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Angiographic Technique to Precede Gamma Knife Radiosurgery for Intracranial Arteriovenous Malformations

Larry R. Sadler,^{1,2} Charles A. Jungreis,¹ L. Dade Lunsford,^{1,3} and Matthew M. Trapanotto⁴

Stereotactic radiosurgery of small arteriovenous malformations (AVMs) and certain benign and malignant brain tumors using a gamma knife with 201 sources of cobalt-60 has been used to treat 300 patients at our institution since August 1987. This gamma knife—like earlier units developed in Stockholm, Buenos Aires, and Sheffield, England—was designed for closed-skull destruction of selected AVMs and neoplasms [1, 2]. The site of interest must be precisely localized by means of cerebral angiography (for AVMs), CT, or MR imaging. The three-dimensional coordinates of the target are necessary data required to complete computerized dose planning. By use of imaging data, a final dose plan is formulated that includes the isodose configuration, total dose, and treatment time [3]. The postulated benefit of gamma knife radiosurgery over conventional external beam therapy is the rapid drop-off of radiation just outside the intended focus, thereby sparing the surrounding brain parenchyma potentially damaging radiation (Jungreis CA, personal communication).

For precise localization of AVMs, meticulous attention to angiographic technique and patient positioning must be applied. Through initial trial and error, an angiographic technique has evolved at our institution that allows both excellent lesion resolution as well as stereotactic coordinate frame visualization. This technique requires changing our routine diagnostic angiographic methods.

Materials and Methods

All gamma knife angiograms are obtained on a GE Biplane L-U Fluoroscopy unit with an MX-125 X-ray tube using a 0.2-mm focal spot (GE Medical Systems, Milwaukee, WI) and an Elema-Schonander Puck-U4 film changer. Omnipaque 300 (Winthrop Pharmaceuticals, New York, NY) is the contrast agent. In our suite, only the posteroanterior tube has fluoroscopic capability. The patient arrives in the angiographic suite after a stereotactic rectilinear coordinate frame (Elekta Instruments, Decatur, GA) has been applied to his head using local anesthesia supplemented by IV sedation. Prior to head frame fixation, gamma knife patients are premedicated with intramuscular 50 mg Demerol (Winthrop Pharmaceuticals, New York, NY), 50

mg Vistaril (Roerig, New York, NY), and 0.4 mg IV atropine. Additional sedation with 1–2 ml fentanyl (Elkins-Sinn, Cherry Hill, NJ) is given as needed. If the patient requires general anesthesia for this study (children less than 14 years old), the frame is applied in the angiography suite after anesthetic induction. Magnets at the base of the stereotactic head frame connect to a stabilizing device that interfaces between the stereotactic frame and the angiographic table in order to secure the patient's head and eliminate any motion (Fig. 1). This also allows for proper alignment of the front, back, and side coordinates, which are inscribed onto the head frame. The coordinates are inscribed in millimeter increments on the head frame with the "100" mark on each axis (x, y, and z) defined as the center of each axis. The marks are visible fluoroscopically owing to filling with titanium inserts. By convention, the x axis is right to left, the y axis is posteroanterior, and the z axis is craniocaudal. The groin is prepped and draped in the usual sterile fashion, and a standard cerebral catheter is inserted into the femoral artery using the Seldinger technique. The vessels supplying the AVM are selectively catheterized. The decision as to which vessel to examine is established by reviewing the patient's previous MR, CT, and angiographic results.

To align the central beam at the "100" mark on the x and z axes of the head frame (posteroanterior coordinates), the image intensifier is positioned directly over the patient's head (0°) with the U arm at 90° with respect to the angiographic table. No tube angulation is used since the tubes must be square to the head frame. The frame is considered aligned when the "100" marks on the front, back, and sides of the frame superimpose in the horizontal and vertical planes. Owing to parallax, only the "100" marks will be precisely superimposed when this is done correctly. To align the posteroanterior coordinates, the fluoroscopic image is magnified and the cones are positioned such that only the upper pair of horizontal coordinates (x coordinates) are viewed. The locks on the table are released, and the table is gently moved until the "100s" are exactly superimposed. This determines the horizontal or left-to-right position (x coordinate). The locks are then reapplied and the technologist marks this position on tape (which has been affixed to the underside of the angiographic table) using the crosshair shadows from the light beam of the X-ray tube. The craniocaudal (z) coordinates are then similarly aligned. For anteroposterior (y) coordinate alignment the technologist positions the lateral film holder against the patient's left shoulder or as close to the head frame as is practical. The central beam of the lateral tube is made to coincide with the "100" marks on the y and z positions on

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¹ Department of Radiology, Division of Neuroradiology, Presbyterian-University Hospital, Pittsburgh, PA 15213.

² Department of Radiology, Mayo Clinic and Mayo Foundation, 200 First St., SW, Rochester, MN 55905. Address reprint requests to C. A. Jungreis.

³ Department of Neurosurgery, Presbyterian-University Hospital, Pittsburgh, PA 15213.

⁴ Department of Radiology, Presbyterian-University Hospital, Pittsburgh, PA 15213.

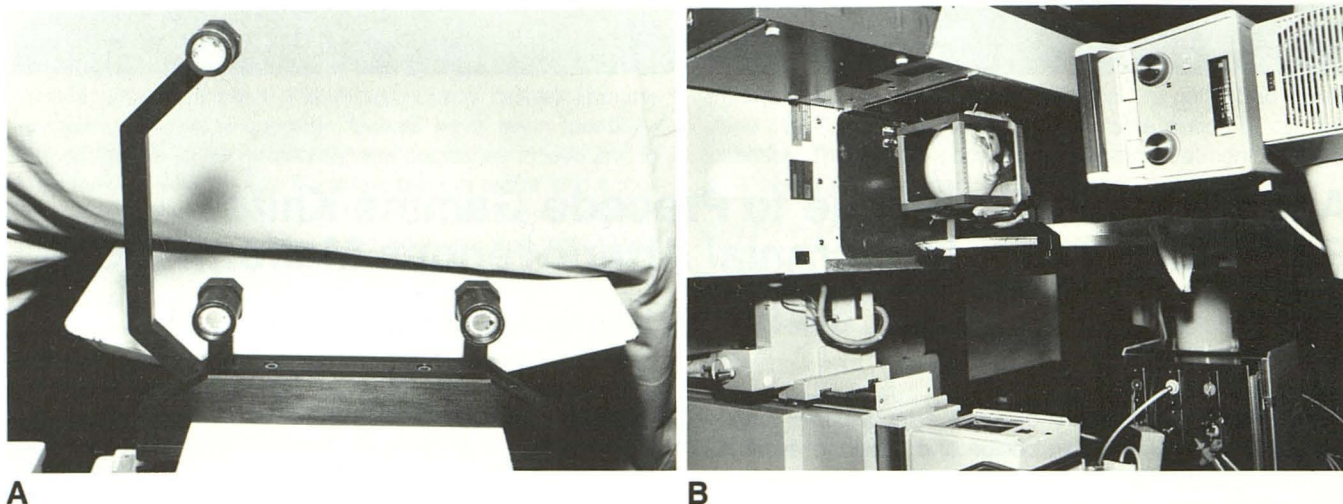


Fig. 1.—A, Stereotactic head frame holder (stabilizing device) viewed from head end of angiographic table. The three round magnets connect to the stereotactic frame.

B, Stereotactic head frame attached to holder with skull phantom immobilized inside frame. The film changers are positioned as close as possible to the head frame to minimize magnification. Focused grids are in place.

the frame (Fig. 2). Because the light beam generally does not align perfectly with the central beam, scout films are required. Adjustments can then be made. For example, in our angiography suite the vertical crosshair of the lateral tube is placed on the "104" mark (z coordinate) and the horizontal crosshair on the "99" mark (y coordinate).

Posteroanterior and lateral scout films are obtained at a 40-in. focal film distance. A 14-in. square film format is used. To have a field of view large enough to include the head frame, maximum magnification must not exceed $\times 1.4$. This is accomplished in the posteroanterior projection by raising the table until the anterior head frame almost touches the film holder. These maneuvers not only increase the field of view but also eliminate the air gap. To reduce the scatter in the absence of the air gap, focused radiographic grids (12:1) are used.

The following filming sequence is used: four films/sec for 3 sec, one film/sec for 3 sec, a pause of 2 sec, then a final film, all shot with simultaneous biplane exposures. The radiographic technique on non-gamma knife patients without grids is usually 4 mAs at 75 Kvp for the posteroanterior view and 4 mAs at 70 Kvp for the lateral. The gamma technique (with grids) requires that the mAs be increased to 6.4 without changing the Kvp setting.

As the films become available, the radiographic technique, positioning, alignment of the coordinates, and appearance of the AVM are evaluated. If necessary, repeat runs with oblique or highly magnified images of small AVMs may be obtained in order to better define the nidus.

Pertinent images are selected for subtraction. The darkroom subtraction process differs from routine subtraction techniques in that the subtraction exposure is two to four times longer than usual. The mask and film are just slightly off-centered with respect to each other during the subtraction process to allow the head frame coordinates to be clearly identified on the subtraction images (Fig. 3).

After the subtraction images are viewed, the catheter is removed and pressure applied to the puncture site. The patient is then transferred to the gamma knife suite to complete the radiosurgical procedure.

Discussion

Although gamma knife radiosurgery of selected intracranial AVMs and brain tumors is a relatively new treatment in this

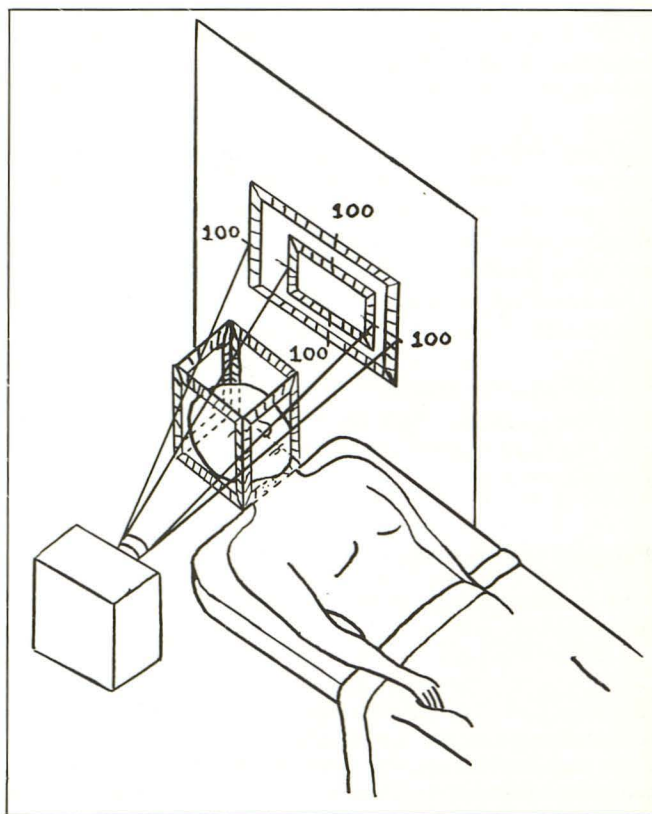


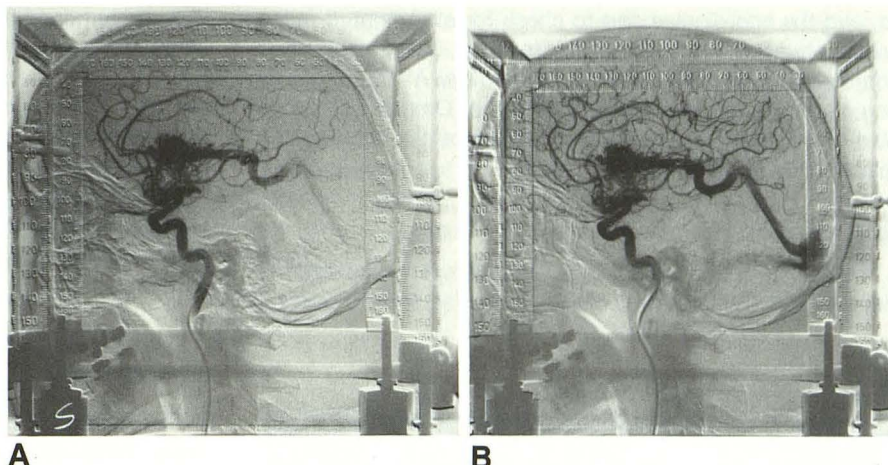
Fig. 2.—Diagram shows proper alignment of the frame on a lateral projection. The "100" marks align in both planes. The other marks are slightly off alignment owing to parallax (see other figures).

country, radiosurgery has been used extensively at the Karolinska Institute in Stockholm since 1975, where more than 1500 patients have been treated [1]. Several gamma knife units are now operating in North America. By using three-dimensional coordinates obtained from either angiography,

Fig. 3.—Subtracted films from early and mid arterial phases demonstrate rapid filling of a deep left basal ganglia AVM with a large vein draining into the dilated vein of Galen.

A, Early arterial phase lateral angiogram provides excellent visualization of both z coordinates and inner y coordinates. The outer y coordinate fiducial marks are blurred.

B, Subtracted film from later in the run demonstrates excellent identification of the fiducial marks on both z and y coordinate bars.



CT, or MR, a precisely defined and sharply focused dose of radiation can be delivered to a small target volume in a single treatment session. The gamma knife at our institution delivers highly focused and collimated photons (gamma radiation) using 201 sources of cobalt-60 arranged around the patient's head in mechanically fixed positions [3].

Numerous steps are necessary before, during, and after the therapy angiogram that are crucial in obtaining an adequate examination.

Prior Studies

These are required. Only those vessels supplying the AVM are reinjected at this time.

Premedication

On the morning of the examination, premedication consisting of intramuscular Demerol (50 mg), Vistaril (50 mg), and IV atropine (0.4 mg) is given to the patient prior to placement of the stereotactic head frame. This is to diminish any pain or vasovagal reaction that might occur while drilling into the outer table of the skull for fixation of the head frame. The patient continues to be mildly sedated during the angiogram, which decreases the chance of patient motion and reduces anxiety. Supplemental IV fentanyl (1–2 mg) is also administered if needed.

Frame Alignment and Centering

As discussed above, meticulous attention must be paid to frame alignment to accurately localize a patient's AVM. Perpendicular alignment of the posteroanterior and lateral tubes to the stereotactic head frame is essential for the accurate plotting of the intended radiation focus. Improper alignment or patient motion will necessitate a repeat diagnostic run after correcting the problem. It is frequently necessary to recheck the alignment fluoroscopically immediately before the angiographic run is made. Care must also be taken to assure that the head frame is attached securely to the table by the

magnetic connectors. If inadvertently detached, accurate coordinates will not be obtained.

Lack of Magnification

The images are magnified minimally (average, $\times 1.25$) on the posteroanterior view as the head frame is placed in direct contact with the posteroanterior film holder. Slightly more magnified images (average, $\times 1.32$) are obtained on the lateral films because of a small but unavoidable air gap caused by the film changer being against the shoulder of the patient rather than against the head frame. The relative lack of magnification is necessary to increase the field of view and to include the head frame. A focal film distance of 40 in. is used. Magnification and/or oblique views may be obtained after the coordinate run if necessary to better define the vascular nidus.

Radiographic Technique

Since we cannot use an air gap to reduce the scatter, focused grids (12:1) are used. Scatter radiation is of special concern during gamma knife angiograms because the posteroanterior and lateral images are obtained simultaneously and "cross-scatter" becomes significant. Simultaneous exposures are required on our particular equipment during rapid filming (four films/sec in both planes). Alternatively, single plane runs could be obtained but this would require twice as many injections and double the patient's contrast load. The price of grid use is increased patient exposure in order to obtain the same film density, since the grid absorbs some of the primary radiation in addition to the secondary scatter radiation. For our studies, the mAs is increased by 60% over baseline (4.0 mAs to 6.4 mAs). The cones are also brought in to the outside edge of the head frame to help decrease the scatter. A small focal spot, preferably 0.2 mm, is used to enhance image sharpness in an attempt to visualize the fine angioarchitecture of the malformation and define the nidus as precisely as possible.

The technique usually causes overpenetration of the head frame markings on unsubtracted films, but allows good visualization of the vessels. Use of a bright light is often required

to read the coordinates and to check for alignment. If faced with a situation in which there is only air between the two coordinate bars (such as with a superficial AVM), a 500-ml bag of sterile saline injected with 20 ml of Omnipaque 300 is placed between the coordinate bars to better equalize the radiodensity of the region [4] (Fig. 4).

Film Sequence

A rapid film sequence is used in an attempt to visualize the nidus of the AVM without overlap from feeding or draining

vessels. In general, radiosurgery is directed only to the nidus of an AVM, and feeding arteries and draining veins need not be included in the field of treatment. In routine angiography, we use two films/sec for 3 sec followed by one film/sec for 6 sec. Gamma knife patients are imaged at four films/sec for 3 sec, followed by one film/sec for 4 sec, a skip of 2 sec, and a final film. The sequence is designed to maximize early arterial-capillary structures. All components and compartments of the AVM must be identified for proper radiosurgery plotting.

Film Selection

The films are available for review immediately after developing. They are scrutinized closely for proper technique and alignment. Attention is paid to the magnetic head holder to assure that the magnetic feet of the head frame have not detached from the stabilizing device. Several early arterial films and one or two later films are selected for subtraction. At present our digital subtraction angiography has insufficient resolution to use for radiosurgical localization, particularly with the low-magnification images required.

Subtraction Technique

Subtraction images are obtained while the patient is still in the angiography suite. A 40-sec darkroom exposure is used in making the subtraction instead of the usual 10-sec exposure. While this technique is satisfactory for visualizing the AVM, it is excellent for identifying the stereotactic coordinates. Subtraction images of 10-sec duration have not been adequate to see the coordinates. Allowances are generally made in this step because the subtraction process is highly dependent on the light source used, the film speed, and the density of the specific angiographic series. Furthermore, the

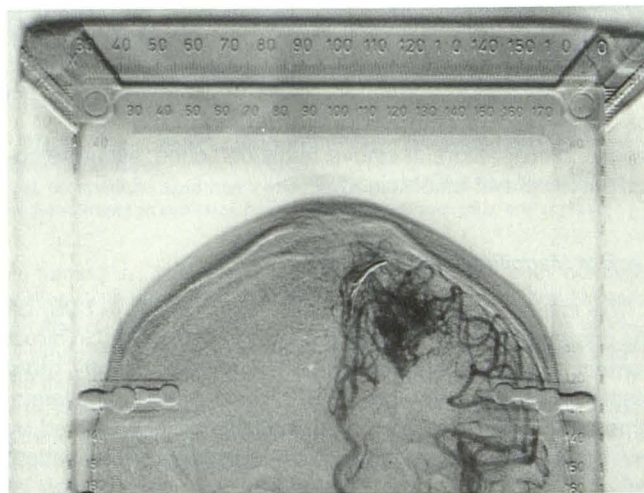
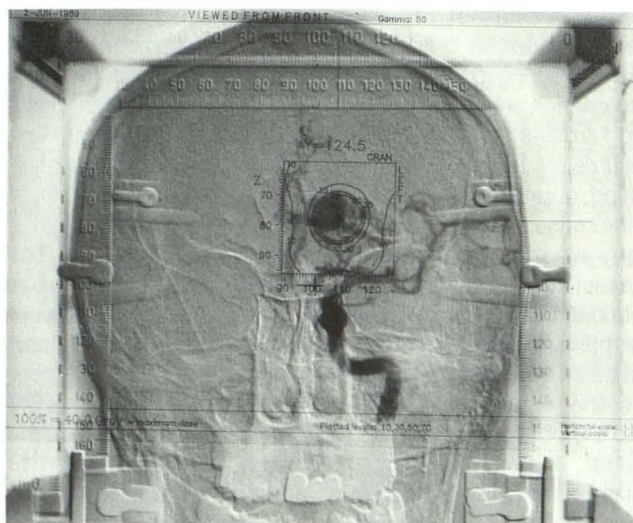
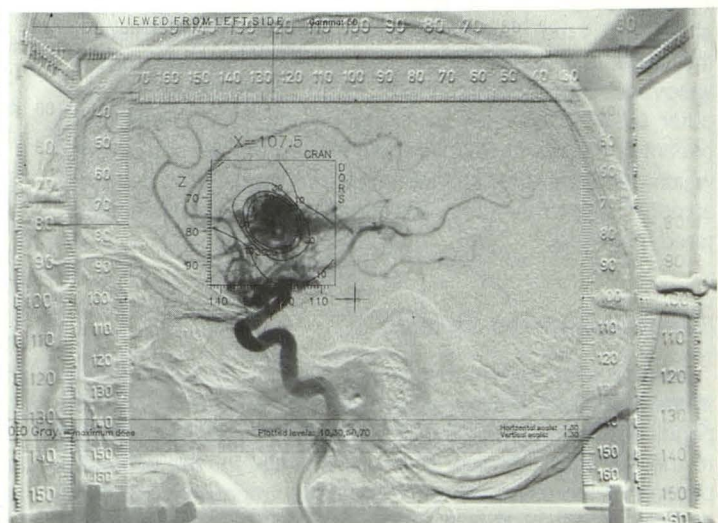


Fig. 4.—Subtracted angiogram gives markedly improved visualization of the x coordinates after a 500-ml bag of saline to which 20 ml of Omnipaque (300 concentration) has been added is placed between the coordinate bars. This results from greater beam filtration by the iodinated saline bag. Lack of filtration over the z coordinate bars results in poorly visualized fiducial markings. A clip from prior surgery can be seen adjacent to the right parasagittal parietal AVM.



A



B

Fig. 5.—A, Posteroanterior subtraction angiogram with superimposed isodose plan. The concentric plots surrounding the AVM denote the percentage of radiation delivered at these locations. The 100% dose (40 Gy) is marked in the lower left-hand corner of each film.

B, Lateral subtraction angiogram with superimposed isodose plan.

mask is misaligned slightly in order to see the coordinates because, if aligned exactly, the coordinates are subtracted from the final image.

Isodose Plotting

The coordinates from the angiogram are required to devise the isodose plan. The "100" marks are used as the reference points (Fig. 5). The actual dose plan is not carried out by the diagnostic radiologist.

Conclusions

Closed-skull obliteration of AVMs and intracranial tumors using gamma knife radiosurgery has been accomplished in more than 2100 patients worldwide. This technique has proved to be a safe, effective, and cost-saving alternative to conventional neurosurgery in selected patients who have intracranial AVMs or brain tumors [5]. Since the gamma knife became operational at our institution in 1987, several other gamma knife units have been installed at other institutions and many more are planned. The techniques we have outlined have not been adapted from any prior radiosurgical experi-

ence and merely represent a system we devised after making many mistakes requiring repeat angiograms and repositioning of patients. By avoiding such a trial and error period, other centers may be able to reduce start-up time and improve image quality and patient care. Each institution will be somewhat constrained by the available equipment, but we hope that our experience may serve as a framework on which to develop angiographic techniques useful for gamma knife patients.

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