Chapter 7

New Developments in Arc Radiation Therapy: A Review

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Abstract
Arc therapies have gained widespread clinical interest in radiation oncology over the past decade. Arc therapies have several potential advantages over standard techniques such as intensity modulated radiation therapy, with implications for patients, administrators, and oncologists. This review focuses on the rationale for arc therapy, descriptions of the modern arc techniques that are currently clinically available, and highlights some distinguishing features of arc therapies, such as dose distributions, treatment times, and imaging capabilities. Arc therapies are exciting examples of progress in radiotherapy through technological innovation, aimed at ultimately improving the therapeutic ratio for patients receiving radiation.

Introduction
The technologies available for delivering radiation therapy have advanced dramatically in the past few decades. In the 1980’s, two-dimensional radiotherapy was the standard of care, relying on radiographs and anatomical knowledge for target localization. The advent of CT scanning for radiotherapy planning ushered in the era of 3D conformal radiotherapy (3D-CRT, Figure 1A), in which 3D images of tumours, normal structures, and dose distributions could be constructed (1).

In the 1990’s, intensity-modulated radiotherapy (IMRT) was introduced. IMRT divides each large radiation beam into numerous small beamlets, and adjusts the intensity of each beamlet individually (2). With IMRT, it is much easier to achieve complex dose distributions (such as the sparing of the spinal cord and parotid shown in Figure 1B) that are difficult to create with 3D-CRT. As a result, IMRT treatment plans are more conformal and allow for lower doses to organs at risk. Like 3D-CRT, IMRT is delivered using fixed beams that do not rotate while the beam is on, although the shape of the beam may change. IMRT generally requires more beams than 3D-CRT – often 5-9 beams are used for each fraction. Beam directions are chosen that allow the whole target to be encompassed while avoiding normal tissues as much as possible. Unfortunately the best angles for treatment are not always obvious (3).

Compared to 3D-CRT, IMRT provides greater flexibility in controlling each beam, ultimately improving dose distributions and reducing toxicity (2;4). IMRT can also
allow for dose escalation, delivering higher doses to the tumor while maintaining acceptable doses to critical organs at risk, such as the spinal cord. A systematic review of comparative clinical IMRT studies, including 3 randomized trials, confirmed that IMRT can reduce toxicity for various treatment sites, although effects on local control and survival outcomes are inconclusive (4).

Figure 1. Treatment plans for 3D conformal radiotherapy (3D-CRT) [Panel A] and intensity modulated radiation therapy (IMRT) [Panel B]. IMRT plans are more conformal and allow for dose intensification at areas of highest risk. Note the avoidance of one parotid (arrow) and the spinal cord. (Planning target volume outlined in red; dose legends at left)

A.  
B. 

The benefits of IMRT come at a cost. Firstly, IMRT plans are more complex and take longer to deliver, prolonging the time that a patient spends on the radiotherapy machine and decreasing patient throughput. Secondly, IMRT can result in increased integral dose – a larger volume of normal tissues receives low doses of radiation. This effect can be seen in the areas around the target (where the beams enter and exit) and also in areas far from the target. This increase in integral dose with IMRT has in turn led to
concerns about an increased risk of secondary malignancy (5;6). Thirdly, the increased treatment time with IMRT has led to concerns about increased tumor cell repair during the time required to deliver treatment (7).

Two clinical developments in radiation oncology underscore the drawbacks of fixed-field treatments, whether delivered by IMRT or 3D-CRT: image-guided radiotherapy and hypofractionation. Image-guided radiotherapy (IGRT) refers to the use of imaging (such as x-rays or CT scans) immediately before or during treatment, to ensure that the patient and tumor are in the correct position. IGRT allows radiation oncologists to reduce the ‘safety margins’ that account for uncertainty in positioning, thereby reducing the volume of tissue that receives radiation (4). However, use of image guidance increases the time that a patient spends on the radiotherapy table and can also increase the integral radiation dose, further compounding the drawbacks of IMRT. The second development, hypofractionation, refers to the practice of delivering large daily doses, more than the conventional 2 Gy per day. With hypofractionation, fraction sizes can be very large: for stereotactic lung radiotherapy, 3 fractions of 20 Gy are commonly employed, and achieves excellent rates of local control (8). However, when delivered with fixed-fields using image-guidance, these treatments can require up to 45 minutes to deliver.

Arc therapy has emerged as a technique to address some of the limitations of fixed-field treatments. In contrast to fixed-field IMRT, arc therapy incorporates rotation of the beam relative to the patient while the beam is on. In most cases, the patient is treated from all angles, in one or more 360-degree rotations. The major conceptual advantage of arc therapy over standard fixed-field IMRT techniques is that since the radiation source is rotating around the patient, all angles are available to deliver radiation to the target while avoiding critical structures, and time is used efficiently because the radiation delivery does not stop in between different beam angles. Selection of angles for fixed-field IMRT can be difficult (3), and arc therapies can overcome this difficulty by allowing the tumor to be treated from all angles.

In essence, all modern arc therapies are a form of intensity-modulated radiation therapy (IMRT), and theoretically they retain the same advantages and disadvantages over 3D-CRT, trading off improved dosimetry for higher integral dose and in some cases
increased treatment time. However, arc therapies have several potential advantages over IMRT (Table 1), most importantly improvements in dose distributions and treatment times.

**Table 1.** Potential advantages of arc therapies over conventional fixed-field intensity modulated radiation therapy (IMRT).

<table>
<thead>
<tr>
<th>Potential Advantages of Arc Therapies over Standard IMRT</th>
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<tbody>
<tr>
<td>1. Improved dose distributions. Using arc techniques, the target can be treated from all angles, negating the issue of beam angle selection when using fixed beams.</td>
</tr>
<tr>
<td>2. Improved treatment times. Treatment times may be fastest with ‘volumetric’ arc techniques that treat the whole target volume at once.</td>
</tr>
<tr>
<td>3. Decreased monitor unit requirements due to improved efficiency, which can result in a lower dose to normal tissues.</td>
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</table>

Modern arc therapies can be broadly classified as one of two types: tomotherapy (Figure 2) and volumetric arc therapy (Figure 3). Tomotherapy was first introduced in 1993 (9), and is analogous to CT imaging in that a thin beam of radiation is used to treat the patient in slices (axial tomotherapy) or in a spiral (helical tomotherapy) as the patient moves through the tomotherapy machine (10). Volumetric modulated arc therapy (VMAT) differs in that it can treat the whole tumour volume at once, rather than in slices, and is delivered using a standard linear accelerator (11). There are several variations on VMAT, with names such as RapidArc™, SmartArc™, intensity modulated arc therapy (IMAT) and arc-modulated radiation therapy (AMRT), but the general concepts of these are similar (11-14).
Tomotherapy

Tomotherapy is literally defined as ‘slice therapy’, and is best described as a combination of a CT scanner and a linear accelerator (9;15). As in CT scanning, the patient is moved through the machine as a radiation source rotates through 360° (figure 2A-B). The machine produces a thin fan-shaped beam of radiation, and as the beam rotates, the shape of the beam is adjusted. Axial tomotherapy involves treating a slice of the target and then translating the patient before treating the next slice. For this method, high levels of precision are required in translation to avoid hot or cold spots at the junction of slices (16). Helical tomotherapy (TomoTherapy® Inc., Madison, WI, USA) was first used for treatment in 2002 (17), and avoids the problem with junctioning by treating the patient in a continuous spiral, similar to spiral CT scanning, and the patient is moved continuously during the treatment. The rate of movement of the couch, relative to the thickness of the fan beam, is referred to as the pitch (15).

Figure 2. Tomotherapy

A tomotherapy machine with CT-like geometry [Panel A]. The patient is moved through the treatment unit while the radiation source rotates around the patient [Panel B] in slices (axial tomotherapy) or a helix (helical tomotherapy). Figure 2A courtesy of Dr. Jason Pantarotto, Ottawa Regional Cancer Centre. Figure 2B provided courtesy of TomoTherapy Incorporated, Madison, Wisconsin, USA, reprinted with permission.

A.            B.
The unique geometry of tomotherapy allows for integrated CT scanning, where the patient can be imaged immediately prior to treatment, and adjustments in patient positioning can be made on a daily basis. Furthermore, during treatment, the exit dose can be captured to reconstruct the actual dose distribution in the patient (15). The slice-by-slice acquisition of the CT scan can prolong the CT acquisition time, requiring the patient to spend a longer period of time on the treatment couch (18), but this imaging may only be necessary for a few fractions for some patients (19).

Since tomotherapy treatments are delivered axially, they are not limited by the usual field size of linear accelerators (often 40 cm x 40 cm), and tomotherapy can treat fields of up to 160 cm without junctioning (15;20). However, tomotherapy machines cannot deliver treatments in non-axial planes, a technique that in some cases can improve dose distributions compared to coplanar beams.

Helical tomotherapy has been evaluated for the treatment of numerous tumor sites. A prospective comparison of helical tomotherapy with 3D-CRT was undertaken for 60 patients with a variety of treatment sites, and found that the tomotherapy plans were equivalent or superior to 3D-CRT in 95% of cases (21). In comparison to IMRT, in general, helical tomotherapy tends to provide equal or improved dose distributions (10;22;23). Treatment time comparisons with IMRT have not been uniformly reported (sometimes including time for imaging and registration), and appear to be quite variable between studies. For example, a planning study by Lee et al compared helical tomotherapy with IMRT for treating nasopharyngeal carcinoma, and reported improved dose distributions with tomotherapy, and a reduction in treatment time from 14 to 8 minutes (24). Integral doses appear to be similar with IMRT and tomotherapy (25).

Volumetric Modulated Arc Therapy (VMAT)

In 2007, a novel form of arc therapy called VMAT was introduced (11). With VMAT, the gantry is rotated while the beam is on, and three parameters can be changed as the beam is rotated: the dose rate, the shape of the beam, and the speed of rotation (11). VMAT is analogous to tomotherapy, in that radiotherapy can be delivered from up to 360º of beam angles, but differs in that it can be delivered on a conventional linear accelerator, and that the whole volume can be treated at once. VMAT can deliver a
radiotherapy fraction using only a single rotation, although in some cases additional rotations can be used to improve the dose distribution. Since VMAT techniques treat the whole volume at one time, treatment times are not generally dependent on the size of the target, as long as the target can be encompassed in a single field.

**Figure 3. Volumetric modulated arc therapy (VMAT)**

With VMAT, the patient is treated on a standard linear accelerator, which rotates around the patient, treating the whole target at once [Panel A]. Panel B: a schematic of VMAT for treatment of a right-sided lung cancer (red). The beam (yellow) rotates along the red circular path. *Figure 3A courtesy of Varian Medical Systems of Palo Alto, California, USA. Copyright 2009. All rights reserved. Reprinted with permission.*
Since the initial reports of VMAT in the published literature (11;26), the term ‘VMAT’ has been expanded to refer to a broad category of conceptually similar treatment approaches. This can lead to some confusion, as two systems called ‘VMAT’ can produce different results, depending largely on the computer algorithms that each vendor has developed to design the treatment. Currently, there are three commercially available VMAT systems: RapidArc™ (Varian Medical Systems, Inc, Palo Alto, CA, USA), Elekta VMAT™ (Elekta, Inc., Stockholm, Sweden) and Phillips SmartArc™ (Phillips, Inc., Andover, MA, USA).

RapidArc (and its predecessor algorithm) has been evaluated in comparison to IMRT for several tumor sites. Compared to IMRT, these studies have generally shown that RapidArc is able to produce similar or improved dose distributions, while achieving a reduction in treatment time to about 1.5-3 minutes, and a reduction in monitor units by about 50% (26-31). Monitor units are a measurement of the amount of radiation produced by the linear accelerator, and increases in monitor units are associated with a larger amount of scatter radiation from the machine, which could theoretically increase the risk of secondary malignancies (6). As a representative example, two studies have evaluated RapidArc for treatment of head and neck cancer, and reported dose distributions equivalent to IMRT or better, with reductions in monitor units of 50-60%, and significant reduction in treatment times (31;32).

RapidArc plans have been extended to using more than one arc. In some cases, use of two arcs rather than one has resulted in improved dose distributions (27;31). RapidArc has also been used for delivering stereotactic hypofractionated lung radiotherapy, while achieving short treatment times of 4.5-11 minutes, depending on the dose per fraction (33). A dose distribution for a patient treated with RapidArc for a stage 1 non-small cell lung cancer is shown in Figure 4.

The body of peer-reviewed published literature evaluating the Elekta VMAT system and the Phillips SmartArc system is more limited than for RapidArc, restricting the ability to fully assess their capabilities as of yet. A planning comparison of the Elekta VMAT technique with 3DCRT for lung cancer showed that the Elekta VMAT system achieved faster treatment times (2.7 min for 3DCRT vs. 1.7 min for VMAT), but the dose distributions were not necessarily better than 3DCRT (34). The Phillips SmartArc
system has been compared to IMRT in one study, which also reported faster treatment times than with IMRT, but multiple arcs were required for to achieve good dose distributions in complex cases (14).

**Figure 4. Volumetric modulated arc therapy (VMAT) dose distribution**

A dose distribution for a patient with stage 1 lung cancer treated with hypofractionated stereotactic radiotherapy using VMAT, with the target outlined in red. The dose-color scale is shown at left. The high dose region avoids the spinal cord and great vessels.

Direct Comparisons between Systems

Since VMAT is a relatively new innovation, it has not yet been comprehensively compared with tomotherapy, although a few early reports have been published. For example, Fogliata et al compared RapidArc with helical tomotherapy as components of two planning studies, and concluded no clinically significant dosimetric differences could be seen between the RapidArc and tomotherapy plans (35;36).

Since VMAT, tomotherapy, and fixed-field IMRT are all highly sophisticated techniques, it may be that dosimetric differences between them are small and of little clinical significance, depending more upon the expertise of the user than the individual technology (37). Distinctions between the different treatment approaches are more likely to be based on other factors, such as efficiency and versatility.
Efficiency and Treatment Time

The major difference between VMAT and the other techniques (fixed-field IMRT and tomotherapy) appears to be improved efficiency, resulting in faster treatment times. Prolonged treatment time has been identified as one of the drawbacks of standard fixed-field IMRT. In some cases, the time required to deliver a fraction of a complex IMRT plan can be in excess of 15-30 minutes (38-40), whereas most fractions of 3D-CRT require only a few minutes, depending on complexity. This has been often accepted as an unavoidable consequence of providing highly conformal radiotherapy, a trade-off for the improved dose distributions produced by IMRT.

The prolongation of treatment time has several negative implications. At the institutional level, it limits the number of patients who can be treated treatment unit per day. It requires patients to spend a longer period time on the radiotherapy couch, which can lead to patient discomfort and increases the risk of intra-fraction movement of the tumor or of the patient (41). Intra-fraction movement can be particularly important when tumors are treated on a slice-by-slice basis, as an axial tumor shift could cause a portion of the tumor to be underdosed, especially when large single fractions are used (42). Prolonged treatment times also increase the amount of machine time required by physics staff to conduct quality assurance of IMRT plans, which is done prior to the patient’s arrival to measure and confirm the dose distribution to be delivered.

In addition to these practical considerations with prolonged treatment time, there may also be detrimental radiobiological consequences. Some authors have suggested that by increasing treatment times, tumor cells are given the opportunity for DNA repair and proliferation (7;43). This theoretical reduction in tumor control has been supported by studies modeling cell kill and repair (7;43), and by in vitro data from several investigators (44-46). For example, Wang et al used radiobiological calculations to suggest that prolonging treatment time beyond 10-15 min per fraction results in decreased tumor control probability (7). A study by Moiseenko et al compared treatment times of 75 sec, 5 min, and 10 min for three cell lines radiated in vitro. They found that increasing the treatment time increased tumor cell survival substantially for a radiosensitive SiHa cervical cancer cell line (39% vs. 53% vs. 59% surviving fraction respectively), but not
for all cell lines (45). This apparent reduction in \textit{in vitro} cell killing with longer treatment times requires further study, as it has not been confirmed \textit{in vivo}, and clinical studies comparing IMRT against 3D-CRT have not demonstrated a reduction in local control (4).

Treatment times for VMAT/RapidArc have been shown to be shorter than with fixed-field IMRT, generally reported in the range of 1-3 minutes for a standard 2 Gy fraction with RapidArc (28;29;31). Stereotactic lung radiotherapy treatments, which are particularly challenging in that they deliver up to 20 Gy per fraction to a moving target and generally require 30-45 minutes to deliver using IMRT, can be delivered in 4-11 minutes using RapidArc (33). The improved treatment times with VMAT are a result of several efficiencies: IMRT plans require more monitor units to deliver, and therefore the machine is turned on for a longer time; and with IMRT, there can be a substantial period of time between the delivery of each separate field, time that is required to send information to the treatment machine, rotate the gantry, set the field to the correct shape, and verify the field (47). With VMAT, the arc is considered as one field and this step is only required once per arc.

Treatment times for tomotherapy, by nature of its ‘slice-by-slice’ delivery, are related to the overall length of the target, the thickness of the beam, and the amount of beam modulation (10). Treatment time can be prolonged as target length increases. Comparisons of treatment times between RapidArc and tomotherapy have resulted in some recent debate in the literature (37;48;49), as treatment time and efficiency have been cited as major differences between the two technologies (50). Table 2 outlines representative publications reporting treatment times for tomotherapy and VMAT techniques. In general, reported treatment times with tomotherapy are longer than with VMAT, although there is some variability based on tumor site, institution, and plan complexity.

Overall, given that volumetric techniques, by definition, can generally treat the whole target volume at once, it follows that the treatment should be faster and more efficient than treating in a helical fashion (51). In light of the clear practical benefits of reducing treatment time, and a theoretical radiobiological benefit, delivering treatment quickly while preserving dosimetry is a worthy objective.
Versatility

Like IMRT, VMAT is delivered using a standard linear accelerator, which allows the flexibility to employ the other features of the linear accelerators (e.g. electrons, varied energies of photons) for other patients who do not require VMAT. Tomotherapy machines are constrained to deliver only tomotherapy, although a new modification is forthcoming that can allow the beam to remain stationary, for situations where fixed beams are more appropriate (52).

By nature of its design, tomotherapy has the advantage of incorporating CT imaging for setup verification, allowing for a built-in method of IGRT, without the need to add in other technologies. Linear accelerators do not have an inherent CT scanning capability, although in-room imaging can be done using a cone-beam CT, which is mounted to the linear accelerator (33), or other on-board x-ray imaging devices.
Table 2. Representative treatment times with Volumetric Modulated Arc Therapy (VMAT) techniques and Tomotherapy. Treatment times may not be directly comparable across studies due to variation in plan complexity. 3D-CRT: 3D-conformal radiotherapy; IMRT: intensity modulated radiation therapy; *excludes time for patient setup or imaging

<table>
<thead>
<tr>
<th>Treatment Site</th>
<th>Authors</th>
<th>Dose per Fraction</th>
<th>Modalities Reported</th>
<th>Treatment times* in minutes (mean or range, unless specified)</th>
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</thead>
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<tr>
<td>Several sites</td>
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<td>Tomotherapy</td>
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<td>Bijdekerke et al (18)</td>
<td>Various</td>
<td>Tomotherapy</td>
<td>11</td>
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<td></td>
<td>Sterzing et al. (58)</td>
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<td>10.7</td>
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<td>IMRT</td>
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<td>Naso-, oro-, hypopharynx</td>
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<td>2 Gy</td>
<td>RapidArc</td>
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<td>IMRT</td>
<td>8 – 12</td>
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<td>Up to 2.65 Gy</td>
<td>Tomotherapy</td>
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<td></td>
<td>Shaffer et al (60)</td>
<td>Up to 2.4 Gy</td>
<td>VMAT (RapidArc predecessor)</td>
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<td>IMRT</td>
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Hypofractionated Stereotactic Treatments

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<tr>
<th>Treatment Site</th>
<th>Authors</th>
<th>Dose per Fraction</th>
<th>Modalities Reported</th>
<th>Treatment times* in minutes (mean or range, unless specified)</th>
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<td>3D-CRT</td>
<td>11 – 13</td>
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<td></td>
<td>Hodge et al (61)</td>
<td>12 Gy</td>
<td>Tomotherapy</td>
<td>22</td>
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Future Directions

Tomotherapy and VMAT are still relatively new technologies in radiation oncology. They will continue to be tested and refined, and new systems and algorithms and are likely to come into clinical use in the near future (12;14). Recently, a new system has been introduced, named Vero, which can deliver arc therapy and may provide more flexibility in tumor tracking (53). Data on cost-effectiveness and long-term efficacy are anticipated as these treatments mature. It is likely that in the future, different techniques will be able to produce dose distributions that are clinically equivalent, in which case the techniques will be judged by their efficiency, versatility, and ease of integration with image-guided and adaptive radiotherapy techniques. The potential implications of these
new treatment techniques for concurrent chemo-radiotherapy regimens should be examined. It is unknown as to whether the changes in dose distributions or treatment times will affect tumor control or normal tissue toxicity in the presence of concurrently delivered chemotherapy. In addition, emerging \textit{in vitro} data suggests that tumor cell kill may differ if a tumor is irradiated volumetrically or in parts, and this hypothesis requires further research (54;55).

The evidence-based evaluation and introduction of new technologies in radiation oncology is challenging. Technological innovations are not usually supported by the high levels of evidence that would be required for the introduction of a new drug treatment. Innovation is often the result of an iterative process, in which the end result is due to numerous small innovations that are difficult to individually test (56). Wherever possible, clinicians should try to produce the highest level of evidence possible (as has been done in recent randomized trials evaluating newer techniques such as IMRT (4) or stereotactic hypofractionated lung radiotherapy (57)). In the absence of such data, new technologies should be assessed by rigorous testing, with careful collection of baseline patient and treatment data and prospective ascertainment of disease outcomes and toxicity.

Conclusions

Arc-based radiotherapy is a complex approach to IMRT made possible by advances in technology. Compared to standard fixed-field IMRT, arc-based radiotherapy allows tumors to be treated from all angles, and can provide advantages in terms of dose distribution, ease of real-time imaging, reduced treatment time, and/or reduced monitor unit requirements. Tomotherapy has the longest history of clinical experience, and can produce highly conformal dose distributions using a helical delivery analogous to spiral CT scanning. VMAT algorithms treat the whole target volume at once, using a standard linear accelerator. Most of the published VMAT data has evaluated RapidArc, which can quickly deliver highly conformal plans, often in 1-3 minutes. As these technologies are further refined in the future, it is likely that differences in dose distributions will be small, and distinctions will be made based on efficiency and versatility.
References


45. Moiseenko V, Duzenli C, Durand RE. In vitro study of cell survival following

Radiobiological investigation of dose-rate effects in intensity-modulated radiation

47. Wu QJ, Yoo S, Kirkpatrick JP, Thongphiew D, Yin FF. Volumetric Arc Intensity-
Modulated Therapy for Spine Body Radiotherapy: Comparison with Static
Intensity-Modulated Treatment. *International Journal of Radiation
Oncology*Biology*Physics* 2009 Dec 1;75(5):1596-604.

and Charybdis: Longer Beam-on Time or Lesser Conformality--the Dilemma of
Tomotherapy. *International Journal of Radiation Oncology*Biology*Physics

49. Mehta M, Hoban P, Mackie TR. Commissioning and Quality Assurance of
RapidArc Radiotherapy Delivery System: In Regard to Ling et al. (Int J Radiat
Oncol Biol Phys 2008;72;575-581): Absence of Data Does Not Constitute Proof;
The Proof is in Tasting the Pudding. *International Journal of Radiation
Oncology*Biology*Physics* 2009;75:4-6.

Commissioning and Quality Assurance of RapidArc Radiotherapy Delivery
System. *International Journal of Radiation Oncology*Biology*Physics

Analysis of Best Fitting Tomo Treatment Planning Parameters for Prostate, Lung,
Breast, Brain, Liver, Head & Neck, Breast, Pelvis and Pancreas Lesions From


