

## **Clinical Implementation of IMRT**

Arthur L. Boyer, Ph.D.

Stanford University School of Medicine

There has been wide-spread interest in investigating intensity-modulated radiation therapy (IMRT) as an advanced treatment delivery technique<sup>1</sup>. Broadly speaking, the fundamental ideas behind IMRT is the computation and delivery of radiation fluence distributions that in some sense optimize the treatment dose distribution characteristics. Academic radiotherapy centers have undertaken extensive projects to develop and test the many variations possible with the IMRT concepts of inverse treatment planning, leaf sequence computation, and treatment delivery. Vendors of radiotherapy treatment planning and treatment delivery systems have been proactive in investing resources to develop commercially available components applicable to IMRT. It is possible to acquire and commission a treatment planning and treatment delivery system for IMRT along the lines depicted graphically in the flow chart in Figure 1. However, implementation of IMRT should be started with due consideration of the gravity of the task. In order to realize the benefits of IMRT, resources must be in place before embarking on an IMRT venture. The human resources must be sufficient to not only install the components initially but also to keep pace with upgrades and improvements in the technology in this rapidly changing field.

It is appropriate to plan and deliver a course of IMRT for a patient only when it is medically necessary. IMRT is appropriate for cases in which a concave target volume is in close proximity to critical structures or tends to wrap partially or wholly around a normal sensitive structure. IMRT is also warranted when treating a volume immediately adjacent to previously irradiated tissue. In cases where IMRT is to be used, the use of high precision imaging with CT and MRI is needed to assure small treatment margins. Additionally maneuvers such as respiratory gating and ultrasonic or radiographic imaging should be used to insure precise treatment positioning.

Temporary billing codes G0178 and G0174 have been approved by the Health Care Financing Administration (HCFA) to reimburse the technical effort (Medicare Part A) for IMRT treatment planning and treatment delivery in the hospital outpatient setting. It is anticipated that CPT codes will be recognized by HCFA and private insurance carriers in freestanding centers and for professional services by January 1, 2002.

Radiation Safety. The impact of the larger workload for IMRT on the shielding barriers should be given due consideration. In general, the primary barriers will not be effected by IMRT implemented with dynamic MLCs. However, existing secondary barriers may be insufficient to dedicate a machine entirely to IMRT. An analysis that includes the door and maze should be performed. In addition, the patient's whole body exposure will increase. At high energies using techniques that require an increase of monitor units by an order of magnitude, the risk of inducing a second carcinoma may be significant.

## IMRT Process

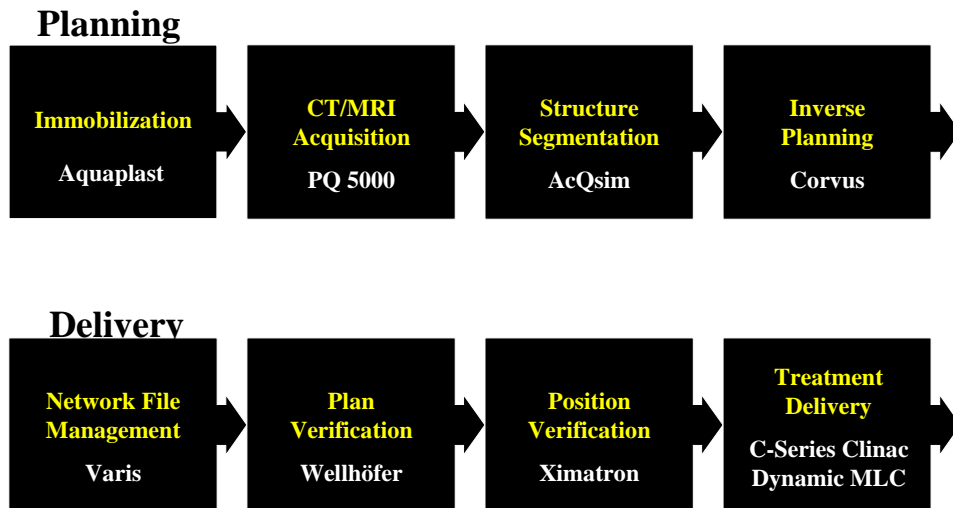


Figure 1. IMRT treatment planning and treatment delivery flow chart. Examples of subsystems supplied by various vendors are shown in each box.

**Treatment Planning.** IMRT depends on the acquisition and use of high resolution, accurate Computerized Tomography (CT), Magnetic Resonance Imaging (MRI), and (more recently) Positron Emission Tomography (PET).

**Immobilization.** Means are required to stabilize the patient comfortably in the treatment position. Various casting technology is available that can be reproducibly aligned with the treatment table top.

**CT/MRI Acquisition.** Spiral CT scanners are available with single or multiple rows of detectors that rapidly acquire scans with a voxel resolution on the order of 1mm in each dimension. When acquiring these studies, immobilization and positioning issues must be resolved. It is desirable for the CT scanner to be equipped to acquire images using some form of gating to allow means for accounting for respiration motion. MRI distortions should be known so that selection of treatment margins smaller than the distortions in the tumor volume can be avoided. Positron emission tomography (PET) is rapidly emerging as an important data set for use with IMRT. A network path should be in place to move CT, PET, and MRI studies to the planning system and to transfer leaf sequences and treatment data to the therapy machines. Interfaces between systems that are written to the DICOM-RT specifications are becoming available on commercial systems. Means for spatially correlating (often referred to as fusing) MRI or PET image data sets with CT image data

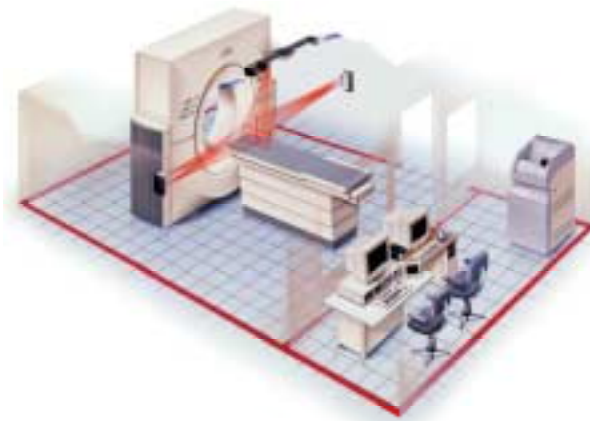


Figure 2. Configuration of a spiral CT scanner for IMRT. A flat couch top with means to register immobilization devices is an essential component.

sets are rapidly improving. Mutual Information techniques show promise of being the most effective general methodology.

*Structure Segmentation.* The identification of the surfaces that enclose treatment volumes and normal anatomical structures is an essential part of IMRT treatment planning. The target is specified by nested volumes named using the ICRU 50 convention. These volumes are the Gross Tumor Volume (GTV), the Clinical Target Volume (CTV), the Planning Target Volume (PTV), and the Irradiated Volume. Depending on the complexity of the case, structure segmentation can consume considerable human and temporal resources. Automated segmentation is not yet available as an option since generally applicable and reliable techniques have not been identified although there are a number of promising methods under investigation.

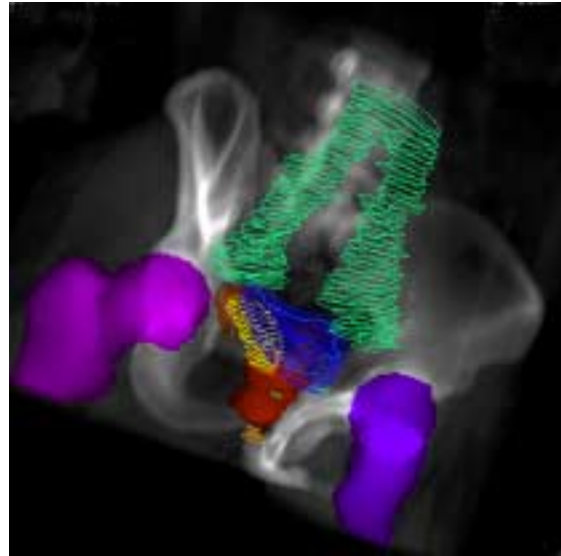


Figure 3. Segmentation of the prostate and seminal vesicles surrounded by the bladder and rectum. The lymph nodes and bulbourethral gland are secondary target volumes.

*Inverse Planning.* Computer-assisted optimization of the IMRT dose delivery strategy is generally referred to as inverse treatment planning. Commissioning an IMRT treatment planning system cannot be accomplished adequately without sufficient human and technical resources. As with any new system, time will be required to learn the software and to develop skill at using it. Physicians must be prepared to make radical changes in their approach to prescribing and evaluating IMRT treatment plans.

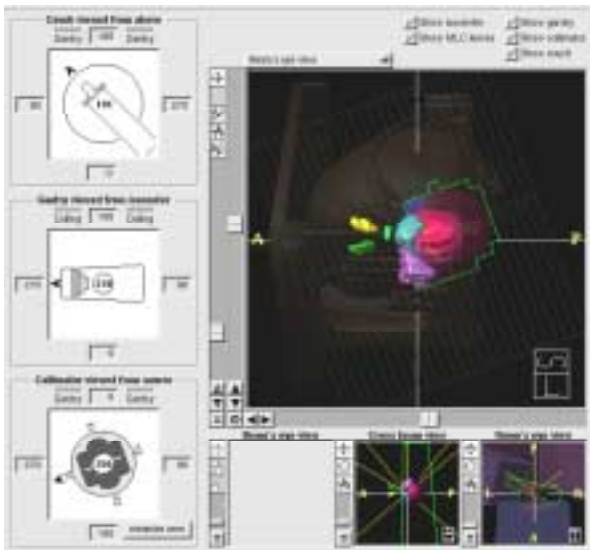


Figure 4. Beam's-eye-view of a field placement showing the MLC setting that defines the maximum extent of the modulated field.

Most commercial systems require that the location of treatment beams or arcs be selected using manual graphical tools such as those depicted in Figure 4. Research into automated means to optimize treatment field placement is on-going. The prescription for IMRT is made more complex by the ability to specify to the systems the many parameters that must be selected to concentrate dose in the target volume and to avoid the normal structures (Figure 5). Different Inverse Planning Systems use different beam intensity optimization techniques. In general they all allow the user to strike a balance between the conformity and homogeneity of the dose delivered to

the GTV or PTV and the degree of protection provided to the Organs at Risk (OARs). The expansion of the GTV to the PTV is a parameter that should be selected based on objective evaluations of the uncertainties in structure segmentation and patient positioning. Dose-volume histograms (DVHs) are used to control the inverse planning process and to summarize for the radiation oncologists the complex three-dimensional features of the dose distribution. Other parameters that are important is any importance weighting that can be controlled for PTVs and OARs. There are parameters that must be selected in the algorithms that compute the leaf sequence. For example, one may have a choice between selecting a step-and-shoot sequence and a continuous dynamic sequence. One may also be able to turn of and off a tongue-and-groove correction.

The strategy for treating the PTV may include treating a loco-regional PTV for occult disease to a lower dose. Embedded in this secondary PTV there may be a primary PTV that contains the GTV that will receive a higher dose. This can be viewed as delivering a concomitant boost. The dose per fraction will be accelerated in this target

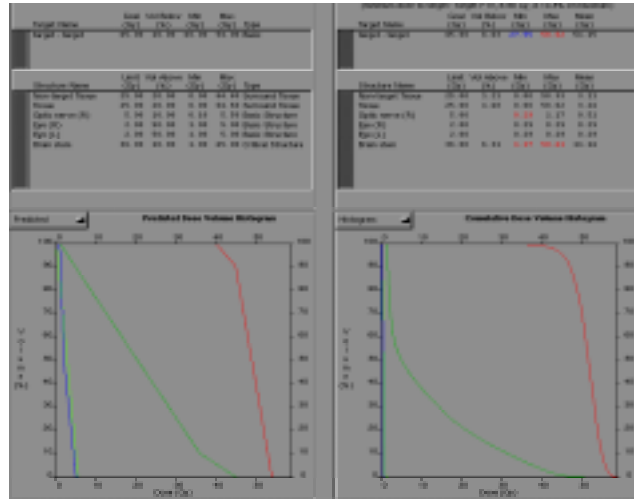


Figure 5. Prescription parameters and the graphical representations of their specification and achievement by an IMRT treatment plan.

volume. These are advanced treatment strategies that are being investigated systematically by the RTOG and other study groups.

Although IMRT fields contain internal modulation, they still are bounded by a limiting contour beyond which no direct irradiation is to be delivered. This is the field boundary that corresponds to the open field that would be shaped by the MLC if there were no intensity modulation. It is useful to examine this field boundary in relation to the GTV and PTV and the OARs. The digitally reconstructed radiograph (DRR) is the tool that can be applied to make this information available for the multiple fields used in the IMRT plan. An example of a composite set of DRRs of IMRT fields printed on radiographic film with a laser printer is shown in Figure 6.

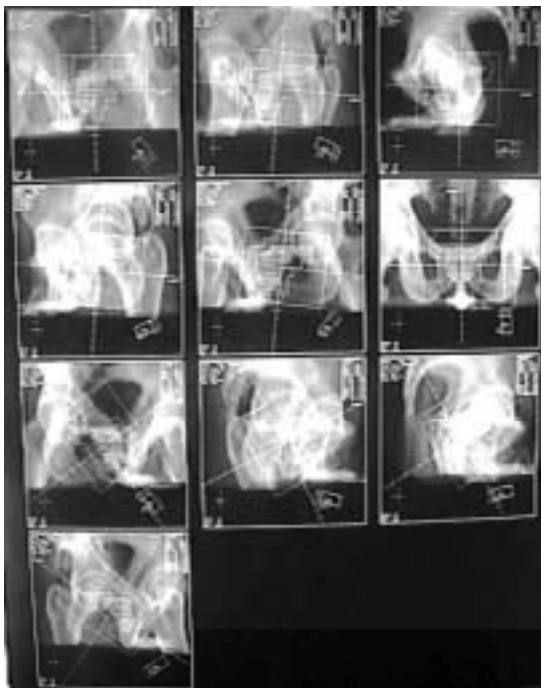


Figure 6. DRRs used to approve the final IMRT treatment plan before treatment is initiated.

This image set can be produced for the radiation oncologist to evaluate and approve the treatment plan. This is a quality assurance tool useful for detecting errors in selecting the isocenter, the PTV, collimator rotation, or other aspects of the treatment plan.

There is concern that the complex computer-controlled delivery, based on monitor units calculated by the planning system, will fail to produce the prescribed dose in the patient. Conventional wisdom has dictated that computer calculations of monitor units be checked by a hand calculation. In the case of IMRT, it is not feasible to extract sufficient information manually to compute the monitor units by hand. One approach is to make a physical measurement with a phantom of the treatment plans prepared for each patient before the treatment is delivered. In general the treatment plan is recomputed substituting the CT data set of the patient with the CT data set of the measurement phantom. If all parameters of the plan are otherwise unchanged, the results will be a dose distribution that resembles that in the patient but reflects differences between the phantom and patient. Nevertheless, if measurements in the phantom agree with the calculated dose for the phantom, one has

achieved a level of assurance that the doses delivered in the patient will be accurate. A number of geometric and anthropomorphic phantoms have been devised and used for this purpose. One example of a purely geometric phantom is shown in Figure 7. Such measurements should be made as part of the commissioning process before the initiation of IMRT.

Measurements should be made on a patient-by-patient basis after the initiation of IMRT or the initiation of significant changes in the IMRT system. Making such measurements on every IMRT patient treated in a facility is a significant commitment of human resources.

The patient must be positioned accurately on the planned isocenter. This point can not in general be selected accurately at the time the CT scan is acquired. It may shift during treatment planning for a variety of reasons. Therefore, it is important to check the isocenter position at the beginning of the treatment sequence and to recheck it at appropriate times throughout the treatment sequence. A check of the isocenter position with a conventional simulator can be used before the first treatment. An example is given in Figure 8. It may also be possible to carry out this check on the treatment machine itself, depending on logistical exigencies.

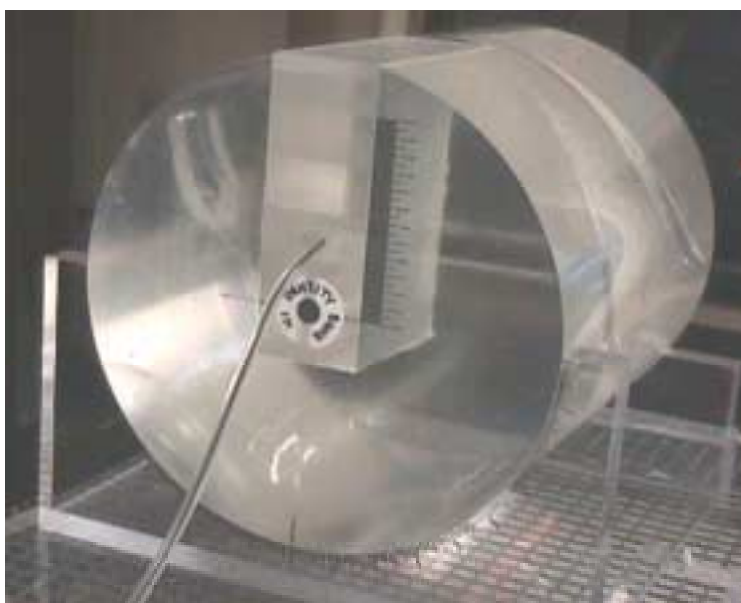


Figure 7. A cylindrical phantom that can be used for verification of IMRT treatments using ionization chambers or film.

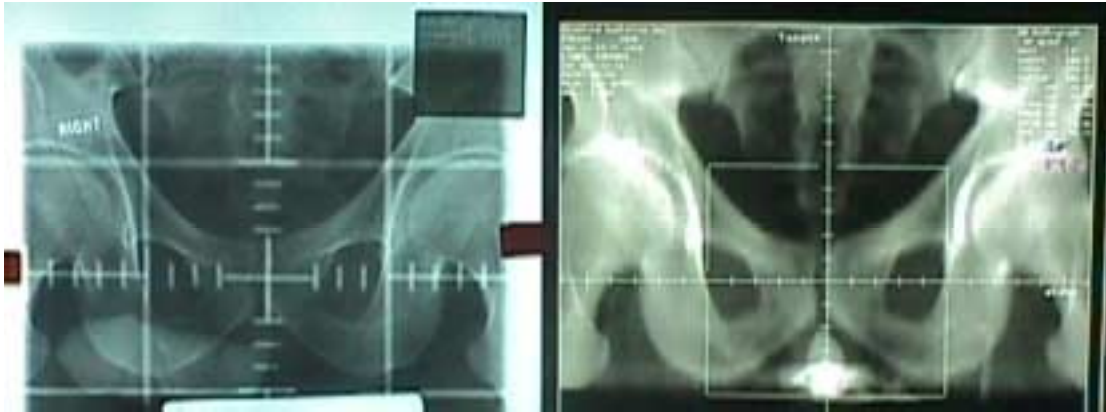


Figure 8. A conventional simulation (left) can be used to verify skin marks and other setup indicators against a pair of orthogonal DRRs of an arbitrary 10cm x 10cm field (right) that will not be used in the treatment.

A temporary billing code G0178 has been approved by (HCFA) to reimburse the technical effort (Medicare Part A) for IMRT treatment planning in the hospital outpatient setting. In order to use the G0178 code the computer-generated inverse treatment plans with three-dimensional PTVs and OARs, inverse planning dosimetric objectives, and dose-volume histograms must be documented along with evidence of dose verification and physician review.

**Treatment Delivery.** Treatment delivery systems include the linear accelerator, the MLC, and the control systems that link them together with an information storage and transfer system. A typical system is shown in Figure 9.

The computer control systems consist of multiple linked computers and microprocessors that form a complex digital measurement and control system containing feedback loops. The computer network and associated file servers are an important part of the system. Maintaining the network is an

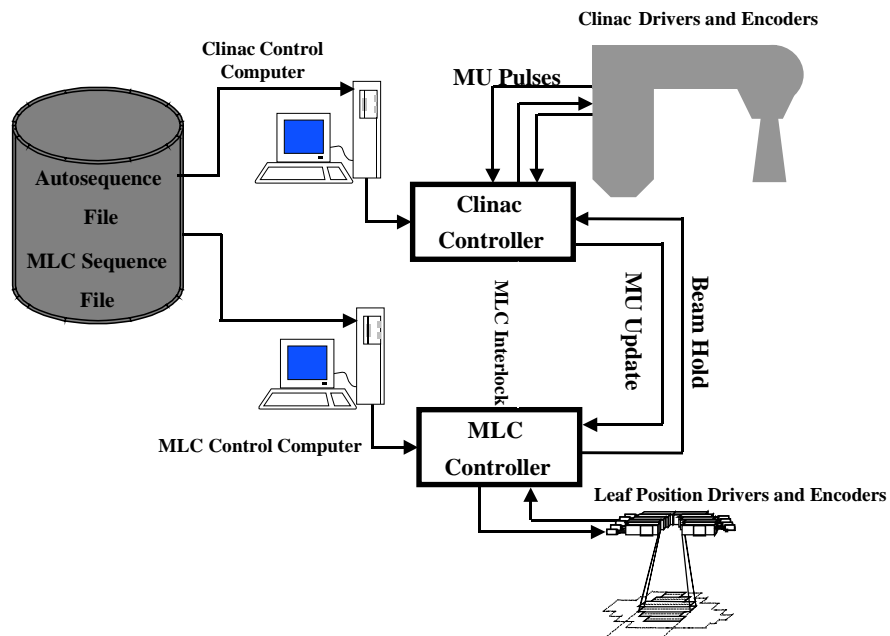


Figure 9. Schematic of an IMRT Treatment Delivery System. Multiple microprocessors are interconnected with device drivers and position and state encoders.

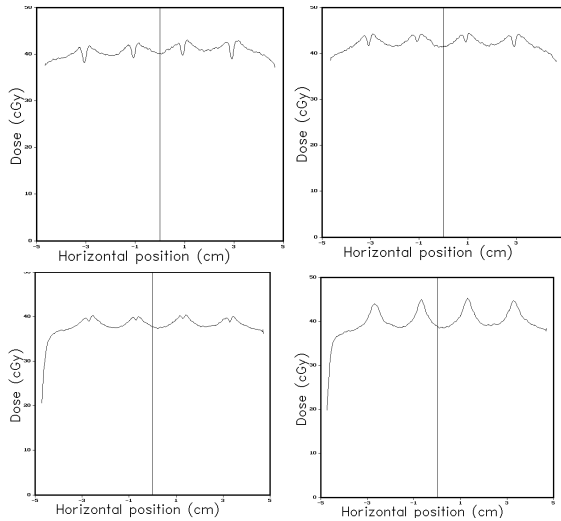


Figure 10. Film measurements of field abutment regions at leaf ends with different offset parameters.

especially important resource commitment. A radiation oncology center will need one or more skillful system administrators on site if the system is to be reliable.

Selecting, installing, and commissioning an IMRT delivery system requires its own defined effort. The effects of parameters in the inverse planning system of the treatment delivery must be understood. For example, the parameters describing the leaf end are particularly important for both dynamic and step-and-shoot delivery. The offset of the leaf end profile on abutted fields is illustrated in Figure 10. For treatments effected by respiration and internal

organ motion, special techniques may be needed such as beam gating, ultrasonic soft tissue verification, and portal imaging.

**Quality assurance procedures.** An appropriate effort must be planned and implemented to insure that the delivery system produces the planned doses and dose distributions.

Checks on individual treatments should be carried out until confidence in the system is established. More human and technical

resources will be required for IMRT than for

conventional treatments for ongoing verifications of monitor units, treatment

portals, and leaf sequences prior to

treatment. Direct links between the treatment planning system and the

information management file server allows efficient transfer of the IMRT planning parameters and the dynamic leaf sequence.

An example of a screen in an information management system is given in Figure 11.

Comparison of the parameters that appear in

such a screen with the values derived from the treatment planning system provides a cross check within the planning and delivery system.

Given adequate verification of the setup isocenter at the beginning of treatment, it is necessary to verify the setup throughout the course of treatment. A comparison of isocenter DRRs with megavoltage port films or megavoltage imaging is adequate unless multiple couch positions are used. An example is given in Figure 12. CPT code 77417 (Therapeutic radiology port films) may be charged for patient position verification per session.

The treatment itself is relatively simple to delivery using an autosequencing system. However, the therapists need to be well trained in the use of the computer



Figure 11. Interactive screen in the Varis (Varian Medical Oncology) information management system.

delivery systems. A well-developed team and an efficient computer delivery system can deliver IMRT treatments in times comparable to or slightly longer than conventional treatment times.

A temporary billing code G0174 has been approved by HCFA to reimburse the technical effort

(Medicare Part A) for

IMRT treatment delivery in the hospital outpatient setting. For either multiple fixed-gantry delivery of IMRT by either the dynamic or step-and-shoot method, or for multiple arcs of modulated fan beams, the G0174 code may be used once per session. In order to use the G0174 code the computer-generated inverse treatment plans must meet the criteria of the G9178 code.

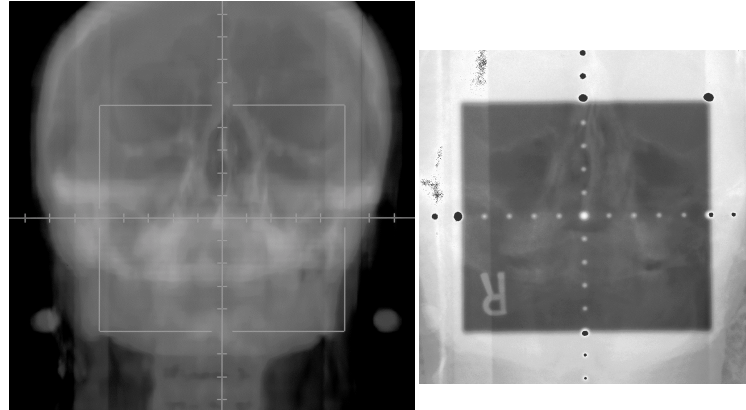


Figure 12. Isocenter check DRR (left) compared with a port film taken using a fiducial tray to indicate the field center and field crosshairs.

Research. IMRT cannot yet be considered to be a routine treatment procedure. IMRT is developing and investments in equipment and manpower at this time should be made with the expectation that new developments will make current technology obsolete within a few years. In addition, radical technical departures from conventional linear accelerator configurations are being investigated such as tomotherapy and robotic stereotactic radiotherapy. Novel MLCs have been proposed as well. IMRT with any technology should be implemented with sufficient attention to record keeping and quality assurance to discover systematic errors and to interpret the long-term results of the treatment. More than ordinary resources should be devoted to keeping records on the plans, treatment delivery, and outcomes for IMRT patients. Increases in reimbursement for IMRT should be used to provide these additional resources to insure that patients receive the potential benefits of this technique.

<sup>1</sup> Steve Webb. 2001 Intensity-Modulated Radiation Therapy (Bristol and Philadelphia: Institute of physics Publishing)