Arc IMRT for head and neck cancer

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Background
Radiotherapy plays an integral role in the treatment of early and locally advanced stage head and neck cancers (HNC). Due to the anatomical location of these tumours and the close proximity to critical structures, the challenge at this tumour site is achieving local control while sparing the organs at risk (OAR), including the spinal cord, brainstem, optic structures, parotid glands, etc.

Advances in radiotherapy in the last two decades have led to progressively more sophisticated methods for delivering treatment. A major improvement in radiation delivery techniques came with the introduction of intensity modulated radiotherapy (IMRT). This technique, introduced in the late 1990s, uses multileaf collimators (MLC) to vary the shape and intensity (dose) of radiation across each single beam. The combination of several fixed beams (5-9 most frequently) allows a high dose to be conformed to the target volume, but with improved sparing of the OARs and therefore a reduction in the toxicity from the treatment.1 In the UK, a randomised control trial or 3D-RT vs IMRT in head and neck cancer (PARSPORT) showed a significant reduction in xerostomia (dry mouth) in patients treated with IMRT.2

Over the past few years IMRT has become the standard of care for patients with locally advanced head and neck cancer who require radical radiotherapy. Additional advantages are that several dose levels can be planned, allowing for treatments to be delivered in one single phase as well as evaluation of dose escalation and de-escalation approaches. Two identified disadvantages are the prolonged delivery time and increased number of monitor units.

Arc-based IMRT (or intensity modulated arc therapy – IMAT) combines the concepts of arc therapy (delivering treatment with a continuously rotating gantry) in combination with IMRT to potentially improve dose distributions and allow more efficient delivery. It includes serial tomodotherapy, helical tomodotherapy (HT) and IMAT.3 HT uses a binary MLC with a narrow slit with the treatment couch moving continuously through the gantry bore as the gantry rotates.1 IMAT was first proposed in 1995 as an alternative to HT. Later, the development of a direct aperture optimisation algorithm (an inverse planning technique for static-field IMRT) that required constraints on dose rate, gantry speed and MLC leaf motion speed during optimisation by Otto et al4 led to the first commercial adaptation of IMAT. Since then, other authors have developed commercial solutions. These techniques have been referred to as volumetric modulated arc therapy (VMAT) and are the focus of this review.

VMAT treatment planning
There are a number of different planning systems for VMAT including RapidArc from Varian, Elekta’s VMAT and Philips’ SmartArc. Once the target volumes have been defined, the planning process involves optimisation of the continuous 360º gantry rotation. There are three main parameters that are adjusted: The beam aperture (by changing MLC position), the dose rate and gantry rotation speed.5 In contrast to fixed-field IMRT, radiation can be delivered from all angles, giving a highly conformal dose distribution.

There have been a number of studies confirming similar target coverage when compared to IMRT, with at least equivalent sparing of OAR.6-13 A reduction in dose to the normal tissues will give reduced acute and late toxicity from treatment, and although these studies are small, there are data to show improved sparing of the spinal cord,7 parotids8-10,11 and cochlea.11,13

VMAT: One or multiple arcs – is more better?
Just as with IMRT, where an increase in the number of fixed beams leads to greater conformity, studies have shown that treatment plans with two or more arcs are superior to those using just the one. However, there are conflicting data and comparison of studies is further complicated by the varied planning systems, dose prescriptions and target volumes.

A planning study by Bertelsen et al14 compared single arc VMAT plans for 25 patients previously treated with IMRT for carcinoma of the oropharynx and hypopharynx. They concluded that target coverage using just the single arc was similar comparing VMAT to IMRT. However, it must be noted that the IMRT plans in this study used five to seven fixed coplanar fields, compared to other studies using seven to nine fields.

There are more data to show that, given the more complex nature of the target volumes for HNC, multiple arcs are required.8-11 A retrospective planning study comparing IMRT to VMAT using one to three arcs10 showed that for prostate cancer, single arc VMAT was sufficient to give a plan that was comparable. However in the same study, for HNC patients the quality of the single arc VMAT plan was in fact inferior to that of IMRT and therefore two or three arcs were required to give a plan that was at least equivalent.

A second arc adds more degrees of freedom and as a result can improve PTV homogeneity10-11 and subsequently tumour control. As expected though, the addition of an arc will increase the number of monitor units and the treatment time, more of which will be discussed below.

Advantages of VMAT
Shortened delivery times
A reduction in treatment delivery times with VMAT has been universally confirmed by a number of studies.15 Reductions in delivery times from two minutes16 to 15 minutes17 have been reported. Verbakel et al18 reported VMAT treatment completion times of less than three minutes versus IMRT at eight to 12 minutes. As expected, the differences in reported improvements in delivery times vary widely between studies as the treatment time is dependent on the planning and delivery techniques. For example, an increase in the number of fields for an IMRT plan will
increase the IMRT treatment time, giving greater gains with VMAT. Similarly, using dual arc VMAT will increase the treatment time giving a smaller benefit.

There are a number of benefits that come with a reduction in treatment delivery time. For the patient, this improves comfort and compliance. This is especially of value in HNC patients where treatment becomes more of a challenge due to the immobilisation mask and toxicities from treatment including mucositis and increased secretions. From a practical point of view, reduced treatment time can lower the risk of intra-fraction movement and, for the department, the gain in time can be used to increase patient throughput and/or utilise image guided techniques to minimise geographical miss.

A decrease in monitor units

Two studies have reported large reductions in the number of monitor units (MUs) required with VMAT. Verbakel et al. reported a reduction of 59% with single arc VMAT compared to IMRT, with double arc treatment needing only 5% more (mean of 1,108 MUs for IMRT, 439 for single arc and 459 for double arc treatment). A prospective study has shown a similar reduction in MUs of 66% for double arc VMAT compared to IMRT.

Other studies report more modest reductions of a 10-35% reduction in MUs in single arc compared to IMRT or a 29% decrease in the mean number of MUs with dual arc VMAT compared to IMRT. Note is made, however, that of the studies showing the biggest reductions, both use the sliding window (dynamic) IMRT technique. The discrepancy may therefore be explained by the fact that there is an increase in the number of MUs needed for the sliding window IMRT technique compared to step-and-shoot IMRT and therefore a greater reduction in MU to be gained.

In fact Alvarez-Moret et al. found that the lowest number of MUs was seen with single arc VMAT but that dual arc gave similar or higher MUs to IMRT. However, this may be explained by the fact that the IMRT plans used in this study had a lower number of MUs compared to the techniques used in others.

Overall, however, most studies have reported a reduction in the mean number of MUs required with VMAT. The clinical implication is that the reduction in MUs leads to a reduction in the mean number of MUs with VMAT compared to IMRT. Therefore total treatment planning and found this to be seven minutes for IMRT and 28 minutes for dual arc VMAT. The number of cycles is dependent on the complexity of case, which can vary drastically for both the planner and the planner. Therefore total treatment planning time will vary. The authors also reported a 20-fold increase in data requirement – 50.4MB for IMRT versus 1008MB for dual arc VMAT.

Conflicting data was reported by Verbakel et al. where treatment planning times were not recorded but it was reported that optimisation was faster for VMAT.

Studenski et al. found that optimisation time did not differ between IMRT and VMAT. However, dose calculation was longer for VMAT with four minutes per arc compared to two minutes for an entire IMRT plan. Overall planning time was longer, sometimes by up to three times.

An increase in planning time and resources was in fact a major disadvantage when IMRT was first used. Planning times do improve with experience and the increase is thought to be offset by the advantages gained with reduced treatment delivery time.

Other planning issues

The studies discussed have a small numbers of cases each. However, there have been a number of planning issues encountered.

The study by Guckenberger et al. showed that in the group of five patients planned for carcinoma of the paranasal sinuses, IMRT was superior to VMAT (whether single or multiple arc) due to the region between the orbits where there was an increased dose to the lenses together with inferior target coverage.

Fung-Kee-Fung et al. found that IMRT was superior to VMAT in two out of 20 patients due to concentric irradiation of the spinal cord with the VMAT plan. This persisted despite changing the planning technique for VMAT including use of a spinal cord avoidance structure.

In a study of 20 HNC patients, VMAT plans for six of the patients were rejected due to unacceptable dose to OAR. Four of these plans were nasopharynx or sinus patients where the high dose was to small structures. The authors suggest one reason may be that due to the continuous arc in VMAT, the gantry can only slow down rather than stop at the most optimal angles for delivering dose to the target volume. In all, it may be that for certain primary sites it will be more difficult to achieve adequate target coverage with VMAT without compromising the OAR doses. Further experience in planning and delivering VMAT may eventually overcome these limitations.

Tomotherapy versus VMAT

In tomotherapy, literally meaning ‘slice’ therapy, machines essentially combine a CT scanner and linear accelerator. The patient is moved through the machine with treatment delivered in a fan-shaped distribution. There are two types – ‘axial’ where treatment is delivered slice by slice, and ‘helical’ tomotherapy where treatment is delivered in a continuous spiral. Studies confirm that dose distributions are equivalent to those produced by IMRT. Clemente et al. found superior target coverage with HT compared to VMAT but there is limited dosimetric data comparing the two and a well-documented short delivery time with VMAT.

Conclusions

Arc IMRT is an efficient method of treatment delivery with at least equivalent, if not better, target coverage and OAR sparing to IMRT. The reduction in treatment delivery time and monitor units with VMAT has a number of benefits for a radiotherapy department. The increase in planning time required remains, hopefully, a temporary hurdle. There are no clinical studies comparing the different techniques but the small dosimetric differences reported in different studies are highly unlikely to translate into differences in clinical outcomes. For any department implementing arc therapy in HNC it is important to ensure that VMAT plans are at least of the same quality, both in terms of target coverage and OAR sparing, as those delivered with IMRT.

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References


Figures 1-3
Axial (A) and coronal (B) slices of different oropharyngeal HNC treatments showing dose distributions using Elekta-VMAT (figures 1A and 1B), helical tomotherapy (figures 2A and 2B) and Varian RapidArc (figures 3A and 3B). Elekta VMAT and HT images courtesy of RL and AD from GSTT. Varian RapidArc images courtesy of AE from HSC.