Compensator-intensity-modulated Radiotherapy—A Traditional Tool for Modern Application

a report by
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Sha Chang is an Associate Professor and Chief of the Physics & Computing Division in the Department of Radiation Oncology at the University of North Carolina Medical School. In the 1990s Dr Chang's group were pioneers in the development of a dose optimisation algorithm and compensator-intensity-modulated radiotherapy (IMRT) technique, and implemented it in their in-house treatment planning system (PLanUNC) before multi-leaf collimators (MLCs) became commercially available. She has carried out extensive work on evaluation of the compensator-IMRT technology in clinical application and comparison between compensator and segmental MLC based IMRT techniques. The group's publication on the topic in the *Journal of Applied Clinical Medical Physics* was nominated as the paper of the year in 2004 by the journal. Dr Chang has been invited to speak at compensator-IMRT meetings worldwide. Her group has also developed a compensator-based 4-D dose optimised IMRT for treatment with intra-fractional motion. Dr Chang has no financial relationship with any commercial compensator-IMRT vendors.

There is hardly anybody in the field of radiotherapy who has not heard, performed, or wanted to carry out dose sculpting intensity-modulated radiotherapy (IMRT), which promises improved treatment outcome. IMRT is widely used in the US and is gaining increasing acceptance in Europe and the rest of the world. For radiotherapy centers that have not yet implemented the technology one common concern is related to resources, or the lack of them. Indeed, considerable resources—software, hardware and staff—are needed to successfully implement an IMRT program, and it can be very costly. Multi-leaf collimator (MLC) is commonly used as IMRT delivery hardware and newer accelerators with MLC and IMRT delivery functions cost significantly more than the basic models, and they can be out of reach for many radiotherapy centers. Many people incorrectly assume that an accelerator with MLC function is essential for IMRT delivery, but MLC is not the only hardware that can deliver IMRT.

The University of North Carolina has treated approximately 1,200 patients using compensator-IMRT since 1996 and has used both MLC and compensator for IMRT delivery since MLC became available in 2001.[1,2] Mail order compensator services in the US are gaining increasing acceptance and popularity, especially among smaller radiotherapy centers, by providing quality, easy-to-use, and swift customized compensator-IMRT services. As compensator-IMRT has gradually received more and more attention and acceptance worldwide[3–8] most treatment planning software vendors have added the compensator-IMRT function as an option. It is hoped that more compensator-IMRT-friendly commercial products will be developed to serve the needs of many radiotherapy centers worldwide.

Different to the commercially available MLC-IMRT technologies, compensator-IMRT technologies, until recently, were primarily developed in-house and not readily available to the radiotherapy community at large. Thus, many opinions of compensator-IMRT might not be based on adequate information and knowledge of the technique. Common misunderstandings include "Compensator-IMRT is not as good as the high-tech MLC-IMRT", "compensator is an old tissue compensation technology but not IMRT", and "compensator-IMRT is an emerging technology that requires further testing before clinical use". However, what is often overlooked in the debate around IMRT delivery hardware is the core of IMRT (i.e. what makes IMRT a better treatment choice for cancer patients). The core of IMRT is the dose optimizing treatment-planning software, and not the delivery hardware.

In today's high-tech age it can be difficult to make a sensible selection for IMRT hardware, especially if it is for the first time. Delivery hardware should be evaluated in terms of treatment dosimetric quality, treatment throughput, and operating cost. It is important to point out that there are different compensator-IMRT techniques, as well as different MLC-IMRT techniques. There are also different treatment planning systems and different radiotherapy centers can run their IMRT procedures differently. The dosimetric quality, operating cost, and treatment throughput of an IMRT program are determined jointly by software, hardware, and the local procedure. Therefore the details in the discussion below may not be applicable to all IMRT programs.

Dosimetric Quality

An ideal IMRT treatment depends on the quality of the dose optimizing IMRT treatment-planning software. For a given set of anatomical structure-specific dosimetric requirements the optimization algorithm often generates the treatment field intensity distribution maps, based on which the IMRT delivery parameters are determined. *Figure 1* shows an intensity modulation map from a dose optimization that assumes no hardware limitations in treatment delivery.[9] IMRT delivery techniques have a strong influence on the dosimetric quality of the treatment through its spatial and intensity resolutions and other physical constraints. An ideal IMRT delivery technique should pose no resolution or other limitations and be able to create any intensity modulation pattern called for by the dose optimization with high fidelity. With everything else being equal, the finer resolution IMRT delivery technique generally can deliver higher treatment quality.[10–12] For MLC-IMRT the spatial resolution is determined by the MLC lead width (1mm or 5mm) and the intensity resolution by how the MLC segment fields are generated.

In principle, a compensator can be designed to produce the high-resolution intensity map (see *Figure 1*). Computer-controlled milling machines can be used to fabricate either a solid compensator metal directly (see *Figure 2*) or a negative Styrofoam mold[13] (see *Figure 3*). The mold is then sealed and filled with compensator material, metal granules[1,14] or liquid cerrobend,[15] to form the IMRT compensator. For examples of the readily available granule materials, copper and tin granules (size: 20 mesh) see *Figure 4*. Placed in the wedge or the block tray slot in an accelerator the IMRT compensator can be used together with blocks on any accelerator (see *Figure 5*), even on a Co-60 unit, as well as on MLC accelerators.

Because of its high resolution, compensator-IMRT generally can produce a dosimetric quality that is equal or superior to that of MLC-IMRT techniques.[12] One might argue that there is no gain for a finer IMRT resolution. This may be true for specific clinical cases that do not require high-resolution intensity modulation; however, significant efforts by accelerator vendors on MLC leaf size reduction indicate otherwise. It has also been shown that treatment quality is closely related to IMRT resolution.[1,11] Note that not all compensator-IMRT techniques are the same. Some use 1cm x 1cm or other discrete resolutions similar to MLC-IMRT and thus should have comparable dosimetric quality.[16,17]

Dosimetric quality of a compensator-IMRT technique also depends on the maximum intensity modulation it can produce. If a granular material of low-density and a design with small maximum depth are used the compensator-IMRT technique will have a limited intensity modulation range, which can reduce the dosimetric quality for clinical cases requiring large intensity modulation. On the other hand, MLC-IMRT techniques have the largest intensity modulation range, which is defined by the transmission factor of MLCs. Studies have shown that for certain clinical cases the lack of intensity modulation range can offset the benefit of the fine resolution of compensator-IMRT.[1,16] Therefore, careful consideration should be given in compensator-IMRT method design to achieve adequate intensity modulation range.

Figure 1: Intensity Map from Dose Optimization that Assumes no IMRT Delivery Limitation

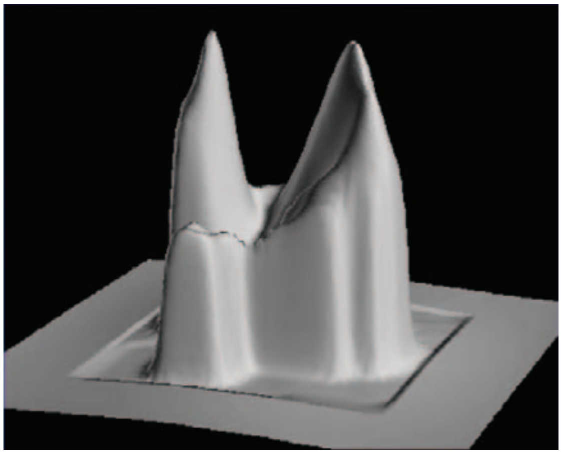


Figure 2: Brass IMRT Compensator (.decimal, Inc.)

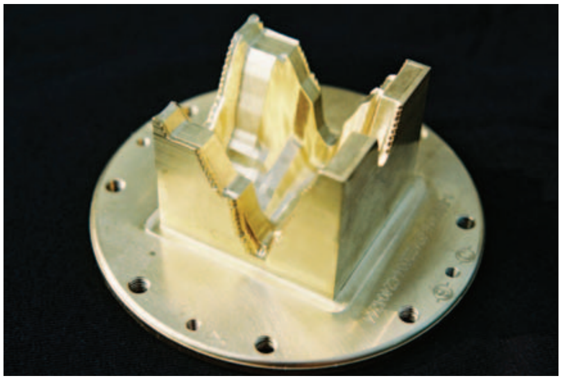
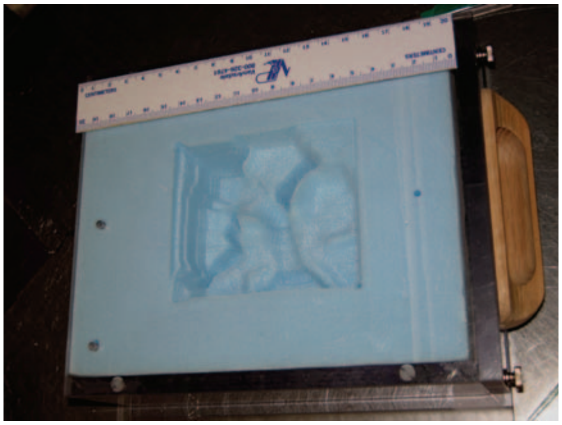


Figure 3: Compensator Mold in the Compensator Box



Treatment Throughput

The major benefit of MLC-IMRT techniques is treatment delivery automation. Owing to record and verify systems, an MLC-IMRT treatment is now totally automatic. For a compensator-IMRT treatment, the compensators generally need to be changed manually

Figure 4a

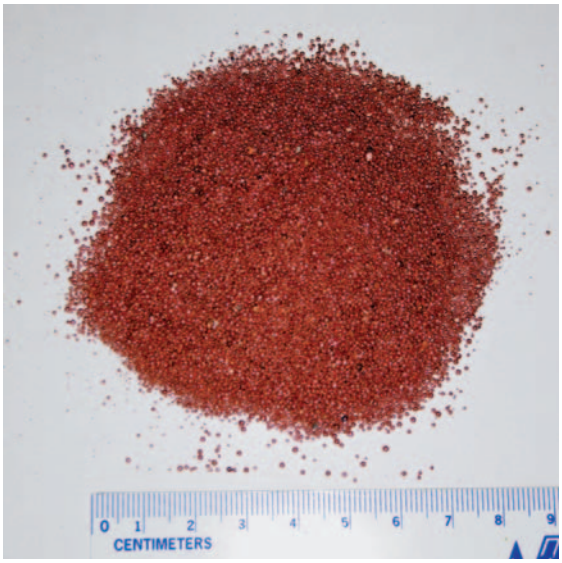


Figure 4b

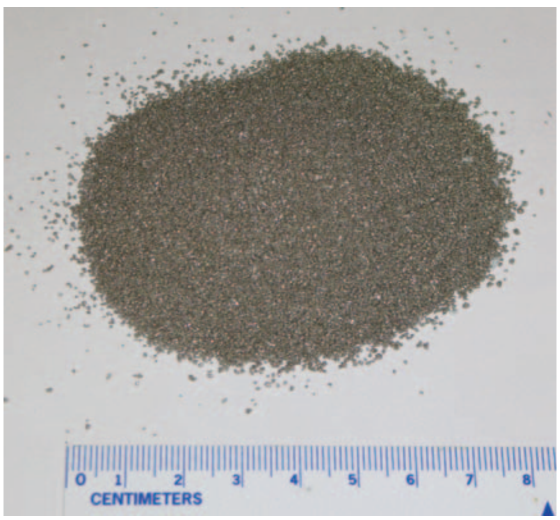


Figure 5: Demonstration of IMRT Compensator Box Insertion. Block Tray is Another Location for IMRT Compensators

by therapists between treatment fields. Several automated compensator-IMRT techniques have been developed in Japan,[7,17] Canada,[18] and the US,[19] where the IMRT compensator change is automatic between treatment fields. A study by Daniel et al.[20] also showed that it is possible to design a single multifield IMRT compensator to optimize the entire multi-field paranasal sinus treatment. Most compensator-IMRT treatments in clinical use, however, rely on manual compensator change.

In reality, the throughput of IMRT patient treatment does not solely depend on the level of treatment automation. Therapists at the University of North Carolina prefer to enter the treatment room between fields to manually change compensators than the automated one-push-button 'step and shoot' MLC-IMRT. Why do therapists not prefer the automated treatment? The answer is that they know the compensator-IMRT is significantly faster than the MLC-IMRT (on Siemens accelerators). This is supported by studies, including a retrospective analysis of clinical IMRT treatment time record on the record and verify system for 95 randomly chosen patients.[1,11] Studies on different compensator- and MLC-IMRT techniques showed that the throughputs are comparable.[20]

Clinical physicists may also prefer compensator-IMRT for faster IMRT quality assurance (QA) procedure.[8] The static intensity modulation of a compensator allows them to give fixed monitor units (MUs) (50 or 100) for IMRT QA measurement, independent of the actual MUs used for patient IMRT treatment, while for MLC-IMRT the same lengthy treatment delivery as used for patient treatment is needed.

The longer beam on-time of MLC-IMRT is due to the fact that the intensity-modulated field must be delivered sequentially, a portion (segment) at a time, while in compensator-IMRT treatment the entire intensity-modulated field is delivered simultaneously. Furthermore, small segment field irradiation is inefficient and more MUs are needed to deliver a given dose. Among MLC-IMRT delivery hardware Varian's accelerator is known to deliver the fastest treatment.

Operating Cost

After an IMRT program is established there can be different operating costs depending on the IMRT delivery hardware used. For instance, MLC-IMRT consists of a large number of segment fields per field and thus is significantly labor-intensive for clinical physicists and dosimetrists to manage in terms of point dose tracking, chart checks and, especially, handling fractional dose change in treatment planning and record and verify systems. For compensator-IMRT such managements are very similar to that of a non-IMRT treatment. If one uses a mail order compensator-IMRT service, there is a 'per compensator cost' added to the operating cost. If one wants to establish an in-house compensator-IMRT program at the present time considerable physics resource is needed to establish the program initially. The in-house compensator-IMRT program of the University of North Carolina relies on a milling machine (ADC 3, Par Scientific) specially designed for radiotherapy application and uses a recyclable metal granule material. Fabricated Styrofoam compensator molds are then filled with the metal granules (~20 mesh in size) by a medical physics technician. Tin, copper, steel, and tungsten granules may be used. Although this type of compensator-IMRT program has the lowest long-term overall cost—not requiring MLC purchase and no per compensator cost from mail-order service—it does take more physical resources initially.

One often overlooked difference in operating cost between compensator-based and MLC-based IMRT is related to accelerator wear and tear. The accelerator collimator mechanical wear and tear due to MLC-IMRT treatment is understandably more severe than for compensator-IMRT treatment. The accelerator usage in terms of beam on-time for MLC-IMRT treatments can also be much longer than for compensator-IMRT treatments due to the inefficient radiation delivery through many small segment fields.

As a result, the accelerator components related to beam production (electron gun, thyratron, and magnetron/klystron) might not last as long as if a compensator-IMRT technique had been used instead. The accelerator vault shielding requirement, another costly item, can also be different depending on which IMRT delivery technique is used. A compensator-IMRT technique is likely to require fewer MUs and thus less secondary beam shielding than an MLC-IMRT technique.

Other IMRT Delivery Hardware Concerns

'Beam hardening' through the compensator is a commonly mentioned concern for compensator-IMRT.[21] Beam hardening refers to the average photon beam energy change after it goes through a high-density material, such as physical wedges. All dose computation algorithms in treatment planning systems handle quite well the beam hardening through physical wedges, which in fact are compensators themselves. The dose algorithms, with modifications if necessary, should be capable of handing the beam hardening through IMRT compensators as well.[1,22,23] The compensator-IMRT approach compared with the MLC-IMRT approaches has encountered far more dose computation challenges—due to MU calculation—including small segment field, beam profile modeling of small and irregular fields, outside-segment-field dose calculation, interleaf leakage and leaf position accuracy. These are also challenges for accelerator commissioning. Free of the MLC related issues, compensator-IMRT techniques are generally easier to manage and more straightforward to commission. Independent of what IMRT hardware is used, compensator or MLC, a good treatment planning system that can model well the treatment delivery process including physical limitations is essential.

Compared with the MLC-IMRT technique, the compensator-IMRT technique can deliver equal or higher treatment dosimetric quality and a comparable or higher patient treatment throughput.

In summary, compensator-IMRT is a proven radiotherapy technology both in methodology and clinical application. Compared with the MLC-IMRT technique, the compensator-IMRT technique can deliver equal or higher treatment dosimetric quality and a comparable or higher patient treatment throughput. Additional benefits of using compensators as IMRT hardware can include faster IMRT quality assurance (QA), easier dosimetry data management, less accelerator wear and tear, and less accelerator vault radiation-shielding requirement. IMRT compensators can be fabricated using either in-house systems or mail order IMRT compensator services. Currently, over 150 cancer treatment centers in the US use compensator-IMRT at a rate of 400–500 patients per month (based on data from .decimal, Inc.) and almost all commercial treatment planning systems have added compensator-IMRT options. More efforts from different commercial vendors are still needed to make implementation of different types of compensator-IMRT technique more a 'turnkey' solution. Thirteen years following the commencement of the University of North Carolina's in-house compensator-IMRT program, the radiotherapy community has come a long way in recognizing compensator-IMRT for its quality, efficiency, and cost-effectiveness. ■

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