

# A Prospective Study of Carbon Dioxide-Digital Subtraction vs Standard Contrast Arteriography in the Evaluation of the Renal Arteries

David Z. Schreier, MD; Fred A. Weaver, MD; Joseph Frankhouse, MD; George Papanicolaou, MD; Ernest Shore, MD†; Albert E. Yellin, MD; Frances Harvey, RN

**Objective:** To compare carbon dioxide-digital subtraction arteriographic (CO<sub>2</sub>-DSA) images of renal artery anatomy with standard iodinated contrast arteriographic (ICA) images.

**Design:** One hundred patients with vascular disease who required abdominal aortography were evaluated by both CO<sub>2</sub>-DSA and ICA modalities. Two blinded readers interpreted arteriograms for the degree of renal artery stenosis, and a third reader was employed to resolve differences in reader interpretations.

**Setting:** University medical center.

**Main Outcome Measures:** The sensitivity, specificity, negative predictive value, positive predictive value, and accuracy were calculated for the ability of CO<sub>2</sub>-DSA to demonstrate a 60% or greater stenosis of the main renal artery;  $\kappa$  values for CO<sub>2</sub>-DSA

and ICA were calculated to assess intraobserver variability.

**Results:** Of the 200 main renal arteries imaged, 17 (9 by means of CO<sub>2</sub>-DSA, 8 by means of ICA) were eliminated because of inadequate visualization of the renal artery. In identifying a renal artery stenosis of 60% or greater, CO<sub>2</sub>-DSA had a sensitivity of 0.83, specificity of 0.99, positive predictive value of 0.94, and negative predictive value of 0.98. The overall accuracy was 0.97. The  $\kappa$  statistic was 0.75 for CO<sub>2</sub>-DSA and 0.70 for ICA, hence, the variation in the interpretations of CO<sub>2</sub>-DSA and ICA were comparable.

**Conclusion:** Images by means of CO<sub>2</sub>-DSA accurately reflect pathologic changes in renal arteries and are thus useful in the diagnosis of clinically occult occlusive renal artery disease in patients at risk of contrast medium-related nephrotoxicity.

(Arch Surg. 1996;131:503-508)

**O**F THE ESTIMATED 30 to 60 million Americans with hypertension, 1% to 10% have hypertension because of critical renal artery stenosis.<sup>1,2</sup> Renal artery stenosis is found on aortograms in 31% to 60% of patients with documented abdominal aortic aneurysm, aorto-occlusive disease, or lower-extremity occlusive disease.<sup>3</sup> In those patients found to have critical renal artery stenosis, loss of renal mass is common, and diameter stenosis progression occurs at a rate of 4.6% per year.<sup>4</sup> Ischemic nephropathy, defined as the presence of anatomically severe occlusive disease of the extraparenchymal renal artery in a patient with excretory renal insufficiency, is the primary cause of end-stage renal disease in 6% of patients and in 14% of those older than 60 years.<sup>5</sup> In addition, occlusive renal artery disease contributes to renal excretory dysfunction in another unknown percentage of

patients with azotemia who do not require dialysis.<sup>6</sup> The frequency of ischemic nephropathy as a cause of end-stage renal disease has increased from 6.7% for the period of 1978 through 1981 to 16.5% for 1982 through 1985.<sup>7</sup> As a result, surgical intervention for occlusive renal artery disease, which historically focused on the amelioration of hypertension, is now most frequently employed to preserve or retrieve renal excretory function.<sup>8,9</sup>

In most medical communities, arteriography remains the principal and most reliable diagnostic test for occlusive renal artery disease. Despite advances in less invasive methods of renal artery assessment such as renal artery duplex ultrasonography, arteriography is eventually re-

From the Department of Surgery, University of Southern California School of Medicine, Los Angeles.

†Deceased.

See Patients and Methods  
on next page

## PATIENTS AND METHODS

### PATIENTS

From 1991 to 1995, 100 patients seen at and evaluated by the vascular surgery service who required a diagnostic arteriogram were entered into a study designed to compare CO<sub>2</sub>-DSA with iodinated contrast arteriography (ICA). Patients with renal insufficiency (serum creatinine level, >1.8 mg/dL), congestive heart failure, or known contrast-medium allergy were excluded. Institutional Review Board approval was obtained prior to the initiation of the study, and informed consent was obtained prior to participation.

Patients' ages ranged from 24 to 85 years, with a mean age of 62 years. Forty-five percent of patients were female, and 55% were male. Risk factors for vascular disease were tobacco use in 57%, diabetes in 48%, and hypertension in 50% of patients. The indications for arteriography were rest pain in 27%, claudication in 32%, ischemic ulcer or gangrene in 34%, hypertension in 12%, and femoral artery pseudoaneurysm in 3% of patients.

### METHODS

All studies were performed using digital subtraction technique, with the patient in the supine position. Views of the renal arteries were obtained by flush aortogram only. Selective renal artery injections and repositioning to obtain other views of the renal arteries were not performed. Arterial access was obtained via femoral artery cannulation with 5F to 5.5F catheters. The CO<sub>2</sub>-DSA study was performed first by sequential hand injections of 50 mL of

CO<sub>2</sub>; ICA followed using a power injector and nonionic iodinated contrast medium.

For each patient, the digital subtraction images obtained with either CO<sub>2</sub> or iodinated contrast were identified by a four-digit number. All images were first reviewed by two of us (G.P. and E.S.), and those found to be technically inadequate were removed from further evaluation. For the images further evaluated, 1 or 2 optimal views of the renal arteries were selected, placed in separate envelopes, and identified only by a 4-digit code number. These films were placed in random order and analyzed independently by 2 vascular surgeons blinded to patient and study results.

Readers were instructed to focus on renal artery anatomy and assess the location and degree of main renal artery stenosis. Location was classified as proximal (orificial), middle, or distal third of the renal artery. Renal artery stenosis was graded as 0% stenosis, 1% to 59% stenosis, 60% to 99% stenosis, or occlusion. Left and right renal arteries were each separately evaluated. Visualized accessory renal arteries were also noted. In addition, the CO<sub>2</sub>-DSA images were evaluated by a single reader (G.P.) regarding the visualization of branch anatomy of the renal artery and renal nephrogram.

If reader interpretation of renal artery anatomy for either the CO<sub>2</sub>-DSA or ICA images differed, a third blinded reader was employed as a tiebreaker for the purposes of statistical calculations. Using the ICA findings as the "gold standard," the sensitivity, specificity, positive predictive value, negative predictive value, and accuracy of CO<sub>2</sub>-DSA renal artery images compared with ICA images were determined. Intraobserver variability for both the CO<sub>2</sub>-DSA and ICA studies was determined by means of the  $\kappa$  statistic.<sup>19</sup>

quired when surgical or endovascular intervention is being considered.<sup>10</sup> A diagnostic evaluation that requires administration of nephrotoxic contrast medium may harm excretory renal function and is particularly troublesome if renal artery anatomy is found to be normal. Furthermore, despite improvements in contrast media and refinements in techniques, morbidity and mortality related to the use of iodinated contrast agents remains significant.<sup>11</sup> Clinical experience has demonstrated the nephrotoxic potential of ionic and nonionic contrast agents to be equivalent,<sup>12</sup> and deterioration in renal function following contrast arteriography has been reported to be as high as 11%.<sup>13,14</sup>

Carbon dioxide-digital subtraction arteriography (CO<sub>2</sub>-DSA) was introduced in 1982 and offers the advantages of a nontoxic, nonallergenic gas as the contrast agent. These attributes make it ideally suited as a diagnostic tool for renal artery disease in the patient with azotemia.<sup>15</sup> Since its introduction, the safety and efficacy of CO<sub>2</sub>-DSA in demonstrating arterial anatomy have been documented by several investigators.<sup>16-18</sup>

A focused investigation on the validity of renal artery pathology demonstrated by CO<sub>2</sub>-DSA has not been reported. In this study, a blinded comparison of CO<sub>2</sub>-DSA renal artery images with standard iodinated contrast images was performed to determine the reli-

ability of CO<sub>2</sub>-DSA and, hence, its usefulness as a tool to arteriographically screen patients with azotemia for occlusive renal artery disease.

### RESULTS

All studies were completed, and no adverse events occurred following either CO<sub>2</sub> or iodinated contrast injection. The CO<sub>2</sub>-DSA required up to 15 hand injections of 50 mL of CO<sub>2</sub>, and ICA required between 50 and 125 mL of nonionic iodinated contrast. The entire procedure lasted 1.5 to 4 hours. Of the 200 main renal arteries available for comparison, 17 were excluded because of poor technical quality, excessive overlying bowel gas, or poor contrast enhancement of the renal arteries (8 being ICA and 9 CO<sub>2</sub>-DSA images). There was no overlap between the 8 ICA and 9 CO<sub>2</sub>-DSA images. In fact, the excluded ICA studies had a CO<sub>2</sub>-DSA comparison that was evaluable. The failure rate in demonstrating the anatomy was comparable for both CO<sub>2</sub>-DSA and ICA (approximately 8.5%). This left 183 renal arteries for comparison.

The 2-reader interpretations for ICA and CO<sub>2</sub>-DSA are listed in **Table 1** and **Table 2**. The  $\kappa$  statistic was 0.75 for ICA and 0.70 for CO<sub>2</sub>-DSA. A third reader, the

**Table 1. Comparison of Reader Interpretations for ICA\***

Reader 2	Reader 1		Total
	Positive (60-100)	Negative (0-59)	
Positive (60-100)	14	6	20
Negative (0-59)	2	161	163
Total	16	167	183

\*ICA indicates iodinated contrast arteriograms; parenthetical values, percentage of stenosis (range).  $\kappa$  Statistics = .75.

**Table 2. Comparison of Reader Interpretations for CO<sub>2</sub>-DSA\***

Reader 2	Reader 1		Total
	Positive (60-100)	Negative (0-59)	
Positive (60-100)	18	10	28
Negative (0-59)	3	152	155
Total	21	162	183

\*CO<sub>2</sub>-DSA indicates carbon oxide-digital subtraction arteriograms; parenthetical values, percentage of stenosis (range).  $\kappa$  Statistics = .70.

tiebreaker, was required in the evaluation of 21 renal arteries.

The main renal artery was completely demonstrated in 183 CO<sub>2</sub>-DSA images, primary segmental branches in 154 images, and secondary branches in 86 images (Figure 1). A nephrogram was observed in 36 images (Figure 2). Accessory renal arteries noted to be present in 4 CO<sub>2</sub>-DSA images were confirmed by ICA; ICA demonstrated an additional 12 accessory renal arteries not seen on CO<sub>2</sub>-DSA. Stenotic lesions of the renal artery ranging from 1% to 99% were found in 29 CO<sub>2</sub>-DSA images and confirmed by ICA in 20 (Table 3). Of the 15 CO<sub>2</sub>-DSA images interpreted as showing stenoses of 60% or greater, the locations of the stenoses were correctly identified in all when compared with ICA images.

There were 164 true-negative, 15 true-positive, 1 false-positive, and 3 false-negative CO<sub>2</sub>-DSA images. Analysis of the 1 false-positive result demonstrated that a stenosis was present but called a greater-than-60% stenosis on CO<sub>2</sub>-DSA compared with a less-than-60% stenosis on ICA. For 1 false-negative image, the reverse was true, a less-than-60% stenosis was called on the CO<sub>2</sub>-DSA and a greater-than-60% stenosis on ICA (Figure 3). In the remaining 2 false negatives, CO<sub>2</sub>-DSA failed to demonstrate a greater-than-60% stenosis (Table 4). The sensitivity, specificity, positive predictive and negative predictive values and the accuracy of CO<sub>2</sub>-DSA to detect a greater-than-60% stenosis were 0.83, 0.99, 0.94, 0.98, and 0.97, respectively.

#### COMMENT

Arteriography has been considered the "gold standard" for the diagnosis of renal artery stenosis since the mid-1960s.<sup>20-22</sup> However, it is recognized that the veracity of

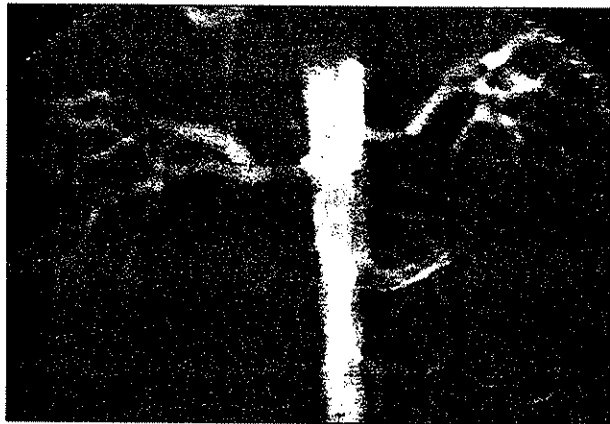


Figure 1. Carbon dioxide-digital subtraction arteriogram demonstrating renal artery anatomy.

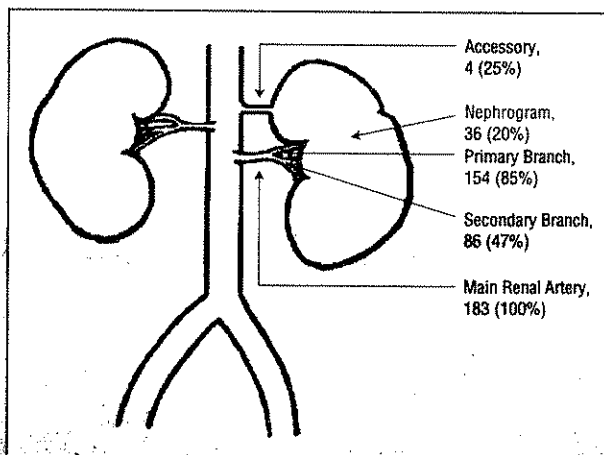


Figure 2. Renal anatomy demonstrated by carbon dioxide-digital subtraction arteriography. The branch anatomy and renal parenchyma successfully visualized are tabulated.

arteriographic findings can, in certain circumstances, be compromised. Dean et al<sup>20</sup> have delineated 5 anatomic patterns of renal artery anatomy, in which the detection of stenotic lesions may be problematic: (1) renal artery originating from the anterior or posterior aortic wall; (2) renal artery coursing from the aorta in an anterior posterior plane; (3) 2 renal arteries to 1 kidney that are superimposed; (4) complete occlusion of a midrenal, anterior, or posterior segment of the kidney; and (5) masking of renal artery stenosis by other intra-abdominal arteries. These 5 anatomic patterns may also have an impact on CO<sub>2</sub>-DSA. Selective injection of the renal artery or positional changes may rectify these problems in imaging for both CO<sub>2</sub>-DSA and ICA modalities. Because of the different properties of CO<sub>2</sub> and iodinated contrast, we elected to image the renal artery in a single position and without selective orificial injections, so as to not bias image quality in favor of one method over the other.

The difficulties with renal artery imaging also have an impact on the interpretations of individual readers. The  $\kappa$  statistic provides an estimate of test interpretation based on a blinded interpretation of 2 observers. A  $\kappa$  of 0 reflects random agreement, whereas a  $\kappa$  of 1 reflects complete agreement. The  $\kappa$  values for CO<sub>2</sub>-DSA and

ide study alone? This is a model for the objective analysis of a new technique.

**James J. Peck, MD, Portland, Ore:** We have been less happy with our results with CO<sub>2</sub>-DSA for renal artery disease in Oregon. In our experience, the CO<sub>2</sub> tends to float up into the anterior vessels and the hairpin distal renal arteries, obscuring our view. Without oblique views CO<sub>2</sub>-DSA has not been very helpful, especially when you use it selectively. The authors did mention 1 of the patients was missed because of a posterior placement of a vessel. Secondly, there have been several recent studies reporting similar results with MRA, magnetic resonance angiography, which is a noninvasive screening technique. Even with the commercially available 2D TONE, there has been a sensitivity of 91% reported from the University of Pennsylvania, with an overall accuracy of 81%. If you simply add 3D TONE, which is simply increasing the flip angle, you can get the sensitivity to 100% with a specificity of 89%. There are patients who, because of ferromagnetic implants or because of claustrophobia, are not candidates for MRA. On the other hand, the cost is very similar to this invasive procedure.

**Jonathan B. Towne, MD, Milwaukee, Wis:** We have used CO<sub>2</sub> angiography in very select patients in whom we have been concerned about with contrast. I do not think it is as good, in my experience, as the classic selection of catheterization with contrast, but it serves the purpose in a pinch. We are in a process of very rapidly evolving technology. One technique that has not been mentioned is spiral CT. As the super CT programs get developed, it is absolutely mind-boggling the type of visualization you can get and, in this case, with a totally noninvasive technique, although one that does require the injection of contrast.

**Dr Weaver:** With regard to Dr Gewertz' questions, we too were a little disappointed in the number of lesions that were ultimately diagnosed in this comparative study. However, there were 29 renal arteries that had some degree of stenosis. Consequently, this is about what you would expect if you investigate patients with vascular disease and occult clinical renal artery disease. Concerning the diagnostic accuracy of CO<sub>2</sub> compared to duplex scan, we have not done a comparative study. We have a very good renal artery duplex scanner at our institution and use it liberally. In my experience, the expertise that is required to provide high-quality renal artery duplex scans is considerable, as well as very time-consuming, and very tech-

nically dependent. The CO<sub>2</sub>-DSA is another option for those medical communities that do not have renal artery duplex scanning available.

The CO<sub>2</sub>-DSA is certainly cheaper than conventional arteriography, simply because of the cost of contrast. Non-ionic contrast presently costs about \$1/cc. You can perform about 50 CO<sub>2</sub>-DSA studies with 1 tank of carbon dioxide, which is very inexpensive; CO<sub>2</sub>-DSA is more expensive than a renal artery duplex scan. There is a learning curve in interpreting and creating the images, and I think this goes to what Dr Peck was saying about their difficulty in Oregon in using carbon dioxide. It took us a while to learn how to optimize the technique, and how to interpret it. The learning curve is no different from that for interpreting the "gold standard" of iodinated contrast arteriography; it is just that we are used to looking at conventional contrast arteriograms. If you look at the κ values we found for CO<sub>2</sub>-DSA and ICA, which basically looks at the variability of interpretation between 2 interpreters, it is quite similar between the CO<sub>2</sub>-DSA and the iodinated contrast. Selective injection might help; position probably helps the most. The buoyancy of gas does allow rapid filling in nondependent-placed structures, so that if you place the patient in an oblique position, you are more likely to get better views of the renal arteries than is possible in the supine position. One of the interesting findings in this study is that we found such good resolution of the renal arteries and parenchymal vessels keeping the patient in the supine position alone.

Do we feel comfortable in planning a renal artery intervention? We do, and we have. We have actually performed at least 2 renal angioplasties using CO<sub>2</sub>. We have also done a dozen or so renal artery revascularization procedures based on CO<sub>2</sub>. To date, we have not been disappointed. The other technologies that are available are more costly. The spiral CT does provide magnificent images, but it also requires iodinated contrast and thus eliminates it as a possible option in the azotemic patient population. As far as MRA is concerned, in our institution, we have not had the kind of good results that have been reported in the literature. Selected institutions have access to a tremendous amount of experimental software, and they can provide renal artery images by MRA that most centers on the West Coast cannot reproduce, not to say that this will not occur in the future.

#### Surgical Anatomy

**Axiom.** On cutting through the abdominal wall, the encountering of a layer of loose areolar tissue is a signal that a change in direction of muscle fiber is imminent.

1. Grant JCB. *A Method of Anatomy: Descriptive and Deductive*. 5th ed. Baltimore, Md: Williams & Wilkins Co; 1952:215.

patients at risk of progressive loss of renal function caused by renal artery disease. In contrast, the lower sensitivity indicates that significant stenoses may be missed. However, 1 false-negative result was caused by a difference in interpreting the severity of a recognized stenosis. Ultimately, only 2 studies clearly and completely missed a significant stenosis seen on ICA.

There are other modalities available to evaluate renal arteries, each with its own advantages and disadvantages. Duplex scanning of the renal arteries has vastly improved the capacity to noninvasively screen the patients with hypertension and azotemia for occult renal artery disease. However, the efficacy of duplex scanning in this role is dependent on operator expertise, body habitus, and the dedication of selected centers in developing this valuable tool. In institutions where duplex technology is advanced, it should be the primary screening examination. In those institutions lacking this capability, CO<sub>2</sub>-DSA is an accurate alternative and has the additional advantage of providing a visual road map for surgical or endovascular intervention.<sup>23</sup>

Magnetic resonance angiography with gadolinium has also been used to evaluate the renal arteries. This approach is expensive, of limited availability, and software dependent. Other problems include motion artifact from patient respiration,<sup>24</sup> as well as patient discomfort in the claustrophobic environment of the magnetic resonance imaging gantry. Spiral computed tomography is also being investigated as a modality for evaluated branches of the arterial tree. However, iodinated contrast medium is necessary, and computer time for processing the images is lengthy and expensive.

This comparative study establishes the accuracy and reproducibility of CO<sub>2</sub>-DSA renal artery images when objectively compared with ICA images. The advantages of this form of diagnostic arteriography are well suited to the population of patients with azotemia, and it provides another safe avenue of investigation for patients suspected of having occult occlusive renal artery disease.

Accepted for publication January 20, 1996.

Presented at the 102nd Scientific Session of the Western Surgical Association, Chicago, Ill, November 13, 1995.

Reprints: Fred A. Weaver, MD, Department of Surgery, Division of Vascular Surgery, University of Southern California School of Medicine, 1510 San Pablo St, Suite 514, Los Angeles, CA 90033-4612.

## REFERENCES

- Hillman BJ. Imaging advances in the diagnosis of renovascular hypertension. *Am J Radiol.* 1989;153:5-14.
- Mann SJ, Pickering TG. Detection of renovascular hypertension: state of the art 1992. *Ann Intern Med.* 1992;117:845-853.
- Olin JW, Melia M, Young JR, Graor RA, Risius B. Prevalence of atherosclerotic renal artery stenosis in patients with atherosclerosis elsewhere. *Am J Med.* 1990;88:46-51.
- Tollefson DF, Ernst CB. Natural history of atherosclerotic renal artery stenosis associated with aortic disease. *J Vasc Surg.* 1991;14:327-331.
- Novick AC. Atherosclerotic ischemic nephropathy: epidemiology and clinical considerations. *Urol Clin North Am.* 1994;21:195-200.
- Hansen KJ, Starr SM, Sands E, Burkart JM, Plonk GW, Dean RH. Contemporary surgical management of renovascular disease. *J Vasc Surg.* 1992;16:319-331.

- Mailloux LU, Bellucci G, Mossey RT, et al. Predictors of survival in patients undergoing dialysis. *Am J Med.* 1988;84:855-862.
- Weaver FA, Modrall JG. The role of renal revascularization in ischemic nephropathy. *Surg Annu.* 1994;26:135-150.
- Bredenberg CE, Sampson LN, Ray FS, Cormier RA, Heintz PA, Eldrup-Jorgensen J. Changing patterns in surgery for chronic renal artery occlusive diseases. *J Vasc Surg.* 1992;15:1018-1024.
- Guzman RP, Zierler E, Isaacson JA, Bergelin RO, Strandness E Jr. Renal artery and arterial stenosis: a prospective study with duplex ultrasound. *Hypertension.* 1994;23:346-350.
- Halls KA, Wong RW, Hunter GC, et al. Contrast-induced nephrotoxicity: the effects of vasodilator therapy. *J Surg Res.* 1992;53:317-320.
- Schwab SJ, Hlaty MA, Pieper KS, et al. Contrast nephrotoxicity: a randomized controlled trial of a nonionic and an ionic radiographic contrast agent. *N Engl J Med.* 1989;320:149-153.
- Paredero VM, Dison SM, Baker JD, et al. Risk of renal failure after major angiography. *Arch Surg.* 1992;118:1417-1420.
- Parfrey PS, Griffiths SM, Barrett BJ, et al. Contrast material induced renal failure in patients with diabetes mellitus, renal insufficiency, or both: a prospective controlled study. *N Engl J Med.* 1989;320:143-148.
- Hawkins JF, Wilcox CS, Kerns SR. CO<sub>2</sub> digital angiography: a safer contrast agent for renal vascular imaging? *Am J Kidney Dis.* 1994;24:685-694.
- Weaver FA, Pentecost MJ, Yellin AE, et al. Clinical applications of CO<sub>2</sub> digital subtraction arteriography. *J Vasc Surg.* 1991;13:266-273.
- Weaver FA, Pentecost M, Yellin AE. CO<sub>2</sub> digital subtraction arteriography: a pilot study. *Ann Vasc Surg.* 1990;4:437-441.
- Seeger J, Self S, Harward T, et al. Carbon dioxide gas as an arterial contrast agent. *Ann Surg.* 1993;217:688-698.
- Cohen J. Intraobserver variability. *Educ Psychol Meas.* 1960;20:37-46.
- Dean RH, Burko H, Wilson JP, Mulherin JH, Foster JH. Deceptive patterns of renal artery stenosis. *Surgery.* 1974;76:872-881.
- Foster JH, Klatte EC, Burko H. Arteriographic pitfalls in the diagnosis of renovascular hypertension. *Arch Surg.* 1969;99:792-801.
- Eyler WR, Clark MD, Garman JE, Rian RL, Meininger DE. Angiography of the renal areas including a comparative study of renal arterial stenoses in patients with and without hypertension. *Radiology.* 1962;78:879-891.
- Frankhouse JH, Ryan MG, Papanicolaou G, Yellin AE, Weaver FA. Carbon dioxide/digital subtraction assisted transluminal angioplasty. *Ann Vasc Surg.* 1995;9:448-452.
- Kim D, Edelman RR, Kent KC, et al. Abdominal aorta and renal artery stenosis: evaluation with MR angiography. *Radiology.* 1990;174:727-731.

## DISCUSSION

Bruce L. Gewertz, MD, Chicago, Ill: The authors have presented a very clear and well-designed study comparing a new and nonnephrotoxic imaging technique with standard angiography in the evaluation of renal artery lesions. There is much to recommend their careful work: It is prospective, consecutive, and scrupulously objective.

A few of the limitations are already discussed in the manuscript. For example, it is possible that the value of angiography was limited by avoiding selective injections, which are commonly used clinically in the evaluation of renal stenoses. It may have improved the accuracy of the iodinated contrast studies. However, a greater concern is the nature of the clinical sample. Only 12% of patients had hypertension, and only 15 or so had stenoses greater than 60%. Hence, the real utility of the studies was not tested in a large number of patients with lesions. I might add that I do not expect that the usefulness of the technique will suffer greatly in broader application.

I have the following questions for the authors: Has the diagnostic accuracy of the carbon dioxide studies been compared to duplex ultrasound, which is currently the preferred screening test? How does the cost of carbon dioxide angiography compare to duplex studies or conventional angiography? Is there a "learning curve" for performing and interpreting the images? Can selective injection be performed, and would they improve the resolution of obscure lesions? Finally, the \$64,000 question: Do the authors feel comfortable planning a renal artery reconstruction or angioplasty with a carbon diox-

ICA were similar, indicating that variability in interpretation of renal artery anatomy is equivalent. Furthermore, of the 200 renal artery images reviewed, 17 were removed because of poor visualization of the renal artery. The studies discarded were evenly divided between CO<sub>2</sub>-DSA and ICA. The familiar difficulties in timing of contrast injection and radiograph exposure, patient cooperation, or overlying bowel gas equally compromised both modalities.

The unique properties of CO<sub>2</sub> as a contrast agent may explain why 1 renal artery was incorrectly identified as

stenotic. Because of the buoyancy of CO<sub>2</sub>, dependent vessels may not be perfused by CO<sub>2</sub>.<sup>13</sup> Posterior displaced renal arteries may not opacify and, thus, may take on the appearance of a critical stenosis. Conceivably, had this patient been placed in an oblique or lateral decubitus position, a better image would have been obtained.

Renal artery anatomy was demonstrated beyond the first bifurcation (154 images [86%]); beyond the second bifurcation (86 images [47%]); and to nephrogram phase (36 images [20%]). Accessory renal arteries were not well demonstrated. Since branch anatomy and accessory pathologic features are less reliably imaged than the main renal artery, critical lesions could be missed. In this respect, CO<sub>2</sub>-DSA suffers from the same limitations as renal artery duplex ultrasonography.<sup>10</sup> Again, clarity may be positional, and accuracy and distal detail may be enhanced with positional changes.

Substantial variability occurred in differentiating a normal main renal artery from 1 with a subcritical stenosis on ICA and vice versa. However, for critical lesions ( $\geq 60\%$  stenosis), CO<sub>2</sub>-DSA had a specificity and a negative predictive value of 0.99 and 0.98, respectively. As a screening test, it therefore accurately excludes those

**Table 3. Comparison of CO<sub>2</sub>-DSA and ICA Findings\***

ICA	CO <sub>2</sub> -DSA			
	0%	1%-59%	60%-99%	Occlusion
0%	140	9		
1%-59%	10	5	1	
60%-99%	2	1	13	
Occlusion				2

\*CO<sub>2</sub>-DSA indicates carbon dioxide-digital subtraction arteriography; ICA, iodinated contrast arteriography.

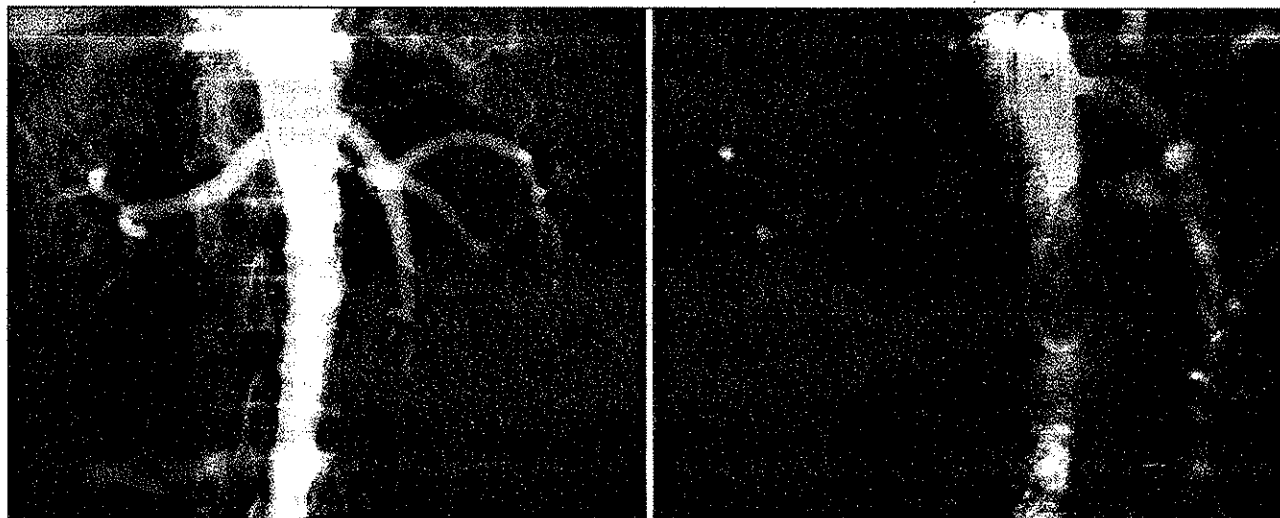


Figure 3. Side-by-side comparison of iodinated contrast arteriographic (left) and carbon dioxide-digital subtraction arteriographic (right) images, in which right renal artery stenosis on carbon dioxide-digital subtraction arteriogram was incorrectly categorized as less than 60%.

**Table 4. CO<sub>2</sub>-DSA Incorrect Interpretations**

Result	Side	CO <sub>2</sub> -DSA/ICA, % Stenosis			Comments
		Reader 1	Reader 2	Tiebreaker	
False negative	R	0/0	0/>60	x/>60	Tiebreaker agreed with reader 2; both studies were somewhat difficult to interpret
False negative	R	>60/>60	0/>60	0/x	Tiebreaker agreed with reader 2 on CO <sub>2</sub> -DSA; no stenosis seen despite >60% on ICA
False negative	L	<60/<60	<60/>60	x/>60	Renal artery stenosis close call; ICA demonstrates low-end 60%-99% stenosis, and CO <sub>2</sub> -DSA demonstrates high-end 1%-59% stenosis
False positive	L	>60/>60	>60/<60	x/<60	Renal artery stenosis close call; ICA demonstrates high-end 1%-59% stenosis, and CO <sub>2</sub> -DSA demonstrates low-end 60%-99% stenosis

\*CO<sub>2</sub>-DSA indicates carbon dioxide-digital subtraction arteriography; ICA, iodinated contrast arteriography; and x, no disagreement between readers 1 and 2.