Gamma Knife for brain cancer: a patient case study

Andras A Kemeny FRCS MD

Consultant Neurosurgeon at the Royal Hallamshire Hospital and the Gamma Knife Centre at BMI Thornbury

Lucy (not her real name) felt as if the whole world was collapsing around her. She thought that her breast cancer, treated with surgery and chemotherapy four years earlier, was a thing of the past. And now her Oncologist was telling her that it had returned in her brain.

Four years back, when she recovered from her chemotherapy and all her tests came back negative, she hoped that she would never have to face this word again. With each passing year she felt more and more reassured. Over the past three months however, she had had several episodes of tingling and heaviness in her left arm and flickering lights in her eyes. Her GP was sympathetic and quick to act, referring her to a Neurologist, who organised an MRI scan of her brain. She was due to go back to her Oncologist for her yearly check up, so it fell on him to break the bad news. Lucy had three tumours in the brain. They were quite far from each other and apparently all three in a different but tricky position in the brain. The Oncologist was clear: the only way forward was by radiation. Two options were offered. She could have the conventional fractionated radiotherapy. This would treat the whole brain including all the normal parts with the same amount of radiation as the tumours. The treatment would be spread out over several weeks. She was told of the expected side effects of hair loss, tiredness and the possibility of dementia some years down the line. The alternative was to use Gamma Knife, a focused radiation technique, irradiating only the tumours in a single day procedure. Lucy leapt on the chance to avoid a lengthy treatment again. It also appealed to her not to have her normal brain irradiated. She was referred to the Gamma Knife Centre at BMI Thornbury in Sheffield.

Gamma Knife Surgery or Stereotactic Radiosurgery was invented as far back as the 1950s. The inventor, the Swedish neurosurgeon Professor Lars Leksell, dreamt of bloodless brain surgery. Rather than opening the head, he wanted to destroy the abnormal parts using finely focussed radiation beams. After experimenting with X-rays, proton beams and other charged particles, Leksell decided that gamma rays, from a heavily shielded static array of Co60 sources, directed towards a central point by narrow metal tubes, provided the simplest and most practical system for daily clinical use. The first “Gamma Unit”, or “Leksell Gamma Knife” as they are now called, was completed in 1967 and became operational in Stockholm in 1968. After the initial experience became known, further Gamma Units were installed in 1984 and 1985 in Buenos Aires and Sheffield respectively. Several generations of the machine have been developed since, and more than 200 are operational worldwide. The most recent, the so-called Perfexion, is rapidly gaining popularity (Fig 1). But the essence of the technique has not changed, which is a tribute to the ingenious original concept.
The treatment involves delivering high dose radiation to a small volume in the brain with sub-millimetre precision in a single sitting, crossfiring 200 or so fine radiation beams. The target, like each of Lucy’s tumours, has to be visible on a radiological image, relatively small in size (3-3.5 cm maximum diameter is the usual upper limit for each tumour) and the patient should be sufficiently well to make the treatment appropriate.

Leksell envisaged using it for functional disorders like Parkinson’s disease and pain, but it became rapidly obvious that the potential applications were much broader: the machine was also able to treat vessel malformations (sources of brain haemorrhages) and brain tumours. But Leksell was limited by the technology of the day, particularly computing and neuroimaging: the methods of showing the abnormality, and so the target, were crude and imprecise. They had to develop dramatically to make radiosurgery what it is now: a routine treatment option for neurosurgery’s most difficult problems. Indeed with the arrival of MRI scanning, cancer deposit (metastasis) in the brain became the commonest target for this technique worldwide.

The patient is usually admitted to hospital the night before but if they wish they can come in the morning and leave by the afternoon. The procedure starts with the application of a stereotactic frame. This is a crown-like metal ring which is placed around the head and, once the skin is "frozen" with local anaesthetic in four points, the frame is fixed to the skull with four sharp tipped screws. This frame will then act as a reference from where all measurements are taken to ensure absolute precision. After this first five minutes of discomfort the rest of the day is easy. With a special imaging box fixed to this frame a new MRI scan is taken, allowing each image to be perfectly referenced to the frame. The tumours are then identified by the Radiologist and a precise outline drawn on the computer screen. Each point of this contour is represented by a point in the "coordinate system" provided by the frame, allowing the Neurosurgeon to build up a 3-dimensional model of the patient’s head and the tumours within it. With the aid of the Physicist, the Radiosurgeon (Neurosurgeon or Radiotherapist) prepares the treatment plan (Fig 2). This delicate computer work demands patience, meticulous attention to detail and experience. It is vital that the plan is drawn up in such a way that the important structures in the brain, often a few millimetres in size, are protected from any harmful effect of the radiation. This is particularly important when the tumour or tumours are situated in the eloquent part of the brain, where losing any function would be unacceptable.

![Fig 2. Gamma Knife treatment plan. The small brain tumour is targeted with high precision. The tiny amount of radiation which falls into the neighbouring brain helps kill the locally invading tumour cells.](image)

Next the patient is transferred into the treatment unit. The treatment is similar to having a scan. By supporting and fixing the frame to the couch, the patient is taken by the hydraulic system head first into the treatment unit. After all the checks are done, the computer positions the patient’s head so that one by one the individual target points - the individual tumours - are placed into the focus point into which radiation is then delivered. The "robotic" positioning ensures sub-millimetre precision. The treatment itself is silent and pain-free: many decide to have a snooze through the whole treatment which may take around an hour. Others choose to use the built-in music system, listening to the music of their choice. When the treatment is finished the frame...
is removed and after a short rest on the ward the patient is ready to go home. Patients particularly like the fact that they can return to their normal life after a one-off treatment.

The success rate of the treatment is usually measured in "local control", that is halting the growth and converting the cancer to scar tissue or dead material. This is achieved in around 90% of cases (Fig 3a,b).

Because modern MRI imaging with high dose contrast material demonstrates even millimetre-sized cancer deposits and treating another spot only adds another few minutes to the treatment, Gamma Knife can cope with a large number of small tumours in the same treatment. Usually there is no need for more treatment in the brain. If there are further microscopic tumours (invisible at the time of treatment, which was the rationale behind the use of whole brain radiotherapy), they can be "mopped up" by a second procedure a few months later when they show up on follow-up MRI scans. More importantly, if in later months and years new brain metastases appear because the cancer has escaped systemic treatment, it is safe to use Gamma Knife Surgery again. With a one-day interference in the patient's everyday life the brain disease is back in control.

Of course this focal treatment does not affect the rest of the body so patients need help from the new anti-cancer drugs and other treatment methods offered by modern oncology. And this is precisely what is happening: with the combination of the aggressive use of novel extracranial treatment regimes to treat the body and wider use of Gamma Knife Surgery for the brain, more and more patients achieve increased survival following the dreaded diagnosis. In the past, brain deposits were almost invariably terminal with only 2-3 months survival and whole brain radiotherapy only added another three months or so. In the best prognostic groups now the time is measured in years and much of it depends on how the rest of the body behaves.

Lucy has had three monthly scans since the treatment. At nine months she is still clear of cancer and all tumours have responded. She is not worried about the brain any more: she knows that any further metastases will be nipped in the bud by the Gamma Knife thanks to the Swedish inventor and the team at the Gamma Knife Centre at BMI Thornbury.