Image guided radiation therapy (IGRT) is a hot topic in radiation oncology today but it is not an entirely new concept. Imaging has been part of the set-up verification for radiation therapy patients for many years and there is no hard line in the sand between port films (or electronic portal images (EPI)) and modern IGRT. However, we would argue that there has been a significant qualitative change with the focus on actual structures of interest and very frequent high quality imaging.

One of the first integrated radiographic image guidance devices was reported in 1958 in a clinic in Canada. It was a portable x-ray machine that was mounted on the counterweight of a cobalt-60 Theratron machine. In Australia in 1995, an x-ray unit was combined with a linear accelerator such that a 37° rotation would bring the x-ray source into the exact position of the megavoltage (MV) beam. It had a mobile image intensifier with digital storage and processing facilities and thus the prospect of real time imaging. The impetus behind these devices was the poor quality of port films produced both from a cobalt source and MV radiation. It is interesting to note that neither of the innovations was accepted into clinical practice at the time, probably because they were cumbersome and time consuming to operate. Portal imaging and EPI remained the tool of choice; largely to immobilise the patient (according to skin marks and bones) rather than to verify the position of the actual tumour. The resurgence and availability of image guidance devices is probably due to both the high quality of images that is produced and that they have been seamlesly and unobtrusively integrated into our treatment rooms. The onslaught of IGRT is opening many opportunities for radiation therapists and radiographers to collaborate and as such is a very appropriate topic for this journal.

The Trans Tasman Radiation Oncology Group (TROG) IGRT quality assurance (QA) working party has adopted the following definition: “IGRT is radiotherapy based on data pertaining to the relationship between beam and patient geometry acquired at the point of treatment delivery with the intent to ensure geometric accuracy of radiation delivery appropriate to the clinical scenario.”

The distinguishing factor of IGRT is the transition from conventional verification imaging of the skin and bones infrequently during the course of radiation therapy, to visualising structures of interest (surrogates such as fiducial markers for prostate and lung, surgical clips for breast) every day and/or the actual soft tissue tumour volume (bladder, post-prostatectomy site and lung are examples) as well as other normal tissues surrounding the tumour. There are several key issues that need to be considered when discussing IGRT:

1 The role of imaging within the overall treatment chain particularly in relation to the imaging used for treatment planning and reference image generation
2 Imaging modalities and the associated training requirements for staff
3 Applications ranging from positioning to adaptive radiotherapy and motion management
4 Risks associated with IGRT.

**IGRT and the radiotherapy sequence**

To put IGRT into perspective, it is helpful to consider that it is only one of many important “imaging instances” and stages in the radiation therapy process. When used in tandem with the computed tomography (CT) simulation image, which in itself is often fused with magnetic resonance imaging (MRI) or positron emission tomography (PET) to better delineate the extent of the tumour, IGRT would intuitively be better at ensuring that what was planned is actually also treated. IGRT is not limited by the complexity of treatment delivery or the target structure in the first place. Imaging technology such as 4D CT and PET are able to generate target volumes that represent the motion of the tumour at different phases of the breathing cycle. Another important element in the radiation therapy sequence is the planning technique. Highly conformal or intensity modulated radiation therapy (IMRT) allows the high dose region to be closely tailored to a variety of tumour shapes and sizes while limiting the dose to adjacent normal tissues.

**IGRT imaging modalities**

In the last 10 years many high quality imaging devices have been integrated into the treatment room. Our staple planar MV EPI which has improved in recent years with amorphous silicon panels compete with 2-D planar radiography and volumetric imaging devices that include MV and kilovoltage (kV) cone beam CT (CBCT), conventional CT and ultrasound. The availability of CT in the treatment room allows the same type of image from planning to treatment to be compared directly. CBCT has limited contrast when compared with conventional CT and because of the slow acquisition process it can be affected by patient and organ motion giving rise to artefacts in the image. One would expect however, that this technology will only continue to improve over time. In-room CT options also allow an examination into the response of the tumour to radiation and the variability of the size and shape of surrounding critical structures (bladder and rectum for example) throughout the course of treatment.

Immobilisation is particularly important in light of high precision hypo-fractionated or stereotactic radiation therapy techniques. This is because the image we take to decide how to proceed with treatment is usually only a snap-shot of what is “actually” treated. In particular, volumetric imaging cannot (yet) occur in unison with the treatment beam. Electromagnetic transponders (Calypso™, Seattle, WA, USA) that can be implanted in or near the tumour volume are an exception. Their position can be detected using a magnetic array (rather than ionising radiation) during the delivery of treatment where corrections are made in real time based on the motion of transponders. Interestingly, this is not imaging in the conventional sense – however the information pertains to the geometry of the true target as stated in the definition of IGRT.

One potential and exciting new in-room imaging possibility is that of MRI. MRI offers superb definition of the soft tissues and has been shown to be the superior imaging modality for contouring the prostate. The proposed integration of MRI would allow real time volumetric imaging to occur. For urological and gynaecological malignancies this presents an opportunity to correct for intra-fraction movement of the tumour or critical structures such as the bowel, rectum and bladder.

Many departments have created multidisciplinary IGRT groups that consist of radiation therapists, medical physicists and radiation oncologists to coordinate the clinical implementation of IGRT. Given the importance of the daily decision making at the...
treatment unit under time pressure and the potentially unfamiliar imaging systems such as Calypso, ultrasound or MRI, there is a great need for training and education. Journals such as The Radiographer have a role to play as they bring together imaging and therapy professionals.

**IGRT applications**

Perhaps the most widely adopted IGRT practice is the verification of prostate position by imaging small implanted fiducial markers. Many authors, including the papers presented by Brown and Day; and Hilder in this issue of The Radiographer have demonstrated the benefits of using fiducial markers instead of the bones to more accurately locate the prostate for radiotherapy.\(^{13}\) This IGRT technique has revolutionised the treatment of prostate cancer. It has facilitated the safe escalation of dose, which is known to improve biochemical survival,\(^{14}\) it is efficient and can be performed “online” on a daily basis by the radiation therapist with a minimum of fuss. This has led to an increase in responsibility of the radiation therapist who has become the independent decision maker in terms of routine field placement, not only in prostate but in a wide variety of techniques. In prostate cancer the role of IGRT is usually confined to positioning the prostate gland as the target in the correct position for treatment. However, IGRT can be used for more than verification of patient position.

There is no doubt that IGRT has a clear but different role in the application of other complex high precision radiotherapy techniques such as hypo-fractionated stereotactic radiotherapy for lung cancer (TROG 09.02 CHISEL) and online adaptive radiation therapy for bladder cancer (TROG 10.01 BOLART). For the investigational arm of the CHISEL trial (54 Gy in three fractions over two weeks) the institution must be able to introduce of helical tomotherapy in Queensland in the coming months. IGRT enables larger doses to be delivered precisely to treatment and at different time points during the delivery of “better” targeting.

One potential disadvantage of IGRT is the extra imaging dose delivered to the patient, particularly with CBCT.\(^{17}\) It has been argued, however, that since IGRT provides a more accurate means of delivering radiation fields, there is the potential to reduce the safety margin or the high dose region around the CTV, which in turn reduces the overall dose received by the patient.\(^{19}\)\(^{20}\) Nonetheless, consideration should be given to the addition of any extra radiation delivered to the patient. Any research undertaken must demonstrate that the potential benefits of the additional imaging outweigh the risks and should be submitted for approval by the appropriate ethics committee.

**Risks of IGRT**

A different and more subtle risk with the introduction of IGRT is that conventional interpretation of the outcomes of IGRT may not always be possible. An important example is demonstrated by Engels, et al., where despite using implanted fiducial markers for image guidance and a conformal arc radiotherapy technique for prostate treatment, a sub-group of patients who had a distended rectum on the planning CT were found to be at an increased risk of biochemical failure.\(^{21}\) These researchers reduced the margins for prostate radiotherapy too quickly after the introduction of fiducial markers and IGRT for prostate cancer. This resulted in an increased rate of biochemical failure in these patients despite “better” targeting.

IGRT is an evolving technique. It can be applied both prior to treatment and at different time points during the delivery of treatment. IGRT enables larger doses to be delivered precisely to the tumour volume while minimising the dose to the surrounding tissues. IGRT should be used synchronously with the appropriate reference image for verification and matching, relevant immobilisation technique to ensure the patient is stable throughout treatment delivery and a highly conformal or IMRT treatment plan to obtain the best results. New in-room imaging modalities such as MRI are promises for continuing to advance in the future. The introduction of helical tomotherapy in Queensland in the coming...
year will expose the radiation therapist to a variation on the theme of tomographic imaging: MV CT.

Rebecca Owen PhD, BAppSc, Med Rad Tech (RT) Division Cancer Services, Brisbane, Australia

Tomas Kron PhD, FCCPM, FACPSEM, FInstP(UK) Peter MacCallum Cancer Centre, Melbourne, Australia

Correspondence Rebecca_Owen@health.qld.gov.au

References