POINT/COUNTERPOINT

Suggestions for topics suitable for these Point/Counterpoint debates should be addressed to Colin G. Orton, Professor Emeritus, Wayne State University, Detroit; ortonc@comcast.net. Persons participating in Point/Counterpoint discussions are selected for their knowledge and communicative skill. Their positions for or against a proposition may or may not reflect their personal opinions or the positions of their employers.

Because of the advantages of rotational techniques, conventional IMRT will soon become obsolete

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OVERVIEW
In recent years, a variety of intensity modulated radiation therapy (IMRT) delivery techniques have been developed that have provided clinicians with the ability to deliver highly conformal dose distributions. The delivery techniques include step-and-shoot IMRT, sliding window IMRT, volumetric modulated arc therapy (VMAT), and tomotherapy. A key development in the field of IMRT was the introduction of new planning algorithms and delivery control systems in 2007 that made it possible to coordinate the gantry rotation speed, dose rate, and multileaf collimator leaf positions during the delivery of arc therapy. With these developments, VMAT became a routine clinical tool. The use of rotational techniques has continued to increase in recent years and some would argue that this will soon make conventional IMRT obsolete, and this is the claim debated in this month’s Point/Counterpoint.

Arguing for the Proposition is Richard A. Popple, Ph.D. Dr. Popple obtained his Ph.D. from Rice University, Houston, TX, and, after 2-yr postdoctoral fellowships at Rice and the University of Texas MD Anderson Cancer Center, Houston, moved to the Department of Radiation Oncology, The University of Alabama at Birmingham, where he is currently Professor and Medical Physics Residency Director. Dr. Popple is certified in Therapeutic Radiologic Physics by the American Board of Radiology. He has been active on several AAPM committees and serves as a Section Editor for the Journal of Applied Clinical Medical Physics. His major research interests include volumetric modulated arc therapy, dosimetry of small fields, treatment planning optimization, and quality assurance, and he has published over 50 papers in peer-reviewed journals.

Arguing against the Proposition is Peter A. Balter, Ph.D. Dr. Balter obtained his Ph.D. in Medical Physics from the University of Texas Houston Graduate School of Biomedical Sciences, Houston, TX, having already worked as a Medical Physicist for several years in the Department of Radiation Physics, Division of Radiation Oncology, The University of Texas MD Anderson Cancer Center, Houston, where he is currently Associate Professor and Associate Director of the Accredited Dosimetry Calibration Laboratory. Dr. Balter is certified in Therapeutic Radiologic Physics by the American Board of Radiology and examines on the Board. He has been active on several committees in the AAPM and has served as President of the Southwest Chapter. His major research interests include Cyberknife stereotactic radiosurgery, 4D-CT simulation and CT perfusion, advanced volumetric imaging and adaptive radiotherapy for detecting and correcting for interfractional change, flat-panel based cone beam CT for 3D chest imaging, and proton therapy. He has published over 50 papers on these and related topics in peer-reviewed journals.
FOR THE PROPOSITION: Richard A. Popple, Ph.D.
Opening Statement

From the beginning of civilization, increasingly sophisticated technologies have replaced older, less efficient ones. Conventional IMRT using stationary gantry locations will not escape this paradigm and will be displaced by rotational techniques. The first rotational technique for delivery of intensity modulation was proposed by Mackie and coworkers in 1993. Although tomotherapy, first serial and then helical, was adopted by a modest number of centers, widespread adoption was limited by the need for specialized equipment. Shortly after the introduction of tomotherapy, Yu proposed intensity modulated arc therapy (IMAT), a rotational technique based on dynamic multileaf collimation (MLC). IMAT did not require specialized equipment and had the potential for broad implementation on ubiquitous C-arm linear accelerators but was complex to plan and no more efficient than fixed gantry IMRT. Consequently, IMAT remained confined to a handful of academic centers. Rotational techniques languished while static gantry intensity modulated radiation therapy techniques (conventional IMRT) entered widespread clinical use. The situation changed dramatically in 2008 with the introduction of new planning techniques that, in combination with variable dose-rate delivery, were capable of creating treatment plans having dose distributions comparable to static gantry IMRT using a single arc. Consequently, IMAT became substantially more efficient in terms of treatment time than stationary field techniques.

IMAT is a stage in the ongoing evolution of radiation therapy, during which the roles of computer optimization and computer control have been steadily increasing. Static techniques in which the human operator sets machine parameters have given way to dynamic techniques and increasing automation. The dynamic wedge introduced preprogrammed motion of a single collimator jaw during irradiation. Dynamic multileaf collimation increased treatment complexity by moving tens of MLC leaves in a prescribed, patient-specific trajectory. IMAT added gantry rotation to dynamic MLC motion, and VMAT added variable dose rate. Treatment planning has undergone a similar evolution, progressing from the human planner selecting a handful of machine settings and calculating the resulting dose, to the human planner specifying the desired dose distribution characteristics and the computer optimizing the positions and trajectories of hundreds of machine parameters.

Treatment-machine control systems are becoming more sophisticated, providing programmed control of all machine parameters while the machine is delivering radiation. This allows, for example, an entire conventional IMRT plan to be delivered without intervention of the human operator, blurring the distinction between fixed gantry and rotational techniques. Should such a treatment be considered fixed gantry or a “step-and-shoot” type of rotational treatment? Work is underway to optimally mix fixed gantry modulation with IMAT. These hybrid plans can be presented to the machine control system as a single set of control points, further blurring the line between conventional IMRT and rotational techniques. Advanced control systems allow motion of the table and collimator as well, and there is active work on planning techniques that exploit machine trajectories.

Because of the efficiency of rotational techniques, IMAT is displacing conventional IMRT in many clinics. Furthermore, improvements in linear accelerator control systems and nascent developments in machine trajectory optimization are blurring the distinction between rotational techniques and conventional IMRT. Rotational techniques will make conventional IMRT obsolete, just as rotational techniques as we know them today will themselves be displaced by methods which exploit patient-specific optimized machine trajectories.

AGAINST THE PROPOSITION: Peter A. Balter, Ph.D.
Opening Statement

The case for VMAT replacing traditional IMRT is based on the increased speed in delivery. This, however, comes at high costs in complexity, machine reliability, and, potentially, in plan quality and delivery accuracy.

Many publications have demonstrated the improvement in delivery time in VMAT vs fixed field IMRT. These tend to be reductions of treatment time by 50%–80%, which corresponds to a decrease in on-table time of only 2–5 min. Automated field sequencing for fixed field IMRT would somewhat reduce these differences. In addition, the total room cycle time is limited by other aspects of the treatment including time to transport the patient, to setup the patient on the table, and to image and shift. These times can often be on the order of 10 min or twice the treatment delivery time.

Plan quality in VMAT has been evaluated by a number of groups who found VMAT to be noninferior rather than superior. Fundamentally, the greatest degrees of freedom for plan optimization come from fixed field step-and-shoot IMRT with noncoplanar beams. In these cases, beams angles are only limited by the patience and creativity of the planner and can be enhanced by automated beam angle selection and IMRT optimization systems. VMAT, by contrast, is limited by the minimum and maximum allowable dose rates, leaf speeds, and gantry speeds effectively reducing the possible solution space for the optimized plan. More optimal IMRT plans may be realized by delivering fields with different couch positions and angles, which is not possible with VMAT. The increased calculation times required by VMAT optimization would make the planners more willing to accept plans that are “good enough” rather than optimal.

In addition to these concerns, lesions that are away from the center of the patient may also require that VMAT use a physical isocenter away from the center-of-mass of the tumor, violating many of the assumptions made in our QA processes and daily imaging procedures.

VMAT has many higher costs than fixed field IMRT that should force each institution to examine the cost/benefit ratio of switching to this technology. To upgrade an existing Linac
to VMAT requires a small amount of hardware changes but a large software license fee for the Linac, the R&V system, and the treatment planning system (TPS). VMAT calculations are also much more computationally demanding, often requiring an upgrade of the TPS hardware to enable planning of these cases. VMAT also results in lower reliability of Linac. Step-and-shoot IMRT is very forgiving of dose-rate variations and MLC performance. VMAT not only increases the wear on the MLC but also has more demanding tolerances for its motion. VMAT also adds an extra QA burden on the physics staff, adding a planned extra 30 min to monthly QA in addition to the large amount of unplanned QA due to the increased number of MLC failures when using the machine for VMAT treatments.

In conclusion, VMAT has high costs, and the only theoretical benefit is decreased delivery time which may be offset by the decreased reliability of the Linac. Fixed field IMRT has proven to be robust and reliable, and our ability to fully optimize IMRT, including couch angle and position for each beam, is just beginning to be explored. Fixed field IMRT will always be needed for some cases due to tumor locations, will be equal or superior to VMAT for all cases and, for lesions that are away from the center of the patient, will avoid violating many of our assumptions.

Rebuttal: Richard A. Popple, Ph.D.

The argument against the proposition rests on two premises. The first is that VMAT is less accurate and less reliable than conventional IMRT. The second is that the improved efficiency of VMAT is not significant.

The assumption that VMAT is less accurate is contradicted by the literature. MLC leaf positioning is equally accurate for VMAT as for fixed fields. Furthermore, VMAT plans are not more sensitive to MLC errors than conventional IMRT plans and may be more robust against leaf positioning errors than complex step-and-shoot plans. Finally, the proof is in the pudding: VMAT plans are no less likely to fail QA testing than conventional IMRT plans. With regard to reliability, there is no reported evidence to support the supposition that VMAT increases MLC failures.

The advantage of VMAT is expressed by the Latin proverb *ex gravis acervus*: from grains, a heap. For a linear accelerator treating 15 IMRT patients per day, conversion to VMAT results in saving approximately an hour each day, thus reducing operating cost. Although the savings are partially offset by additional planning and QA, technology development will decrease planning and QA time. Furthermore, treatment time is an important component of plan quality. Radiation therapy is uncomfortable and, while a few minutes may not seem long to the team outside of the vault, it is significant to the patient inside. Furthermore, reduced treatment time has the potential to reduce targeting errors resulting from target motion during treatment.

The advantage of VMAT is improved delivery efficiency. All other things being equal, reduced treatment time is better. For VMAT, all other things are equal and consequently rotational techniques will displace conventional IMRT.

Rebuttal: Peter A. Balter, Ph.D.

Dr. Popple has done an excellent job demonstrating that VMAT is on the high end of the technology spectrum and that many treatments will naturally move toward this end. He did not demonstrate a clinical benefit for this move, only a perceived efficiency benefit, which he did acknowledge is made smaller by the advent of autofield sequencing on many of the modern treatment units. He also emphasized that in the future, radiotherapy will be delivered by highly complicated plans including multiple couch positions highly optimized by IMRT autoplanning systems with little human intervention in either planning or delivery. Both machine design and safety concerns will limit the use of rotational therapy with automated combinations of multiple couch positions and angles thus, to best use the optimized benefits of multiple couch positions, it will be necessary to continue using fixed field IMRT in these cases.

I agree with Dr. Popple that technology will inevitably move forward. In order to fully utilize the benefits in treatments made possible by the advent of automated treatment planning with the most possible degrees of freedom, including couch positions and angles, fixed field IMRT will continue to be an important tool and thus will not be replaced by rotational techniques. I also recognize that not all centers will have the resources to support the top-of-the-line planning and delivery equipment to deliver treatments that may be slightly faster but are no better than existing technology, providing another venue where rotation techniques will not replace fixed field IMRT.

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1. R. Mackie, T. Holmes, S. Swerdloff, P. Reckwerdt, J. O. Deasy, J. Yang, B. Paliwal, and T. Kinsella, “Tomotherapy: A new concept for the delivery of dynamic conformal radiotherapy,” *Med. Phys.* 20, 1709–1719 (1993).
2. C. X. Yu, “Intensity-modulated arc therapy with dynamic multileaf collimation: An alternative to tomotherapy,” *Phys. Med. Biol.* 40, 1435–1449 (1995).
3. K. Otto, “Volumetric modulated arc therapy: IMRT in a single gantry arc,” *Med. Phys.* 35, 310–317 (2008).
4. H. Shackford, B. E. Bjargard, and P. Vadash, “Dynamic universal wedge,” *Med. Phys.* 22, 1735–1741 (1995).
5. P. Kallman, B. Lind, A. Eklof, and A. Brahme, “Shaping of arbitrary dose distributions by dynamic multileaf collimation,” *Phys. Med. Biol.* 33, 1291–1300 (1988).
6. M. M. Matuszk, J. M. Steers, T. Long, D. L. McShan, B. A. Fraass, H. E. Romeijn, and R. K. Ten Haken, “FusionArc optimization: A hybrid volumetric modulated arc therapy (VMAT) and intensity modulated radiation therapy (IMRT) planning strategy,” *Med. Phys.* 40, 071713 (10pp.) (2013).
7. Y. Yang, P. Zhang, L. Happersett, J. Xiong, J. Yang, M. Chan, K. Beal, G. Mageras, and M. Hunt, “Choreographing couch and collimator in volumetric modulated arc therapy,” *Int. J. Radiat. Oncol., Biol., Phys.* 80, 1238–1247 (2011).
8. M. T. Davidson et al., “Assessing the role of volumetric modulated arc therapy (VMAT) relative to IMRT and helical tomotherapy in the management of localized, locally advanced, and post-operative prostate cancer,” *Int. J. Radiat. Oncol., Biol., Phys.* 80, 1550–1558 (2011).
9. A. Holt et al., “Volumetric-modulated arc therapy for stereotactic body radiotherapy of lung tumors: A comparison with intensity-modulated radiotherapy techniques,” *Int. J. Radiat. Oncol., Biol., Phys.* 81, 1560–1567 (2011).
10. F. Lee et al., “Comparative analysis of SmartArc-based dual arc volumetric-modulated arc radiotherapy (VMAT) versus intensity-modulated radiotherapy (IMRT) for nasopharyngeal carcinoma,” *J. Appl. Clin. Med. Phys.* 12(4), 158–174 (2011).
11K. Nguyen et al., “A dosimetric comparative study: Volumetric modulated arc therapy vs intensity-modulated radiation therapy in the treatment of nasal cavity carcinomas,” Med. Dosim. 38(3), 225–232 (2013).
12E. M. Quan et al., “A comprehensive comparison of IMRT and VMAT plan quality for prostate cancer treatment,” Int. J. Radiat. Oncol., Biol., Phys. 83, 1169–1178 (2012).
13M. T. Studenski et al., “Clinical experience transitioning from IMRT to VMAT for head and neck cancer,” Med. Dosim. 38(2), 171–175 (2013).
14D. Wolff et al., “Volumetric modulated arc therapy (VMAT) vs. serial to-motherapy, step-and-shoot IMRT and 3D-conformal RT for treatment of prostate cancer,” Radiother. Oncol. 93(2), 226–233 (2009).
15I. Xhaferllari et al., “Automated IMRT planning with regional optimization using planning scripts,” J. Appl. Clin. Med. Phys. 14(1), 176–191 (2013).
16B. Fahimian et al., “Trajectory modulated prone breast irradiation: A LINAC-based technique combining intensity modulated delivery and motion of the couch,” Radiother. Oncol. 109(3), 475–481 (2013).
17K. Bzdusek et al., “Development and evaluation of an efficient approach to volumetric arc therapy planning,” Med. Phys. 36, 2328–2339 (2009).
18J. L. Bedford and A. P. Warrington, “Commissioning of volumetric modulated arc therapy (VMAT),” Int. J. Radiat. Oncol., Biol., Phys. 73(2), 537–545 (2009).
19C. C. Ling et al., “Commissioning and quality assurance of RapidArc radiotherapy delivery system,” Int. J. Radiat. Oncol., Biol., Phys. 72(2), 575–581 (2008).
20A. Agnew, C. E. Agnew, M. W. Grattan, A. R. Hounsell, and C. K. McGarry, “Monitoring daily MLC positional errors using trajectory log files and EPID measurements for IMRT and VMAT deliveries,” Phys. Med. Biol. 59, N49–N63 (2014).
21M. Oliver, I. Gagne, K. Bush, S. Zavgorodni, W. Ansbacher, and W. Beckham, “Clinical significance of multi-leaf collimator positional errors for volumetric modulated arc therapy,” Radiother. Oncol. 97, 554–560 (2010).
22G. M. Mancuso, J. D. Fontenot, J. P. Gibbons, and B. C. Parker, “Comparison of action levels for patient-specific quality assurance of intensity modulated radiation therapy and volumetric modulated arc therapy treatments,” Med. Phys. 39, 4378–4385 (2012).
23T. Sanghangthum, S. Suriyapee, S. Srisatit, and T. Pawlicki, “Statistical process control analysis for patient-specific IMRT and VMAT QA,” J. Radiat. Res. 54, 546–552 (2013).
24K. M. Langen, T. R. Willoughby, S. L. Meeks, A. Santhanam, A. Cunningham, L. Levine, and P. A. Kupelian, “Observations on real-time prostate gland motion using electromagnetic tracking,” Int. J. Radiat. Oncol., Biol., Phys. 71, 1084–1090 (2008).