Saline Chasing Technique with Dual-Syringe Injector Systems for Multi-Detector Row Computed Tomographic Angiography: Rationale, Indications, and Protocols

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Computed tomography (CT) technology has significantly changed over the last two decades. The advent of multi-detector row CT (MDCT) has resulted in rapid acquisition times and improved z-axis resolution that paved the way for CT angiography. With MDCT technology, CT angiography has become more dependent upon optimal vessel opacification and, consequently, contrast administration protocols have had to evolve. We examine the use of intravenous contrast from a historical perspective and discuss the latest methodologies, such as saline chasing techniques, that optimize the contrast bolus with CT angiography.

Powered injection systems for computed tomography (CT) were developed in the mid-1980s. The injection systems control the timing of contrast delivery by adjustments to flow rate, volume, and injection duration. The goal is to optimize target organ opacification to improve contrast resolution. The initial protocols were sufficient for early generation CT scanners. However, as the CT scanner technology advanced, the injection protocols were no longer able to reliably optimize peak enhancement. Today, the challenge is to update new injection protocols for the ever-evolving CT scanner and injector technology.

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Several developments in the past few years have impacted CT imaging, including multi-detector row computed tomography (MDCT) technology, the use of saline flush, and usage of nonionic contrast material. Shorter acquisition times are now enabled with MDCT with a dramatic decrease in examination times, so that even large anatomic volumes can be scanned within a matter of few seconds. Traditional contrast media injection protocols still could be transferred from single-slice CT to the first generation of four-slice MDCT systems with acceptable, albeit suboptimal results. With the simultaneous acquisition of 16 or more slices and ever-shorter acquisition times, however, accurate scan timing and tailoring of clinical injection protocols is increasingly challenging yet still paramount.

The use of nonionic contrast agents is quickly becoming routine. These agents are preferred because they are tolerated better by the patient and because the complications associated with contrast extravasation tend to be less severe. The downside of using these agents are their nephrotoxic effects and their exorbitant cost. This has compelled radiologists to try and minimize the overall volume of contrast administered.

These advances have prompted much research in how to consistently administer the "optimum bolus" of intravenous contrast to maximize contrast enhancement and minimize dosage, all within the temporal confines of shorter scan times. One technique that holds much promise is the saline chase technique. Use of a saline chase technique has been hypothesized to reduce the total amount of contrast media needed by creating a more "compact" contrast media bolus. A "compact" bolus had many advantages. It facilitates

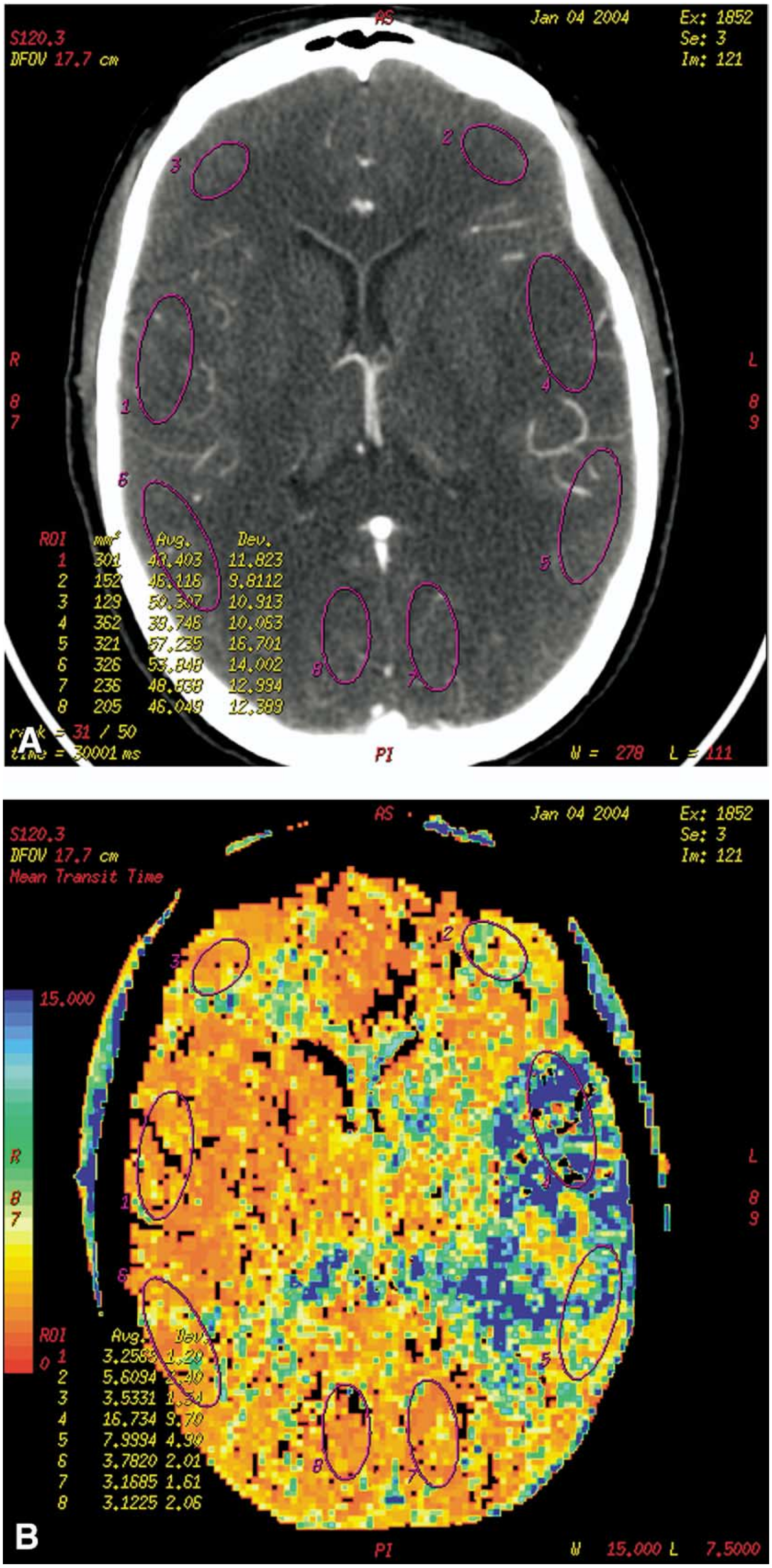


FIG 1. Contrast-enhanced CT of the brain with brain perfusion following saline flush. Axial source image with ROI placement (A) and color-coded perfusion map (B). Adding saline to the injection protocol has the potential to generate a more compact and defined bolus, which facilitates mathematical derivation of perfusion parameters. (Color version of figure is available online.)

FIG 2. Double-barrel injector with the two syringes adjacent to one another. The "Y" connector is not shown. (Color version of figure is available online.)

TABLE 1. MUSC contrast reduction plan

Study	Current rate	Current volume (mL)	Proposed rate	Proposed volume
Chest	2.0	100	2.5	80 mL C 20 mL S
Abdomen*	2.0	140	2.5	125 mL C 25 mL S
Chest PE	3.5	100	4.0	80 mL C 20 mL S
CTA†	3.5	140	4.0-5.0	125 mL C 25 mL S
Neck	2.0	100	2.5	80 mL C 20 mL S
Brain CTA	3.5	100	4.0-5.0	80 mL C 20 mL S
Perfusion	4.0	40	4.0-5.0	40 mL C 20 mL S

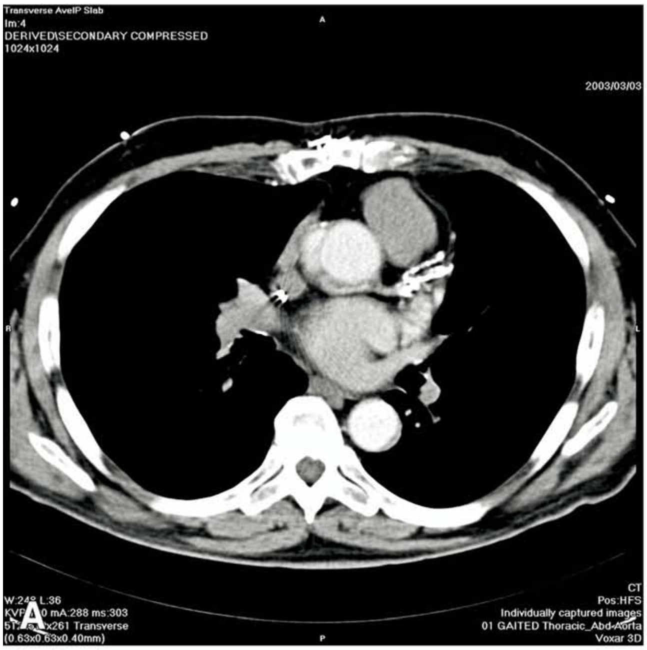
*Consider use of 350 concentration for hepatic studies.
†Must use 350 concentration.

the derivation of tissue perfusion parameters at CT perfusion measurements (Fig 1). It has been shown to reduce artifacts, especially in regard to CT imaging of the thorax. More importantly, use of a saline chaser bolus may help to better utilize the injected contrast media by prolonging the plateau-phase of contrast media bolus, resulting in higher and more consistent, homogenous vascular enhancement. High and consistent vascular enhancement within the vessel lumen is a prerequisite for successful CT angiography and serves as the basis for threshold-dependent 3D visualization techniques that are currently gaining increasing importance in medical imaging.

Technical Principles of Dual Syringe System

One of the first descriptions of the concept of power injection of contrast material followed by an injected saline chaser solution was published by Hopper and coworkers.[1] This technique included the use of a single-barrel injector: First, the contrast material is drawn into the syringe with its nozzle in the vertical position, followed by loading saline in the same syringe. Because the contrast is heavier than the saline, the saline can be layered on top of the denser contrast material with only slight mixing of the two liquids. With a continuous steady slow motion, the injector is inverted with its nozzle pointing down. During this inversion, the saline flows over the top of contrast material and their positions in the syringe are reversed. This approach, although used for years by some institutions, including ours, proved too laborious and cumbersome for a widespread general embrace of this method in clinical practice. It also presented limitations in contrast delivery techniques, as one could deliver only contrast followed by saline.

The next step in developing an injector capable of delivering two separate fluids was the construction of prototypes consisting of two separate injectors, one delivering contrast, the other saline, mounted in a combined mechanical configuration and connected with a unique tubing set. This apparatus provided validation of the double-syringe concept and also showed the need for more effective fluid management techniques as well as technology improvements. It was apparent that further refinement would be required to demonstrate not only improvement to the contrast enhancement capabilities, but to mini-



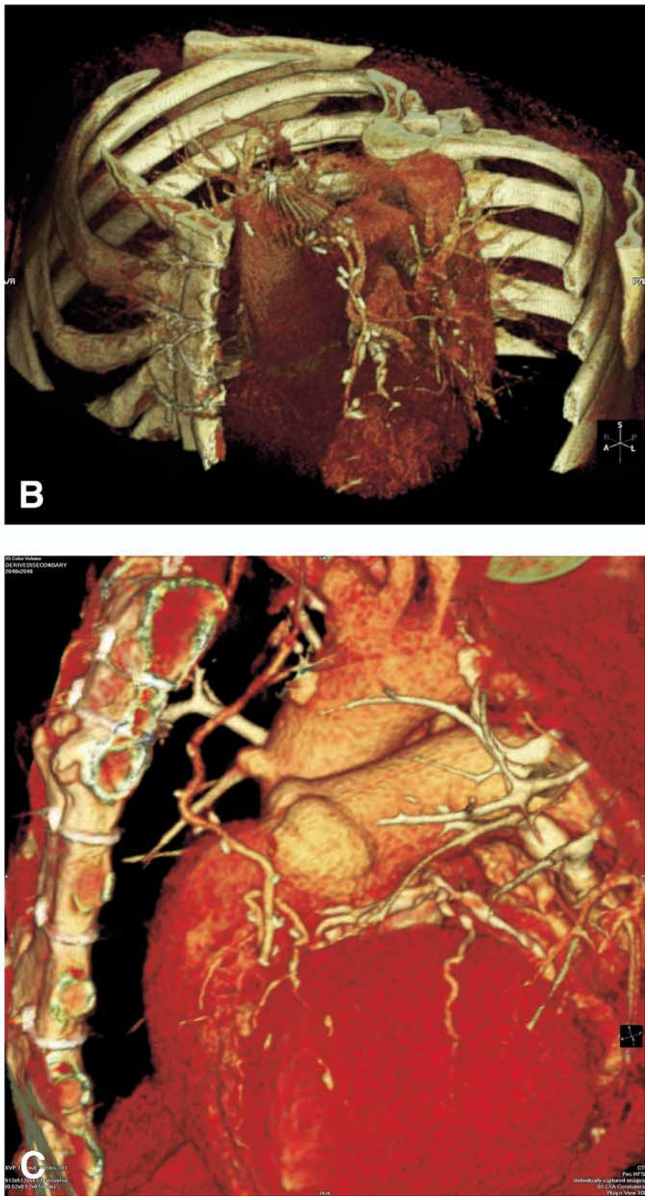


FIG 3. Axial CTA (A) and volume rendered display (B) of the chest following gadolinium administration with a saline flush in a patient with impaired renal function scheduled to undergo redo coronary artery bypass graft surgery. Saline enables maximal utilization of a triple-dose (60 mL) bolus of gadolinium, which provides sufficient radio-opaque intravascular contrast for a short 16-detector-row CT scan. This approach enables obtaining similar image information before redo surgery as an iodine-enhanced scan (C) in a comparable patient. (Color version of figure is available online.)

mize any impact that might be realized in throughput, due to the addition of additional syringe loading requirements brought about by a double injector. It also be came clear that a very graphical user interface would be required to enable the user to easily and competently program an injection protocol using two fluids and numerous phases. The evolution of this technology resulted in the design of double-barrel injectors with two adjacent syringes, one for the contrast material and the other for saline interconnected with a Y-connector (Fig 2) and controlled by one easy-to-use color touch screen. The use of double-barrel injectors facilitates the procedural preparation (minimizing the amount of time and steps to use the product) and avoids unwanted mixing of the two components. Providing automation processes for dual-syringe loading avoids any negative impact to throughput gains achieved with MDCT data acquisition speed. In addition, it is very important from a cost perspective that as the amount of contrast media that is injected into the patient is decreased that these savings show up by a reduction in the amount of contrast media that the department purchases. Therefore, it is critical that the injection system (injector, disposables, contrast media packaging) enables the institution to

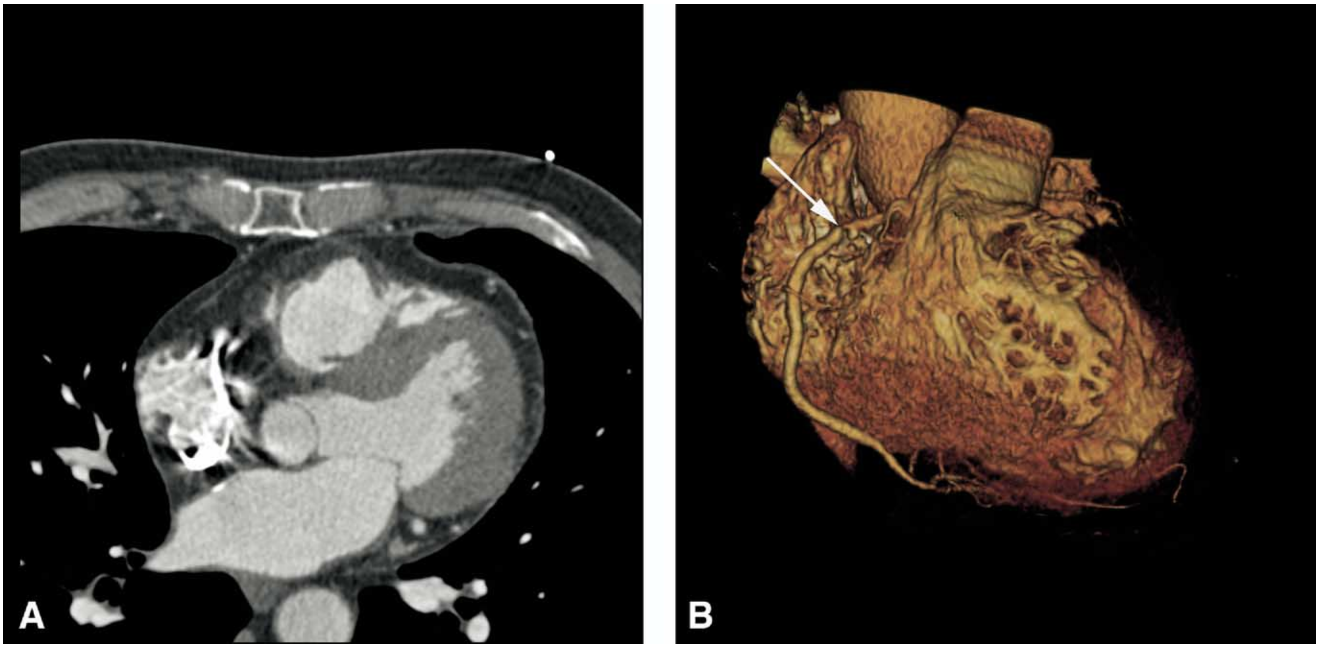


FIG 4. Contrast-enhanced CT coronary angiography without saline chasing technique. Display as axial MIP (A) and volume rendering (B). A streak artifact emanating from dense contrast material in the right heart overlies the right coronary artery (A) and causes artifactual stenosis of the proximal right coronary artery in the volume rendering. (Color version of figure is available online.)

"bank" this savings in contrast media with the use of "Bulk" contrast containers and systems.

Injection parameters can also be modified for the contrast material and the saline bolus independently, if desired, and now provide for the ability to easily program and deliver contrast and saline in any order, no longer constrained by the limitations inherent in a single-syringe delivery system. An additional benefit of delivering contrast and saline in any order or combination is the ability to pretest the patient's IV injection site with a benign injection of saline, before the delivery of contrast. This capability can be programmed into one injection protocol and to minimize steps and errors and allows aggressive flow rates to be evaluated before delivery of contrast, thus adding a measure of confidence in the IV site stability.

Benefits of Saline Chasing Technique

Reduction of Contrast Material

Nonionic contrast materials play an increasingly important role in medical imaging. However, their high costs as well as potential nephrotoxicity have been prohibitive. This has compelled radiologists to investigate the possibility of reducing the dosage of contrast material without compromising the quality of the examination (Table 1). Flushing with saline solution avoids pooling of contrast material in the injection system and in the arm veins leading to better utilization of the contrast material bolus. Several studies have demonstrated that depending on the type of examination (abdominal, thoracic, or CT angiography), if the saline flush technique is used, between 15 and 50 mL of contrast material can be saved. A study by Schoellnast and coworkers[2] evaluated the reduction of cost and contrast material using saline flush in abdominal MDCT. Their results demonstrated iodine dose reduction of approximately 6 g or 17% and a cost reduction of \$7.30 per patient (120 mL nonionic contrast versus 100 mL nonionic contrast followed by 40 mL saline). Savings will increase accordingly if greater reduction in contrast dose is achieved (eg, \$12 savings per patient if dose is reduced by 50 mL nonionic contrast). Although the price of nonionic contrast material has decreased over time, nonionic contrast material still represents a significant expense to radiology departments because of the increasing number of CT examinations. Hospitals that have an injection system (injector, disposables, bulk contrast media) designed to "bank" the contrast

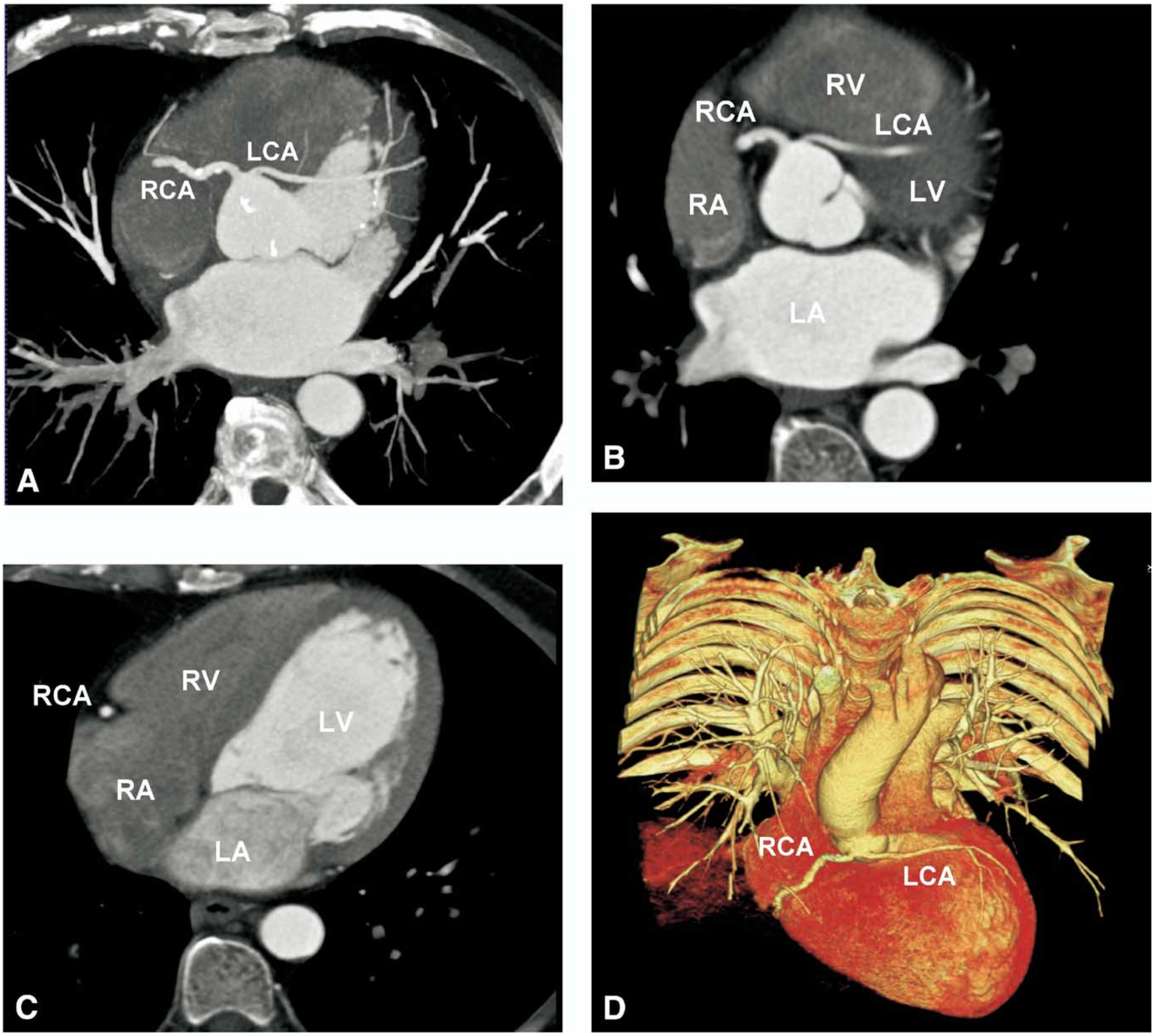


FIG 5. Contrast-enhanced CT coronary angiography with saline chasing technique in a patient with anomalous origin of the left coronary artery from a common ostium with the right coronary artery. Use of a saline chaser bolus results in contrast enhancement almost exclusively of the arterial side of the cardiac circulation (left ventricle, LV; left atrium, LA) with high and consistent opacification and exquisite delineation of the right coronary artery (RCA) from the significantly less enhanced right ventricle (RV) and right atrium (RA). This facilitates threshold-dependent 3D visualization (D) of this vascular anomaly, since a single, predetermined threshold enables uniform rendering of the entire coronary artery tree. (Color version of figure is available online.)

reductions to patients can save $60,000 per year if 5,000 injections are performed, while saving $12 per patient.

Reduction of contrast material may also benefit patients with renal impairment, where the risk of contrast-induced nephropathy may be mitigated by limited use of iodinated contrast. Furthermore, in cases with manifest impaired renal function, use of gadolinium has been described as an alternative for CT angiography.[3] Gadolinium, ordinarily used for contrast enhancement at magnetic resonance imaging (MRI), is radio-dense, although not to the same degree as iodine. The introduction of MDCT with the saline chaser technique has increased the potential usefulness of this agent as an alternative to iodine, as the increased scan speed enables acquisition during fast injection of a small bolus resulting in satisfactory vascular contrast enhancement (Fig

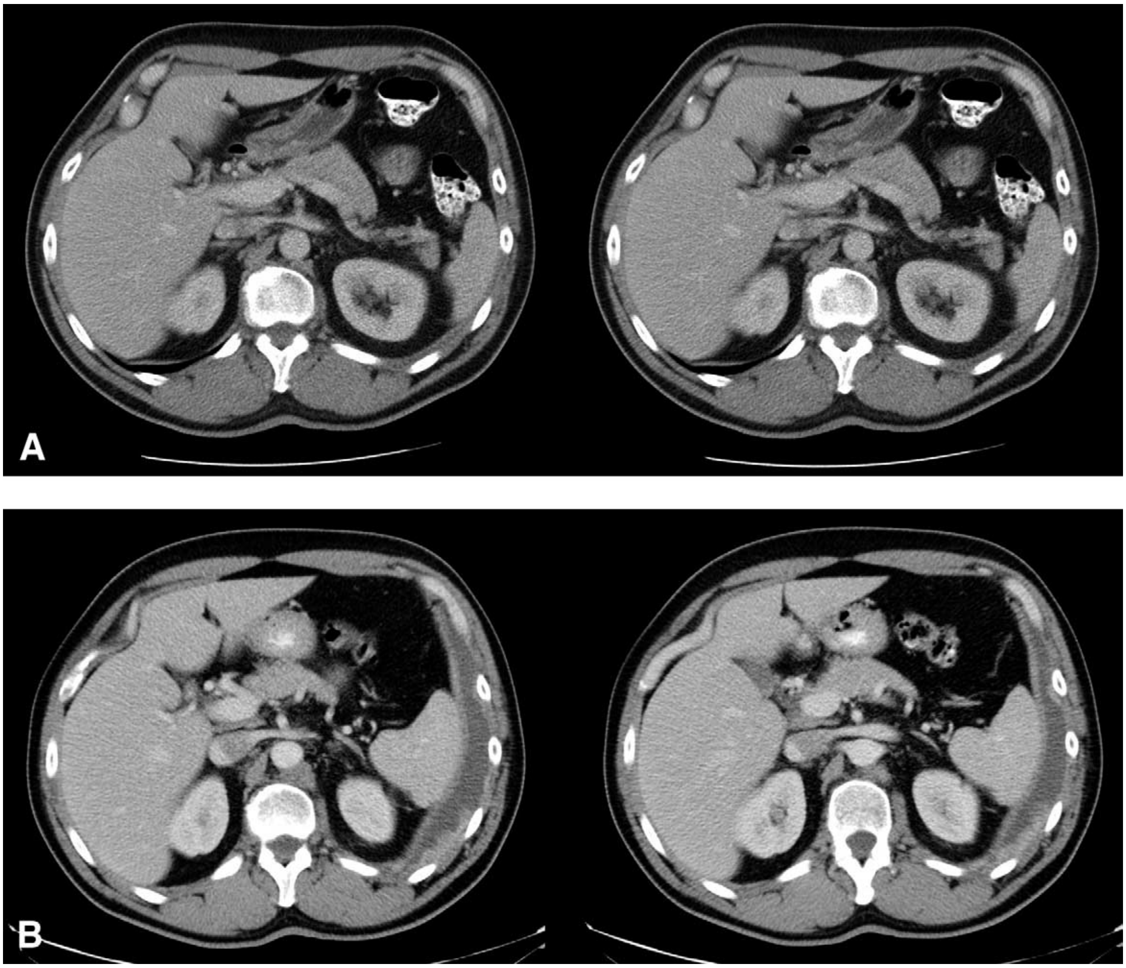


FIG 6. Axial CT scan of the abdomen without saline flush (A). The same patient then received a subsequent axial CT of the abdomen with the same amount of contrast media but with use of a saline flush (B). Increased enhancement of the abdominal aorta as well as visceral organs are demonstrated.

3). Injection of a larger bolus of gadolinium is restrictive because of cost and because at higher doses gadolinium is thought to possess similar nephrotoxic properties as iodine. Saline chasing technique enables optimized use of gadolinium by keeping the bolus compact and flushing residual gadolinium from the injection tubing and the patient's afferent venous system.

Reduction of Artifacts

A particular problem at CT angiography is streak artifact from dense contrast media in the superior vena cava and the right heart chambers (Fig 4). This type of artifact may obscure mediastinal or hilar pathology. In addition to decreasing contrast media, and improving timing, the use of a saline chaser bolus was shown to reduce this type of artifact,[4] without affecting the attenuation of the target vessels within the thorax. Injection of contrast material followed by saline solution bolus using a double-syringe injector allows a 20% reduction of contrast material to 60 mL with a similar degree of enhancement.[4] In addition Haage and coworkers demonstrated that the saline chase technique resulted in a lower mean net attenuation in the superior vena cava, with a mean difference of 107 HU, and no significant difference in the attenuation of the mid aorta and pulmonary trunk. This culminated in a statistically significant reduction in artifacts, while maintaining satisfactory central arterial enhancement.[4]

An application where the use of the saline chaser technique is mandatory is CT coronary angiography. Ever faster MDCT technology with added

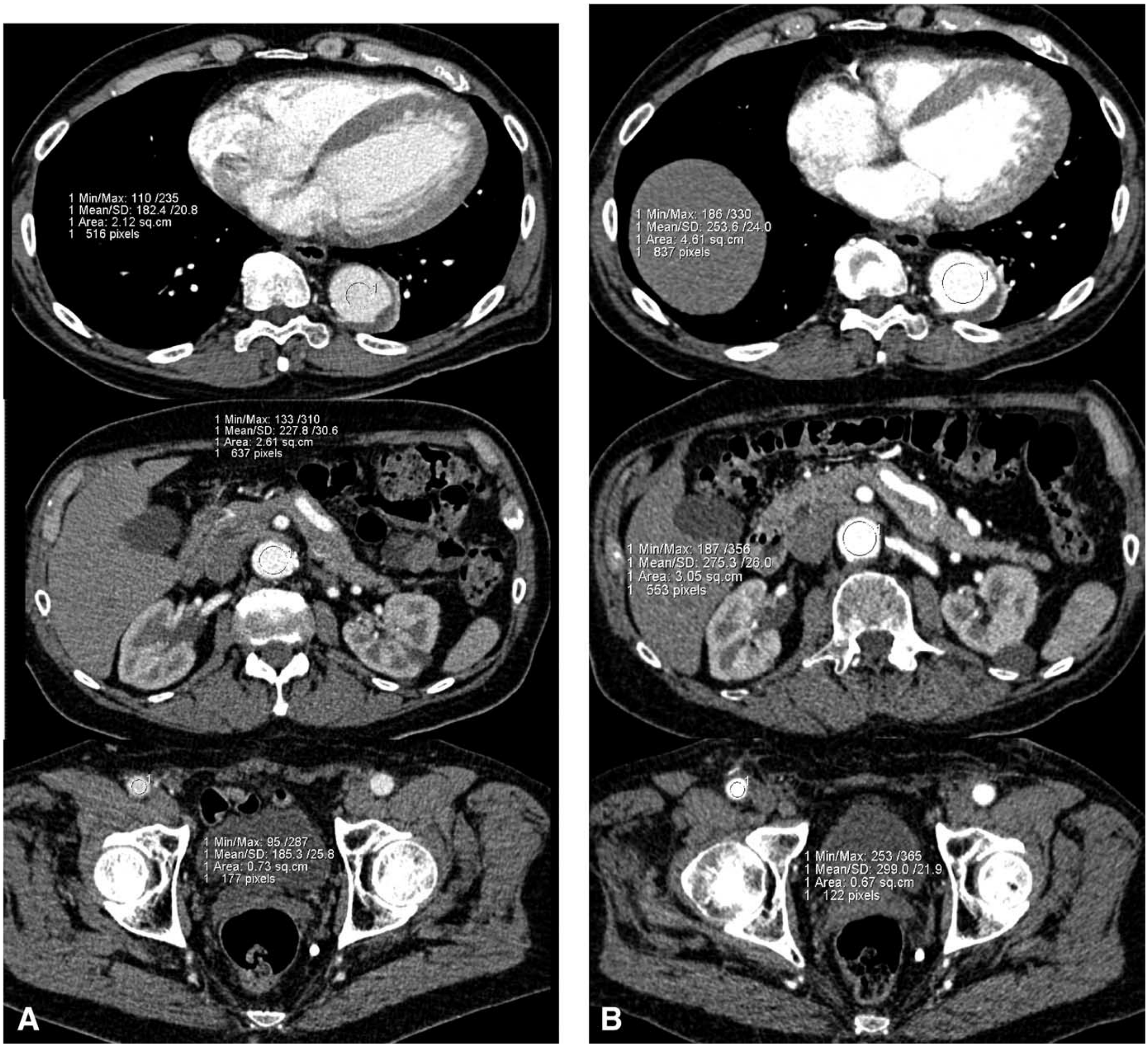


FIG 7. Sixty-two-year-old man with abdominal aortic aneurysm. The patient underwent contrast-enhanced CT for preinterventional evaluation of the abdominal aorta and the aneurysm and for therapeutic planning (A and C). After successful placement of the stent, a control scan was performed (B and D) with saline chasing. Use of the saline chaser bolus enabled us to reduce the total contrast volume from 100 to 80 mL for performing the scan. More importantly, use of the saline chaser bolus resulted in more consistent and higher vascular contrast opacification throughout the entire acquired scan volume, from the most cranial to the most caudal portions (A and C). While there is a marked decrease in contrast attenuation in the proximal abdominal aorta and the iliac arteries in the initial scan without saline chasing (a), there is higher and more uniform contrast enhancement throughout the entire abdominal vascular system when a saline chaser bolus is used (C). This also facilitates threshold-dependent 3D visualization (F) of vascular anatomy and pathology, since a single, predetermined threshold enables uniform rendering of the entire vascular system with saline chasing technique (F), while the proximal abdominal aorta and the iliac arteries "fade out" in different hues in the initial scan (E) due to differing contrast attenuation. In addition, the higher contrast enhancement of the control scan with use of saline chasing enables improved visualization of small mesenteric vessels (F) as compared with nonsaline scanning (E). (Color version of figure is available online.)

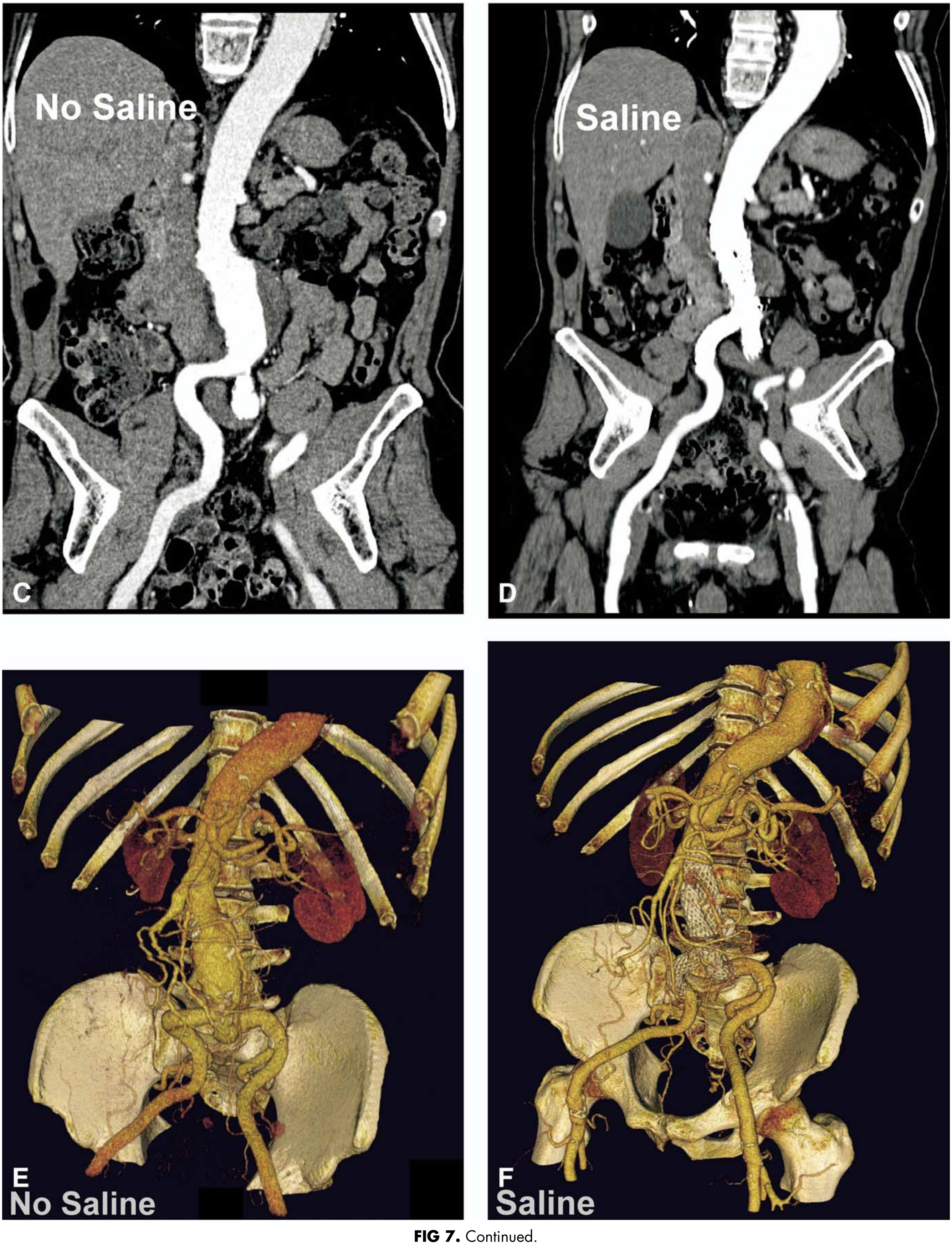


FIG 7. Continued.

detector rows, faster gantry rotation times, and sophisticated methods of ECG synchronization hold great promise for noninvasively imaging the heart. In CT coronary angiography, the streak artifacts (arising from dense contrast in the SVC and the right heart as previously described) significantly limit the evaluation of the right coronary artery and may simulate stenosis especially at 2D and 3D image postprocessing. These streak artifacts may be reduced or avoided entirely, if at the time of image acquisition the contrast material is flushed from the venous system by use of saline chaser technique with dual-syringe injection system (Fig 5).

Precise Timing of Peak Enhancement

Several methods of determining optimal enhancement timing are currently used in clinical CT practice. One such method is the so-called timing bolus. A small volume of contrast is injected through the peripheral injection site via the power injector and the time to peak enhancement is determined by evaluating the amount of time that passes from injection start to contrast peak at a specific anatomical location. However, Cademartiri and coworkers observed[5] that the lack of continuous flow, either by a saline push or by the larger full bolus of contrast, causes the small timing bolus of contrast to pool in the venous system. The result is a diluted, delayed peak enhancement when compared with a timing bolus followed by saline chase. As depicted in Fig 6 this can result in a peak enhancement difference of 4 seconds when comparing saline chase to contrast only and a peak enhancement that can be as much 30% less without a saline chase. It is therefore recommended that when employing the contrast timing bolus that a saline chase be utilized for optimal timing accuracy.

Improved Organ and Vascular Enhancement

Use of a saline chaser bolus may also help to better utilize the injected contrast media by prolonging the plateau-phase of the contrast media bolus, resulting in a higher and more consistent homogenous vascular enhancement while using a small volume of contrast media. The concentration of contrast begins to decrease immediately after the dense contrast media contacts the blood-filled aorta. The saline flush pushes the contrast media into the venous system and adds extra volume to the tail of the bolus, which results in prolongation of the time to the peak aortic enhancement. General CT angiography benefits the most in this scenario. Prolonging peak aortic enhancement allows for more consistent opacification throughout the entire scan volume, from the most cranial to the most caudal portions. This facilitates threshold-dependent 3D visualization of vascular anatomy and pathology since a single, predetermined threshold enables uniform rendering of the entire vascular system (Fig 7).

Developments in spiral CT technology have had a significant impact on abdominal CT imaging. Due to shorter scanning times with MDCT technology, a more consistent level of parenchymal enhancement is achieved when compared with conventional CT. A recent study by Schoellnast and coworkers[6] compared the utility of a saline flush following a low-dose intravenous contrast injection to the same low-dose contrast material without a saline flush for parenchymal enhancement during abdominal MDCT. The study showed that the use of a saline flush following the contrast bolus led to significantly higher parenchymal enhancement. Using a double-syringe power injector, the mean parenchymal and the mean aortic enhancement was 8 and 10 HU higher, respectively, when compared with low-dose contrast alone (Fig 6). Dorio and coworkers compared hepatic tumor conspicuity with CT after injection of either 150 mL of contrast material or 100 mL of contrast material followed by 50 mL saline chaser and failed to demonstrate a meaningful difference in liver parenchyma attenuation or lesion conspicuity. The kidney, spleen, aorta, and inferior vena cava, however, enhanced more with 150 mL of contrast than with 100 mL of IV contrast and a saline chaser by approximately 29, 17, 42, and 15 HU, respectively.[7]

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