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New Dimensions in Renal Transplant Sonography: Applications of 3-Dimensional Ultrasound

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Abstract

Background—The aim of this study is to demonstrate the usefulness of adding 3-dimensional (3D) ultrasound in evaluation of renal transplant vasculature compared to 2-dimensional (2D) Duplex ultrasound.

Methods—113 consecutive renal transplant 2D and 3D ultrasound exams were performed and retrospectively reviewed by 2 Board-certified radiologists and a radiology resident individually; each reviewed 2D and then 3D images, including color and spectral Doppler. They recorded ability to visualize the surgical anastomosis and rated visualization on a subjective scale. Interobserver agreement was evaluated. Variant anastomosis anatomy was recorded. Tortuosity or stenosis was evaluated if localized Doppler velocity elevation was present.

Results—The reviewers directly visualized the anastomosis more often with 3D ultrasound ($\bar{x}$ = 97.5%) compared with 2D ($\bar{x}$ = 54.5%) [difference in means (DM) = 43% (95% confidence interval (CI) = 36%–50%), ($p < 0.001$)]. The reviewers visualized the anastomosis more clearly with 3D ultrasound ($p < 0.001$) [difference in medians = 0.5, 1.0, and 1.0, (95% CI = 0.5–1.0, 0.5–1.0 and 1.0–1.5)]. Detection of variant anatomy improved with 3D ultrasound by 2 reviewers [DM = 7.1% and 8.9% (95% CI = 1%–13% and 4%–14%, respectively), ($p < 0.05$)]. There was high interobserver agreement [$\bar{x}$ = 95.3%, (95% CI = 91.9%–98.7%) regarding anastomosis visualization among reviewers with wide-ranging experience.

Conclusions—Direct visualization of the entire anastomosis was improved with 3D ultrasound. 3D evaluation improved detection of anatomic variants and identified tortuosity as the likely cause

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of borderline localized elevation in Doppler velocity. The data added by 3D ultrasound may obviate confirmatory testing with MRA or CTA following equivocal 2D ultrasound results.

Introduction

Renal transplant is the most common whole organ transplant. In 2009 in the United States, there were 16,829 renal transplants, including 10,442 from deceased and 6,387 from living donors (U.S. Organ Procurement and Transplantation Network). Vascular complications of renal transplants, estimated to affect between 1% and 4% of transplanted kidneys, are important causes of graft loss in the postoperative period; therefore, detection of vascular complications is important to renal graft longevity (1, 2, 3). Posttransplantation imaging is used to monitor the transplant and evaluate for complications (4). Ultrasound is the most efficient, cost-effective, and least invasive imaging modality for post-operative imaging and long term surveillance of renal transplants (5, 6, 7). Spectral Doppler assessment of the arterial system is routinely utilized to exclude renal artery stenosis (8, 9).

While 3-dimensional (3D) sonography has proved useful in many clinical applications, especially in obstetrics and gynecology, it is not yet routinely performed in postoperative renal transplant patients. 3D ultrasound allows reconstruction of images in orthogonal planes and can also provide surface and volume-rendered images (10, 11). Though 3D ultrasound has been used to evaluate renal transplants, it is not routinely used and its clinical utility has yet to be established (10, 11). The goal of this paper is to assess the usefulness of adding 3D ultrasound to 2D duplex techniques, for evaluation of the transplanted renal vasculature.

Materials & Methods

Following approval by the Institutional Review Board, 113 sequential 3D renal transplant ultrasound exams performed by 1 of 5 technologists for a variety of clinical indications between February 1, 2012 and June 1, 2014 (Table 1) were reviewed without any selection criteria. All images were obtained from renal transplant ultrasounds performed in the outpatient setting, using the automatic sweep on a GE Logiq 9 3D ultrasound system, with a RAB 6-D transducer with an 80° FOV, 2–8 MHz bandwidth, or a RAB 2-5-D transducer with an 88° FOV and a 1–5 MHz bandwidth. Each probe was a single crystal matrix phased array transducer.

The protocol utilized for performing the exams was as follows: First, 2D ultrasound in sagittal and transverse orientation was obtained. Color Doppler perfusion views in sagittal orientation were then acquired in 3 segments —upper, middle, and lower pole. Spectral Doppler assessment of these segments was obtained. The donor renal artery was then evaluated from the origin to the most distal portion in small increments with color and spectral Doppler. The peak systolic velocity of the iliac artery proximal to the origin of the donor renal artery was documented.

3D ultrasound was then performed with a color Doppler sweep, 4 dimensional (4D) ultrasound; either 1 or 2 sweeps were acquired in any orientation to best visualize the arterial anastomosis (SDC Video). On average, only 1 sweep was required to obtain a data set for optimal reconstruction. The acquisition of the 3D data set takes less than 1 minute in

comparison with the longer time it takes to image the entire region with 2D color Doppler. The reconstructed images were created by the radiologist on a dedicated workstation using Viewpoint© software (GE Healthcare). This software enables utilization of different reconstruction modes, whose utility is summarized in Table 2. When evaluating the transplant vascular anatomy with 3D techniques, a multiplanar display was utilized. The surface rendered images were generated from the same volume data set. Surface-rendered images with color Doppler were optimized for visualization of the arterial and venous anastomoses (Figures 1, 2). Additionally, tomographic ultrasound imaging (TUI©) can be used for incremental evaluation, often adding to clarity of visualization (Figure 3). Review of the electronic medical record was performed and patient-specific factors were recorded for each case including age, gender, clinical indication for the ultrasound exam, and whether the renal transplant was from a living or deceased donor. The technologist responsible for scanning the patient was also recorded.

In our retrospective study, images from each case were independently reviewed by 2 Board-certified radiologists, each with more than 30 years of experience in body/ultrasound imaging as well as 2 and 5 years of experience in 3D ultrasound technique, respectively. Additionally, images were reviewed by a senior radiology resident with 1 year of experience in 3D ultrasound. The reviewing radiologists had no knowledge of specific surgical results and reviewed only ultrasound images. All radiologists reviewed each case, first evaluating the 2D color and 2D duplex Doppler images, followed by the 3D images.

Findings regarding the transplanted vasculature were recorded— whether or not the arterial anastomosis was directly visualized, and the presence of anatomic variants, including separate upper and lower pole renal arteries with a single anastomosis or multiple anastomoses (Figure 4). If the anastomosis was visualized, the reviewing radiologist rated the clarity with what was seen on a scale of 1 to 3 (1=poorly seen, 2=partially seen, 3=completely well seen). If focal abnormal elevation in Doppler velocity was found on 2D Doppler imaging, the reviewer recorded whether this was due to tortuosity or stenosis if possible.

The findings and ratings with 2D ultrasound were then compared to those with 3D ultrasound. McNemar's test was used to assess for a statistically significant difference in the ability to directly visualize the anastomosis with 2D ultrasound compared with the addition of 3D ultrasound. Further analysis using the Wilcoxon paired rank sum test and Hodges-Lehmann median difference was performed to assess the difference in ratings when visualizing the anastomosis with the addition of 3D as compared to 2D alone. The agreement among reviewers regarding visualization of the anastomosis was then compared. The frequency of identification of variant anastomotic anatomy, was compared using 2D ultrasound alone and with the addition of 3D. Finally, if a localized elevated Doppler velocity was detected in the donor renal artery, the presence of vessel tortuosity or stenosis was evaluated with 3D. In all cases where focally elevated velocity was determined to be due to tortuosity and when follow-up imaging at a minimum interval of 12 months was available, the absence of stenosis was confirmed.

Results

Table 1 summarizes the patient-specific factors for our 113 patients. With the addition of 3D ultrasound, the anastomosis was directly visualized in a significantly higher proportion of cases by all 3 observers ($\bar{x}=97.5\%$) [DM = 43% (95% CI = 36%–50%), ($p<0.001$)] and a significantly higher quality of visualization, according to a subjective rating scale, was reported by each reviewer (Table 3). Direct visualization is different from the indirect evaluation of the anastomotic site routinely obtained with Doppler ultrasound on the 2D exam. We found high levels of agreement between all readers regarding visualization of the anastomosis (ranging from 94% to 96.5%). No significant difference in visualization of the anastomosis or rating score was observed between patients with living (22%) or cadaveric (78%) renal transplants (p-values range from 0.60 to 0.89). There was no significant difference in the ability to visualize the anastomosis amongst cases performed by the 5 technologists.

Variant anastomotic anatomy, including multiple renal arteries, is occasionally seen by 2D ultrasound. Our results demonstrate an improved ability to detect variant anatomy with 3D ultrasound for 2 out of 3 reviewers [DM = 7.1% and 8.9% (95% CI = 1%–13% and 4%–14%, respectively), ($p<0.05$)] (Table 3). When localized elevated velocity is identified, focal tortuosity must be distinguished from stenosis. Although the small population of patients with these findings preclude valid statistical comparison, we found that 3D ultrasound enhances the diagnosis of tortuosity, compared with 2D imaging. In cases where tortuosity was visualized with 3D ultrasound, no case of stenosis was reported when follow-up imaging was available at a minimum interval of 12 months (56% or 10/18 cases). The single case of donor renal artery stenosis among our study population was confirmed by diagnostic angiography, leading to intervention with endovascular stent placement (Figure 5).

Discussion

Our study demonstrates that adding 3D ultrasound to a 2D ultrasound exam of the arterial anastomosis allows significantly more consistent visualization of the anastomosis. This improvement was present among all reviewers regardless of experience level. Not only were the reviewers more likely to see the anastomosis, but it was consistently more clearly visualized. Overall, more anatomic variations were identified by 3D ultrasound.

It has been proven that 2D duplex ultrasound alone accurately evaluates the condition of the anastomosis (12); however, the clarity of visualization differs from that obtained on a 3D ultrasound exam, which affords superior visualization and clarification of anatomic variations in the often intertwined proximal donor renal artery and vein. One utility of 3D ultrasound elucidated by our study is differentiating stenosis from vascular tortuosity in the setting of focal borderline elevated Doppler velocity on 2D imaging.

Roughly half of renal transplant arterial stenoses occur at the anastomosis (Figure 6) (13). As a stenosis can occur in any of the renal arteries, adequate visualization of all these vessels has clinical import (Figure 5). Since there are so many surgical variations, it is imperative to understand the transplant anatomy in each patient scanned. Conventional surgical anatomy

of a normal renal transplant includes one renal artery and one renal vein end-to-side anastomosis with the common or external iliac artery and vein. In 18–30% of cases of renal donors, there are multiple renal arteries (14, 15, 16) that cannot be sacrificed: for example, an accessory lower pole renal artery may provide the vascularization to the ureter (17).

When a donor kidney with multiple renal arteries is used as a renal transplant, there are several types of anastomoses that can be utilized: conjoined anastomosis, 2 separate renal anastomoses, or end-to-end anastomosis of 1 of the arteries with the internal iliac artery. With deceased donor transplants, a Carrell patch is utilized: the renal artery/arteries are anastomosed to an iliac artery with the use of a donor aortic patch (Figure 7). With living donor transplants, when renal arteries are of similar size, the vessels can be joined side-to-side via bench surgery (conjoined anastomosis). When the vessels are of different size, the smaller artery is often replanted into the larger (16). An assortment of anastomoses as visualized by 3D ultrasound are illustrated in Figure 8, demonstrating the utility for 3D techniques in identifying many of these variants.

In our study, 78% of patients received deceased donor renal transplants. In the literature, it has been noted that patients who receive cadaveric transplants more frequently experience vascular complications such as renal artery stenosis (18). In our study, the type of renal transplant did not impact ultrasound evaluation of the graft vascular anastomosis.

If possible, communication directly with the transplant surgeon or correlation with the operative report is preferred before imaging evaluation (19, 20). In our institution, we often see patients post renal transplant referred from elsewhere without ready access to this information. In our retrospective review, when multiple renal arteries were detected by 2D or 3D ultrasound, confirmation with additional modalities or the operative note was often not available. However, the observed rate of multiple renal arteries with 3D ultrasound in our study is comparable to the reported rates nationally (14, 15).

The sensitivity and specificity of 2D Duplex ultrasound, the standard modality for diagnosis of renal artery stenosis in posttransplant patients, are partly determined by the technical experience of the examiner and by the presence of postoperative tortuosity (9, 20). Depending on the clinical scenario, questionable abnormal velocity findings are often expectantly followed with an additional imaging examination, such as magnetic resonance angiography (MRA). Although spectral Doppler allows inference of the hemodynamic status of the anastomosis without direct visualization, 3D ultrasound affords the opportunity to carefully manipulate the data to optimally visualize the entire anastomosis and provide a more complete appreciation of the anatomy. 3D ultrasound as an adjunct dataset is analogous to information provided by MRA, which can demonstrate anatomy but poorly quantitates the degree of stenosis (3, 21). For example, when an elevated renal artery velocity does not meet ultrasound criteria for stenosis is identified, vessel tortuosity is usually inferred. However, it may be difficult to clarify this with 2D ultrasound alone. With 3D ultrasound, the dataset may be manipulated to clearly display local tortuosity and delineate its margins (Figure 9), thereby avoiding an unnecessary MRA. If there is an elevated arterial flow velocity but stenosis cannot be excluded on 3D evaluation, proceeding directly to angiography and intervention may be considered. In our study, vessels with

elevated velocity due to tortuosity remained clear of stenosis when follow-up imaging at a minimum interval of 12 months was available.

The 3D sweep may reveal unsuspected additional renal arteries and facilitate complete spectral Doppler evaluation of all the feeding vessels. Indeed, in 1 case, the additional renal artery discovered by 3D ultrasound was shown to be stenotic, prompting subsequent angiographic evaluation and endovascular stenting. This finding may have been overlooked by 2D ultrasound evaluation alone.

Generally, the venous anastomosis is not as clinically relevant as the arterial anatomy. But, when analysis of this vessel is indicated, the information may be generated from the single arterial sweep about 30% of the time. In other cases, an additional sweep to optimize the venous anastomosis may be obtained in a short period of time.

Comprehensive storage of the data in the entire 3D real-time sweep contributes to improved patient throughput, as it allows the radiologist to further explore anatomic relationships of vessels with volume rendered and surface rendered images after the patient has left the department (22). This postprocessing of the 3D image data is similar to CT and MRI multiplanar reconstruction by the radiologist or technologist (11). In our experience, the very process of manual reconstruction fosters a more sophisticated understanding of anatomic relationships within the scanned region. In our study, we found no difference in the ability to visualize the anastomosis amongst the technologists performing the exam; therefore, there is no additional operator-dependency compared with 2D ultrasound.

The cost of adding 3D ultrasound capability to a practice can be amortized over all the patients scanned. In our practice, performance of 3D ultrasound adds up to USD\$100 to the charge for the exam, compared to a more expensive MRA. Therefore, in a busy practice, adding this useful modality to routine exams adds little overall additional cost to the patient.

One limitation of our study is that the number of delayed complications developing with postoperative renal transplants both nationwide and particularly at our institution is low (3, 23). Multi-center studies with larger numbers of patients would provide an opportunity for more robust statistical analysis. Additionally, the lack of a gold standard such as angiography or a consistently accurate operative report, limits some options for rigorous statistical analysis in our study. A study involving patients with additional angiographic imaging would be helpful to assess the sensitivity and specificity of 3D ultrasound in evaluation of anastomotic variations/complications.

In conclusion, the addition of 3D ultrasound to duplex 2D ultrasound evaluation of renal transplants enabled more precise and thorough delineation of the arterial anastomosis than did 2D ultrasound alone. Multiple features including surface-rendered, multiplanar reformatting with color Doppler, TUI ©, and the 4D cine sweep enhanced visualization of anastomotic detail (Table 2). 2D ultrasound detected only a minority of cases of anastomotic anatomic variants that were clearly detected when 3D ultrasound was added to the examination. We believe that 3D ultrasound should be added to the routine exam of renal transplant, as it has the capability to add important information to a 2D sonographic exam that may obviate the need for confirmatory testing by MRA or CTA. We suggest additional

larger studies be obtained to confirm that adding 3D ultrasound to the 2D exam for routine use in renal transplant evaluation facilitates the diagnosis of complications that may jeopardize graft longevity.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Abbreviations

2D	2-dimensional
3D	3-dimensional
4D	4-dimensional
CI	confidence interval
CT	computed tomography
CTA	computed tomographic angiography
DM	difference in means
MRA	magnetic resonance angiography
MRI	magnetic resonance imaging
TUI ©	tomographic ultrasound imaging
VOCAL©	Virtual Organ Computer-aided AnaLysis

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Figure 1.

Figure 2.

Figure 3.

Figure 4.

Figure 6.

Figure 7.

Figure 8.

Figure 9.

Table 1

Patient Characteristics of Study Population

Age (years) *	55 ± 11.9
Gender	
Women	41 (36)
Men	72 (64)
Time from transplant (months) *	47 ± 19
Donor type	
Cadaveric	88 (78)
Living	25 (22)
Indication	
renal failure	35 (31)
hydronephrosis	21 (19)
hypertension	11 (10)
mass	10 (9)
hematuria	8 (7)
urinary tract infection	7 (6)
pain	6 (5)
other	15 (13)
Technologist Performing Exam **	
YL	59 (53)
SX	24 (21)
CM	11 (10)
AK	9 (8)
MH	9 (8)

Total number of cases is 113. Number of cases are reported with percentage of cases in parentheses unless otherwise indicated.

* Reported as mean ± standard deviation.

** Total sums to 112 because one case was omitted as it was the only case performed by someone other than the five usual technologists in our Department.

Table 2

3D US reconstruction modes in the renal transplant arterial anastomosis

Mode	Created View/Reconstruction	Utility	Figure
Multiplanar reformatting	Simultaneous color Doppler orthogonal views	Visualization of anatomy & vascular anastomosis	1
TUI ©	Image series 0.5–10mm	Incremental evaluation (stenosis and thrombus)	3
Surface rendering	Transparency mode	Visualization of vascular anatomy & anastomosis (with color Doppler)	2
4D	Volume data set cine	Cine sweep of anatomy	SDC 1
Vocal ©	Volume rendering	Volume estimation for sequential follow-up (peri-transplant collection, mass)	N/A

Table 3

Comparison of 3D Ultrasound Added to 2D Ultrasound with 2D Alone

		Anastomosis Visualized*	Rating Score**	Anatomic Variation*
Reviewer 1	2D	49(43)	2	29(26)
	2D+3D	110(97)	3	37 (33)
	p-value	<0.001	<0.001	0.02
	MD% (95% CI) [†]	54(44–64)	0.5(0.5–1.0)	7(1–13)
Reviewer 2	2D	73(65)	2	15(13)
	2D+3D	109(96)	3	14(12)
	p-value	<0.001	<0.001	0.57
	MD% (95% CI) [†]	32(23–41)	1.0(0.5–1.0)	-1(-4-2)
Reviewer 3	2D	63(56)	2	15(13)
	2D+3D	112(99)	3	25(22)
	p-value	<0.001	<0.001	<0.001
	MD% (95% CI) [†]	43(34–53)	1.0(1.0–1.5)	9(4–14)

Total number of cases is 113. Reviewer 1 has 5 years of experience with 3D ultrasound, Reviewer 2 has 2, and Reviewer 3 has 1 year of experience.

[†] Mean differences and confidence intervals reported as % unless otherwise indicated

* Number of cases are reported with percentage of cases in parentheses unless otherwise indicated. p-values calculated using McNemar's test.

** Reported as median scores; p-values calculated using Wilcoxon paired rank sum test and median differences with confidence intervals calculated using the Hodges-Lehmann median difference. Median differences and confidence intervals are not reported as %.