# Non-Contrast Renal MR Angiography at 3T Using NATIVE TrueFISP

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**Citation**

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**Abstract**

It is important to develop reliable non-contrast magnetic resonance angiography (MRA) protocols for patients with renal impairment who are at risk of developing nephrogenic systemic fibrosis (NSF) from gadolinium-contrast-enhanced MRA. This study used a NATIVE-true fast imaging with steady-state free precession (TrueFISP) protocol to investigate whether non-contrast MRA at 3T is a viable alternative to contrast-enhanced MRA in patients with renal insufficiency. Thirteen patients without renal compromise were scanned using an optimized NATIVE-TrueFISP protocol with respiratory triggering. While images acquired with NATIVE TrueFISP correlated well with contrast-enhanced MRA, future research should determine how to optimize visualization of segmental and accessory vessels. Overall, NATIVE TrueFISP is a promising technique that can be used to evaluate the renal vasculature in patients with renal disease.

## INTRODUCTION

As the incidence of hypertension and diabetes mellitus rise in the population, cardiac and vascular disorders have become more prevalent [1, 2]. Atherosclerotic renovascular disease is especially common in patients older than 50 years, which, in many cases, involves both renal arteries [2]. Renal artery stenosis is an important cause of secondary hypertension and chronic renal failure [3].

Recently, contrast-enhanced computed tomographic angiography (CTA) and magnetic resonance angiography (MRA) of the kidneys have replaced highly invasive catheter angiography (conventional digital subtraction angiography) in the diagnosis of renal artery stenosis [4-7]. Because contrast-induced nephropathy (CIN) often occurs in patients with renal impairment as a result of the iodinated contrast agent used in digital subtraction angiography and CTA, these modalities are currently no longer used as primary screening tools [8].

MRA was clinically introduced in the 1990's and has become an important tool in evaluating the renal vasculature [9]. Its benefits include a lack of ionizing radiation, non-invasiveness, and no dependence on iodinated contrast agents [10]. The early use of magnetic resonance imaging (MRI) for the depiction of blood vessels used 3D time of flight (ToF), in which unsaturated blood enters the imaging volume, and phase contrast (PC) techniques [11, 12]. For high resolution and multi-planar results, 3D data sets were preferred [11, 13]. The accurate separation of arterial and venous flow is challenging, relying on pre-saturation regions outside the imaging region to reduce flow in the opposite direction. In phase contrast, phase information relative to the flow velocity is used, and extremely low flow in vessels results in insufficient demonstration of those vessels [12, 14, 15]. These early flow-dependent MR approaches (black and bright blood techniques) did not use contrast agents [16]. Since these techniques took quite some time to acquire, they were not well suited for applications in the body. Time-of-flight sequences led to artifacts from turbulence, lack of signal consistency if the flow remained in the imaging volume, and the typical signal-void artifact overestimating the degree of stenosis [17, 18]. Because of deterioration of the images due to cardiac and respiratory motion, researchers sought to establish a synchronized acquisition that would reduce artifacts arising from these motions.

Over time, it has been shown that tracing a normal dose of a gadolinium (Gd) based contrast agent (GBCA) improves the clarity of the vasculature, leaving the stationary background tissue low in signal (dark) and displaying the blood vessels bright [19, 20]. With their high signal-to-noise ratio,

vascular images obtained with contrast-enhanced 3D MRA techniques are only weakly affected by many of the flow-related artifacts of earlier MRA techniques [20]. Gd reduces T1 relaxation times, an intrinsic tissue parameter, which enhances the signal of tissues where GBCA is present. Careful timing in contrast-enhanced MR angiography (CE-MRA) of blood cells carrying GBCA arriving in the imaging plane also allows the separation of arteries and veins [20, 21]. Thus, three-dimensional contrast-enhanced MRA has become the preferred imaging technique for detecting renal artery stenosis [8, 9, 22].

However, in 2006, GBCA was reported to possibly cause nephrogenic systemic fibrosis (NSF), a debilitating and sometimes fatal fibrosing disease affecting patients with renal failure [23-25]. Careful analysis has correlated the occurrence of NSF with compromised renal function [23, 26, 27]. Based on these reports, non-enhanced MRA techniques have gained more attention and importance [28].

Therefore, there is a need to establish non-contrast 3D MRA techniques to visualize renal vasculature using true fast imaging with steady-state precession (TrueFISP), a hybrid T2/T1 weighted acquisition, allowing detailed depiction of the anatomy and morphology of organs and vessels [29]. This steady-state free precession (SSFP) MRA has been used in vascular areas, including the coronary arteries, carotid arteries, and renal arteries [30-35]. Breath-hold [32, 33] and respiratory navigator-gated [34, 35] SSFP MRA techniques simultaneously applied at 1.5T (Tesla) enabled highly sensitive detection of renal artery stenosis. Moreover, recent studies have shown the usefulness of non-contrast renal MRA performed on a 3T unit, suggesting that the better image quality in higher field units is due to an increase of blood signal and a decrease of retroperitoneal tissue signal [36].

Using 3D non-contrast MRA techniques to visualize the renal vasculature reliably can be demanding, and using a 3T magnet introduces some additional challenges: susceptibility and motion artifacts are augmented as are field variations both in the magnetic field (B0) and the radio frequency (RF) transmitted field (B1) [37]. We took on this challenge to create a non-contrast NATIVE TrueFISP MRA protocol with which renal arteries can be reliably assessed.

## MATERIALS AND METHODS

In order to gain experience and develop reliable scanning protocols for patients with renal artery disease at 3T, non-contrast MRA was compared with contrast-enhanced (CE) MRA in patients without renal compromise. Our Investigational Review Board (IRB) approved protocol added NATIVE TrueFISP, our non-contrast MRA sequence, to our routine CE-MRA process in patients undergoing abdominal examinations who had agreed to participate in this study by signing an informed consent.
All examinations were performed on a 3T (Magnetom Verio, Siemens Healthcare) whole-body MRI system. All subjects were placed in the supine position on a spine coil with a flexible body matrix coil placed over their abdomen. EKG electrodes were placed on the chest of the patient in earlier experiments when a diaphragmatic navigator was used [34-36, 38]. For this navigator gating, an excitation pulse was used to detect the position of the right hemidiaphragm during normal breathing [39]. However, because cardiac motion did not strongly deteriorate the images, a respiratory transducer in a snug belt around the upper abdomen of the patient was used instead of the navigator gating, and the EKG electrodes were omitted. This change assured a more reliable respiratory signal, enabling us to use respiratory triggering, which ensured proper synchronization between the arterial inflow events and data sampling.

To visualize renal anatomy, a T2-weighted HASTE sequence in the transverse plane was performed. The NATIVE TrueFISP technique inverts all spins in a broad region over the area of interest [40]. It then generates angiographic contrast by using a selective inversion recovery pulse on the region containing the vascular territory of interest; this pulse reduces the signal from stationary tissue and blood that remains in the area (Figure 1) [41]. During a predetermined inversion time, TI, the inverted spins relax back into the transverse plane and thus will not contribute to any signal [41]. However, inflowing arterial blood with unsaturated blood spins enters the imaging area without having been exposed to the inversion, contributing strongly to the MR signal. The graphically placed preparation region allows the desired vessel to be targeted [41]. The slower venous blood spins may linger in the area of interest longer due to their slower flow rate getting exposed to multiple RF excitations that ultimately saturate them out. At the TI time, the 3D imaging slab is excited, and image data is acquired with TrueFISP.

**Figure 1**

Principle of the NATIVE TrueFISP acquisition. In the grey region, all spins are inverted. Inflowing unaffected spins will have signal. The inversion time is set to minimize stationary background signal as well as blood spins already in the region.

A total of 21 patients were enrolled in the study. One patient was claustrophobic and did not undergo the non-contrast portion of the study. The first seven subjects were scanned in order to optimize the sequence. A total of 13 patients were scanned using the final optimized NATIVE TrueFISP protocol. Two radiologists trained in Body MRI and MRA with 18 years of experience (Reader A) and seven years of experience (Reader B) reviewed the studies independently. The studies were analyzed using a Likert scale for overall image quality, aorta, main renal arteries, segmental renal arteries, and maximum intensity reconstructions - MIP (excellent = 1, good = 2, fair = 3, poor = 4, non-diagnostic = 5); inferior vena cava - IVC (visible =1, suppressed = 2); and diagnostic quality compared to contrast-enhanced MRA (better = 1, equivalent = 2, worse = 3).

## RESULTS

Because the renal arteries and the abdominal aorta show significant pulsation, we initially used EKG triggering with a navigator technique to reduce respiratory motion artifacts. In the navigator technique, an imaging based software tracks the excursion of the diaphragm and accepts image data only in predetermined positions [34-36]. EKG triggering allows the synchronized acquisition of the images to the heartbeat. This combination made these sequences more patient dependent, extremely long, sometimes exceeding 10 minutes, and unreliable. We modified our approach to use respiratory triggering rather than the navigator technique. Respiratory triggering starts acquiring data when a certain threshold during the calm expiratory phase in the respiratory cycle is reached. Using respiratory triggering led to improved results and significantly shorter scan times (Figure 2).

### Figure 2a

Axial (A) and coronal (B) reconstruction of descending aorta and renal arteries using NATIVE TrueFISP with respiratory triggering.

### Figure 2b

Axial (A) and coronal (B) reconstruction of descending aorta and renal arteries using NATIVE TrueFISP with respiratory triggering.

The renal arteries could be visualized without contrast material in this study. However, in some instances, the veins of the lower abdomen and pelvis were still visible (Figure 3). Thus, a second inversion region was added to reduce the venous inflow (Figure 4). And yet, we observed a variation in the outcome based on the patient size. In larger patients, the results were not quite as good as expected. This may be due to the increased distance of the coils reducing signal to noise.

### Figure 3a

Axial (A) and coronal (B) reconstruction using NATIVE TrueFISP with respiratory triggering with visible large veins (arrows).

### Figure 3b

Axial (A) and coronal (B) reconstruction using NATIVE TrueFISP with respiratory triggering with visible large veins (arrows).

### Figure 4a

Addition of second, inferior inversion region to reduce the venous inflow. The first inversion region (TI1) is placed over the imaging area of interest (A), and the second (TI2) is placed just below the first to reduce the signal of inflowing venous blood (B). See yellow regions. Highlighted are the anterior (left side of the image, marked B01) and the posterior (right side of the image, marked SP3) coil positions.

### Figure 4b

Addition of second, inferior inversion region to reduce the venous inflow. The first inversion region (TI1) is placed over the imaging area of interest (A), and the second (TI2) is placed just below the first to reduce the signal of inflowing venous blood (B). See yellow regions. Highlighted are the anterior (left side of the image, marked B01) and the posterior (right side of the image, marked SP3) coil positions.

Table 1 lists the main parameters currently used in clinical cases. The acquisition orientation for the 3D slab is axial, since this provides the best flow sensitivity. Coronal reconstructions are then possible, as this is the preferred viewing orientation. Some additional segmentation of the unwanted background enhances the vascular information in maximum intensity projection (MIP) reconstructions.

### Table 1

Sequence Parameters for the Current NATIVE TrueFISP Protocol

The timing of the inversion pulse TI is critical, as it allows the flowing spins to provide signal, while the stationary spins are suppressed. It is also best to use as few coil elements as possible. The axial slab is just thick enough to cover the kidneys, and thus optimal positioning should allow just one anterior body matrix coil cluster (here B01) and one posterior spine coil cluster (here SP3) to be used (Figure 4).

The respiratory signal should be consistent and regular (Figure 5). If the signal becomes more erratic, the images may be acquired at different organ positions making the

images blurry (Figure 6). It is therefore important to have the patient breath regularly and shallowly.

**Figure 5**

Regular, consistent respiratory signal: Red marker indicates the beginning of data collection.

**Figure 6**

Compromised respiratory signal: Marked variation in respiratory rate and depth of inspiration.

Seemingly minor details can impact image quality: Target organs placed appropriately in the center of a coil as well as centered to the magnet and a snug placement of the respiratory bellows improve image quality (Figure 7).

**Figure 7a**

Appropriate coil and bellow placement. (A) Center of coil below center of target organ and relatively loose respiratory bellows. (B) Image quality improved with centering of coil and tightening of bellows.

**Figure 7b**

Appropriate coil and bellow placement. (A) Center of coil below center of target organ and relatively loose respiratory bellows. (B) Image quality improved with centering of coil and tightening of bellows.

Thirteen patients were scanned with the latest technical adjustments. Overall, the majority had good quality exams, with one excellent to good and three with good to fair (Table 2). Only two patients were scored for overall quality of fair by both readers, and there were no non-diagnostic examinations. The aorta was well visualized; however, there was signal loss in the lower one-third of the acquisition volume in many patients, especially noted with large body habitus. All main renal arteries (RA) were well visualized. The accessory arteries were sub-optimally visualized with NATIVE sequence. A main right renal artery had a significant angulation, as it coursed over the IVC, and the turbulent flow caused significant signal loss suggesting stenosis. The contrast examination, however, only demonstrated a tortuous vessel. The segmental renal arteries were less consistently visualized, and the extent of the vessels seen greatly varied. In two cases, the segmental and subsegmental vessels were very well visualized. There was improved suppression of the inferior vena cava (IVC) signal with minor contamination noted in patients with a larger body habitus. Volume MIP varied also depending on body habitus and background suppression. This, however, improved when segmentation and thin MIPs were used.

**Table 2**

Quality of Images Visualized by NATIVE TrueFISP and Comparisons with Contrast-enhanced MRA

| | Sex | Age | Quality A | Quality B | Aorta A | Aorta B | Main RA A | Main RA B | Seg RA A | Seg. RA B | IVC A | IVC B | MIP A | MIP B | Compare to CE A | Compare to CE B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | f | 60 | 3 | 4 | 3 | 4 | 3 | 3 | 4 | 4 | 1 | 1 | 3 | 3 | 3 | 3 |
| 2 | f | 46 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 2 |
| 3 | f | 84 | 4 | 4 | 3 | 3 | 3 | 3 | 4 | 4 | 1 | 1 | 4 | 2 | 3 | 3 |
| 4 | m | 35 | 4 | 4 | 3 | 3 | 3 | 2 | 4 | 3 | 1 | 1 | 4 | 2 | 3 | 3 |
| 5 | f | 73 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 |
| 6 | f | 65 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 3 | 2 |
| 7 | m | 88 | 3 | 2 | 3 | 1 | 2 | 1 | 3 | 3 | 1 | 1 | 3 | 2 | 3 | 3 |
| 8 | m | 72 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 2 |
| 9 | m | 52 | 3 | 2 | 2 | 1 | 2 | 1 | 3 | 2 | 2 | 2 | 2 | 1 | 2 | 2 |
| 10 | m | 71 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 11 | f | 58 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 2 | 2 |
| 12 | m | 66 | 3 | 3 | 2 | 2 | 3 | 2 | 4 | 3 | 2 | 2 | 3 | 3 | 3 | 3 |
| 13 | m | 38 | 2 | 2 | 1 | 1 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 3 | 3 |
| 14 | f | 39 | 2 | 2 | 1 | 1 | 2 | 1 | 3 | 1 | 2 | 2 | 2 | 1 | 3 | 2 |
| 15 | f | 33 | 2 | 3 | 2 | 3 | 2 | 1 | 2 | 1 | 2 | 2 | 2 | 1 | 2 | 2 |
| 16 | f | 41 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 1 | 1 | 2 | 1 | 2 | 2 |
| 17 | f | 56 | 2 | 3 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 2 |
| 18 | m | 79 | 2 | 2 | 2 | 2 | 2 | 1 | 3 | 2 | 1 | 1 | 2 | 2 | 3 | 3 |
| 19 | m | 43 | 3 | 3 | 2 | 2 | 3 | 2 | 3 | 2 | 1 | 1 | 3 | 3 | 3 | 3 |
| 20 | f | 19 | 2 | 2 | 2 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 2 |

Note—Overall image quality, aorta, main RA, segmental RA, MIP: 1=excellent, 5=non-diagnostic; IVC: 1= visualized, 2= not visualized; Comparison to CE: 1 = better, 2 = equivalent, 3 = worse (RA = renal artery, IVC = inferior vena cava, MIP = maximum intensity projection, CE=contrast-enhanced).

## DISCUSSION

Three-dimensional fast gradient echo with contrast media has been the preferred way to perform renal MRA. However, since the widespread report of the association of nephrogenic systemic fibrosis (NSF) with the use of gadolinium contrast agents, it has become important to perform another method of renal MRA without the use of contrast agents in patients with renal impairment [24, 25].

Therefore, performing non-contrast MRA with the TrueFISP sequence is an attractive alternative for patients with renal impairment. In renal MRA, the steady-state data collection, combined with respiratory gating, can provide high-resolution bright blood vessel images without respiratory movement [34, 38, 42-44]. Because of its hybrid T2/T1 weighting, balanced true fast imaging with steady-state precession (TrueFISP) sequence depicts the abdominal aorta and its main branches well and shows intravascular bright signal both in arteries and veins, independently from the direction of the vessel axis with respect to the acquisition plane and from the flow velocity [35, 45]. The TrueFISP sequence is flow-compensated in all three spatial directions because of the symmetric shape of the gradient pulses [29].

## CONCLUSION

At this time, NATIVE TrueFISP may be a useful alternative for performing MR angiography in patients with impaired renal function. The images are of diagnostic quality with good correlation to contrast-enhanced MRA. However, there is a need for continued improvement in background suppression and complete visualization of the aorta to assure inclusion of accessory vessels and improve visualization of segmental vessels.

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