ethanol ingestion increases platelet reactivity to ADP and associated TXB₂ formation. Whether this suggests that an individual risk factor for ischemic brain infarction might be associated with a change in platelet reactivity remains to be elucidated.

Acknowledgment
We would like to thank Mr. Kari Soini (Orion Pharmaceutical Co.) for excellent technical assistance.

References

Impact of Digital Subtraction Angiography
On Carotid Evaluation

DAVID C. ANDERSON, M.D., GREGORY G. FISCHER, M.D.

SUMMARY Impact of digital subtraction angiography by intravenous injection (DSAV) was examined in a private neurology clinic. In the evaluation of threatened stroke, advent of DSAV was associated with reduced use of both traditional noninvasive tests (from 100% of patients to 36%), and conventional arteriograms (from 29% to 4%). Less compelling indications were often prescreened with noninvasive tests; more compelling symptoms usually had initial DSAV. Conventional arteriograms were done for compelling indications and negative or inadequate DSAV. The average cost of evaluation was increased one or more of the traditional noninvasive tests (eg. oculoplethysmography, Doppler flow evaluation, or ultrasound imaging). There has been little disagreement about the preliminary or screening role of the traditional noninvasive tests or about the definitive role of conventional arteriography. The advent of digital subtraction angiography by intravenous contrast injection (DSAV) raises new questions and controversies. DSAV uses computer technology and the subtraction principle to enhance contrast differences, allowing

PATIENTS WITH SUSPECTED CAROTID ATHEROSCLEROSIS were selected for endarterectomy, until very recently, on the basis of conventional contrast arteriography, sometimes after screening with

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visualization of arteries containing relatively low iodine concentrations, easily achieved following an intravenous bolus of dye.\textsuperscript{1-4} While several vascular beds lend themselves to evaluation by the technique, the brachiocephalic arteries are particularly well-suited. Extensive literature has already appeared describing the technical aspects and clinical applications of imaging these vessels.\textsuperscript{5-12} Early experience with DSAV in clinical settings emphasized its use predominantly in a screening role.\textsuperscript{4, 5, 13} More recently, the results of DSAV have sometimes been applied definitively, without confirmation by conventional arteriography, in selecting patients for carotid endarterectomy.\textsuperscript{5, 12} Changing concepts about the value and application of DSAV raise important questions about cost effectiveness and quality of cerebrovascular evaluation.

In communities where traditional noninvasive tests have been used extensively, the availability of DSAV will be expected to alter the pattern of utilization of these tests. DSAV, it now appears, will also affect the utilization of conventional arteriography. The changes will have economic ramifications for patients as well as for noninvasive laboratories and departments of radiology. To learn more about these ramifications, we examined the impact of DSAV on the policies of cerebrovascular evaluation in a large private group neurologic practice.

Methods

We studied the policies of cerebrovascular evaluation of an eleven-neurologist practice group in Minneapolis. Within the membership there is special interest in cerebrovascular disease, which comprises a relatively large part of its practice. Several of the neurologists have extensive interest and experience in traditional noninvasive technologies. B-scan ultrasound imaging has been available in the clinic since 1978, duplex scanning since 1980, and continuous wave Doppler signal analysis since 1980. The ultrasound procedures are performed by the physicians themselves, and they have validated their accuracy by comparison of ultrasound predictions with results of conventional arteriography performed in several hospitals around the city.\textsuperscript{13} A DSAV unit (Technicare Model 260 with C-arm) was installed in the clinic in September of 1981. More than 3200 studies have been performed with the DSAV unit (to March, 1984).

To determine the effects of the availability of DSAV on this group practice, we retrospectively examined policies of cerebrovascular evaluation during two 3-month periods. The period April 1–June 30, 1981 (designated "pre-DSAV"), was representative of the situation before the arrival of DSAV, when the pattern of utilization of traditional noninvasive tests (B-scan imaging and Doppler signal analysis) was well established. The period April 1–June 30, 1982 ("post-DSAV"), beginning some nine months after the DSAV unit was installed, was representative of circumstances since the new technology has been available and clinical application has stabilized. At the beginning of the post-DSAV period, more than 500 patients had been studied on the unit.

All patients included in the survey were referred by individual members of the clinic. Patients referred by nonclinic physicians for either noninvasive studies or DSAV were excluded from further consideration. It was hoped that the inclusion of only patients of the group neurologists would assure that the policies and thinking of physicians most experienced in the technologies of cerebrovascular evaluation would be reflected in the results. In the pre-DSAV period, patients were identified by referral to the ultrasound laboratory. A few patients may have been admitted directly to one of the local hospitals for conventional carotid arteriography, but such a policy was unusual. Ultrasound was used in virtually all cerebrovascular patients evaluated in the clinic, sometimes to establish the urgency of hospitalization. In the post-DSAV period, study patients were identified by referral to either the ultrasound or DSAV laboratory. Again rare cases referred directly to hospital for conventional arteriography could have been missed.

The clinic charts of all identified patients were reviewed and compared for the two study periods. Data of interest included age and sex, indication for cerebrovascular evaluation, the combination of evaluative technologies employed (B-scan, Doppler signal analysis, conventional arteriography, and, in the post-DSAV period, DSAV), temporal sequence of tests, treatments, and, when relevant, the elapsed time between evaluation and surgery.

In tabulating findings, areas of specific interest included: 1. Differences between pre-DSAV and post-DSAV periods in the number and types of tests done and the speed of the evaluation; 2. Differences in treatment in the two time intervals; 3. The effects of clinical variables, specifically indication for study, on the choice of tests in the post-DSAV period; 4. Comparison of costs of cerebrovascular evaluation in the pre-DSAV and post-DSAV intervals.

Results

Effect of DSAV on Evaluation

As shown in table 1, the availability of DSAV was associated with a reduction in the rate of performance of ultrasound studies. All patients in the pre-DSAV period had ultrasound studies, while only about one third of patients in the post-DSAV interval did. There was also a difference in the type of ultrasound noninvasive tests ordered in the two periods. In the pre-DSAV period, all patients referred to the ultrasound laboratory had B-scan imaging. 70 percent as the sole noninvasive evaluation and 30 percent in combination with continuous wave Doppler signal analysis. No patients in the early period were studied by Doppler signal

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Comparison of Test Selection in Pre-DSAV and Post-DSAV Intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-DSAV (158 pts)</td>
</tr>
<tr>
<td>Traditional noninvasive tests</td>
<td>100% (158)</td>
</tr>
<tr>
<td>DSAV</td>
<td>—</td>
</tr>
<tr>
<td>Conventional arteriography</td>
<td>29% (45)</td>
</tr>
</tbody>
</table>
analysis alone. In the post-DSAV period, by contrast, among those who had ultrasound tests, the proportion of patients studied by B-scan imaging alone dropped to 50 percent, and about 10 percent underwent Doppler signal analysis only. Most of this last group were studied with Doppler signal analysis after imaging by DSAV suggested stenosis of intermediate severity. Doppler signal analysis was applied in an effort to establish hemodynamic significance.

An equally or more impressive change was the reduction in rate of conventional arteriograms from about 30 percent of patients in the pre-DSAV period to less than 5 percent in the later interval.

Since there was a reduction in both traditional non-invasive tests and conventional arteriography in the post-DSAV period, it seemed likely that the tempo of evaluation would be increased, with reduction of time “at risk” between appearance of cerebrovascular symptoms and definitive surgery. Unexpectedly, the reverse was observed: The average interval from the first test (usually coinciding with the day of the initial consultation) to surgery was 8.2 days in the pre-DSAV period and 10.4 days in the post-DSAV period. It was thought that special preparations required for DSAV (eg. no solid foods beforehand) might impose some delay. Preparations were not the explanation, apparently, because the average interval from the day of DSAV until surgery was still 10.0 days. The reasons for this delay were not ascertained.

**Management Policies Associated with DSAV**

As shown in table 2, no conspicuous change in the proportion of patients undergoing surgery was associated with the availability of DSAV, nor was there a change in the rate of bilateral endarterectomies. The distribution of other therapies was also similar in the two time periods.

**Clinical Indication and Cerebrovascular Testing**

Table 3, which deals with only the post-DSAV period, displays the relationship between clinical indications for evaluation and the studies actually undertaken. The indications fell rather clearly into two categories. Bruit and “possible TIA” (including patients with ill-defined symptoms and those with complaints which suggested generalized or posterior circulation hypoperfusion) formed one group, considered to have less compelling indications for cerebrovascular study. Carotid TIA, amaurosis fugax, and mild completed stroke in the anterior circulation (partially reversible ischemic neurologic deficit), generally considered stronger indications for evaluation, formed a second category, which was dealt with differently. Patients in the first category (“soft” indications) were usually prescreened with ultrasound. Only one third of this group underwent DSAV as the initial study, and just one underwent conventional arteriography. By contrast, more than 80 percent of patients in the second category (“hard” indications) were studied initially with DSAV. Twenty percent of the patients with amaurosis fugax underwent conventional arteriography, presumably reflecting concern about embolic sources which might require higher spatial resolution for visualization.

**Costs of Cerebrovascular Evaluation**

At the clinic, the combined technical and professional charges for B-scan imaging are $225, for Doppler signal analysis, $105, and DSAV, $600. At the hospital used most often by the clinic, combined hospital and professional charges for arteriography are $867 for the study itself, to which we added $250 for one day in hospital (which may be a conservative allowance for hospitalization necessitated for the test), for a total of $1,117. Using these charges and considering the percentage of patients undergoing each of these tests in the pre-DSAV and post-DSAV intervals, the average cost for cerebrovascular evaluation pre-DSAV was $575 and post-DSAV, $603. For the subgroup of patients undergoing surgery, pre-DSAV ex-

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**Table 2** Comparison of Treatment Selection in the Pre-DSAV and Post-DSAV Intervals

<table>
<thead>
<tr>
<th></th>
<th>Pre-DSAV (158 pts)</th>
<th>Post-DSAV (237 pts)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surgical</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unilat endarterectomy</td>
<td>7% (11)</td>
<td>9% (22)</td>
</tr>
<tr>
<td>bilat endarterectomy</td>
<td>4% (6)</td>
<td>4% (9)</td>
</tr>
<tr>
<td>total</td>
<td>11% (17)</td>
<td>13% (31)</td>
</tr>
<tr>
<td><strong>Nonsurgical</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unknown</td>
<td>14% (22)</td>
<td>22% (51)</td>
</tr>
<tr>
<td>none</td>
<td>31% (49)</td>
<td>27% (65)</td>
</tr>
<tr>
<td>antithrombotic</td>
<td>31% (49)</td>
<td>30% (72)</td>
</tr>
<tr>
<td>anticoagulation</td>
<td>13% (21)</td>
<td>8% (18)</td>
</tr>
<tr>
<td>total</td>
<td>89% (141)</td>
<td>87% (206)</td>
</tr>
</tbody>
</table>

**Table 3** Comparison of Evaluation Policies for Different Indications in the Post-DSAV Period

<table>
<thead>
<tr>
<th></th>
<th>Traditonal non-invasive tests only</th>
<th>Traditonal non-invasive tests and DSAV</th>
<th>DSAV only</th>
<th>Conventional arteriography^†</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Soft&quot; indications</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bruit (22)*</td>
<td>36%</td>
<td>32%</td>
<td>32%</td>
<td>0</td>
</tr>
<tr>
<td>possible TIA (60)</td>
<td>37%</td>
<td>25%</td>
<td>38%</td>
<td>2%</td>
</tr>
<tr>
<td>&quot;Hard&quot; indications</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>carotid TIA (47)</td>
<td>2%</td>
<td>15%</td>
<td>83%</td>
<td>4%</td>
</tr>
<tr>
<td>amaurosis fugax (19)</td>
<td>0</td>
<td>21%</td>
<td>79%</td>
<td>21%</td>
</tr>
<tr>
<td>carotid stroke (43)</td>
<td>12%</td>
<td>2%</td>
<td>86%</td>
<td>2%</td>
</tr>
<tr>
<td>Miscellaneous (49)</td>
<td></td>
<td></td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Total (240)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Number of patients in each group. Total is 240 because three patients were studied twice.
†All patients undergoing conventional arteriography had traditional noninvasive tests and/or DSAV and are included in the appropriate columns.
Heterogenous group including postendarterectomy patency evaluation and syndromes not traditionally associated with threatened stroke, eg., dementia, seizures.
The changes in cerebrovascular evaluation observed in this neurology practice with the availability of DSAV probably herald similar changes elsewhere. We observed a moderate reduction in the number of ultrasound noninvasive tests and a marked reduction in the number of conventional arteriograms. This latter change was not associated with a reduction in surgery, meaning that DSAV was used as the definitive imaging modality for most endarterectomies in this group of patients. The average cost for cerebrovascular evaluation changed little, though the cost for the subgroup of patients who went to surgery was reduced. Somewhat unexpectedly, the tempo of evaluation was not increased by the use of DSAV and omission of other tests.

An interesting and important difference emerged in the approaches to different kinds of indications. The traditional ultrasound noninvasive tests retained their screening role in the evaluation of soft indications, such as asymptomatic bruit and vague or nonhemispheric symptoms. By contrast, DSAV was used as the primary test, without prescreening by ultrasound, in patients presenting with hard indications, such as carotid TIA, amaurosis fugax or mild completed stroke. The changes in cerebrovascular evaluation observed in this neurology practice with the availability of DSAV probably herald similar changes elsewhere. We observed a moderate reduction in the number of ultrasound noninvasive tests and a marked reduction in the number of conventional arteriograms. This latter change was not associated with a reduction in surgery, meaning that DSAV was used as the definitive imaging modality for most endarterectomies in this group of patients. The average cost for cerebrovascular evaluation changed little, though the cost for the subgroup of patients who went to surgery was reduced. Somewhat unexpectedly, the tempo of evaluation was not increased by the use of DSAV and omission of other tests.

The Relationship of DSAV to Traditional Noninvasive Tests

Early speculations about the clinical utility of DSAV emphasized its role as a "super" noninvasive test. Like ultrasound imaging, it would provide a visual display of bifurcational anatomy, but because of its roentgenographic format, the display would have greater credibility. Like the indirect tests, intracranial DSAV projections could provide some information about the status of the vessel distal to the bifurcation. The sequential imaging of the passage of contrast could convey some knowledge about the flow consequences of a lesion. In this way, and by development of special computer programs for estimating blood flow, DSAV may yield more sophisticated hemodynamic information than available from traditional noninvasive tests. The technology might then increase the yield of information compared with traditional noninvasive tests yet share the advantage of relative safety.

If these expectations about DSAV are realistic, the new technology might threaten to supplant traditional noninvasive tests. Early experience in comparing the predictive performance of DSAV with that of traditional noninvasive tests suggested that the former correlates more closely with conventional arteriography, supporting its expected superiority. Recently, however, in a prospective comparison of DSAV and ultrasound predictions against actual endarterectomy specimens, we found no greater accuracy for DSAV. Even if DSAV were superior, it is unlikely that the burgeoning traditional noninvasive technology will collapse. The traditional noninvasive tests will survive in their usual role of screening for conventional arteriography where DSAV is not available. In communities where DSAV does become available, the role of the traditional noninvasive tests will be altered and circumscribed.

Because of the discomfort and, more important, the expense of DSAV, the use of a preliminary screening test of much lower cost may be justified. It must be emphasized that pre-DSAV screening is reasonable only where it provides a significant cost advantage, since the risk of DSAV (the other major rationale for screening) appears to be much lower than that of conventional arteriography and probably does not warrant screening. Appropriate candidates for screening for DSAV with traditional noninvasive tests would be patients with the soft indications for evaluation. The necessity for very low cost would favor the simpler and less expensive noninvasive technologies, especially the indirect tests or Doppler signal analysis. If, for example, OPG with patient charge of $75 had been used as prescreen in the practice we monitored instead of an ultrasound battery, the average cost of cerebrovascular evaluation would have been $300 for those with soft indications. The more elaborate imaging tests, like B-scanning, can probably not be done inexpensively enough so that their use in a screening role would provide a cost advantage in this group with less compelling indications.

The Relationship of DSAV to Conventional Arteriography

In the practice we monitored, the advent of DSAV was associated with a more dramatic reduction in the rate of conventional arteriograms than traditional noninvasive tests. In many patients, including the majority of those having endarterectomies, DSAV replaced conventional arteriography as the definitive test. Conventional arteriography was performed infrequently and almost exclusively in patients with more compelling indications for evaluation, eg. amaurosis fugax, definite carotid TIA, or carotid distribution stroke. Omission of tests should reduce cost. In communi-
ties where traditional noninvasive tests have already been used effectively in a screening role, cost reduction has been previously enjoyed by those not going to surgery (i.e., those "screened" away from conventional arteriography). When DSAV is used in a definitive role, cost reduction is most notable among patients going on to surgery for whom conventional arteriography is replaced by DSAV — clearly the case in the practice we monitored. A reduction of procedure morbidity resulting from the omission of conventional arteriography was not measured in our study. The established reduction in cost to patients going to surgery as well as a presumed reduction in procedure morbidity by replacing conventional arteriography with DSAV are achieved at the expense of a reduction in imaging resolution.

Compared with conventional arteriography, the imaging detail of DSAV is limited by several factors. An irreducible basic limit in currently available DSAV units is spatial resolution of about two line pairs per millimeter compared with 10–12 line pairs for conventional screen-film techniques. To this limitation are added unavoidable superimposition of vessels with DSAV and the adverse effects on DSAV image quality of patient factors like movement or reduced cardiac output. Certain bifurcational configurations and features may challenge or escape definition by DSAV.

In selecting patients whose workup might reasonably omit conventional arteriography, it would be ideal to define prospectively when a negative DSAV study will be adequate to decide against further investigation and when a positive DSAV will be adequate to proceed to surgery without further study. To be differentiated are those in whom we 1) will not accept a negative DSAV but will require a conventional arteriogram for definitive exclusion of operable disease or 2) will not be satisfied with a positive DSAV result without confirmation before proceeding to surgery. If those patients in whom DSAV results are unlikely to be definitive could be identified ahead of time, they might be better studied only with conventional arteriography at a savings in cost, inconvenience, and exposure to contrast media.

In the practice we monitored, clinical indications were important in determining whether conventional arteriography was employed. The more invasive study was used almost exclusively, albeit infrequently, in patients presenting with symptoms which were more discretely localized in the carotid distribution. Resort to conventional arteriography presumably stemmed from the belief that nonstenotic ulcerative disease may be important by an embolic mechanism in the production of focal cerebral or ocular symptoms. Such disease is probably less well defined by DSAV than conventional arteriography. It might be added parenthetically that concerns about insensitivity of DSAV for ulcers are mollified somewhat by continuing uncertainty that conventional arteriography displays them reliably and conflicting ideas about the natural history of nonstenotic ulcerative disease.

Most patients presenting with the hard indications (e.g., amaurosis fugax, definite carotid TIA) do, in fact, have stenosis, which would be well demonstrated by DSAV at a savings of cost and reduced procedure risk. A new role for hemodynamically-based traditional noninvasive tests might be in selecting the most expedient definitive test for those with hard indications. Those patients with positive traditional noninvasive tests, indicative of stenosis, might be definitively studied with DSAV, while those with negative tests referred directly for conventional arteriography.

Defining which patients with positive DSAV need conventional arteriography before surgery is another matter. Certainly pre-operative conventional arteriography is reasonable and indicated when DSAV is seriously suboptimal, though highly suspicious for the presence of bifurcational disease. The reported rate of definitely "inadequate" studies varies from four to 42 percent of cases, There is, unfortunately, no quantitative measure of the "adequacy" of imaging, and images which are sufficient for one surgeon may not be for another.

Another concern is the limitation of intracranial vascular information obtained when DSAV replaces conventional arteriography. DSAV currently does not display intracranial stenoses or aneurysms as reliably as conventional arteriography. These findings, which are considered important in patients who may undergo carotid endarterectomy, are common among those with suspected carotid disease. In 50 patients studied by conventional arteriography for suspected carotid disease, 21 of 100 carotid systems harbored relevant intracranial findings (middle cerebral or anterior cerebral artery stenoses — 8; intracranial carotid stenoses — 7; aneurysms — 5; distal embolic occlusions — 1). The question remains whether the demonstration of such findings does or should alter management decisions in patients with definite and operable bifurcational disease. A recent report suggests that the coexistence of intracranial carotid disease does not influence the outcome in patients undergoing carotid endarterectomy. However, in another retrospective study, findings which changed management in a major way were revealed by conventional arteriography in five percent of a group studied initially with DSAV.

Ultimately, the procedure risk of undertaking conventional arteriography pre-operatively in all endarterectomy candidates must be compared with the intra-operative or long term risk of missing findings by using DSAV rather than conventional arteriography. That information is currently not available.

Acknowledgments

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References

Impact of digital subtraction angiography on carotid evaluation.
D C Anderson and G G Fischer

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