Stereoscopic digital subtraction angiography in neuroradiologic assessment.

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Stereoscopic Digital Subtraction Angiography in Neuroradiologic Assessment

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Digital subtraction angiography (DSA) with stereoscopic imaging was performed in 40 patients for evaluation of a variety of cerebrospinal disorders. It was facilitated by a C-arm mounted x-ray tube and imaging chain with 7° angulation between image pairs. Stereoscopic digital imaging proved particularly useful in the preoperative assessment of aneurysms, arteriovenous malformations, and primary and metastatic tumors. The technique was also found to be useful as a real-time adjunct to therapeutic radiographic procedures, as an aid in stereotaxic procedures, and in follow-up of postsurgical patients. Although the intravenous route was occasionally used, especially in postoperative follow-up of aneurysms, the procedure was most often carried out via an intraarterial approach. Stereoscopy was useful in supplying depth information regarding the relations between lesions and surrounding normal and abnormal vasculature. This technique combines the demonstrated advantages of intraarterial DSA with the unique advantage of stereoscopic imaging to demonstrate three-dimensional detail, thus contributing significantly to diagnostic confidence. Disadvantages are discussed. Further refinements in the equipment are expected: generation of stereo images with one injection, thus increasing procedure efficiency and patient safety; a video stereoscopic viewing unit; and the ability to obtain precise measurements via computer of depth, position, distance between, and true size of objects.

Materials and Methods

A Technicare DR-960 DSA unit was used. This was interfaced with a Philips Maximus-100 500-mA x-ray generator, 0.6/1.5 mm focal spot x-ray tube, mounted on a Philips Neurodi-agnost-B C-arm with a Philips dual mode (6½ and 9 inch [16.5 and 22.9 cm]) cesium iodide image intensifier. The image intensifier, in turn, was coupled to a Technicare Sierra Plumbicon-tube television camera with a 1000:1 signal-to-noise ratio. An eight-bit analog-to-digital converter was used, and the images were acquired on a 512 × 512 × 8 matrix. Exposure factors were in the range of 65–80 kV and 25–100 mAs. Hard copies of the subtracted digital images were recorded by a Medcorp multiformat imager.

Forty patients aged 10–70 years with a wide variety of pathologies were studied. Most studies were carried out via the arterial route, although an intravenous approach was used occasionally, especially in the postoperative follow-up of aneurysms. Arterial studies were all carried out via femoral artery catheterization using the Seldinger technique. A preshaped 5 French catheter with a single end hole was used for selective arterial catheterization. For intravenous studies, a 5 French pigtail catheter with side holes was positioned in the superior vena cava via a basilic vein cannulation. Patient positioning, injection volume and rate, and
fing rate were variable depending on the route used and the indication for the examination. In general, for arterial studies, a bolus of 5–7 ml of Conray-30 or Hexabrix diluted to half concentration was injected into the carotid or vertebral artery over 1–2 sec. Intravenous studies used a bolus of 50 ml of Hypaque-76 injected at 25 ml/sec. Conventional patient positioning was usually used in the study of intracranial vasculature, although occasionally oblique positioning was used to evaluate aneurysms. The standard framing sequence for arterial studies was one frame/sec for 2 sec to obtain mask images, followed after the arrival of contrast material by three frames/sec for 4 sec, two frames/sec for 3 sec, and one frame/sec for 3 sec. In standard angiographic analysis, the power injector was used. Hand injections were made in therapeutic procedures and when a more gentle injection was considered advisable because of the patient’s condition. Stereoscopic views were obtained by rotating the C-arm 7° in the appropriate plane, repeating the sequence, and then juxtaposing the stereoscopic views.

Results

Diagnoses in the 40 patients studied with this technique are summarized in table 1. Pathologies most frequently elucidated were primary and metastatic tumors and vascular anomalies including aneurysms and arteriovenous malformations. In four cases DSA was used as a real-time adjunct to therapeutic radiologic procedures. These included superselective catheterization techniques for intraarterial, intratumoral injection of brain tumor chemotherapeutic agents and superselective catheterization for embolization of tumors and vascular malformations. Eight cases were studied as an adjunct to stereotaxic localization with angiography performed with the patient in a stereotaxic frame. The stereotaxic procedure required localization of vascular structures for tumor biopsy and depth electrode implantation in seizure patients. In five of 40 cases conventional angiograms were obtained in the same patients and compared with the DSA images. In two of these five cases the diagnostic information obtained by DSA was believed to be superior to conventional angiography. In two cases the diagnostic information was believed to be equal to conventional angiography; that is, no additional information was obtained by the conventional technique that aided in diagnosis or clinical management. In one of these five cases the information obtained by DSA was considered to be inferior to that of conventional angiography. This, however, was believed to be due to an inadequate choice of projections for the particular study in question and not due to the quality of the study per se. Two of the 40 patients had intravenous studies for postoperative evaluation of aneurysms. One patient had an arch study of the intracranial vasculature in conjunction with an evaluation of the extracranial vasculature in suspected carotid-occlusive disease. These data are summarized in table 2.

It was found that stereoscopic DSA is particularly useful in preoperative assessment of vascular anomalies and primary and metastatic tumors. Aneurysms can be demonstrated well, and the three-dimensional effect is useful in providing the neurosurgeon with depth information concerning the relations between fundus, neck, and surrounding vessels. This facilitates planning the operative approach. Furthermore, the C-arm can be rotated with ease into a position that provides the best possible angulation on the aneurysm. This is in contradistinction to conventional angiography with its fixed biplane views. Arterial DSA is considered superior to conventional biplane angiography in such cases in which multiple views are desirable but in which the duration of the test and the dose of contrast material are items of concern.

As with aneurysms, arteriovenous malformations can be assessed as to the feeding arteries and draining veins and the relations between these structures in space, again contributing significantly to surgical planning. Assessment of tumors provides the same advantages in terms of analyzing the three-dimensional relations of vascular structures. In general, the information provided in cases of tumor is not as advantageous as in vascular anomalies and is essentially equivalent to that provided by routine biplane stereo film-screen angiography. However, procedure time, injection volume and rate, and patient safety make the digital route preferable. Furthermore, tumor blush or stain is more pronounced in the digital mode than in the conventional mode, in which quite faint blushes are often observed.

The real-time information provided by DSA is an invaluable adjunct in therapeutic maneuvers, including the superselective catheterization of intracranial vessels for administration

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>No. of Cases</th>
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<tbody>
<tr>
<td>Gioma</td>
<td>10</td>
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<tr>
<td>Aneurysm</td>
<td>5</td>
</tr>
<tr>
<td>Arteriovenous malformation</td>
<td>4</td>
</tr>
<tr>
<td>Meningioma</td>
<td>4</td>
</tr>
<tr>
<td>Metastases</td>
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<td>Primary seizure disorder</td>
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<td>Cerebral infarction</td>
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<td>Lymphoma</td>
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<tr>
<td>Medulloblastoma</td>
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<tr>
<td>Porencephalic cyst</td>
<td>1</td>
</tr>
<tr>
<td>Schwannoma</td>
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<tr>
<td>Colloid cyst</td>
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<tr>
<td>Normal</td>
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</tr>
<tr>
<td>Total</td>
<td>40</td>
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<table>
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<tr>
<th>TABLE 2: Summary Data in Stereoscopic DSA Studies</th>
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<tr>
<td>No. of Cases (n = 40)</td>
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<tr>
<td>Intraarterial injections</td>
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<tr>
<td>Intravenous injections</td>
</tr>
<tr>
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<tr>
<td>Therapeutic objectives</td>
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<td>Stereotaxic procedures</td>
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<tr>
<td>Comparison conventional angiograms</td>
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<tr>
<td>Postsurgical follow-up</td>
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</table>

* One patient was studied preoperatively with intraarterial DSA and postoperatively with intravenous DSA.
Fig. 1.—Case 1. AP (A) and lateral (B) film-screen angiograms. Right middle cerebral artery aneurysm. Superimposition of vessels obscures lesion on lateral projection. Involvement of middle cerebral artery branches is unclear on AP projection. C and D, Stereoscopic DSA pair with x-ray tube obliqued about 15°. Aneurysm is well opacified and relations of middle cerebral artery branches are clear.

Fig. 2.—Case 2. A, Film-screen angiogram. Faint tumor blush in reaction to metastatic tumor (arrow). B and C, Stereoscopic DSA pair. Better opacification of vasculature and of lesion (arrow).

of chemotherapeutic agents directly to brain tumors, and in the selective and superselective catheterization for embolization of tumors and arteriovenous malformations. The three-dimensional relation revealed by this technique is also considered to be valuable by the surgeon carrying out stereotaxic techniques, including the implantation of depth electrodes in problem epilepsy patients and the biopsy of deep or "inoperable" tumors.
Representative Case Reports

Case 1

A 54-year-old man was evaluated at Montreal Neurological Hospital for left carotid artery transient ischemic attacks. Intravenous DSA revealed a right middle cerebral artery aneurysm as an incidental finding. The lesion was subsequently studied by selective right internal carotid angiography.

A conventional film-screen angiogram was initially obtained. In the lateral projection the aneurysm was difficult to appreciate due to superimposition of vessels. The anteroposterior (AP) projection showed the aneurysm at the middle cerebral bifurcation, but the relation between the lesion and the middle cerebral artery branches was unclear (figs. 1A and 1B).

DSA was subsequently performed with oblique stereoscopic views. With appropriate adjustment of the tube angle, the anatomy of the aneurysm and its relation to a key middle cerebral artery branch became clear (figs. 1C and 1D). The overall quality of the study was believed to be superior to that of conventional angiography. The dose of contrast material and procedure time were considerably less. In addition, the anterior communicating artery was well opacified without cross-compression. Multiple oblique views in stereo provided the neurosurgeon with significantly more precise anatomic detail of the pathology than could have been obtained with conventional film-screen angiography.

Case 2

A 43-year-old man with renal cell carcinoma had had a previous cerebral metastasis successfully treated by radiation alone. A CT scan subsequently revealed the presence of a second lesion in the right hemisphere. Conventional film-screen angiography was performed and revealed a faint tumor blush corresponding to the lesion seen on CT (fig. 2A). A stereoscopic digital mode angiogram was thereafter obtained and was believed to elucidate the lesion with much greater clarity (figs. 2B and 2C). Again, procedure time and dose of contrast material were markedly reduced.

Case 3

A 55-year-old woman was seen with a 6 month history of progressive high cervical myelopathy. Metrizamide myelography with CT body scanning revealed a well demarcated lesion at the C1 level on the left side displacing the spinal cord to the right (fig. 3A). A left vertebral angiogram in the digital mode confirmed the presence of a well vascularized extradural tumor filling from small branches of the vertebral artery (figs. 3B and 3C). The vertebral artery was not observed to be displaced. Surgical biopsy diagnosis of the lesion was schwannoma.

Case 4

A 52-year-old woman was seen with focal left hemibody seizures and a mild left hemiparesis. Isotopic brain scanning revealed a right hemisphere lesion. CT showed a diffusely enhancing right-hemisphere tumor consistent with a convexity meningioma. The plain skull film revealed a large middle meningeal groove consistent with the CT diagnosis. Selective external carotid artery catheterization with superselective internal maxillary artery catheterization was performed for DSA. A typical meningioma blush was observed with vascular supply via the middle meningeal artery (fig. 4). The diagnosis was confirmed, and the lesion was successfully removed.

Case 5

A 42-year-old man with a previously biopsy-proven, surgically resected, and fully irradiated glioblastoma multiforme of the left temporal lobe was referred with local recurrence and extension of his tumor. Further surgical and radiation therapy was not considered possible, and the patient was referred to an experimental protocol for the superselective intraarterial injection of the chemotherapeutic agent BCNU. A control stereoscopic left internal carotid angiogram was obtained (figs. 5A and 5B). Then, a 2 French balloon catheter was introduced via an 8 French internal carotid artery guiding catheter, using a propulsion chamber, into the left middle cerebral artery from which the tumor received its vascular supply. A stereo lateral superselective left middle cerebral angiogram showed excellent position of the balloon catheter (figs. 5C and 5D). Positron emission tomography using isotope-labeled BCNU injected via the catheter showed selective tumor uptake of the chemotherapeutic agent. After this, the patient received a therapeutic dose of 500 mg of BCNU via the catheter.
Discussion

Stereoscopic angiography has been advocated by a number of authors in the recent literature [9-11]. Although it has never achieved wide acceptance, stereoscopy has been used with great success at the Montreal Neurological Institute for many years. Angiography is performed to show the vascularity of a lesion and the relations between lesions and normal surrounding vessels, as well as abnormal supplying arteries and draining veins. Stereoscopy, with its unique three-dimen-
Stereoscopic digital imaging, offers a much clearer picture of these relations in a spatial context that more nearly approaches reality. It has been demonstrated that observers using stereoscopy can discriminate between quite small differences in depth [12].

Stereoscopic digital imaging is particularly useful in the documentation of aneurysms, giving more precise anatomic detail, showing the relations between neck, fundus, and surrounding vessels. Furthermore, the tube can be rotated with ease into the appropriate orientation. Arteriovenous malformations may also be elucidated in a superior fashion using this technique. A three-dimensional demonstration of the exact number and course of feeding vessels and draining veins is possible. In the case of brain tumors, the extent of the mass lesion, the vascular displacement, and the abnormal tumor vasculature may all be ascertained more clearly. Stereoscopic views were considered more useful as neurosurgical "road maps" as well and were a significant aid in planning the surgical approach. Intravenous stereoscopic DSA was useful postoperatively in assessing the success of aneurysm clipping without resorting to the more invasive arterial approach. Reference to the usefulness of this technique in conjunction with therapeutic and stereotaxic procedures has already been made.

The disadvantages of intravenous DSA have been analyzed in the literature [8, 13]. These include the superimposition of vessels, a particular problem in intracranial analysis, as well as the dilution of contrast material through the pulmonary circulation resulting in the need for a higher contrast load, which in turn results in patient discomfort, motion artifact, and poor image quality. The correlative advantages of intraarterial DSA are fourfold: (1) a higher degree of image resolution; (2) the ability to opacify vessels selectively, (3) decreased incidence of motion artifact, and (4) decreased contrast burden.

Several authors have advocated the use of arterial injection DSA routinely over conventional film-screen angiography [4-7]. There are several advantages: (1) immediate availability of subtracted images in real time, a major advantage in interventional, therapeutic maneuvers; (2) reduced procedure time and therefore reduced catheter time; (3) decreased injection rate and volume and concentration of contrast material; (4) decreased patient discomfort and therefore increased patient cooperation; (5) increased patient safety secondary to 2-4 above; (6) higher degree of image resolution vis-a-vis large vessels; (7) decreased need for selective catheterization in certain circumstances; and (8) lower film cost.

We have developed a new method of stereoscopic angiography by combining the demonstrated advantages of arterial injection DSA over both intravenous DSA and conventional film-screen arteriography and the advantages of stereoscopic imaging with its inherent ability to demonstrate three-dimensional detail. Limitations of the present system may be divided into those that relate to digital angiography per se and those that result from our technique of acquiring stereoscopic images. In the former case, DSA is limited by its small field size and its relatively poor resolution of small vessels. For neurosurgeons and neuroradiologists accustomed to looking at full-size angiograms, the relatively small hard-copy images are considered to be a disadvantage.

In acquiring stereoscopic images, it is currently necessary to rotate the C-arm to the second viewing position and repeat an injection, necessitating longer procedure time and increased contrast burden to the patient. Normally the two views subtend an angle of 7° at the intensifier. Because the intensifier moves with the C-arm, the two views contain some degree of lateral distortion in the form of a slight compression along an axis. This, however, may be easily corrected by the computer using a linear image transformation.

We are currently investigating the acquisition of a new digital angiography system that would include as features a 14 inch (35.6 cm) field and the ability to generate single-frame, full-size hard-copy images. A 1024 × 1024 matrix capability will allow greater spatial resolution, although at the expense of a fourfold increase in x-ray exposure, and a smaller fractional focal spot. We are also actively investigating the installation of a dual-focus x-ray tube allowing stereoscopic views to be obtained with one injection only. This has been done successfully at the Montreal Neurological Institute using a conventional film changer and elsewhere using a mounted image intensifier system [14].

Already, software has been implemented on the Technicare DR-960 computer to facilitate analysis of angiograms made under stereotaxic conditions. Pointlike fiducial markers attached to the stereotaxic frame are recognized by the program, and a computer-generated "frame" is displayed at any selected level within the imaged volume. Frame coordinates of structures at selected levels may be calculated simply by placing a joystick-controlled cursor at the appropriate position on the screen. Currently planned developments include the ability of the computer system to generate two independent stereoscopic images that can be displayed on a special-purpose stereoscopic viewing system. It will then be possible to manipulate a cursor in three-dimensional space and directly calculate coordinates of and distances between structures within the imaged volume.

Stereoscopic images can now be generated with assignments of color values to arteries and veins. This has proven useful in the evaluation of vascular malformations in which the feeding arteries and veins of an arteriovenous malformation may appear red and in which the draining veins appear blue.

ACKNOWLEDGMENTS

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REFERENCES


