

Image-guided Frameless Radiotherapy

a report by

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It is more than half a century since Lars Leksell developed stereotactic radiosurgery and the ability to deliver protons to discrete areas of the brain to irradiate tumours. However, while there have been many improvements made to the nature and method of radiation delivery, the stereotactic head frame used to co-ordinate the beams and keep the patient in position has remained at the core of the procedure – until recently. New devices are now available that use stereo imaging technology to accurately identify, target and destroy tumours with greater accuracy and in shorter time-frames, without the need for a painful and restrictive head frame.

Challenges Faced During Radiosurgery/Radiotherapy

Radiosurgery (a single high dose of radiation) and radiotherapy (where the effective dose is fractionated into a series of lower doses) require immobilisation of the patient and precise target localisation to allow the dose to be concentrated in the target via multiple crossing beams. A single dose is normally delivered in a session that takes about 20 minutes. With fractionated radiotherapy there may be one daily dose five times per week; if 10 fractions are being used, they could be delivered over two weeks, or with two fractions per day for five days with an interval between fractions of at least six hours. Therefore, there are two different errors that must be controlled for: the intrafraction error (movement during a single dose delivery that might affect alignment and therefore dose delivery) and for radiotherapy the interfraction error (differences that may arise between fractions over the course of therapy).

Typical indications for radiosurgery/radiotherapy are: benign brain tumours, such as vestibular schwannomas, pituitary adenomas and meningiomas, which account for about 60% of cases at our practice; malignant tumours, mainly metastases, which account for about 20% of cases; vascular malformations, including arteriovenous malformations (AVMs), which account for roughly 15% of cases; and about 4–5% of cases are functional lesions, such as trigeminal neuralgia. The rest are miscellaneous. Many tumours are in close proximity to eloquent areas of the brain; for example, they will be wrapped around the optic apparatus or the cranial nerves in the brain. This requires heavy fractionation – up to 30 fractions – and very careful, precise delivery.

The Frame-based System

In traditional techniques, a stereotactic head frame was attached to the patient's head using four screws inserted into the skull under local anaesthesia. This ensured the patient was fastened to the linear particle accelerator (linac) so he or she could not move. Once the frame was fitted the patient was scanned using computed tomography (CT) to establish the targeting relationship. Therapy was initiated almost immediately afterwards. One assumption made with the linac was that the patient could not move at all between CT scanning and initiation of

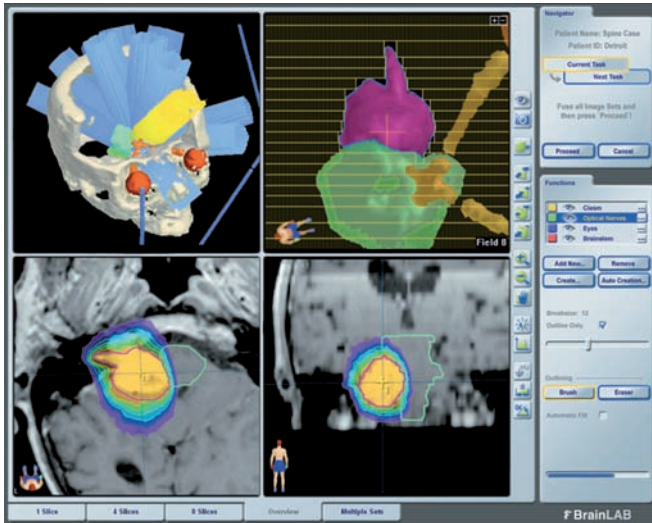
therapy and, furthermore, he or she had to remain still during the treatment. In order to protect healthy brain tissue during conventional radiosurgery/radiotherapy, the target was outlined and then a safety margin added to cope with both any unintentional movements made and the inherent inaccuracies of the equipment. This increased the radius of the irradiated sphere created by a millimetre or so, which effectively doubled its volume.

Image-guided Frameless System

The above procedure has totally changed with the new Novalis Tx™ frameless radiosurgery system. The CT scan is still performed, but the patient is kept still using non-invasive fixation in the form of a thermoplastic mask. There is no invasive head ring involved. Once the CT scan has been performed, the treatment planning computer calculates the spatial relationship between certain landmark features and the therapeutic target. The CT scan and treatment planning can all be carried out hours or days prior to the actual initiation of therapy, maximising efficiency and minimising the stress to the patient. On the day of treatment, the patient once again lies on the linac couch with the mask on. Naturally, there will be some inaccuracy in his or her position because of the re-location, and this is where the ExacTrac X-ray is employed. ExacTrac takes two stereoscopic X-ray images, which are fused to the digitally reconstructed radiograph from the treatment planning CT scan. The deviation between the patient's previous and current position is calculated, and the patient is automatically re-positioned without having to move – the whole couch can move with 6° of freedom to attain the correct position. With the new system there is no need to include the inherent safety margin. This means that much more precise, targeted surgery can be performed with full confidence. The pixel size of the radiation image is 0.7mm and the system provides an interventional threshold of 0.5mm and 0.5°.¹ There is continuous intrafraction monitoring of position for the duration of therapy and, if the patient moves, fresh stereoscopic images are taken and once again fused to the original CT scan. If necessary, the couch is again moved to ensure that the target is within 0.5mm of the correct position. Re-positioning takes less than one minute.

Dynamic Conformal Arc

Alongside the new patient positioning system, the Novalis Tx also employs a dynamic conformal arc to deliver the radiation beams. Essentially, the linac gantry rotates as the multileaf collimator – consisting of fine individual tungsten leaves – shapes the beams to conform to the outer contour of the target. This tailors the dose to the target shape, providing a homogenous dose distribution without affecting the surrounding healthy brain tissue. Conventional static field or circular arc techniques at best create multiple isocentres, resulting in dose heterogeneity across a target, particularly in irregularly shaped formations.²

Figure 1: Image of Intracranial Conformal Radiosurgery

The Berlin Experience

My personal experience encompasses different types of stereotactic radiosurgery and radiotherapy devices spanning more than 15 years. Until about 2004, I used conventional equipment with the invasive head frames. Since then I have used the BrainLAB/Varian Novalis Tx system in combination with ExacTrac X-ray, coupled with the new image-guided navigation system. An initial evaluation of the Novalis image-guided non-invasive system conducted at my hospital achieved an accuracy of 1.04 ± 0.47 mm, with an average in-plane deviation of 0.02 mm on both the x- and y-axes.³

The main advantage of this new system is the treatment we can now offer for benign brain tumours and functional diseases, for example in the treatment of trigeminal neuralgia, which is caused by the fifth cranial nerve and causes a unique, intense type of pain that quite often has a devastating effect on the patient. The target is very close to sensitive areas such as the brainstem and furthermore is very tiny: the diameter of the nerve is less than 1–2 mm and its volume is about 0.09 cm^3 .⁴ This requires a high number of very carefully shaped beams directed to the target in order to spare the surrounding eloquent tissue. With the new system it is now possible for the first time to treat trigeminal neuralgia more precisely and reduce the danger of causing adverse radiation effects. Consequently, in trigeminal neuralgia patients who do not respond well to conventional interventional surgical procedures or drug-based treatments, we have managed to achieve a success rate of at least 70% in terms of reducing pain or even reaching a pain-free state within four to six weeks. Therefore, for the vast majority of patients, medication (including its inherent side effects) can be reduced, which will considerably improve quality of life with a negligible risk.

Tumours – both benign and metastatic – can develop in almost any area, and quite often they are very close to the optic apparatus, brainstem or other sensitive areas of the brain. Previously, with conventional radiosurgery, it could be very difficult to deliver a really high tumoricidal dose because of the proximity of the sensitive area. With the image-guided frameless system, it is now possible to deliver much higher doses more accurately. In addition,

the image-guided system means that it is now possible to treat tumours close to the skull base, such as chordomas and chondrosarcomas, with curative intent (see Figure 1 for representation of intracranial conformal radiosurgery). Previously, with conventional radiation, this was simply not possible. AVMs also respond well to radiosurgery/radiotherapy.⁵

Benefits to the Patient

Clearly, not having to be sedated and screwed into a frame is a good thing from the patient's perspective, and there are other benefits too. The ability to deliver a high dose more precisely than ever before to smaller areas opens up the range of targets that can be treated and improves confidence of a successful outcome. This is particularly true for fractionated treatment, where inaccuracies caused by re-positioning would otherwise have affected the quality of therapy delivered. Treatment times are also reduced in terms of both the patient's requirements and those of the therapy team. Everything no longer needs to be done in one day: for instance, the mask fixation and the CT scan can be completed a few days beforehand. Furthermore, the treatment time in our department is now around 20 minutes, which represents a reduction of about 20–30%.

Summary and Conclusion

Since their introduction in the mid-20th century, radiosurgery and radiotherapy have become indispensable tools for treating a range of tumours, vascular malformations and functional lesions, many of which are inaccessible to other treatment modalities. However, these targets are often close to or intricately involved with delicate areas of the brain. This means that only the most precise and accurate radiotherapy techniques can be used. In order to keep the patient still between imaging and

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starting the procedure, as well as during the procedure, conventional systems used a stereotactic head frame that was literally screwed into the patient's skull. While this was performed under anaesthetic, it was still unpleasant for the patient. Moreover, the head frame could not guarantee perfect immobility and an inherent margin of error needed to be added to guarantee the safety of the procedure.

Advances in radiosurgery technology now mean that the head frames are a thing of the past. Sophisticated imaging techniques, combined with improved radiation delivery, mean that the position of the target is known and it can be irradiated successfully. This improves patient comfort, speed of treatment and accuracy, resulting in radiotherapists being able to treat more indications with curative intent. ■

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