Image-guided radiotherapy (IGRT) can be used to measure and correct target and critical structure positional errors immediately prior to or during treatment delivery. Single-slice megavoltage computed tomography (MVCT) using 50MV for the racetrack microtron (RTME) was first utilised at Karolinska University Hospital in 1987.1 There were some technical and clinical limitations with this system.

Some of the most recently available methods of target localization are transabdominal ultrasound, implanted markers with in-room MV or kilovoltage (kV) X-rays, optical surface tracking systems, implantable electro-magnetic markers, in-room CT, such as kVCT on rail, kV or cone beam (CB) MVCT and helical MVCT.

The image-guided systems provide an increasing amount of information about daily target localization and set-up errors during the course of fractionated treatment. This information can be compared online with the treatment planning system and utilized for the set-up adjustment of the treatment fraction. The verification of the accurate treatment position in conjunction with detailed anatomical information before every fraction is therefore essential for the outcome of the treatment.

The on-board imager (OBI) has been in routine clinical use at the Karolinska University Hospital since June 2004. The OBI consists of a diagnostic X-ray tube and a kV flat panel imager, which are both mounted on robotic arms and designed for three main functions—orthogonal radiographs for three-dimensional (3-D) patient set-up, CB kVCT and real-time tumour tracking, and fluoroscopy. The availability of high-quality tomographic images and automatic tools for online 3-D image registration will lead to the introduction of new clinical applications and protocols. The most beneficial application is high-precision hypofractionated treatment of lung and liver metastases with online tumor position correction.

The OBI has been used for the online set-up correction of patients using internal gold markers since June 2004. Displacements of these markers can be monitored radiographically during the treatment course and the displacements of the markers act as a surrogate for prostate motion. For this purpose, on-board kV-kV seems to be an ideal system in terms of image quality. Prostate patients are treated in the supine position and are given three gold markers (diameter = 0.9mm; length = 3mm) implanted under transrectal ultrasound control. Individually fabricated vacuum cushions are produced to immobilize the legs and to ensure stable positioning of the patient during the application of treatment fields. In the treatment room the patient is positioned according to the laser marks on the skin. Before each treatment, fraction orthogonal kV-kV images from the anterior-posterior (AP) and lateral directions are acquired using the OBI.

Digitally reconstructed radiographs (DRRs) were obtained from planning CT data, and used as reference images, and the marker positions were contoured and displayed. The automatic 2-D matching procedure is based on bony structures used to match the two orthogonal images with reference images (DRRs) followed by a subsequent manual alignment of the fiducial markers. The correction is applied on these gold markers rather than the bony structures, in order to correct the actual target position.

The set-up deviations and required correction are displayed as couch displacements in X, Y, and Z directions, and couch rotation. Each displacement can be selected individually; the rotation of the couch was not considered. The position displacements can be applied using the remote table control. The total positioning errors, combining both set-up and clinical deviations, are corrected using the OBI.

internal organ motion errors after initial positioning according to the laser marks, have been quantified and analysed. The largest position error is due to the internal prostate motion.

The uncorrected results for 12 patients with prostate cancer are shown in Table 1, where $m_{\text{overall}}$ is the overall mean systematic deviation, $\sigma_{\text{set-up}}$ is the random set-up error, and $\Sigma_{\text{set-up}}$ is the set up systematic error. However, correcting AP, lateral, superior-inferior, pitch, and roll will not completely correct anatomical deformation. The majority of the patients treated using OBI were patients with prostate and gynaecological tumours. Other target volumes have also been positioned with OBI such as lung, head, and neck cancers, and brain tumors. The additional workload due to online registration is approximately two minutes added to the time slot booked for the patient.

### CB kV CT

The CBCT function of OBI was installed in March 2005 in the author’s department. It focuses on localizing tumors based on internal anatomy and not just on the conventional external marks or tattoos. The CBCT system provides the capacity for soft-tissue imaging in the treatment position and realtime radiographic monitoring during treatment delivery.

Using the 3-D manual image registration, a match between the planning scan and verification CBCT was achieved and verified using the split view. This gave a good correlation between the two data sets. Currently, the author is using manual online registration tools for clinical set-up correction protocol. The image quality of the CBCT scans is slightly poorer than that of conventional CT scans and it also includes some artifacts from the tabletop. The dose to the patient during CT acquisition is approximately 45mGy for full-fan geometry. The dose to the patient during CT acquisition is approximately 45mGy for full-fan geometry. The linear accelerator with on-board imager seems to be very useful for the set-up of patients and for verification of the irradiation field just before irradiation. These systems will provide high-quality radiotherapy by delivering higher doses to tumors and fewer doses to normal tissue. The 3-D treatment plan verification using online correction based on soft tissue and target position has been used clinically and adds an approximate additional five minutes to the treatment time slot due to acquisition, reconstruction, and 3-D registration.

The radiographic mode with kV-kV images using the on-board imager systems offers a means for the repositioning of patients. Gold markers implanted into the prostate can be safely used for daily organ tracking using online set-up verification by OBI. The patient position is corrected according to the position of the markers detected in the localization images, acquired prior to set-up, and also changes in work flow and responsibilities for the therapist. The workloads generated by set-up correction in relation to their benefits have to be considered. The initial experience of CBCT is very encouraging with the image quality adequate for internal soft target localization.

### Conclusions

Adaptive radiotherapy (ART) is the next step from IGRT and will be a valuable new tool for evaluating online and off-line treatment strategies to account for set-up uncertainty and anatomical changes. The adaptive framework should support different adaptation scenarios, including deformable target, tumor shrinkage, and organ at-risk modelling, re-planning and compensating for residual dose errors. In this treatment process multiple CT scans are acquired for each or few treatment fractions and are used as feedback to form a new planning target volume and modify the treatment plan accordingly. The clinical implementation of ART is now possible in some centers. The off-line adaptive planning approach used the daily scanned CT images during the first week of treatment delivery to shape an average over the planning target volume (PTV), the clinical target volume (CTV), and the critical surrounding organs in the new modified treatment plan. This technique has been implemented in different institutions especially for re-planning the prostate cancer where the target is contoured on each CBCT scan. The online adaptive automatic re-planning and target deformation will be the main issues to be solved in the very near future.

### Future Work

A version of this article containing four graphics can be found in the Reference Section on the website supporting this business briefing (www.touchbriefings.com).
Unlimited choices.
Uncompromised freedom.
One source.

Industry leading solutions and the freedom of choice. Only from Varian.

Only Varian delivers the widest range of innovative, integrated technology so you can make the best clinical decisions for your patient, every time. We call it personalized patient care.

IGRT—Varian’s IGRT solution includes radiographic, fluoroscopic, cone-beam CT, and automated repositioning software, making it possible for more patients to receive advanced treatments of IMRT, and stereotactic radiotherapy.

Dynamic Adaptive Radiotherapy (DART™) – This year at ASTRO, Varian will introduce an unprecedented innovation for unifying the power of a single integrated system, combined with IMRT, IGRT, and real-time motion management.

Your patients bring clinical challenges everyday. Only Varian helps you break the boundaries of limited choices by giving you the most options for customizing patient treatment. Advanced IMRT, IGRT and now DART. The choice is yours.

Come see the future of adaptive radiotherapy. DART – The difference is dynamic.

www.varian.com/DART

VARIAN medical systems