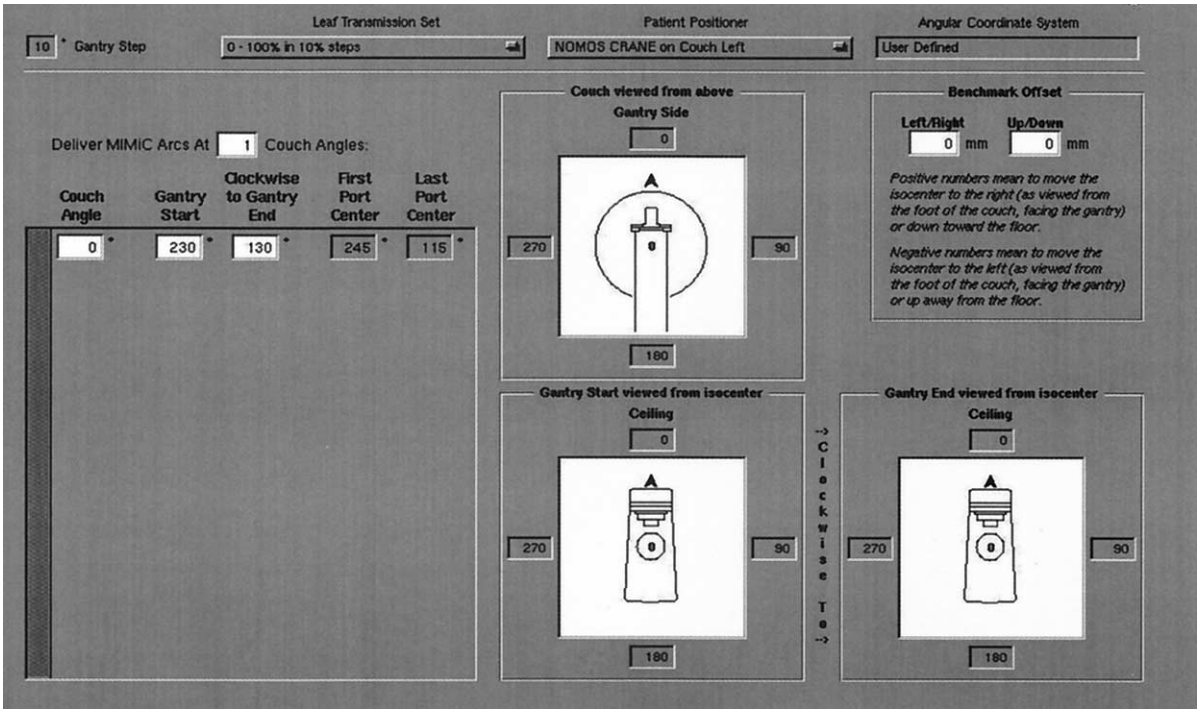


Fig 5. MIMiC-based delivery parameter section.

is determined using the "tissue" tool. This tool is based on the grayscale truncation method and displays tissue in transparent brown. In this manner, the tissue relative to air or couch can be clearly scrutinized. Next, the dose calculation grid is defined over the region where the dose computations are needed.

Image fusion facility is available to perform the fusion of MRI images to CT images. The fusion technique is based on the comparison of defined points on the CT and MRI patient data set. This technique allows for the delineation of targets or sensitive structures that would otherwise not be seen on the CT patient data set. The superimposed images can then be used to define the volume of the targets and sensitive structures.

The anatomy module allows the radiation oncologist to outline the targets and sensitive structures. Various outlining tools are available to assist the radiation oncologist. Once a region is outlined, it has to be filled for the outline to be stored. Once it is stored, the next CT slice can be retrieved to continue with defining the region of interest. Multiple targets can be defined to take advantage of IMRT unique features, allowing the delivery of different doses to separate targets. Sensitive structures that need to be evaluated using dose-volume histograms (DVHs) must be outlined.

After outlining the target and sensitive structures, the CORVUS moves into the prescription module. As shown in Fig. 4, the prescription page for IMRT is drastically different than for a 3D-CRT. It is based on the desired dose goals rather than the selection of a particular isodose line, as in 3D-CRT. More information is therefore needed from the radiation oncologist. These include the allowable percent target volume receiving less than the prescribed dose, minimum dose, and maximum dose within the target. Similarly, quantitative specification of doses and volume should also be made for sensitive structures.

The subset of the prescription module is the specification of the delivery system used. The specification of the MIMiC-based delivery system is shown in Fig. 5. It consists of leaf transmission set (beam intensity steps), coordinate definition, and specification of the start and stop gantry angle. Although it is feasible to have different couch angles, it is generally not needed.[9] The specification of the MLC-based delivery system is shown in Fig. 6. Here, the gantry angles are specified with an association to either the target or the alignment position. In addition, the planning system allows for the minimization of the viewing areas. The proper selection of beam intensity steps is important for MLC-based IMRT because it affects the number of segmentations and hence the treatment times. Like MIMiC-based IMRT, the couch angle is typically left at 0°, reducing the potential risk of device and couch collisions. After the delivery system is specified, CORVUS would perform the computation and arrive at a result.

The result display format is shown in Fig. 7. The isodose distribution is displayed in 3 orthogonal plans. The dose statistics are presented in the fourth window at the lower right of the screen. It should be noted that the isodose line identified with the desired dose is generally lower than 3D-CRT, implying that the inhomogeneity is

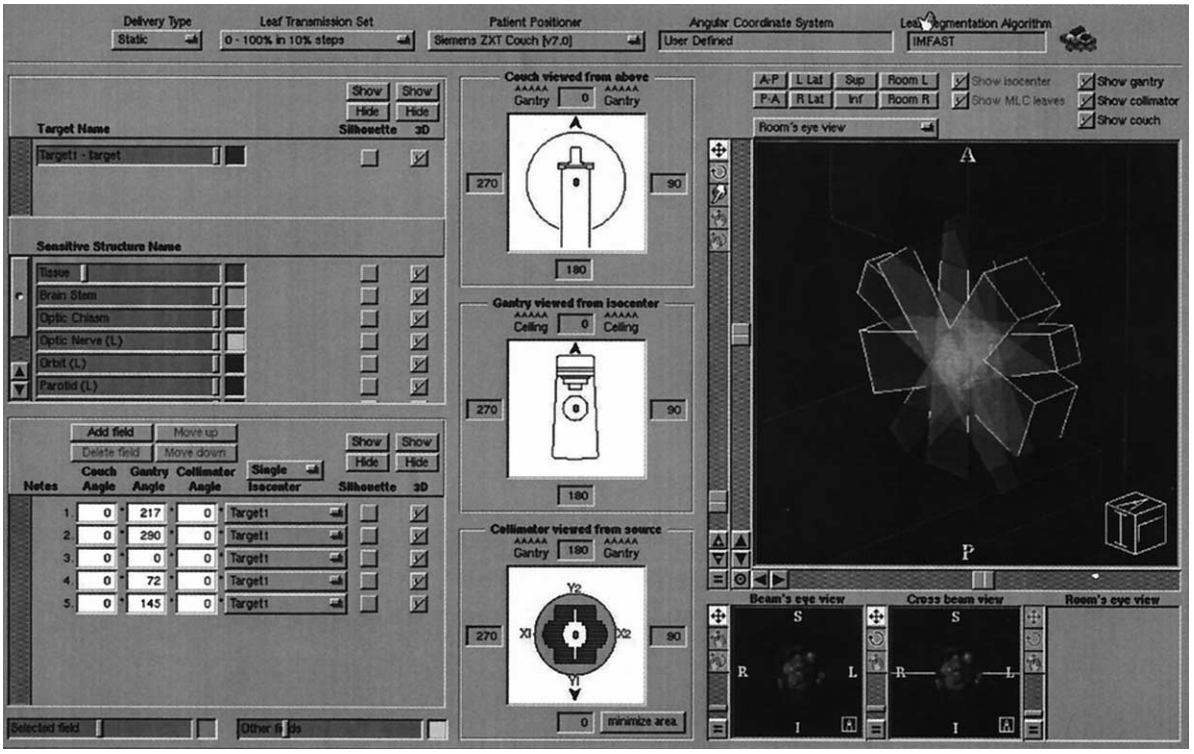


Fig 6. MLC-based delivery parameter section.

higher for IMRT. The shift toward more inhomogeneous dose distribution is the result of the need to be more conformal to the target for IMRT. A critical assessment of the hot spot throughout the patient is therefore warranted. The gain offered by IMRT may be lost if the hot spots are located on the organ at risk. The statistics displayed in red highlights the results exceeding the desired dose goals, while the blue highlights the results within the desired goals. Should there be a need to view a DVH, it can be displayed by selecting the item in the menu of each window. Aside from DVH, 3-dimensional visualization of the patient surface and isodoses can also be obtained.

## RADIATION BEAM DELIVERY SYSTEMS

After the treatment plan has been evaluated and approved, the beam parameters have to be transferred to the beam delivery system. Both MIMiC-based and MLC-based delivery systems are available to perform IMRT at our institution. Head-and-neck IMRT is typically performed using MIMiC-based delivery system. Our early experience with this system represents our bias for MIMiC-based IMRT; however, the use of MLC-based delivery is becoming more routine with our expansion to other clinical sites such as in the pelvic, thoracic, and abdominal regions. MLC-based delivery system has the advantage of no add-on component compared to the MIMiC-based delivery system.

The beam delivery instructions are stored on a floppy disk and downloaded to the MIMiC controller for the MIMiC-based delivery system. The components of the MIMiC-based delivery system have been described by Saw *et al.*[10] When the controller is booted up, it initializes and checks its leaf movements and the gantry position. The controller provides a number of alerts, such as checking the jaw settings and patient disk information and validates them with an approval number. After the patient data is validated, the gantry is rotated to the start position of the arc length. Once the start position is set, the controller begins its program, indicating that it is ready for treatment. Because MIMiC-based IMRT relies on the slice-by-slice paradigm, the therapist has to enter the treatment room to index the treatment couch, as well as to rotate the gantry to the start position of the next arc. The controller responds to the position of the gantry, causing leaf movement per instructions. In the event of a fault, the leaves will be in the closed position and the controller remembers its last position and the monitor units (MUs) delivered. When the fault is corrected, the controller displays the new gantry start position, the remaining arc length, and the remaining MU to be delivered. These features have been very helpful to the therapists and medical physicists in continuing the treatment session following an interruption.

For the MLC-based delivery system, the beam delivery instructions are stored as an RTP file on the CORVUS. This RTP file is pulled to the IMPAC record and verification system and stored in the IMPAC data-

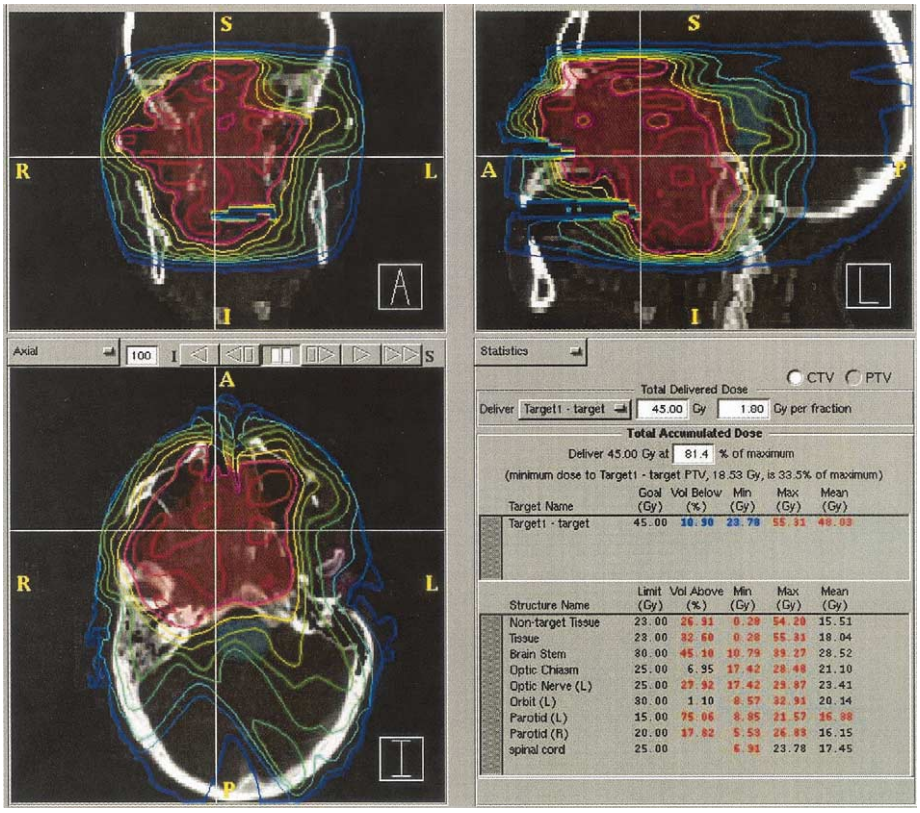


Fig 7. Display results section showing the isodose in 3 orthogonal planes and a statistics window.

base.[11] To take advantage of our recent upgrades with Siemens IMRT capability to improve treatment time, the beam delivery instructions are retrieved into the Siemens Primeview and reorganized into an intensity modulating (IM) group and auto-field sequence (AFS) group through the SIMTEC IM-MAXX IMRT sequencer, as illustrated in Fig. 8. Beam segmentation for a particular gantry angle is grouped as an IM group. The IM grouping permits continual "beam on" time during the delivery of subfields, eliminating the startup and shutdown time of a linear accelerator. These times are overhead times needed to bring the beam delivery system to the appropriate status before allowing the beam to pass through the linear accelerator and to bring down the beam delivery system before proceeding to the next delivery setup. During the formation of the subfield configuration, the electron beam is de-phased with the microwave power. After the subfield configuration is set, the electron beam is accelerated in-phased with the microwave power through the wave guide to the target to deliver the radiation dose. With the implementation of the SIMTEC IM-MAXX IMRT sequencer, the estimated MLC-based IMRT treatment time is about 4 to 6 segments per minute.

## PATIENT SETUP AND LOCALIZATION

Because IMRT requires greater accuracy and reproducibility compared to 3D-CRT, our efforts have been invested at assessing patient setup and immobilizing techniques. At our institution, the lasers have been realigned to a higher degree of precision, even though they satisfy the AAPM TG40 report criteria.[12,13] As mentioned above, immobilization devices are now fixed to the treatment couch using either the peg or interlocking systems.[7] Furthermore, the treatment couch has been modified to allow for wider arc length used in MIMiC-based IMRT, as shown in Fig. 9. This modification has also allowed us to take anterior-posterior localization with a film cassette placed through a slot on the treatment couch.

With the various modifications, our routine patient setup is aided with the use of fiducial markers. These are x-ray markers positioned at the intersections of laser lines at the lateral and anterior of the patient at the time of simulation. All patient movements are made per instructions given by the CORVUS treatment planning system. Movement of the patient or treatment couch is facilitated with the use of the CRANE. The CRANE is an indexing device that has a movement precision to better than 0.01 mm. In addition, laser positions are marked on the thermoplastics to aid in reproducing the indexing position for MIMiC-based IMRT.

The general localization is based on a set of orthogonal radiographs. In the past, only the lateral radiograph is taken. With the modification of the treatment couch, the AP radiograph merely provides an additional assur-

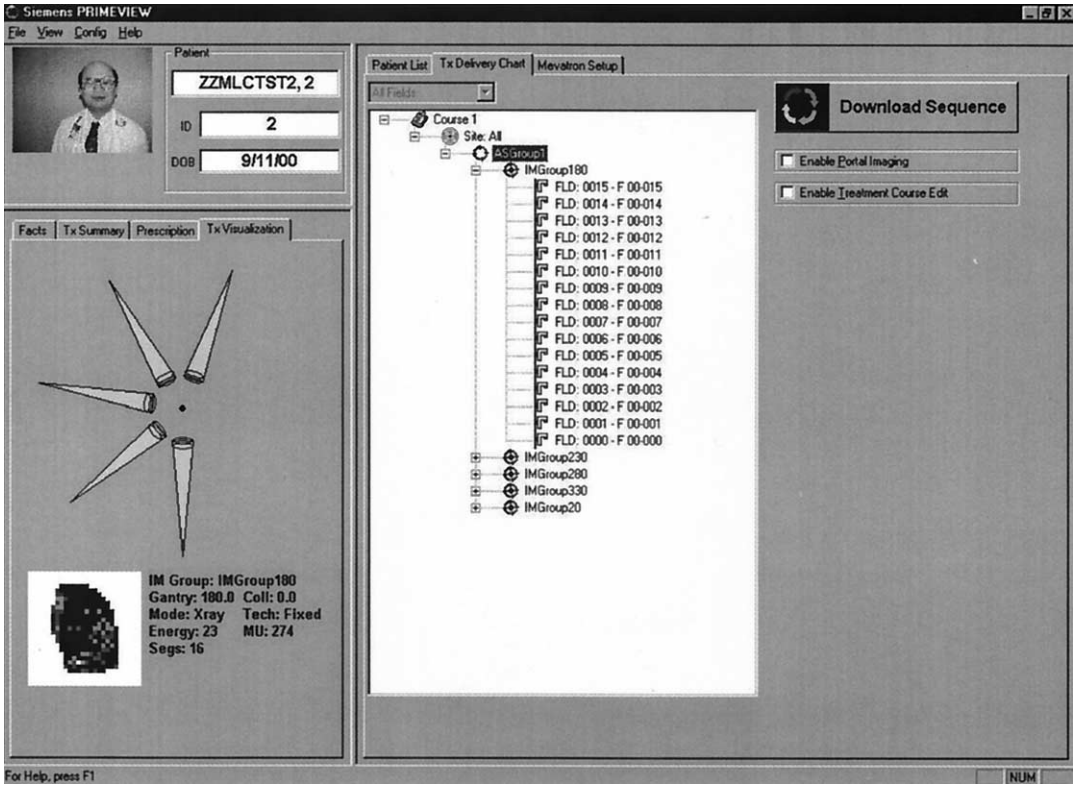


Fig 8. Siemens PRIMEVIEW with AFS (autofield sequencer) and IM (intensity modulation) grouping facility.

ance that the patient is properly positioned in 3 dimensions. These radiographs are compared to simulation radiographs for validation, and in some cases to DRR from the ADAC treatment planning system. Ultrasound imaging system (BAT) is used for prostate localization.

## DOSE VALIDATION

Because IMRT uses radically new treatment planning techniques and different beam delivery systems, it is necessary to be concerned about the dose delivered to the patient. Various dose validation techniques have been reported.[14–16] As a general rule, measurements are made for each individual patient and hence the process is labor intensive. Dosimetric measurements are typically taken using film, ion chamber, or TLD. Relative measurements are typically performed with film dosimetry. Whenever an absolute measurement is made, it is performed using the ion chamber. Beside measurements, there are recent developments of dose-calculation-based validation techniques.[17,18]

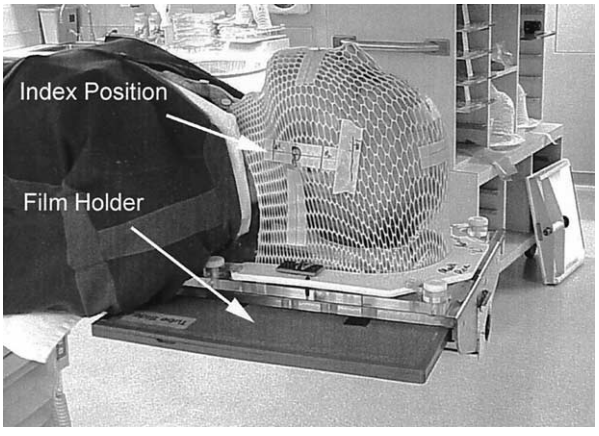


Fig 9. Treatment couch modified to accommodate large arc angle for MIMiC-based IMRT. In addition, the current setup allows for a mechanism of taking AP radiograph for localization.

Our early experience with dose validation involves the performance of both relative dose distribution and absolute dose measurements. Relative dose measurements were performed using film cassette.[10] While the relative dose measurements give a qualitative assessment of the overall dose pattern, the actual overlay of planned isodoses and measured isodoses is cumbersome, and time consuming with little benefits. As such, the relative dose measurements are rarely carried out except when there is concern in the plan or it is requested by the radiation oncologist. However, absolute dose measurements are still being performed. This involves the hybrid plan where patient beam parameters are applied to a $30 \times 30 \times 22$-cm phantom, as depicted in Fig 10. The hybrid plan involves the selection of a point on the patient plan where the dose gradient is minimum. This point is matched to the position of the ion chamber in the

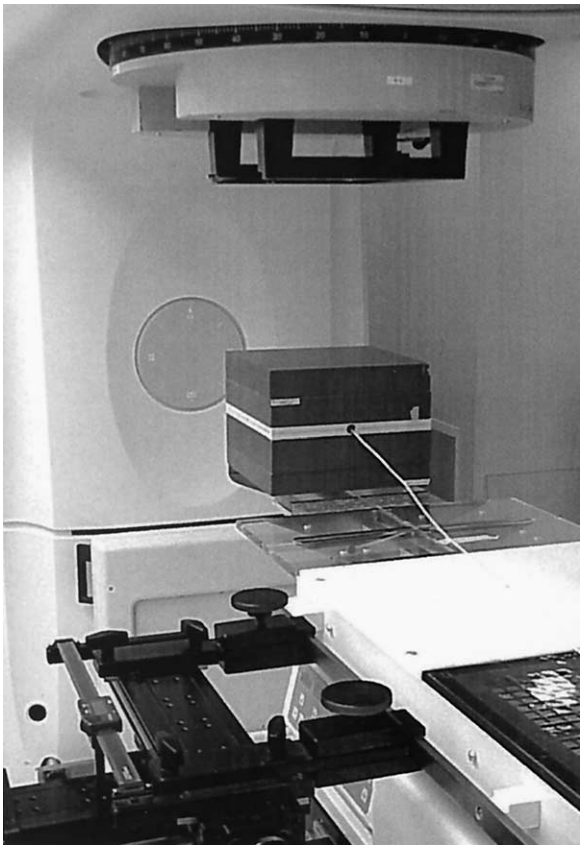

Fig 10. Dose validation by performing absolute dose measurements using a 0.125-cc chamber in standard 30 × 30 × 22-cm phantom.

phantom. The hybrid plan is generated by taking into account the source-to-surface distance (SSD) of each beamlet to the phantom and the application of the beam parameters. The hybrid plan would provide the needed instructions for setting up the machine and phantom. Our ion chamber measurement should be within 5% of planned mean dose over a 0.125-cc ion chamber volume. For those measurements where the difference is greater than 5%, both the patient plan and hybrid plan are re-evaluated. All measurements that showed large difference were due to the selection of measurement points at high-dose gradient region.

## DISCUSSION

The development of IMRT is ongoing. The clinical implementation of IMRT is at its early phase in only a few medical centers around the world. A comprehensive guideline for IMRT has not been established. National protocols for 3D-CRT should be considered inadequate and applied with caution. Review of up-to-date literature, although limited, is important to the familiarization and conceptual understanding of IMRT. The acceptance of the clinical implementation of IMRT is therefore dependant on the experience of medical physicists deciding on what parameters are considered important, how to perform validation, and what range of measurements are considered acceptable. As IMRT evolves, the inverse-planning algorithms and beam-modulating delivery systems will be modified with cooperation of the vendors to address their inadequacy and establish their reliability. Much research and development work has to be performed to develop tasks that will make the clinical implementation of IMRT straightforward and practical.

Before pursuing the implementation of IMRT, an institution should undertake some critical evaluations that include shielding of current facility, general availability of basic equipment, immobilization techniques, and available up-to-date IMRT systems. To create non-uniform fields, there is a significant amount of beam-on time for IMRT. As such, the issue of additional shielding should be addressed. The workload should be increased by at least a factor of 2 to 5, as recommended by the IMRT working group.[19] By virtue of the increased workload, there is an increase in radiation exposure to the whole body due to increased leakage radiation. The whole-body doses have been reported for different beam energies.[20,21] The linear accelerator for IMRT must be evaluated and modified to conform to the precision required of IMRT. These include the tolerance of the isocenter, the alignment of the lasers, and digital readout of the treatment couch. In general, the movement of the treatment couch should have a precision to within 0.1 mm. For MIMiC-based IMRT, the MIMiC is attached to the linear accelerator, requiring an assessment of the gantry rotation mechanism support to handle the torque caused by the additional weight.

An assessment of the available up-to-date IMRT equipment is crucial for the understanding of maturity of the product. Newly introduced products at their early developmental stage will invariably require a significant amount of a medical physicist's time to establish the reliability of the product. Understanding the relative ease or difficulty of the acceptance testing and commissioning processes are important to a successful implementation of IMRT.[11,20] Constant communication between the medical physicist and technical staff of the vendor is required to resolve issues. Medical physicists should be prepared to perform at a higher skill level to assume the additional responsibilities. The expected inconvenience should be anticipated by the medical and technical staff. Likewise, radiation oncologists, dosimetrists, and radiation therapists should understand that the implementation of IMRT is a team project, requiring the support of all personnel. Radiation oncologists should assume responsibilities in learning the concept and practical aspects of IMRT, including selecting predefined parameters and outlining the appropriate structures. Radiation oncologists should also be willing to make time to critically review the treatment plan for potential dosimetric problems prior to implementing the treatment and also to monitor the patient for unexpected acute treatment sequela. Dosimetrists should be involved in immobiliza-

tion, patient setup, and planning of the treatment. Like the radiation oncologists and medical dosimetrists, the radiation therapists are expected to understand the concepts of IMRT and familiarization of the patient setup and treatment procedures. Lastly, resources must be allocated at a radiation facility to support such a project.

## REFERENCES


1. Purdy, J.A. Intensity-modulated radiation therapy (Editorial). *Int. J. Radiat. Oncol. Biol. Phys.* **35:**845–6; 1996.
2. Purdy, J.A. The development of intensity modulated radiation therapy. In: Sternick, E.S., editor. The Theory and Practice of Intensity Modulated Radiation Therapy. Madison: Advanced Medical Publishing; 1997; 1–15.
3. Saw, C.B.; Ayyangar, K.M.; Enke, C.A. MIMiC-based IMRT-Part I (Editorial). *Med. Dosim.* **26:**1; 2001.
4. Saw, C.B.; Ayyangar, K.M.; Enke, C.A. MLC-based IMRT-Part II (Editorial). *Med. Dosim.* **26:**111; 2001
5. Oelfke, U.; Bortfeld T. Inverse planning for photon and proton beam. *Med. Dosim.* **26:**113–24; 2001
6. Chui, C.S.; Spirou, S.V. Inverse planning algorithms for external beam radiation therapy. *Med. Dosim.* **26:**189–97; 2001
7. Saw, C.B.; Ayyangar, K.M.; Zhen, W.; *et al*. Modification of treatment couch for IMRT. *Med. Phys.* **28:**1827; 2001
8. Saw, C.B.; Yakoob, R.; Enke, C.A.; *et al*. Immobilization devices for intensity-modulated radiation therapy (IMRT). *Med. Dosim.* **26:**71–7; 2001
9. Lam, S.; Rogers, L.; Wichman, B. Non-coplanar inverse planning IMRT using the MIMiC system: Clinical significance in choice of 2-cm/1-cm mode and single couch vs. multiple couch angles. *Med. Dosim.* **26:**11–5; 2001
10. Saw, C.B.; Ayyangar, K.M.; Zhen, W.; *et al*. Quality assurance procedures for the peacock system. *Med. Dosim.* **26:**83–90; 2001.
11. Saw, C.B.; Ayyangar K.M.; Zhen, W. *et al*. Commissioning and quality assurance for MLC-based IMRT. *Med. Dosim.* **26:**125–33; 2001.
12. AAPM. Comprehensive QA for radiation therapy: Report of AAPM Radiation Therapy Committee Task Group 40. *Med. Phys.* **21:**581–618; 1994.
13. AAPM Report No.13. Physical Aspects of Quality Assurance in Radiation Therapy. New York: American Institute of Physics; 1983.
14. Tsai, J.S.; Engler, M.J.; Ling, M.N.; *et al*. A non-invasive immobilization system and related quality assurance for dynamic intensity modulated radiation therapy of intracranial and head and neck disease. *Int. J. Radiat. Oncol. Biol. Phys.* **43:**455–67; 1999.
15. Verellen, D.; Linthout, N.; Van Den Berge, D.; *et al*. Initial experience with intensity modulated conformal radiation therapy of the head and neck region. *Int. J. Radiat. Oncol. Biol. Phys.* **39:**99–114; 1997.
16. Low, D.A.; Chao, K.C.; Mutic, S.; *et al*. Quality assurance of serial tomotherapy for head and neck patient treatments. *Int. J. Radiat. Oncol. Biol. Phys.* **42:**681–92; 1998.
17. Ayyangar, K.M.; Saw, C.B.; Shen, B.; *et al*. Independent dose calculations for the peacock system. *Med. Dosim.* **26:**29–35; 2001.
18. Ayyangar, K.M.; Nizin, P.S.; Saw, C.B.; *et al*. Independent dose calculations for the CORVUS MLC IMRT. *Med. Dosim.* **26:**135–41; 2001.
19. Intensity Modulated Radiation Therapy Collaborative Working Group. Intensity-modulated radiotherapy: Current status and issues of interest. *Int. J. Radiat. Oncol. Biol. Phys.* **51:**880–914; 2001.
20. Followill, D.; Geis, P.; Boyer, A. Estimates of whole-body dose equivalent produced by beam intensity modulated conformal therapy. *Int. J. Radiat. Oncol. Biol. Phys.* **38:**667–72; 1997.
21. Mutic, S.; Low, D.A. Whole-body dose from tomotherapy delivery. *Int. J. Radiat. Oncol. Biol. Phys.* **42:**229–32; 1998.
22. Saw, C.B.; Ayyangar, K.M.; Thompson, R.B.; *et al*. Commissioning of peacock system for intensity-modulated radiation therapy. *Med. Dosim.* **26:**55–64; 2001.