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A clinical comparison and analysis between conventional MLC based and solid compensator based IMRT treatment techniques

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A Comparative Analysis of Conventional MLC Based IMRT and Solid Compensator Based IMRT Treatment Techniques

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A CLINICAL COMPARISON AND ANALYSIS BETWEEN CONVENTIONAL MLC BASED AND SOLID COMPENSATOR BASED IMRT TREATMENT TECHNIQUES

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Submitted to the faculty of the Graduate School

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Introduction

In traditional 3-Dimensional conformal radiotherapy (3DCRT) a treatment planner decides on the beam configuration (beam orientation, weights, shape, etc) that will best produce the desired dose distribution. Intensity-modulated radiation therapy (IMRT) is an enhancement to 3DCRT in which non uniform fluence is used to optimize the dose distribution (Khan 2003). In IMRT treatment planning the desired dose distributions are achieved by inputting a set of treatment criteria (tumor dose and critical structure does limits), and the treatment planning system then computes the beam intensities that will achieve the desired dose distribution by an "inverse planning" technique. The criteria used consist of dose volume constraints that define the minimum and maximum doses to the structures in the plan while applying penalty weights to these criteria. This non uniformity or modulation of the beam can produce better dose conformity to the target and better critical structure sparing when compared to 3DCRT, particularly when concave or complex shaped target volumes are considered (Intensity Modulated Radiation Therapy Collaborative Working Group, 2001).

The basic principle of IMRT is to use optimized non uniform fluences delivered from any number of directions to deliver a high dose to the patient's target volume while sparing the surrounding normal tissue. The non uniformity of the individual beams is achieved with a treatment planning system that splits each individual beam into many beamlets of various sizes. An inverse planning process is than used to give the optimal weight to each beamlet that will satisfy the dose volume objectives defined be the planner.

Today's linear accelerators used for radiotherapy treatment use flattening filters to produce an x-ray beam with a uniform distribution within the field. To deliver the intensity modulated beams required for IMRT treatment, the accelerator must be capable of changing the uniform field into any arbitrary beam profile. Wedges, blocks, and dynamic jaws are simple methods used to produce simple changes in the uniformity of the field. However modern IMRT requires more sophisticated techniques in order to deliver the planned highly modulated fluence profiles.

Intensity modulation of the beam is possible with a number of different techniques. Today, multileaf collimators (MLCs) are the most popular IMRT delivery technique (Chang et al., 2004). MLCs allow for automation of the treatment process by moving during the delivery of each field and thus modulating the beam intensity. This may result in a decreased number of trips into the treatment room that a radiation therapist would be required to make.

There are a number of MLC IMRT treatment techniques. Step and shoot delivery involves a sequence of field shapes in each port. The MLC leaves move into position for the first subfield and than the beam turns on. The beam is than turned off while the MLCs move into position for the next subfield and once the MLCs are in position the beam is turned on again. This process is repeated until the treatment of that port is completed. Dynamic MLC or sliding window delivery involves constant radiation delivery during leaf movement. Each pair of MLC leaves forms an opening that travels across the target volume while the radiation beam is on. The speed of the leaves and the size of the opening are both computer controlled functions. Intensity modulated arc therapy is a delivery technique in which the leaves and gantry are simultaneously moving. Yu (1995) described a method that used multiple arcs to produce the desired dose distribution. Each arc had a MLC shape that was constantly changing based on gantry angle and on the results of the optimization.

Physical compensators provide an alternative to MLC based IMRT delivery techniques. In the past, physical compensators were used to compensate for the effects of irregularly shaped patient contours and tissue inhomogeniety to produce a uniform dose distribution at some pre determined plane within the tumor (Jiang and Ayyangar, 1998). The result of this use of a compensator was to produce a dose distribution similar to what would result from a perpendicular beam incident on a flat homogeneous phantom. Additionally compensators can be used to modify the beam intensity. The beam intensity can be modified by varying the compensator thickness resulting in different beam attenuation within the beam profile and thus producing an intensity modulated beam. A transmitted fluence map designed by the dose optimization algorithm is used to determine the shape and thickness of the compensator that appropriately attenuates the open field photon fluence.

While compensators may result in a simpler treatment delivery method, it is for the most part a non automated technique. A series of compensators need to be fabricated and the radiation therapists must enter the treatment room and substitute the physical compensators between each treatment field.

Literature Survey

While MLC IMRT treatment may be a highly automated delivery technique there are limitations to its benefit. The highly conformal nature of this treatment technique results in the delivery of many more monitor units (MUs) than would normally be delivered with conventional 3DRT. This can result in substantially longer beam-on and treatment times and increase radiation contamination (Rawlinson et all, 2002). The increase in treatment time compared to conventional therapy leads to a higher risk of involuntary movements of organs at risk (OARs) and planning treatment volumes (PTVs).

Another downside to MLC IMRT treatments is that difficulties with dose and MU calculations can arise from the numerous and unconventional nature of the MLC segments that make up each beam (Siebers et al, 2002). There are also resolution limitations associated with MLC delivery. The resolution of an MLC based IMRT treatment is based on the width of the MLC, and the largest source of dosimetric degradation with MLC-IMRT is also a result of the leaf width (1cm for the Elekta Precise accelerator used in this study).

Computer controlled milling machines are used to fabricate solid metal compensators either directly or via negative Styrofoam molds. The molds are than filled with a compensator material such as metal granules (Van Santvoort et al, 1995), or liquid cerrobend (Mejaddem et al, 1997). Compensators can produce high resolution intensity maps and are limited in their resolution by the ability of the milling machine that fabricates the metal compensator or the negative Styrofoam mold. As discussed by

Meyer et al. (2000) the size of the cutter head and the distance between adjacent cuts or step-over distance are the factors limiting the resolution of the compensators.

Another factor that can limit the dosimetric quality of a compensator technique is its maximum intensity modulation. A high density compensator material will yield a large intensity modulation range, and increasing the maximum thickness of the modulator will also increase the intensity modulation range. However, even at the maximum thickness of the modulator, a fraction of the beam is transmitted through the compensator resulting in a minimum transmission that can not be completely blocked.

While the majority of departments using compensators use a non automated technique, automated techniques have been developed. The development of a multiportal compensator mount system has been reported by Yoda and Aoki (2003). Their design was comprised of a rotational compensator mount that was affixed to a linac head. The mount included six circular slots for the positioning of six solid compensators. A stepping motor built-in to the mount was used to rotate the system. By eliminating the need to exchange the compensators port by port, the total treatment time is reduced. However the size of the compensators is limited by the fact that multiple compensators must be placed on the mount which in turn must be attached to the linac head.

Another compensator technique aimed at decreasing treatment time involves the use of a single compensator for multiple ports. A new delivery method was developed by O'Daniel et al. in which a single modulator was used to deliver multiple fields for the treatment of Para nasal sinus cancers. Their results showed that a multifield modulator IMRT technique can be superior to 3D conformal plans in terms of improved target coverage and reduced dose to critical structures. When compared to step and shoot

MLC–IMRT, the multifield modulator technique was at least its equivalent. However it was determined that this technique was not as attractive an alternative when large targets that required large fields were involved.

In general external beam radiotherapy strives to preferentially deliver therapeutic doses to target volumes while minimizing as much as possible the dose to surrounding organs at risk and healthy tissue. However an unavoidable consequence of radiotherapy is the dose delivered to areas of the patient's body that are outside the treatment fields, or peripheral dose. There are three main sources of peripheral dose 1) accelerator leakage; 2) beam modifiers such as blocks and wedges and secondary collimators that induce scatter; 3) patient internal scatter.

Brenner et al (2000) showed that although it is small, there is a statistically significant increase in risk of secondary tumors for patients with prostate carcinoma treated with radiotherapy, especially for long term survivors due to the unavoidable peripheral doses to organs outside the target volumes. As stated earlier, MLC based IMRT techniques require many more monitor units than conventional 3DRT. Kry et al (2005a) showed that the increase in MUs required by step and shoot IMRT when compared to conventional radiotherapy produced significantly larger secondary dose equivalents to normal tissues. Meeks et al (2002) showed that the use of serial tomotherapy results in a higher peripheral dose as compared to conventional radiotherapy.

This increase in peripheral dose results in an even larger increase in risk of fatal secondary malignancies with IMRT treatments when compared to conventional treatment as shown by Followill et al (1997), and Hall and Wuu (2003). Followill et al (1997) investigated the increase in whole body dose from step-and-shoot and serial tomotherapy IMRT. They theorized that the whole body dose would increase three and eight fold respectively. These increases were similar to the increase in MU needed for step-and-shoot and serial tomotherapy IMRT techniques. Verellen and Vanhavere (1999) reported an 8.1 times increase in whole-body of head and neck patients treated using serial tomotherapy versus conventional 3DRT.

However a second publication by Kry et al (2005b) that also concluded that IMRT treatments can increase the risk of fatal secondary malignancies when compared to conventional treatment also states that the risk is minor when the primary concern is tumor control and acute toxicity. Thus if normal tissue sparing and target coverage are similar for two treatment techniques, an evaluation of the risk of a secondary malignancy may be useful in determining the optimal treatment technique. Therefore IMRT should not be overlooked when choosing an appropriate treatment. Nevertheless when target coverage implies a high degree of out-of-field dose and especially in patients predicted to have a long term survival rate, a treatment approach that would minimize the unwanted dose would be the optimal treatment.

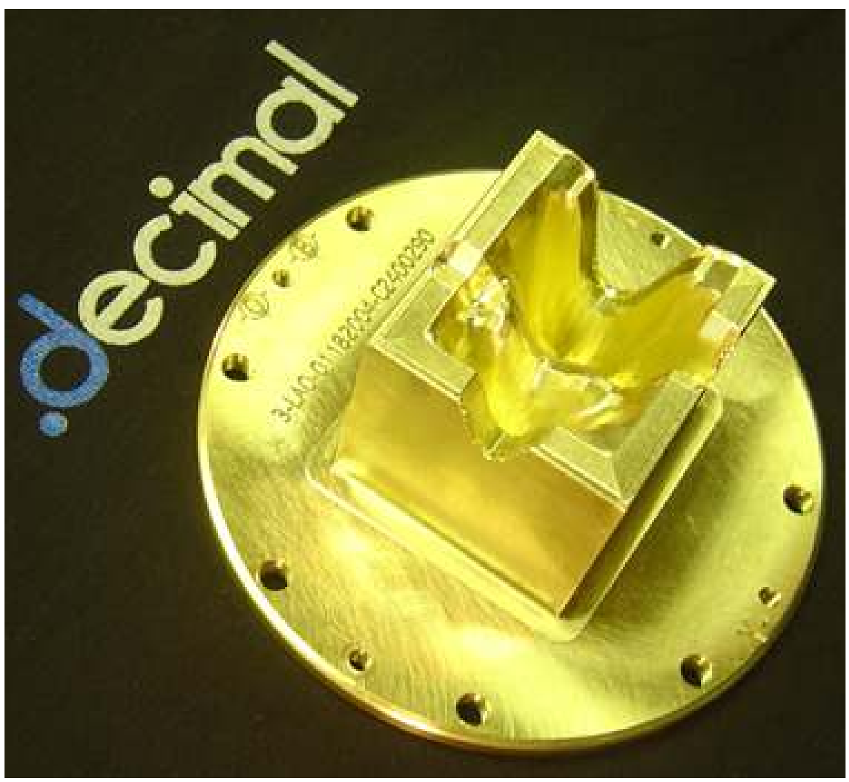
The goals of this study were to evaluate the clinical differences of solid and MLC based IMRT treatments. Investigation included performing 3D dosimetric analysis in target volume and surrounding critical structures. A qualitative assessment of measured fluence maps in various phantom planes as compared with the density matrix generated by the treatment planning computer for both MLC based IMRT and compensator IMRT was undertaken. A dosimetric comparison of the dose outside the target volume was carried out. The investigation was extended to compare the delivery time and monitor unit requirements for the IMRT techniques.

Equipment Used

Hardware:

- *Elekta* Precise linear accelerator
- *CNMC* electrometer model 206
- *Standard Imaging* Exradin Ion Chamber model A14P
- *Standard Imaging* Exradin Ion Chamber model A16
- Standard Imaging IMRT phantom REF 91230
- Med Tec Small Water Tank
- .decimal custom brass compensator filters (Fig. 1)

Figure 1 Brass compensator made by .decimal.



- Kodak EDR2 film
- Vidar VXR-16 Dosimetry Pro digitizer
- Kodak RP X-OMAT film processor

Software:

- P.D. by *.decimal*, used to transform the Open Density Matrices for all treatment IMRT beams into virtual metal alloy profiles.
- Pinnacle P^3IMRT® RTP by ADAC, on a Sun UNIX workstation running the Solaris operating system. It allows the user to enter patient data into the system, use it to construct a plan for radiation therapy, and evaluate the plan.
- RIT113 V4, radiation therapy dosimetry software that produces different analyses for scanned dosimetric films.
- IMPAC by *Elekta*, a software package designed to deal with the increasingly complex treatment protocols, to effectively manage the amount of acquired patient data.

Methods and Materials

An initial step that was necessary in order to carry out this investigation was the commissioning of the dot decimal system. This process consisted of measuring the effective attenuation coefficients for the solid compensator materials for a range of field sizes, and both 6and 10MV. The effective attenuation coefficients were measured for both aluminum and brass compensators for the following field sizes in cm: 2x2, 5x5, 10x10, 20x20, and 30x30. A water tank was set up with an ion chamber at 10cm depth and an SSD of 90cm. An open field measurement was recorded for each of the previously mentioned field sizes, then the alloy slabs were mounted in the modulator tray and measurements were again recorded for the same field sizes. The effective attenuation coefficients were calculated using equation 1. The thicknesses of the brass and aluminum slabs used during commissioning were, 3.0 cm and 2.54 cm respectively.

Equation 1: $$\mu_{eff} = -\ln\left(\frac{N(\text{mod}, FS)}{N(openFS)}\right) \Big/ Thickness$$

μ_{eff} = Effective Attenuation Coefficient

$N(\text{mod}, FS)$ = reading with the modulator for field size FS

$N(openFS)$ = open field size reading of size FS

$Thickness$ = is the exact thickness of the alloy slab

Using Pinnacle's ADAC treatment planning system version 7.4, IMRT treatment plans were developed. Head and neck, prostate, brain, and adrenal plans were analyzed. For each plan physicians determined target volumes and the physics staff delineated the necessary critical structure volumes and any structures that were used purely for assisting in achieving the desired isodose coverage (i.e. cold and hot spots, ring structures, normal tissue etc).

In this study the head and neck and brain plans utilized a nine field coplanar technique with the beams evenly distributed at 40 degree gantry intervals. The prostate and adrenal plans utilized a coplanar seven field technique with a 51 or 52 degree gantry angle separation between the beams. ADAC's inverse planning optimization module was used to determine an optimal plan. Once an acceptable optimal isodose distribution was achieved that adequately covered the PTV and spared the critical structures, two separate tracks were followed.

For the MLC based plans the optimal optical density matrixes were converted into deliverable MLC beam segments. The minimum number of monitor units allowed was 2, and the minimum allowed segment area was $2cm^2$. Once all the individual beams were converted to the MLC segments, the dose was recomputed. The new isodose coverage was rarely satisfactory. At times it was necessary to adjust the objectives and reoptimize. It was also necessary to adjust MLC leaf positions of individual segments in order to decrease hot spots or increase dose to cold spots. Once a satisfactory plan was achieved a doctor reviewed and accepted the plan. This plan was than used for actual patient treatment.

The final optimized plan was also used to create the compensator based plan. A script was created within the Pinnacle treatment planning system that allowed output of the beam opening density matrixes (ODM). This script was used to output the ODMs of the final optimized plan. Then on a windows workstation .decimal's p.d application software was used to convert the optimized ODM into physical modulators. The modulator material used was brass and had a maximum thickness of 7.62cm. Back in the Pinnacle treatment planning system another script was used to import the physical modulator files. Once the modulators were imported, the dose was recalculated. When reviewing the DVH and isodose coverage resulting from the modulator based plans it was never necessary to make any adjustments that required reoptimization.

For all the IMRT plans QA verification was undertaken. The beams were copied to a CT data set of a solid water Standard Imaging IMRT phantom setup (Fig 2). The gantry angles for all the beams were set to 0 degrees and the dose was computed. The solid water phantom consisted of slabs 3cm thick. The set up consisted of four such slabs and in the center of the second from the top slab was a customized drilled slot for an ion chamber. The chamber center was lined up with the beam isocenter (source to axis distance, SAD, of 100cm) and resulted in a source to surface distance (SSD) of 95.5cm. Kodak EDR2 film was placed in between the top two slabs at a source to plane distance (SPD) of 98.5cm. The QA beams were delivered from an Elekta Precise linear accelerator on to the phantom setup and a point dose measurement was obtained using an Exradin Ion Chamber model A14 and compared to the plan dose at this point. The ion chamber measurement was meant to verify that the planned dose was properly delivered. The film analysis was meant to verify that the fluence patterns determine by the plan optimization was properly delivered by the MLC. The film was processed using a Kodak RP X-OMAT film processor. A Vidar VXR-16 Dosimetry Pro Digitizer was used to scan the exposed films, and RIT113 V3 dosimetry software was used to compare the exposed films to planar dose distributions from the treatment plans.

These QA procedures were undertaken for both the MLC and compensator based plans to ensure that the treatment planning system's dose distribution was achieved by the linear accelerator to an acceptable degree. For select plans, film was placed in between other slabs of the phantom resulting in SPDs of 101.5cm, 104.5cm to simulate out of target planes, and exposed as the treatment plan was delivered to the phantom.

Figure 2 Solid Water QA phantom

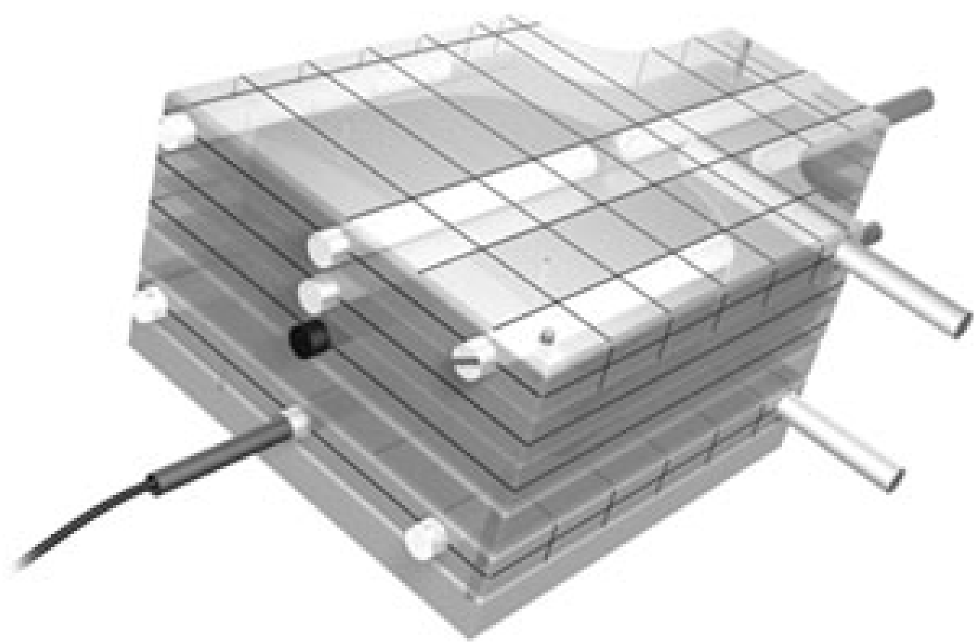
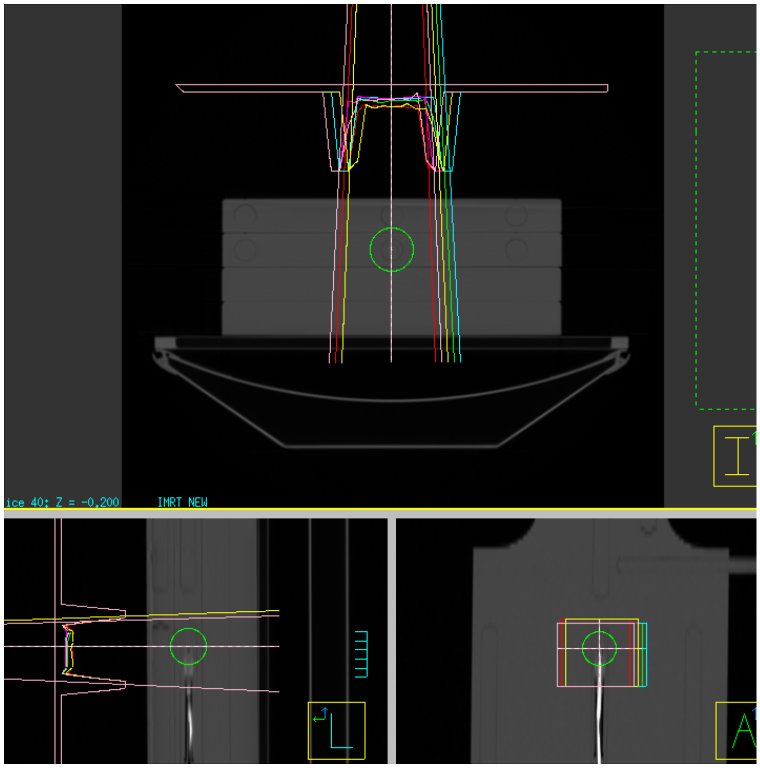
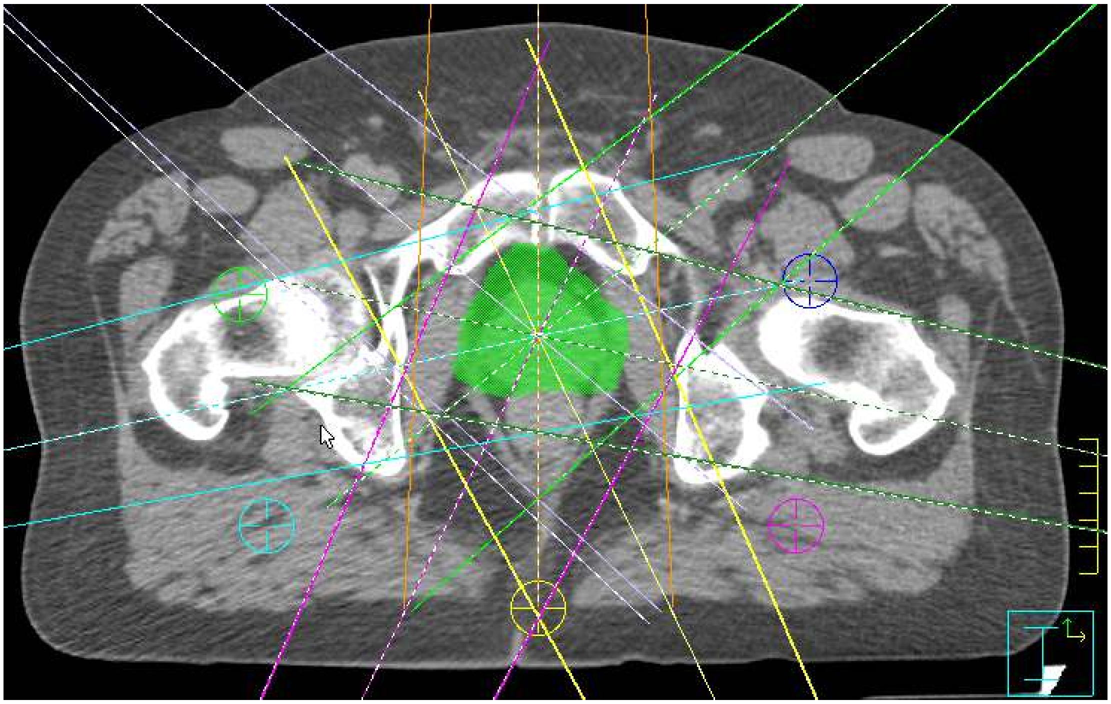


Figure 3 The CT data set of the solid water QA phantom in the Pinnacle TPS shown with all beams at a gantry angle of 0.



For each patient plan, dose points were placed in the patient's CT data set. The points were placed at various locations and depths outside the target (Fig. 4). Points were also placed in out of field locations superior and inferior to field edges. The Pinnacle TPS is capable of calculating the dose to these points. A comparison of the dose to these points from the MLC and compensator based plans was undertaken.

Figure 4 Example of points placed in the CT data sets for dose comparison.



An anthropomorphic Rando Phantom was used to measure dose for a prostate and a head and neck plan. Mosfets and TLDs were placed on the phantom. For the prostate plan the mosfets were placed along the phantoms transverse central axis. TLDs were placed within the phantom at the central axis slab and in superior and inferior slabs. Both the MLC and compensator based plans were delivered to the phantom and the dose to the measurement devices from the two plans were compared. A similar comparison was undertaken for a head and neck plan using the head and neck portion of the phantom. However for this plan the mosfets were placed superior and inferior to the transverse central axis.

There has been a debate regarding compensator delivery and the fact that it could result in increased treatment times. Some believe that the repeated trips into the treatment room by the therapists, who must replace the compensator between each beam, will result in increased treatment times. Others argue that the significant decrease in treatment MUs for compensator delivery more than offsets the additional time required to exchange the compensators. Treatment times of the two delivery techniques were therefore compared. The delivery was timed from the first beam on point until the last beam completed its delivery. Another factor that might influence a patient's treatment time, as the ability of the therapists to manipulate and insert the compensator inserts. Therefore the weight of the compensators was measured.

Results

Table I displays the measured effective attenuation coefficients measured during the commissioning of the dot decimal solid compensator IMRT system. These values were input into the P.D. software and are necessary for optimizing the solid modulator to achieve the optimal fluence. Although measurements were made for both aluminum and brass compensators and for both 6 and 10 MV, this investigation only used brass compensators and 6MV.

Table I. Solid compensator effective attenuation coefficients

Field Size (cm)	Effective Attenuation Coefficient (1/cm)			
	Brass		Aluminum	
	6 MV	10 MV	6 MV	10 MV
2x2	0.335	0.308	0.112	0.094
5x5	0.336	0.308	0.11	0.095
10x10	0.332	0.303	0.11	0.096
20x20	0.32	0.287	0.105	0.089
30x30	0.292	0.259	0.095	0.075

As stated in the previous section, at this institution all MLC based IMRT plans used for patient treatment undergo comparative point dose measurement and film analysis. If the point dose is within 3-4% of the TPS point dose and the film planar dose maps match the TPS planar dose maps the plan is deemed acceptable for patient treatment. Point dose measurements were also obtained for a number of the compensator plans and the results were within 3% of the TPS point dose.

The initial results analyzed were in regard to the monitor unit difference between the MLC and compensator plans. The following table is a side by side comparison of the monitor units generated by the treatment planning system for various treatment sites.

Table II Monitor unit comparison of compensator and MLC IMRT plans.

	MU Comparison											
	Head and Neck Boost		Head and Neck		Brain boost		Prostate		Prostate Boost		Adrenal Gland	
Port	Solid IMRT	MLC IMRT	Solid IMRT	MLC IMRT	Solid IMRT	MLC IMRT	Solid IMRT	MLC IMRT	Solid IMRT	MLC IMRT	Solid IMRT	MLC IMRT
1	141.8	163.4	66.9	97.3	48.1	65.2	73.6	167.8	50.4	33.2	53.3	39
2	57.5	155	70.6	120.4	35.9	77.4	98.4	100.5	62.5	46.9	55.5	36.2
3	110.2	100	58	86.1	83.7	110.4	134.5	241.9	105.6	73.4	53.7	35.8
4	106.2	125.7	57.1	128.2	115.2	47.2	117.7	137.4	54.2	36.7	52.1	35.6
5	141.3	159.9	59.9	123.1	88.4	93.8	73.1	136.4	54.5	37.2	52.3	36
6	120.4	123.5	66.5	115.9	49.3	91.8	124.9	136.2	99.9	78.8	69.1	50
7	97.2	107.9	60.5	104	44.8	78.1	128.3	161.3	61.4	51.4	58	36.1
8	84.6	108.6	47.7	105.7	76.1	88.9						
9	66.5	160	60.7	143.8	129.2	65						
SUM	925.7	1204	547.9	1024.5	670.7	717.8	750.5	1081.5	488.5	357.6	394	268.7

The head and neck compensator IMRT plan required just over half as many monitor units as the MLC plan. The compensator IMRT head and neck boost plan required only 77% of the monitor units that the MLC plan needed. The brain boost compensator plan required 93% of the MLC plan's monitor units, and the compensator prostate plan used 69% of the monitor units used by the MLC plan. There were two treatment areas for which the compensator plans required more monitor units than their MLC counterparts. The prostate boost compensator plans resulted in 37% more monitor units than the MLC plan, while the adrenal gland compensator plan used 47% more monitor units than its MLC equivalent.

The results of the film analysis indicate that compensator plans can more accurately deliver the planned isodose distribution. The following figures compare profiles of measured planar doses of both compensator and MLC plans. Figures 5 and 6 compare the how well the actual MLC and compensator delivered plans match the ADAC calculated profiles and are typical of the film results of all planes and profiles.

The films were placed in between the slabs of the phantom to simulate planes posterior and anterior to the target. Figures 7-12 are vertical and horizontal profiles comparing the compensator and MLC out of field fluence at various depths in the phantom.

Figure 5. Transverse profiles through central axis of a prostate plan at a plane superior to the target

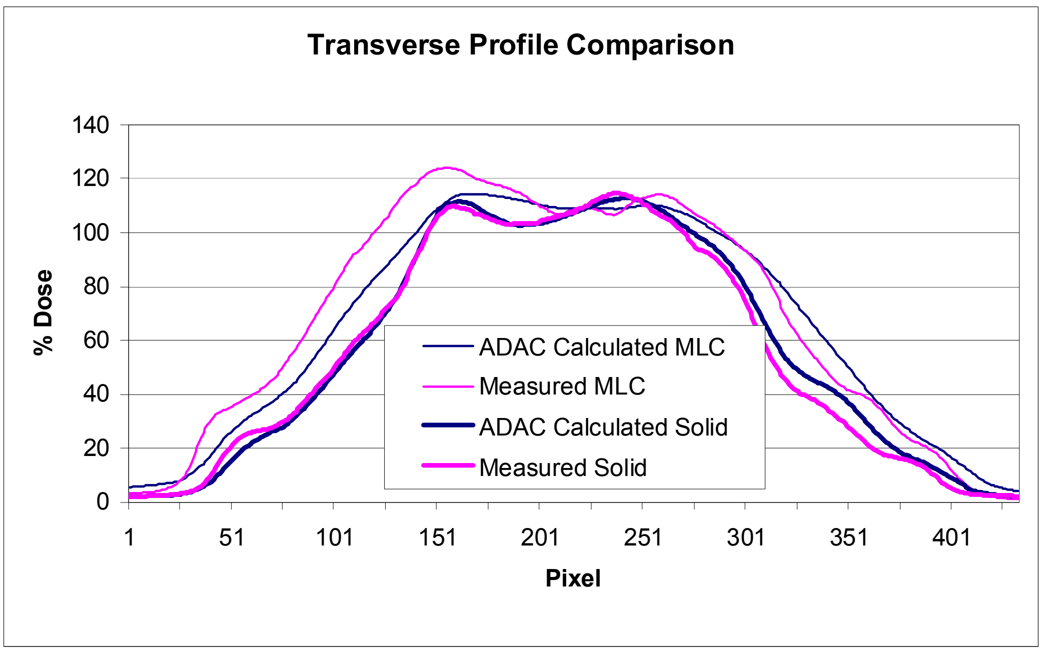


Figure 6. Sagital profiles through central axis of a prostate plan at a plane inferior to the target

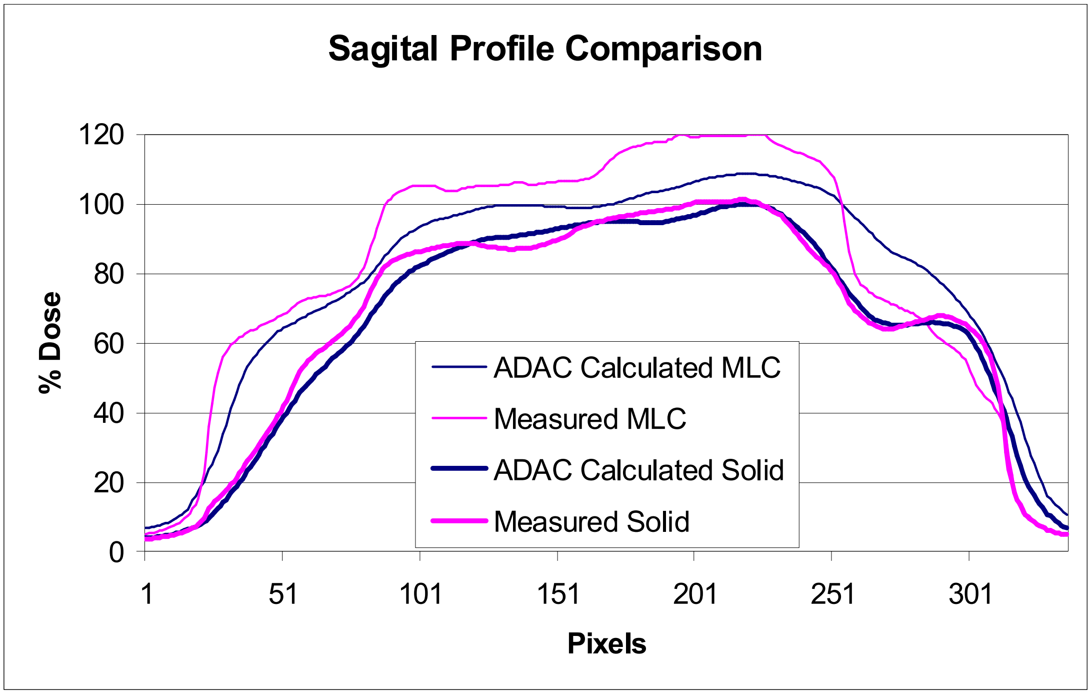


Figure 7. Horizontal plane out of field fluence profile at the target mid-plane

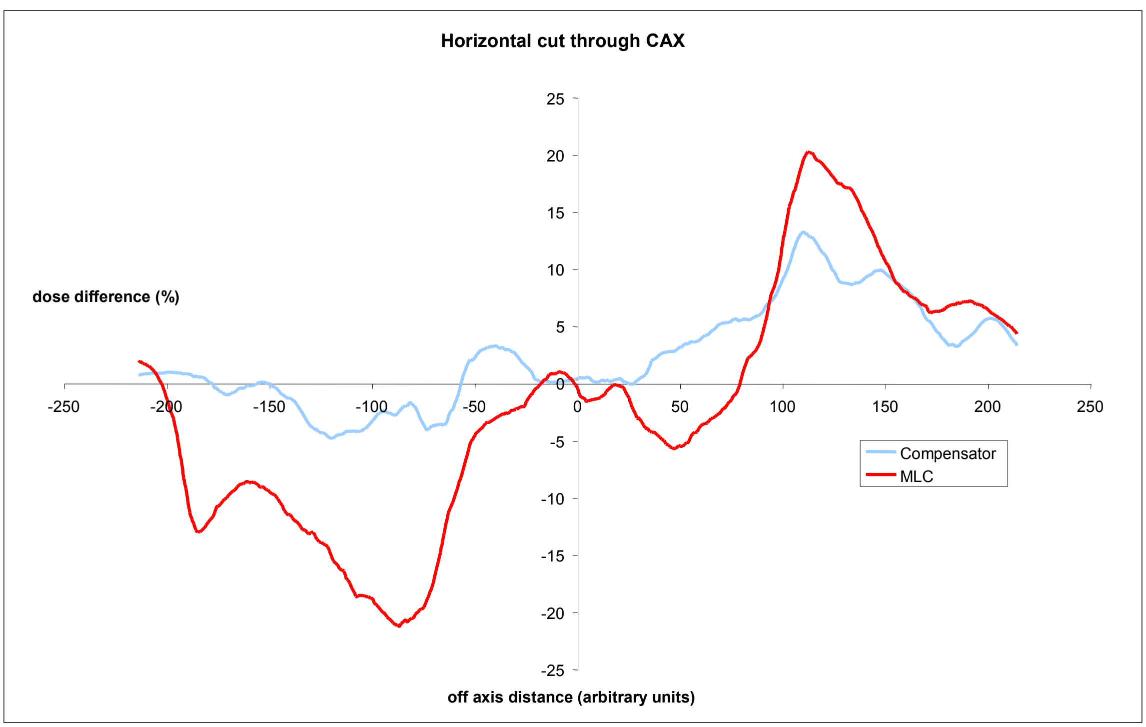


Figure 8. Vertical plane out of field fluence profile at the target mid-plane

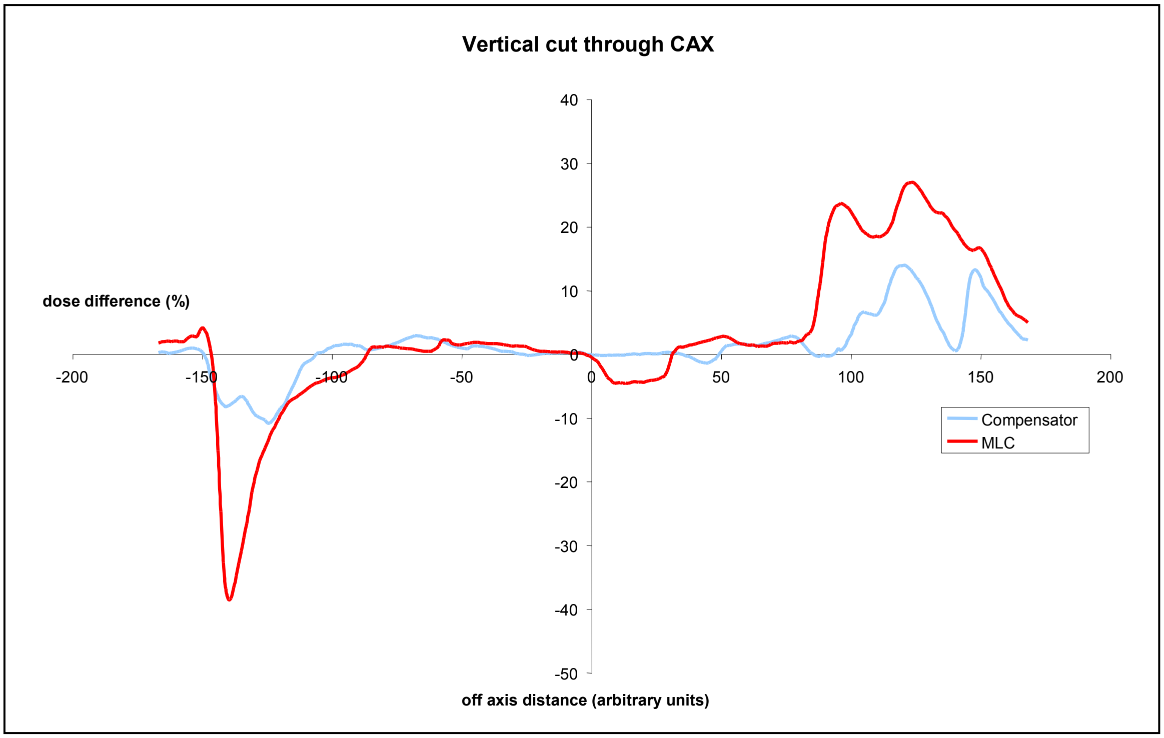


Figure 9. Horizontal out of field fluence profile at a plane in-between dmax and the target mid-plane

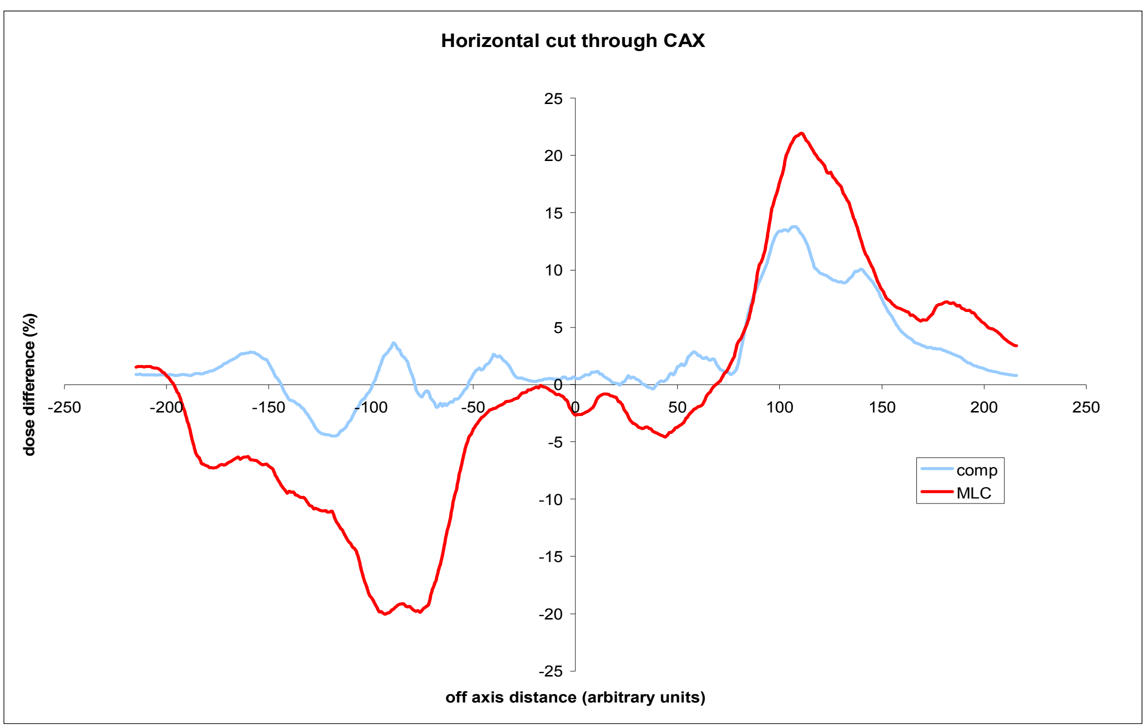


Figure 10. Vertical out of field fluence profile at a plane in-between dmax and the target mid-plane

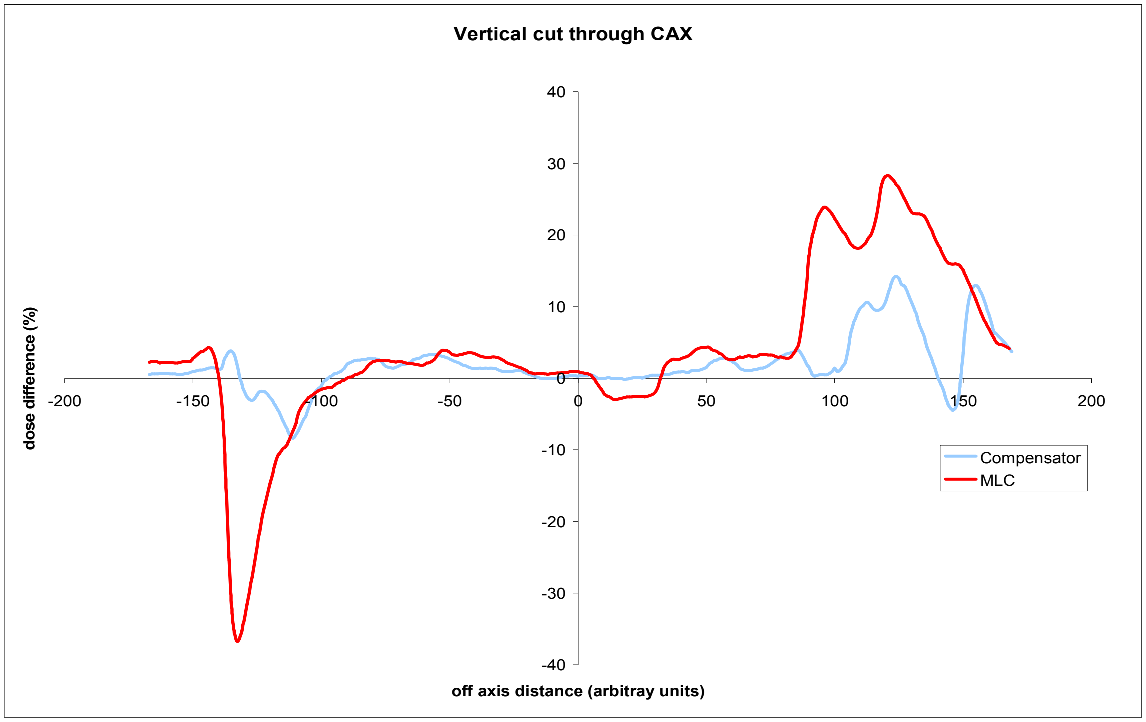


Figure 11. Horizontal out of field fluence profile at dmax

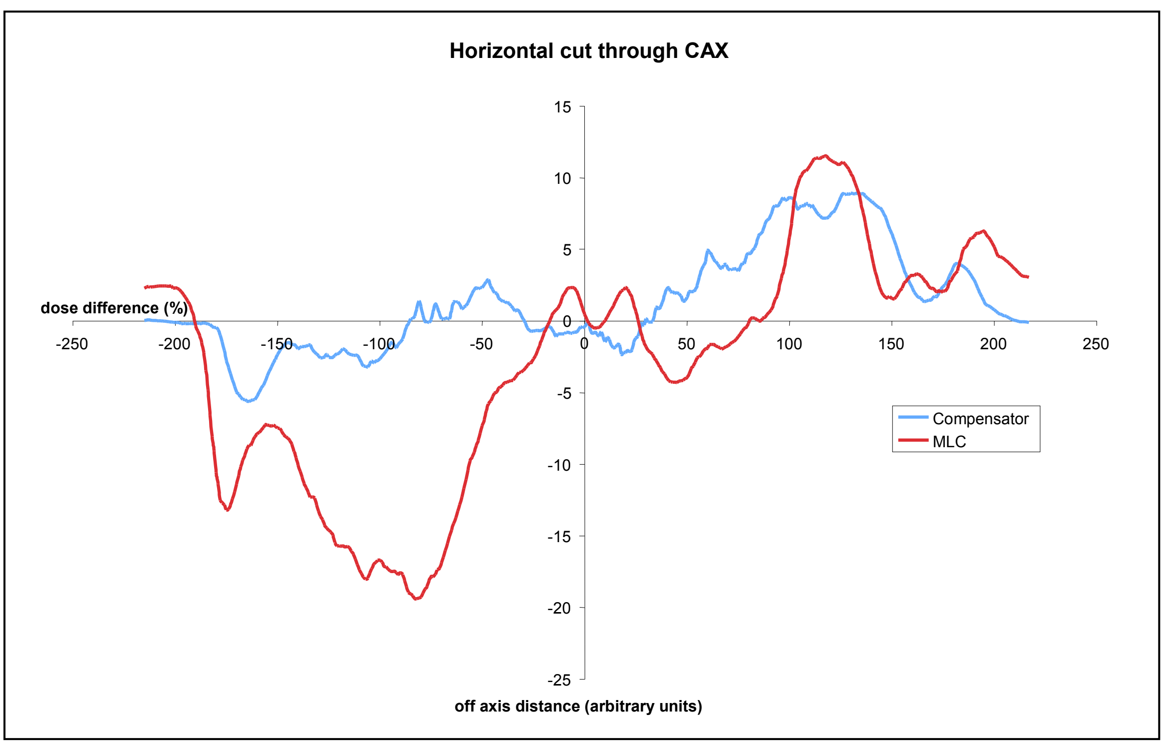
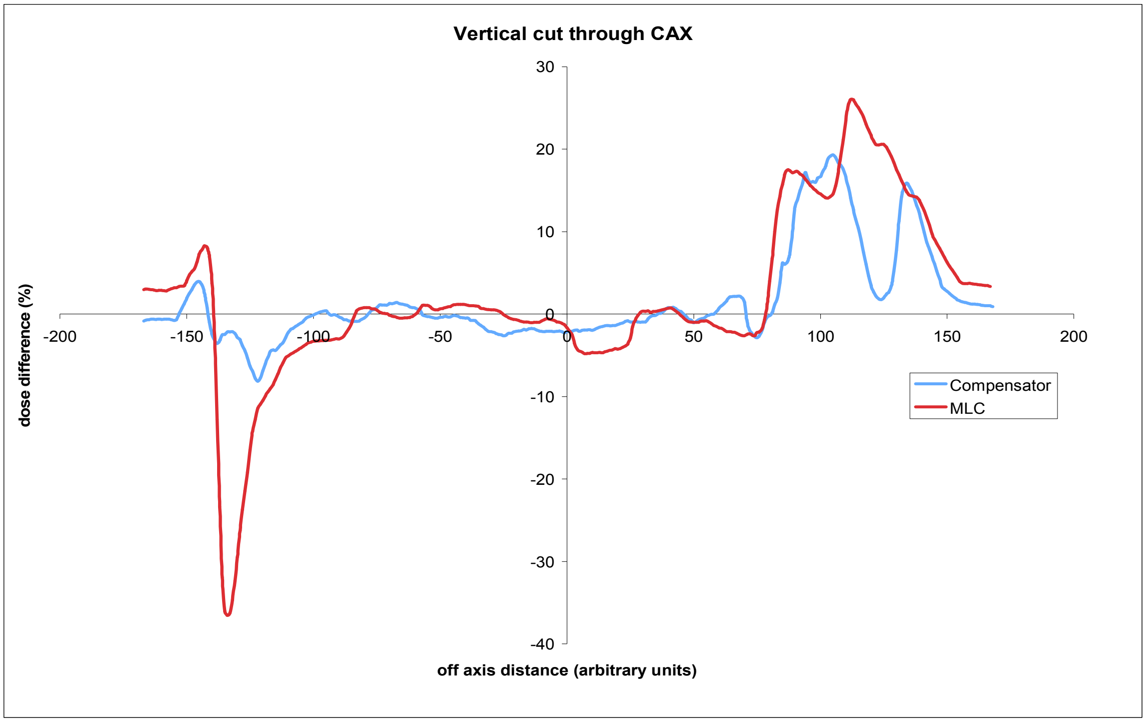


Figure 12. Vertical out of field fluence profile at dmax



Pinnacle has the ability to calculate dose to a point. Points of interest within the patient anatomy were identified in the target plane as well as in positions just outside the radiation fields. The following table is a comparison between the resulting dose to these points with the solid and MLC IMRT plans.

Table III Pinnacle point dose comparison

	Brain boost			Prostate boost			Adrenal gland		
Point	Solid	MLC	Diff cGy	Solid	MLC	Diff cGy	Solid	MLC	Diff cGy
1.0	16.6	18.6	-2.0	46.2	45.0	1.2	20.2	21.6	-1.4
2.0	72.2	77.8	-5.6	30.3	31.1	-0.8	13.0	14.1	-1.1
3.0	52.5	61.6	-9.1	36.2	49.8	-13.6	27.1	25.9	1.2
4.0	105.2	108.1	-2.9	15.7	18.3	-2.6	0.0	0.0	0.0
5.0	65.2	69.0	-3.8	15.1	17.8	-2.7	17.3	18.3	-1.0
6.0	61.2	67.3	-6.1						
	Prostate			**Head and Neck**			**Head and Neck boost**		
Point	**Solid**	**MLC**	**Diff cGy**	**Solid**	**MLC**	**Diff cGy**	**Solid**	**MLC**	**Diff cGy**
1.0	21.8	26.6	-4.8	148.4	152.4	-4.0	130.2	137.1	-6.9
2.0	47.0	68.3	-21.3	157.8	158.9	-1.1	143.3	148.8	-5.5
3.0	56.6	67.0	-10.4	77.6	64.9	12.7	55.2	43.8	11.4
4.0	27.6	67.0	-39.4	132.8	133.0	-0.2	82.3	78.3	4.0
5.0	21.0	27.7	-6.7	143.4	143.5	-0.1	81.6	75.1	6.5
6.0	26.9	20.7	6.2	147.9	146.6	1.3	77.1	72.9	4.2
7.0	14.4	16.1	-1.7	47.8	48.3	-0.5	31.7	34.1	-2.4
8.0	11.3	17.9	-6.6	22.5	26.0	-3.5	24.2	31.3	-7.1

A quick look at Table II and one can easily notice that the solid IMRT plans delivered less dose for most of the points. In fact for 30 of the 40 points investigated, the solid IMRT plan delivered less dose. These 30 points averaged 5.8% fewer cGy than the MLC IMRT plans. The points for which the solid IMRT delivered more dose were higher by an average of 5.4%.

The results of the investigation in which TLDs and mosfets were used to measure dose on and in a Rando phantom for both a prostate and a head and neck case are summarized in Table III.

Table IV Rando phantom measurements using Mosfet and TLDs.

	Prostate			Head and Neck		
mosfet (cGy)	**solid**	**MLC**	**%diff**	**solid**	**MLC**	**%diff**
1	31.8	35.5	-10.3	90.0	79.1	13.8
2	16.4	35.5	-53.8	52.7	55.5	-4.9
3	10.0	9.1	10.0	43.6	40.0	9.1
4	35.5	40.9	-13.3	80.9	63.6	27.1
5	33.6	41.8	-19.6	24.5	10.9	125.0
TLD(cGy)	**solid**	**MLC**	**%diff**	**solid**	**MLC**	**%diff**
1	42.5	61.9	-31.3	12.6	6.8	84.4
2	40.2	37.9	6.1	131.7	137.7	-4.4
3	35.9	39.2	-8.2	92.2	78.3	17.8
4	15.3	24.2	-37.0	9.8	6.2	58.4
5	5.3	10.0	-47.2	8.7	5.7	51.9
6	5.8	12.1	-51.7	63.7	59.8	6.6

All but one of the TLDs and mosfets readings indicate that the prostate plans delivered less dose to the areas of interest using the solid IMRT plan. For the head and neck case the opposite is true. Only one TLD and one mosfet readings showed lower doses for the solid IMRT plan and the rest of the measurements indicate that lower doses were achieved with the MLC plan.

The time required to deliver the MLC and compensator plans are summarized in Table IV. The time was measured from the initial beam on of the first beam until the final beam turned off. Therefore the time required for the treatment console to load the MLC segments, and the time required to go into the treatment room and exchange the solid compensators was included in the measurements.

Table V. Results of the measured time required to deliver various IMRT plans

	Time in Minutes							
	Head and Neck		Prostate Boost		Adrenal Gland		Prostate	
Trial	Solid IMRT	MLC IMRT	Solid IMRT	MLC IMRT	Solid IMRT	MLC IMRT	Solid IMRT	MLC IMRT
1	15.0	35.8	10.2	8.4	8.5	6.9	11.9	19.6
2	13.4	34.4	9.1	9.0	8.3	6.8	12.0	19.5
3	13.5	32.9	9.2	8.7	8.4	6.8	11.8	19.1
Average	14.0	34.4	9.5	8.7	8.4	6.9	11.9	19.4

For the relatively complicated head and neck, and prostate plans the solid compensator delivery required approximately half the time of the MLC delivery. However for relatively simple adrenal and prostate boost plans the compensator delivery actually required slightly more time to complete a treatment than the MLC delivery.

Discussion

The results indicate that for complex IMRT plans solid compensators result in less MU and require less time to deliver, whereas for relatively simple IMRT plans solid compensators result in more MU and require slightly more time to deliver. Adrenal gland, prostate and brain boost plans can be relatively simple. The target shapes can be spherical or cylindrical in nature with relatively little concern for critical structures, and the beams require a relatively small number of segments that are relatively large in area. Head and neck plans and prostate plans that include seminal vesicles can have complex target structures and may include a higher number of critical structures in close proximity to the target volumes. These complex targets with nearby critical structures can pose a greater planning challenge than simple adrenal or brain boost targets. This may result in a more complex plan with a larger number of segments per beam, and the beams may contain a greater number of segments with relatively small areas. Figures 7, 8 and 9 illustrate the difference between simple and complex plans.

Figure 13. On the right a simple spherical shaped adrenal gland PTV (red) with only the kidney (blue) as a critical organ of concern, compared to a larger irregularly shaped head and neck PTV (also red) where dose to the spinal cord, parotid glands, oral cavity and brainstem are all a concern.

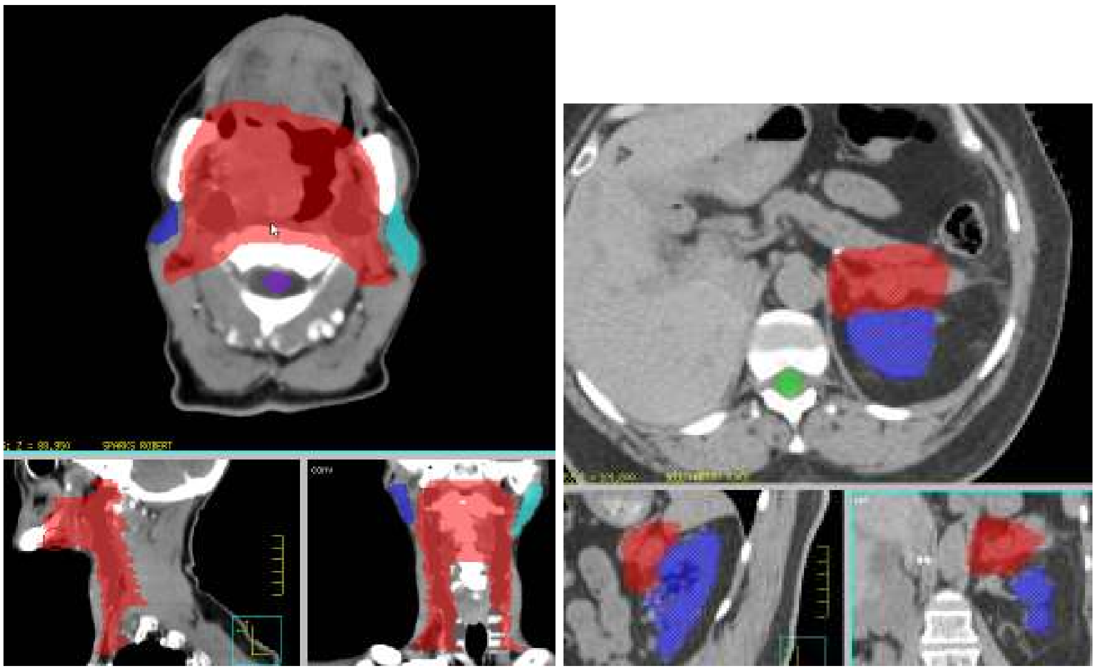


Figure 14. The small number and relatively simple segments of a beam from the adrenal gland plan.

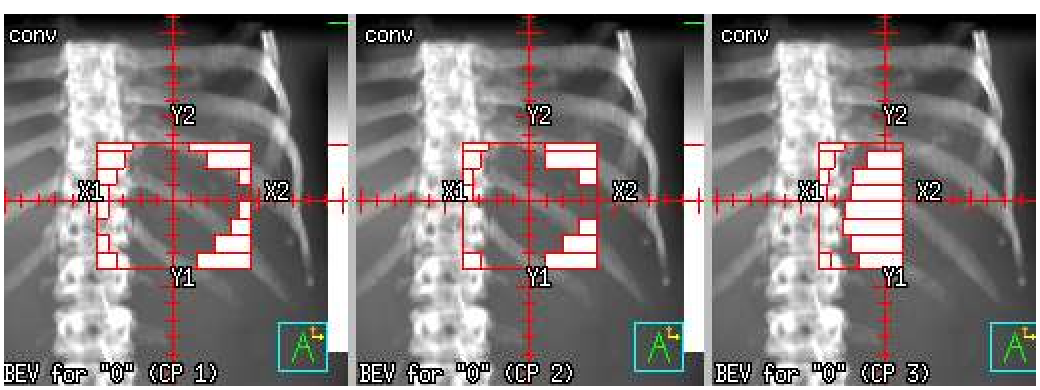
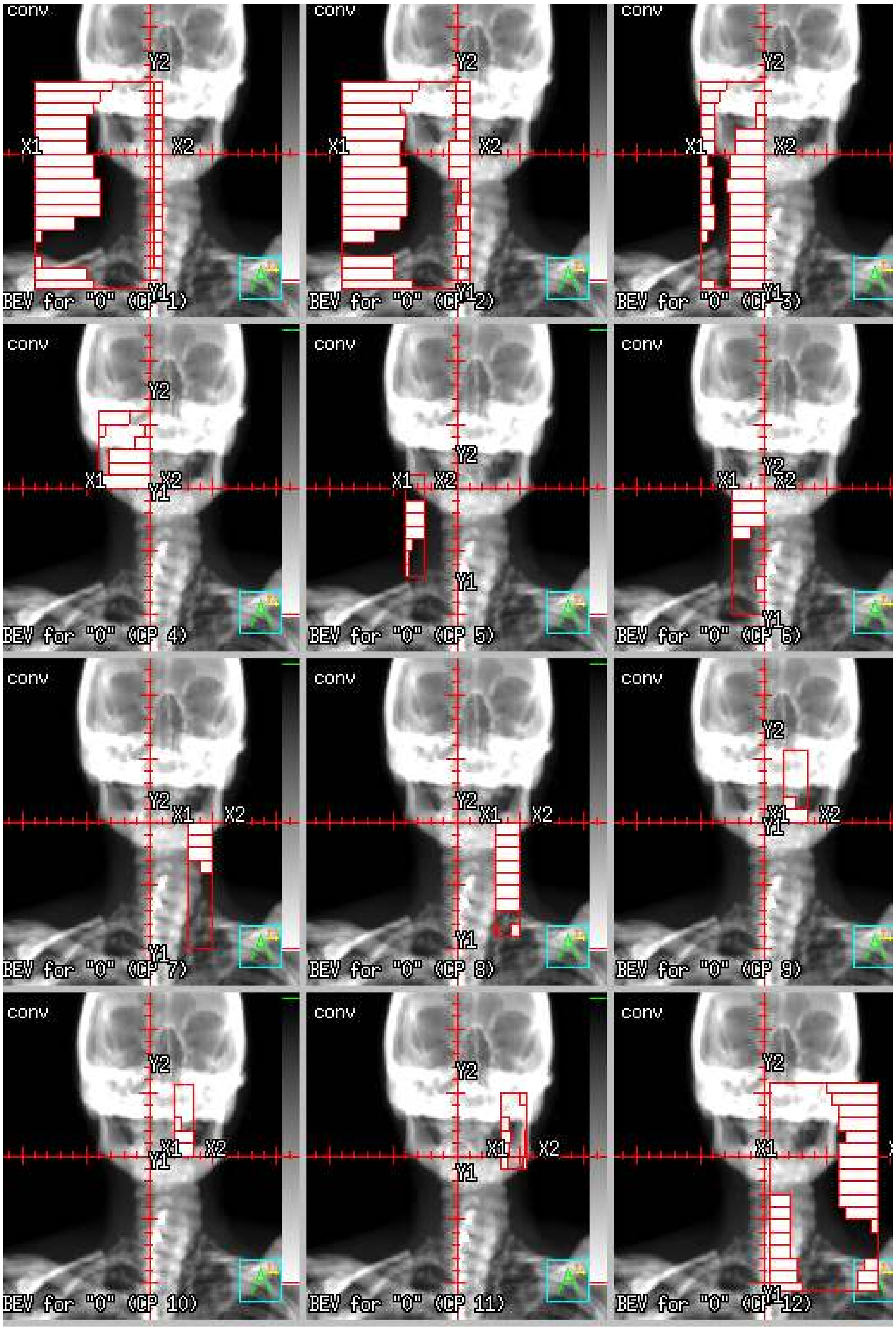


Figure 15. Segments of a head and neck plan. Notice the increased complexity of the segment shapes and the number of small segments.



For the complex MLC plans with numerous segments the increase in treatment time is because each segment must be delivered in sequence. However for the compensator plans each intensity modulated field is delivered all at once. Elekta engineers have stated that upgrading the Precise Linac control cabinet could reduce the time to treat an IMRT patient by a third. The upgraded control cabinet has the ability to load the MLC segments faster than the control cabinet used in this investigation. While this might make delivery times comparable for MLC and solid compensator prostate cases, solid compensators would still have a significant time advantage for head and neck cases.

Conclusions

Compensators are a viable IMRT treatment option that can deliver plans comparable and at times even better than MLC based plans. Compensators may deliver a plan that can more accurately conform to the output of the treatment planning system in areas outside the target volume. However careful consideration must be undertaken when considering compensators vs MLCs for IMRT treatment. While compensators can reduce the treatment time and monitor units required for some plans, the benefit is reduced and may even be eliminated for relatively simple target volumes especially when organs at risk are not in close proximity to the target.

Physicists may also prefer compensator IMRT due to the ability to perform a faster quality assurance (QA) procedure. For MLC-IMRT the QA procedure requires delivery of actual patient MUs, while the static intensity modulation of compensators provides the ability to deliver a set number of MUs that is less than the actual patient MUs.

Another reason physicists may prefer compensator based IMRT planning is related to the planning process itself. As stated previously, version 7.4 of Pinnacle's ADAC treatment planning system was used to develop the IMRT plans. This version of the planning system required that after the optimization algorithm produced the optimal density matrixes, a secondary step must be taken to convert the optimized plan into deliverable MLC segments. Frequently this conversion into a deliverable plan produced unsatisfactory isodose coverage. This required either another round of optimization and conversion or manual adjustment of MLC leaf position. When the optimal density matrices were converted into compensators based plans the resulting isodose coverage and dose volume histograms were always satisfactory and there was no need for a second round of optimization. Therefore the amount of time spent in the planning process was frequently significantly less for the compensator plan compared to the MLC plan. However shortly after the completion of this study the radiation oncology department upgraded its planning system to a version that included Direct Machine Parameter Optimization (DMPO) for IMRT planning. Using DMPO, the optimization of the dose distribution and conversion to deliverable MLC segments was carried out in a single step. This resulted in plans with adequate dose coverage and dose volume histograms, and now rarely requires a re-optimization. Thus with this current version of the planning system, the time spent in the planning process would be similar for the MLC and for the compensator plans.

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Abstract

Intensity Modulation Radiation Therapy (IMRT) using multi leaf collimation systems has revolutionized the delivery of radiation therapy. However, these treatments may result in delivery of very large monitor units (MUs) through very small fields where electronic equilibrium may be compromised. This also raises some concerns in terms of the scattered dose to areas outside the main treatment volume. The goals of this study were to evaluate the clinical differences of solid compensator and MLC based IMRT treatments. The investigation was extended to compare fluence maps at prescription plane, the delivery time, monitor unit requirements, and deposited dose to outside of the target volume. The ADAC Pinnacle inverse planning system was used to generate MLC based IMRT plans and using the .decimal software package, generating the compensator based IMRT plans. Treatment plans were generated for prostate, adrenal gland, brain, and head and neck cases. Delivery of treatment plans were performed on a Rando phantom and mosfet dosimeters, TLDs, and films were used to compare measured doses of MLC and solid IMRT treatments. For the more complex plans the solid compensators resulted in 26.7% fewer monitor units and delivery time was reduce in half when compared with mlc plans. However for relatively simple IMRT plans such as prostate boosts or adrenal gland plans where the target has a relatively simple cylindrical shape the mlc plans resulted in an average of 41.6% fewer MUs and required about 16% less time to deliver than the solid compensator plans. Mosfet skin dose analysis showed that the solid compensators resulted in an average of 17.5% less dose. Film analysis also showed that Compensator plans delivered less out of field fluence. Based on the results it is evident that solid compensators are a viable IMRT treatment option when considering complex

target arrangements that require many beams segments. For relatively simple plans which result in fewer and larger beam segments compensator based plans showed no advantage over mlc plans in regards to MUs and treatment time.