Editors' pick

A novel, minimally invasive, dynamic-shield, intensity-modulated brachytherapy system for the treatment of cervical cancer

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What was your motivation for initiating this study?

Brachytherapy is a tried and tested modality, which is recommended for all cases of localised cervical cancer. The tandem-based, pear-shaped dose distribution has served us well as the basis for treating the cervix for over a century. By enabling us to see what we want to treat, the advent of image guidance has drastically increased local control and reduced toxicities.[1,2]

Intracavitary implants are often inadequate for patients with large and irregular tumours, because the radially symmetrical, pear-shaped dose distribution cannot be scaled anisotropically without overdosing the nearby organs at risk (OARs). Patients with more advanced disease require the addition of interstitial needles in order to extend the tumouricidal dose safely to the periphery of the tumour extension.[3]

Despite the proven outcomes, there are large numbers of women who do not receive this standard of care. The decrease in brachytherapy utilisation, especially for complex interstitial implants, has been investigated by many researchers as of late.[4–8] The decrease may be attributed to a decrease in the number of radiation oncologists who are highly trained in brachytherapy or due to the attractive higher throughput of external beam modalities. No matter the reason, the grim reality is that there are patients who do not have adequate access to this life-saving treatment.

Intensity modulated brachytherapy (IMBT) can achieve highly anisotropic dose distributions as use can be made of high-Z metallic shields inside applicators during treatment. These shields direct the radiation dynamically towards the tumour and away from the OARs.[9] This novel treatment modality is analogous to volumetric modulated arc therapy (VMAT) but it is delivered from within the tumour, which combines the benefits of dose shape modulation with the steep dose fall-off of brachytherapy.

We have developed an IMBT delivery system that is compatible with clinical after-loaders by modifying a Venezia (Elekta Brachytherapy, Veenendaal, The Netherlands) applicator for IMBT.[10,11] The modified cervix applicator contains an MRI-compatible rotating tungsten shield that fits inside the intrauterine tandem. In our prior Monte Carlo study,[12] we investigated three shield designs, the use of which reduced the dose on the shielded side by up to 87%, 96% and 99% when using iridium (^{192}Ir), selenium (^{75}Se) and ytterbium (^{169}Yb), respectively. For this work, we settled on the "Piccolo", a flute-inspired design that has circular emission windows along the length of the tandem shield. The main advantage of the Piccolo is its ability to modulate the dose in the polar and azimuthal directions, which enables the dose to be shaped such that it mimics the tumour lateral spread while reducing the dose above and below the tumour and spares the OARs.

We believe that IMBT has the potential to revolutionise brachytherapy much in the way that use of multi-leaf collimators has revolutionised external beam radiotherapy.

What were the main challenges during the work?

On the mechanical side, one major challenge was designing a system that enabled the shield to be dynamically rotated at an angle. It was of utmost importance to maintain a clear path along which the high-dose-rate source would travel and to ensure that there was no binding of the source cable. Our current design enables the rotating shaft to rotate at an angle through use of a flexible joint that can transfer torque and maintain the angle that is defined by the tandem.

On the dose calculation side, we wanted to model the geometries exactly as they are in reality. To achieve this, our Monte Carlo research treatment planning system, RapidBrachyMCTPS,[13,14] imports full computer-aided designs of the applicator and shield and enables the user to define the elemental composition of each component. Our Monte Carlo engine is based on a layered-mass

geometry,[15] which allows individual components to rotate and articulate while fully modelling the patient. This system enables the production of simulations of the dynamic dose delivery.

What are the most important findings of your study?

For patients with advanced parametrial involvement of the cancer, IMBT can offer similar dosimetry to that offered by hybrid interstitial implants but with no needle implantation. Needle-free IMBT naturally has the hotspot in the centre of the cervix, unlike hybrid interstitial implants, use of which has limitations because during needle loading, hotspots may occur outside the target. For patients with less advanced disease, use of IMBT can significantly increase tumour dose and reduce OAR dose compared with conventional intra-cavitary implants.

What are the implications of this research?

IMBT is a promising modality that may help to revitalise use of brachytherapy. It has the potential to improve further the therapeutic ratio that is provided by image-guided brachytherapy. The dose distributions that are obtained through use of complex interstitial implants, which are often only used at large centres of excellence, may soon be available to many patients without implantation of a single needle.

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