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Digital Subtraction Angiography of the Abdomen: Henry Ford Hospital Experience

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Digital subtraction angiography (DSA) produces high-contrast digital images of the abdominal vasculature with minimum patient discomfort. We summarize the Henry Ford Hospital experience with DSA in evaluating various abdominal vascular disorders. The methods and merits of intravenous and intraarterial approaches, the advantages and disadvantages compared with those of conventional angiography, and the current limitations of DSA are discussed.

Digital subtraction angiography (DSA), first introduced for clinical use in 1979 (1), is especially useful for evaluation of the extracranial, renal, and peripheral vascular systems. DSA integrates standard radiographic and angiographic procedures with the high-speed digital data storage and image processing capabilities of computers to produce high-contrast digital images of the vasculature with minimum patient discomfort and reduced technical and radiographic costs. Although DSA was initially performed after intravenous administration of contrast media, both intravenous (IV-DSA) and intraarterial (IA-DSA) approaches are now used.

DSA has been available at Henry Ford Hospital for approximately three years. During this period, more than 5,600 DSA examinations have been performed. About 15% of these have involved abdominal imaging for evaluating mainly renovascular hypertension. The application of DSA to abdominal angiography is described here.

Imaging and Injection Techniques

Using a Technicare DR-960 DSA system with a 512 x 512 x 8-bit digital computer matrix and a temporal subtraction technique, digital radiographic images were obtained before, during, and after passage of radiopaque contrast material through the vasculature. A high-contrast image of this vasculature was subsequently obtained by subtracting one of the images that contained little or no vascular contrast enhancement (ie, background organ contrast only) from the image obtained at or near peak vascular opacification. Since background and contrast-enhanced images are obtained at different times, the technique is called temporal subtraction.

DSA of the arterial vasculature is performed after intravenous administration of highly iodinated contrast agents (IV-DSA), which are rapidly diluted in the circulation. Most IV-DSA studies in this series were performed using meglumine/sodium diatrizoate, 76% weight per volume (wt/vol) containing 370 mg iodine/mL. In adults, single doses of 30 to 35 mL were typically injected at flow rates of 25 to 30 mL/sec. Repeat injections seldom raised the total volume to 150 mL, and only in extraordinary circumstances did the total volume exceed 200 mL.

Because of the inherent high-contrast resolution of DSA and the diminished prearterial vascular dilution of the media, IA-DSA procedures may be performed after administration of relatively dilute contrast material (ie, meglumine/sodium diatrizoate, 15% to 30% wt/vol, 70 to 150 mg iodine/mL). Consistent with conventional film angiography, volumes of contrast agent are minimal to reduce media-induced flow artifacts. For example, a single 30 mL dose of contrast agent injected at a rate of 15 mL/sec is satisfactory for IA-DSA examination of the abdominal aorta.

Originally in this series, IV-DSA procedures were performed after injection of contrast agent into the superior vena cava; however, right-atrium injections are now routinely used. Experience has demonstrated some image superiority associated with right-atrium injections (compared with images obtained after superior or inferior vena cava injections) and clear-cut image superiority (compared with images obtained after direct injection into the antecubital [basilic or cephalic] veins). A 5-F, 70-cm, pigtail catheter is typically used for injections into the right atrium. This catheter can withstand a maximum pressure of 1,080 psi and is capable of delivering up to 30 mL/sec of a 76% wt/vol contrast medium. If possible, it is preferable to introduce the catheter via the basilic vein because of frequent difficulty in negotiating the cephalic subclavian junction. Inadequate venous access from

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the antecubital approach requires catheter placement via the femoral vein in approximately 5% of patients. Central venous lines and arteriovenous shunts have also been used for the injection of contrast media.

The relatively low injection rate and less viscous, dilute contrast material required for IA-DSA also permits the use of 4- or 5-F catheters. The new 4-F, 65-cm, high-flow catheters can deliver contrast material at approximately 25 mL/sec at 1,050 psi. These small-diameter, high-flow catheters have made outpatient IA-DSA procedures a reality.

DSA procedures are typically performed on an outpatient basis. Most adults require no premedication or preparation other than a clear fluid diet, with hydration commencing four hours prior to the procedure.

A major problem encountered in abdominal and other DSA procedures is misregistration artifacts associated with patient, organ, and vasculature repositioning during the temporal imaging sequence. Failure of the patient to suspend respiration during imaging, or involuntary patient movement frequently results in such artifacts. Bowel peristalsis may also result in artifacts. The intravenous injection of 1 mg of glucagon one to two minutes before the DSA procedure diminishes peristaltic artifacts in 60% of patients and eliminates them entirely in 40% (2). Abdominal compression or prone positioning to displace the bowel away from the kidneys will also help to decrease peristalsis artifacts in DSA renal studies.

Clinical Applications

Hypertension of renovascular origin accounts for approximately 4% of the total incidence of hypertension in the United States (3); the most common cause of renovascular hypertension is renal artery stenosis. The standard for the preoperative diagnosis of renovascular hypertension has been conventional renal arteriography combined with renal vein renin assay. However, the associated technical complexity, film costs, and requirement for hospitalization make conventional renal arteriography economically unfeasible for routine screening of hypertension patients to evaluate for renal artery stenosis. The advent of outpatient DSA procedures to aid in diagnosing renal artery stenosis provides a more cost-effective method for such a screening program (4,5). In this regard, DSA is a more sensitive and specific diagnostic tool than rapid sequence intravenous urography (6). Additional economic advantages may be realized if renal vein sampling for renin and IV-DSA are performed via the femoral vein in the same sitting. The two procedures are complementary; IV-DSA identifies morphology (i.e., renal artery stenosis) while renin assay confirms its physiological significance. Furthermore, DSA can be both a diagnostic screening study and a satisfactory pretherapy study, providing an adequate vascular road-map for subsequent balloon angioplasty or surgery (Figs 1, 2).

In the renal DSA procedure, a frontal aortogram series is usually obtained (9-inch field of view) to evaluate the abdominal aorta and the renal arteries. Subsequent lateral oblique views are obtained (6-inch field of view) to demonstrate the origins and middle-to-distal portion of each artery. Although the renal artery and its second-order branches are usually well demonstrated by IV-DSA, a branch stenosis can be easily missed. In this regard, the quality of DSA images of the aortorenal vasculature is usually better with an IA-DSA approach. If the IV- or IA-DSA renal study is rendered nondiagnostic by bowel misregistration artifacts or if renal vein sampling reveals lateralization of renin in absence of demonstrated stenosis, conventional renal arteriography is required.

In screening for renovascular hypertension, IV-DSA is useful in detecting large arteriovenous malformations and renal artery aneurysms and large hypervascular renal masses. Smaller and/or hypovascular renal masses can be easily missed, however, due to the relatively poor spatial resolution of IV-DSA and/or diminished vascular contrast. It should be noted that selective IA-DSA has proven to be far superior to IV-DSA for the evaluation of renal masses.

IA-DSA is an extremely useful interventional radiological technique for procedures such as percutaneous transluminal angioplasty (PTA) of the renal arteries (7). Subsequent follow-up evaluations of the PTA are usually performed using IV-DSA (8). Similarly, IV-DSA can provide postoperative information concerning the patency and function of renal artery bypass grafts (Fig 3).
Initial enthusiasm over the use of the IV-DSA for the preoperative evaluation of potential renal donors has diminished because small accessory arteries are missed in 17% to 18% of cases (9). It is anticipated that larger fields-of-view may reduce this error rate. Accuracy can also be improved by routinely obtaining oblique views and acquiring the images at a faster rate.

Radiographic examination of azotemic hypertensive patients is difficult because of their abnormal renal function, hypertension, and frequently related medical problems (conditions further complicated by the intravascular administration of ionic contrast material) (10). In this regard, the reduced volume and concentration of contrast material necessary for IA-DSA makes this approach more suitable for their examination (8). Furthermore, an adequate intravenous bolus of contrast material may not be propelled to the renal arteries in a patient who has decreased cardiac output, and the result may be a poor IV-DSA study.

IV-DSA of the abdominal aorta is useful primarily for the assessment of atherosclerotic changes, including aneurysm formation (Fig 4), and in the evaluation of postoperative aortic grafts (Fig 5). With IV-DSA the aortic aneurysm or graft is totally opacified since the contrast material is completely
mixed with blood prior to its passage through the aorta (11). This provides an advantage over catheter aortography where layering of the contrast material against the posterior wall of the aorta often occurs when the patient is in the supine position. With IV-DSA, however, renal and visceral arteries may not be adequately visualized due to poor cardiac output or vascular motion artifacts. Hence, contrast-enhanced computed tomography (CT) is often used in conjunction with IV-DSA to demonstrate the proximal and distal extent of abdominal aortic aneurysms and their relationship to the renal arteries.

IV-DSA is ideal for the evaluation of aortic occlusion (Fig 6), aortic stenosis, and Leriche’s syndrome (12). In conventional aortography, injection of contrast material above the aortic occlusion often fails to image adequately the iliac or femoral vasculature below the occlusion. With IV-DSA, however, contrast material reaches the postocclusive vasculature by way of all collateral vessels, thus providing adequate images of the iliac and femoral vasculature and additional information.

IV-DSA may also provide useful information regarding aortic dissection (13). Unlike conventional angiography where only the injected lumen is clearly demonstrated, IV-DSA provides visualization of both the true and false channels following a single injection of contrast material. Intimal disruption can be subtle, however, and may be easily overlooked due to the diminished spatial resolution of IV-DSA and associated image degradation resulting from the motion artifacts of vascular pulsations and respiration. Some patients are hemodynamically unstable and have poor cardiac output, and results of IV-DSA studies are poor. Preliminary experience suggests an improvement in results when using the IA-DSA approach for the evaluation of aortic dissections, especially in the visualization of false lumen. Extensive prospective trials comparing findings of IV-DSA, IA-DSA, conventional aortography, and CT are necessary to clarify the final role of DSA in the evaluation of aortic dissection.

IV-DSA is useful in the evaluation of intestinal ischemia. Major mesenteric vessels and their first-order branches can be
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readily visualized with IV-DSA, although smaller branches are frequently obscured due to overlap and peristaltic activity (Fig 7). Video densitometry may provide a method to quantitate the degree of mesenteric stenosis; however, this procedure requires further evaluation (14).

IA-DSA is typically performed for analysis of the hepatic arterial and portal vasculature. Hypervascular, primary, or metastatic hepatic tumors are clearly demonstrated by IA-DSA via catheterization of the hepatic artery. The capillary phase stain (ie, diffuse retention of contrast media) associated with malignant tumors is better demonstrated with DSA than with other radiographic procedures (15). This characteristic is a major advantage of DSA, and this finding can be used to document conclusively metastatic disease in the presence of the doubtful or equivocal CT study. Cavernous hemangiomas may also be imaged by IV-DSA, but the IA-DSA approach is superior in demonstrating this condition. The left lobe of the liver is well visualized by IA-DSA via the common hepatic artery without the need for performing selective left hepatic artery catheterization. Furthermore, in conventional film angiography, the spine often obscures visualization of the left lobe of the liver, but with DSA, bony structures are eliminated from the final image by virtue of the inherent background subtraction.

Portal venous anatomy, flow direction, and portal systemic shunts are usually evaluated using the venous phase of conventional celiac and superior mesenteric angiography (16). For the past two years, the use of IA-DSA has been evaluated for examination of the portal venous system (17). The presence of motion artifacts has been problematic, but when these artifacts are avoided, the IA-DSA procedure provides better evaluation of the portal system than conventional angiography. In addition, the IA-DSA procedure is better tolerated by the patient. The total workup of portal hypertension, including determination of hepatic wedge pressures, left renal venography, and IA-DSA of the portal system can be performed in 30 minutes. Technically adequate IA-DSA portogram studies, suitable for surgical planning, can be obtained in approximately 90% of patients (Figs 8, 9, 10). If
findings of the DSA study are inconclusive, conventional film angiography may be required.

The diagnosis and localization of acute and subacute gastrointestinal bleeding aided by findings of DSA is limited by the presence of artifacts, which can easily obscure areas of extravasation.

Discussion

Future applications of DSA to evaluations of the abdominal vasculature will depend on the recognized advantages and disadvantages of this technique compared to conventional film angiography and on the development of modifications to overcome its current limitations.

General disadvantages of DSA include decreased spatial resolution relative to conventional angiography. Because of this poorer spatial resolution, fine details of angioarchitecture are often lost. Fortunately, for most abdominal applications, fine resolution is not needed for a diagnosis. The inherent better contrast resolution of DSA does provide partial compensation for this disadvantage by augmenting the visualization of small vessels. Second, with IV-DSA, all vessels are opacified, resulting in vascular overlapping on the final images. Finally, DSA cannot be performed on uncooperative patients due to the deleterious influence of motion on the imaging process. Postprocessing, increased imaging rates, and ECG-gating of images addressed this motion problem to some extent. However, postprocessing is not universally successful due to the complex nature of patient motion, and increasing the imaging rate results in an increased radiation exposure to the patient. A current research technique, dual-energy subtraction, may provide an alternative to temporal subtraction for the elimination of motion artifacts (18). With this modification, both the background and contrast-enhanced images are obtained simultaneously, thus avoiding problems with motion-induced misregistration of the temporal image sequence. Another subtraction technique, hybrid subtraction, eliminates motion artifacts by subtraction of two dual-energy temporal images (19).
Conclusion

DSA is a well-accepted diagnostic imaging modality with several applications. Abdominal images of acceptable quality are obtained in more than 90% of patients who undergo DSA, and in many instances DSA is the only angiographic procedure necessary for a definitive diagnosis. Motion artifact is the major cause of nondiagnostic DSA examinations. Further technological developments, such as dual-energy subtraction, will further increase the application and will reduce the limitations of DSA.

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