Treating Vascular Malformations In The Brain With X-Rays: The Role For The Cyberknife

P Francescon, C Cavedon, J Stancanello, S Cora, F Colombo
Medical Physics Department (fisica@fisica-vicenza.it)
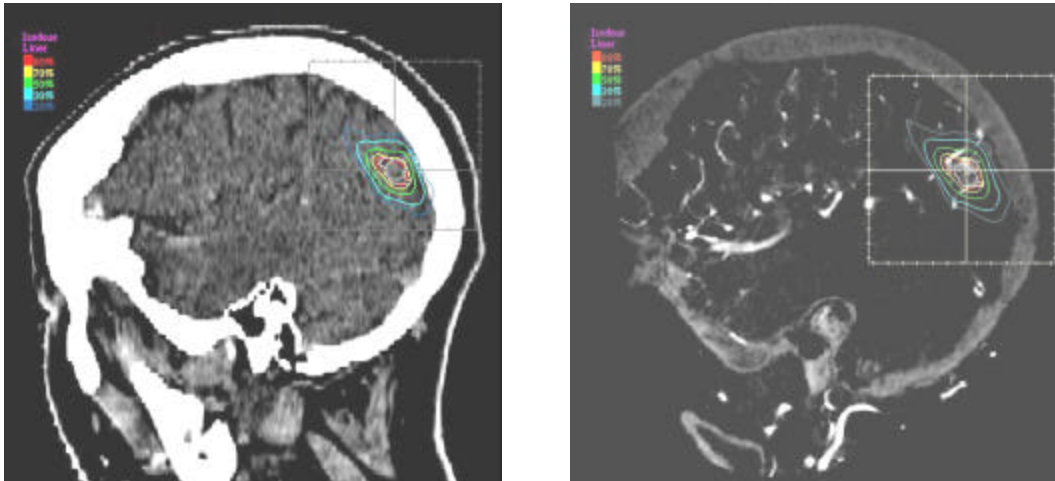San Bortolo Hospital
Vicenza, Italy

Fig. 1: CyberKnife radiosurgery treatment plan on a CT image (left) and on a 3DRA image (right), seen on a single plane. Color lines represent radiation dose levels. AVM structure and vessel details are clearly visible only on 3DRA, while bone and brain structures are better defined in CT.

An arteriovenous malformation (AVM) is a congenital disorder involving a tangled web of blood vessels, typically in the brain or spinal cord. Abnormally high blood flow can occur in AVMs, causing seizures, paralysis, and other problems.

Since the late 1970s, cerebral AVMs have been treated by delivering high doses of ionizing radiation, using linear accelerators and GammaKnife, a technique that employs high-energy gamma rays to destroy unwanted cells. However, both modalities require the patient to wear a head frame that keeps the skull fixed. Besides entailing some discomfort to the patient, traditional techniques limit the ways in which radiation can be delivered to treat the AVM due to "isocentric operation," *i.e.,* a constraint on possible movements of the accelerator/source mounting.

Recently, new radiosurgical techniques have eliminated the need for a "stereotactic frame" to remove AVMs. Among the different techniques of "frameless surgery" that stand out is the CyberKnife, a system based on a linear accelerator mounted on a robotic arm. By firing x-rays at many different angles and at many different intensities, the Cyberknife delivers the desired amount of radiation to a precisely defined 3D target. An advanced image-targeting system ensures that the radiation dose is aimed at the proper target site, even if the patient moves during the surgery. For this reason, the patient does not need to stay fixed in a head frame.

The CyberKnife provides additional advantages compared to linear accelerators and GammaKnife. For one, it can deliver a 3D distribution of x-rays that matches the irregular shapes of many targets (*"conformality"*). Another advantage is the *uniformity* of dose within the target. *Conformality* allows physicians to spare healthy tissue surrounding a lesion; *uniformity* is of particular importance

for AVMs, for which dose inhomogeneity could lead to imbalances which increase intracranial pressure. In turn, this increased intracranial pressure can result in increased risk of bleeding during the typical 6-to-18 month period from irradiation to complete AVM obliteration.

So far the CyberKnife has been widely used for treatment of tumors, while its use for removing AVMs has been uncommon. In fact, to plan out the actual radiosurgery, Cyberknife requires the patient to get a CT scan, which provides 3D images of the surgical target. However, AVMs are not clearly seen in CT scans, as the top figure demonstrates.

On the other hand, AVMs are clearly visible in angiographic studies. In angiography, a substance known as a contrast medium is injected in the patient. Then the patient receives xrays that interact with the contrast medium in the bloodstream to provide a high-quality image of the AVM. However, angiography is useless for treatment planning if a stereotactic frame is not fixed on the skull, due to lack of markers defining a system of coordinates. Furthermore, standard angiography yields multiple flat, 2D images which are distorted relative to the 3D images in CT, just as the countries in a flat, 2D map of the world are distorted relative to their actual appearance on a 3D globe.

Recently a new type of angiographic examination has been available. It is called 3D rotational angiography (3DRA), which is capable of three-dimensional reconstruction of the head volume. The CyberKnife group in Vicenza, Italy, used 3DRA to obtain slice-by-slice images of the vascular structure. They then developed a technique for correlating the 3DRA data to CT, superimposing the two data sets by maximizing mutual information between them. Finally they used the "fused" data set for treatment planning and delivery.

With this method, one can precisely estimate the maximum error that could be introduced by correlating 3DRA to CT, thus providing a decision-making tool for critical situations. The three-dimensional visualization of AVM structure together with dose distribution also helps treatment planning in cases where the nidus (the "nest") of the AVM would be partially or totally hidden by big vessels in standard angiography. The frameless operation and the use of standardized data format finally allows physicians to use 3DRA examinations performed some time before treatment, even in a different hospital.

The method has been entirely developed by Dr. Carlo Cavedon and Dr. Joseph Stancanello of the Medical Physics group of San Bortolo Hospital in Vicenza, Italy, led by Dr. Paolo Francescon.
"This work permitted us to be the first group to treat AVMs by means of the CyberKnife and 3DRA. 20 AVM patients have been treated in the first three months, but the trend is rapidly increasing," says Dr. Francescon. "Vicenza Hospital has been among the first radiosurgery centres to treat AVMs, beginning in 1982; our current number of AVM treatments is over 700. The use of the CyberKnife represents one of the most important milestones in the activity of Vicenza radiosurgery centre and has already put the quality of our AVM treatments at top level."

Additional information:
Press Release from Accuray Corporation, Maker of the Cyberknife
http://www.accuray.com/news/press032803.htm