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Original article

Three-dimensional imaging of living transplanted kidney vasculature by 3D color Doppler ultrasonography

Jinfang Xing, Lianfang Du

Department of Medical Ultrasound, Shanghai Jiaotong University Affiliated First People's Hospital, Shanghai 200080, China

Background: It is of clinical importance to display the vasculature of transplanted kidney in three-dimensional (3D) and in non-invasive way. 3D color Doppler ultrasonographic imaging (3D-CDUI) is a non-invasive technique to display the 3D vasculature of living organs.

Objective: Probe into characteristics of 3D vasculature of living transplanted kidney by 3D-CDUI, and evaluate the clinical value of 3D-CDUI on monitoring complications after operation of renal transplant.

Methods: Nine patients who received allogeneic transplantation of kidney were monitored with 3D-CDUI. The instruments used included ACUSON Sequoia 512 and TomTec computer station of 3D-CDUI. Using magnetic positioning free-hand scanning, the 3D reconstruction and display of renal tissue structure and blood flow were performed off-line.

Results: All patients underwent 3D-CDUI examinations without any side effect or complication. When acute rejection occurred, the 3D distribution change of renal blood flow signal could be observed clearly. During treatment of acute necrosis of renal tubules, changes of renal blood flow signal in 3D color Doppler images could be detected earlier compared with 2D color Doppler images. The position of embolized vassels could be diagnosed accurately by 3D-CDUI.

Conclusion: The 3D-CDUI was helpful to improve diagnosis level of ultrasonography by monitoring complications after renal transplantation.

Keyword: Color Doppler, post-operative complication, renal vasculature, 3D-ultrasonography, transplanted kidney

It is of clinical importance to monitor transplanted organs by noninvasive methods. Two-dimensional (2D) color Doppler ultrasonographic imaging (2D-CDUI) is a usual non-invasive method to monitor the vasculature of transplanted kidney in 2D views [1-10]. Since the vasculature of transplanted kidney is of three-dimensional (3D) structure, many researchers have desired to display it in 3D and non-invasive way.

3D color Doppler ultrasonographic imaging (3D-CDUI) is a non-invasive technique that enables us to display the 3D vasculature of living organs [11-27]. It has special superiority on monitoring the vasculature of living organs. In this project, we studied the characteristics of 3D vasculature of living transplanted kidney using 3D-CDUI, and evaluated clinical values of 3D-CDUI by monitoring complications after operation of renal transplant.

Correspondence to: Lianfang Du, Department of Medical Ultrasound, Shanghai Jiaotong University Affiliated First People's Hospital, Shanghai 200080, China. E-mail: xingshi7018 @163.com

Materials and methods

Patients

Nine adult patients (seven men and two women, age range: 20 to 56 years) were studied by 3D-CDUI. The transplanted kidneys were placed in right or left iliac fossa, the end-to-end anastomosis of renal artery and internal iliac artery and end-to-side anastomosis of renal vein and external iliac vein were done. Three patients were diagnosed as normal transplanted kidneys vasculature according to clinical symptom, physical examination, laboratory examination (e.g. renal function) and digital subtraction angiography (DSA). One patient was diagnosed as acute rejection by needle biopsy. Three patients were proved as acute necrosis of renal tubules by needle biopsy. One patient was proved as embolism of renal segmental artery by DSA. One patient was proved as embolism of renal artery and vein by magnetic resonance angiography (MRA). All patients provided written consent to participate.

Equipments

The equipments used in our study were 1) an ACUSON Sequoia 512 Color Doppler ultrasonic diagnosis instrument (Siemens, Mountain View) with a 3.5MHz convex array transducer, 2) a 3D Color Doppler Imaging System (TomTec, Munich, Germany), 3) a magnetic positioning free-hand scanning system linked with the Imaging System and controlled by a computer.

Examination methods

The patients lay supinely. The probe was placed on the region of right or left iliac fossa. At first, the transplanted kidneys were examined routinely to observe the renal tissue structure and blood flow of kidney. The entire kidney was fan-scanned (or parallel-scanned) along long-axis view.

The sequential longitudinal 2D images with message of spatial position were collected by the three-dimensional images collecting system when all the views displayed well during scanning. The time of scanning was normally preset to be 30 seconds, and the time can be prolonged (or shortened) according to actual need. The scanning processwas stable, even and slow, and was done as soon as possible while the patients kept calm and immobile.

Processing and reconstructing of threedimensional images

After scanning, a series of 2D images with information of spatial position were processed by fitting and interpolating, to produce a three-dimensional database. From the database, views were reconstructed and displayed by any cut plane. The 3D images of tissue and blood flow in the region of interest were reconstructed and displayed. After reconstruction, the 3D images can be displayed rotatably according to the angle range of selection and the direction of rotation.

Results

Nine patients underwent successfully 3D-CDUI examinations for 16 times. All patients were willing to accept the examination, and no side effect or complication was observed. The 2D images of 3D Doppler ultrasonographic imaging were acquired two to five times in each examination. According to each 3D database produced after acquiring two-dimensional images, three-dimensional images were reconstructed and analyzed. The 3D reconstructed images of all patients accorded with the analytic criterion.

Normal transplanted kidney

Three patients who were diagnosed as normal transplanted kidneys according to clinical symptom, physical examination, and laboratory examination underwent 3D-CDUI within twenty-four hours after digital subtraction angiography (DSA) of transplanted kidney artery.

The 3D-CDUI showed that the volume and shape of transplanted kidney were the same as that of normal kidney, the renal capsules were smooth and intact, the tissue structures were clear, and the bounds of renal cortex and medulla were distinguished clearly (see **Fig. 1**). The arteries and veins were distributed among entire renal parenchyma in form of coral. The color flow signals were uniform, symmetrical, and complete (**Fig. 2).** The effect of 3D-CDUI of artery was close to DSA (**Fig. 3**).

Acute renal transplant rejection

One patient was diagnosed as normal transplanted kidney according to clinical symptom, physical examination, laboratory examination within 30 days post-operation. Furthermore, the distribution of renal blood flow signals displayed well in three-dimensional color Doppler images (**Fig. 4A**). However, acute rejection was suspected according to clinical symptom, physical examination, laboratory examination at the 38 day after operation. The same day, the patient underwent 3D-CDUI. The 3D-CDUI showed that the distribution of renal blood flow signals became obviously sparse compared with previous display (**Fig. 4B**). The patient underwent needle biopsy within 24 hours after 3D-CDUI and was diagnosed as acute rejection by a pathologist.

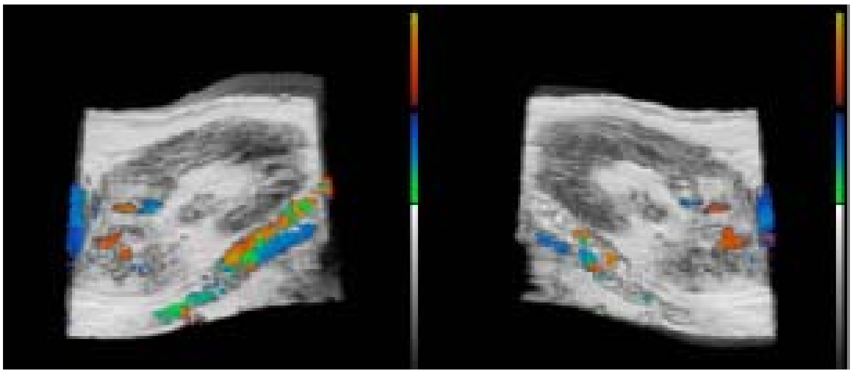

Fig. 1 The 3D-CDUI showed that the renal capsules were smooth and intact, tissue structures were clear, and the bounds of renal cortex and medulla were distinguished clearly.

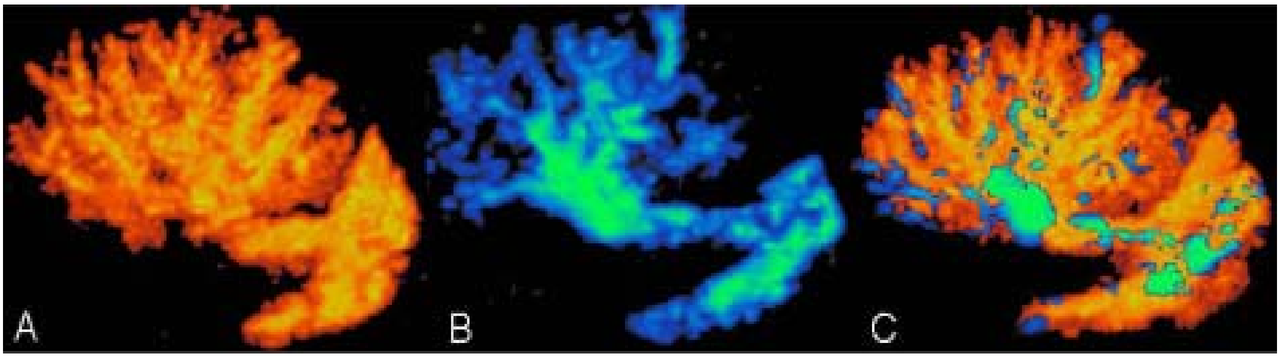

Fig. 2 The 3D-CDUI showing that the arteries and veins were distributed among entire renal parenchyma in form of coral, and the color flow signals were uniform, symmetrical and complete. **A**: distribution of artery; **B**: distribution of vein; **C**: distribution of artery and vein.

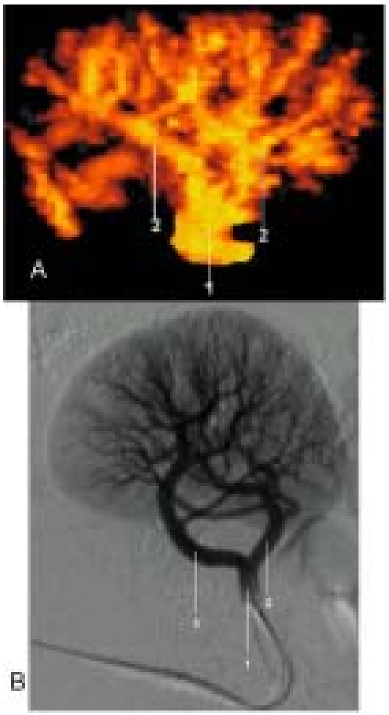

Fig. 3 The display of 3D-CDUI of artery (**A)** was similar to DSA (**B**). 1: renal artery; 2: segmental artery.

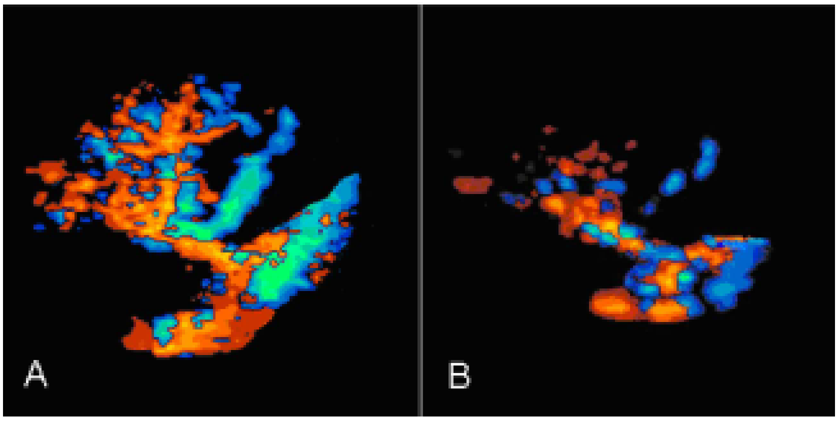

Fig. 4 The 3D-CDUI showing that the distribution of renal blood flow signals changed when acute rejection occurred. **A**: acute rejection did not occur; **B**: acute rejection occurred.

Acute necrosis of renal tubules

Three transplanted kidneys were diagnosed as acute necrosis of renal tubules by needle biopsy. The 3D color Doppler imaging of renal blood flow showed that the distribution of renal blood flow signals improved clearly at the 10 day after treatment of dialysis (**Fig. 5**). On the other hand, the 2D color Doppler ultrasonographic imaging (2D-CDUI) did not show much change (**Fig. 6**), the function of transplanted kidney and resistance index (RI) of renal artery was still above normal (RI>0.8) (**Fig. 7**).

Vascular embolism of transplanted kidney

The three-dimensional color Doppler image of one transplanted kidney showed that volume of inferior segment became small and the blood flow signals of inferior segment disappeared (**Fig. 8**).

The patient was diagnosed as embolism of renal inferior segmental artery by 3D-CDUI. The diagnosis was proved by DSA of renal artery.

One patient underwent an examination with ultrasonography. The 3D-CDUI showed that the volume and shape of transplanted kidney were not abnormal, but color signal of blood flow in the entire kidney disappeared completely. Only the color signals of internal iliac artery and external iliac vein appeared. The color signals of blood flow inflood into transplanted kidney did not display (**Fig. 9**). The embolism of renal artery was diagnosed by 3D-CDUI. The patient underwent magnetic resonance angiography (MRA) within 24 hours after examination with the 3D-CDUI. The MRA showed that the right internal iliac artery was interrupted, no vessel was leading to the transplanted kidney, and the transplanted kidney could not be visible (**Fig. 10**). The patient was diagnosed as the embolism of renal artery by MRA.

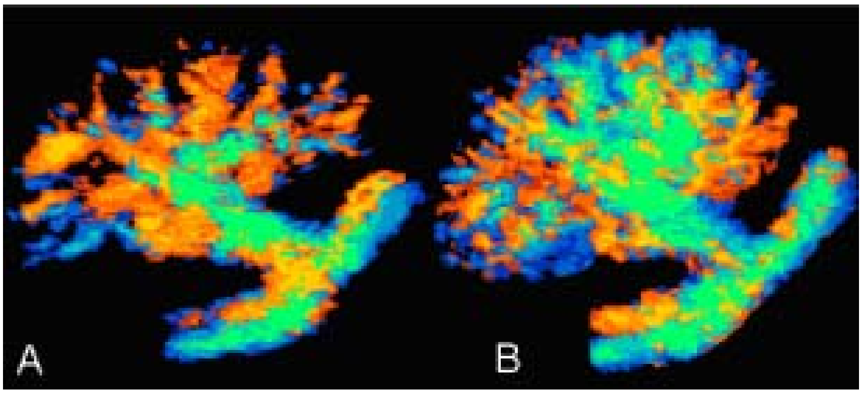

Fig. 5 The 3D color Doppler imaging of distribution of renal blood flow signals improved obviously at 10 day after treatment of dialysis. **A:** before treatment, **B:** 10 day after treatment.

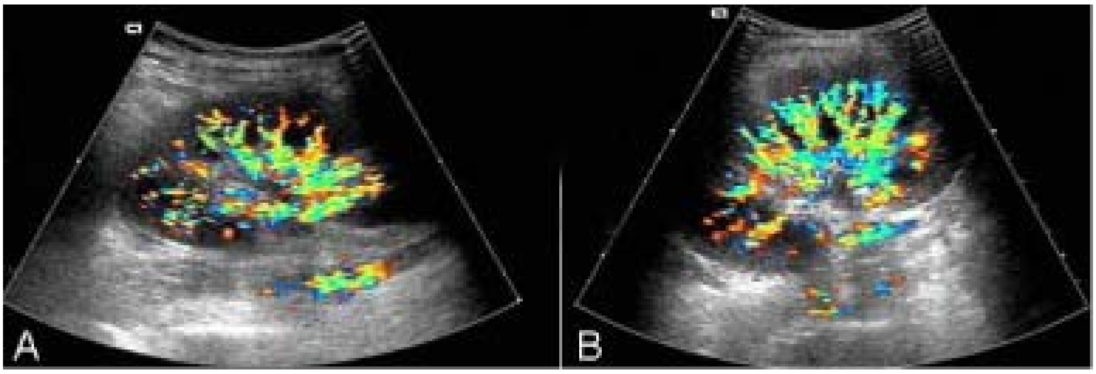

Fig. 6 The two-dimensional color Doppler imaging did not change when change of 3D-CDUI was already obvious. **A**: before treatment; **B**: 10 day after treatment.

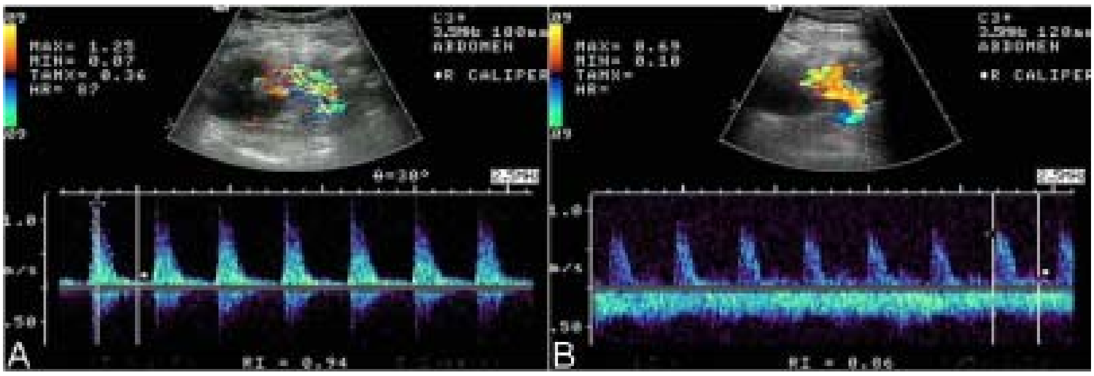

Fig. 7 The resistance index (RI) of renal artery was still above normal. **A**: before treatment; **B**: 10 day after treatment.

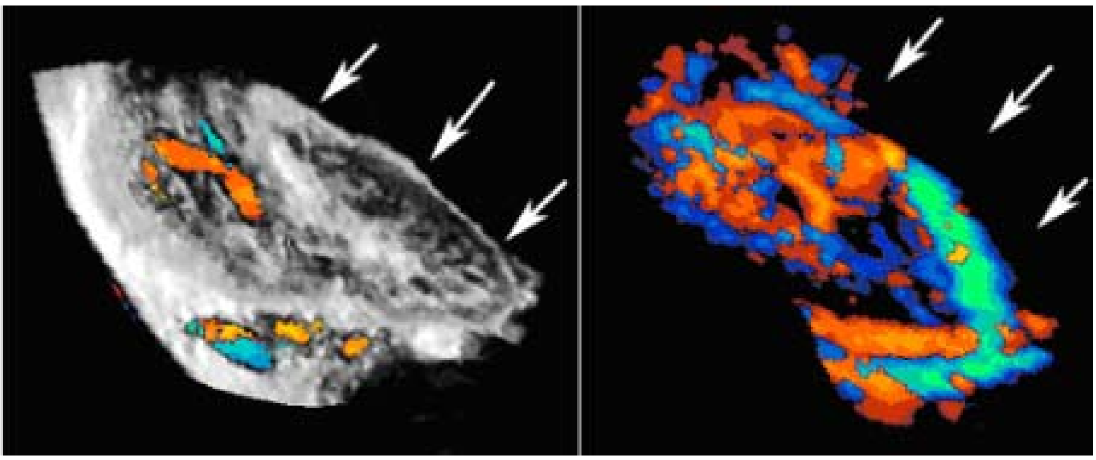

Fig. 8 The three-dimensional color Doppler image of one transplanted kidney showing that the volume of inferior segment became small and the blood flow signals of inferior segment disappeared (arrows: inferior segment).

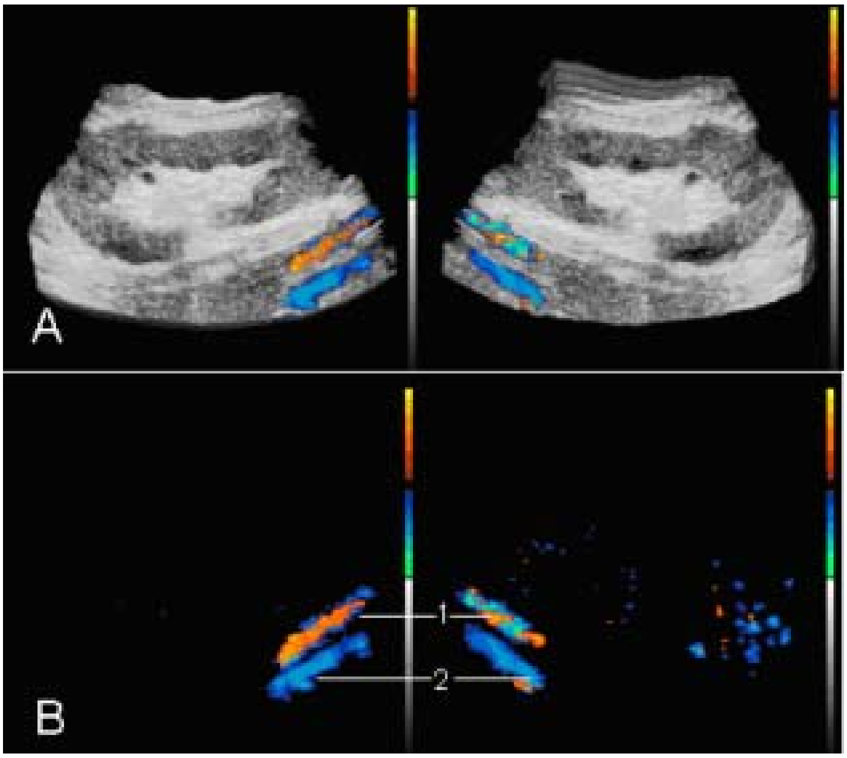

Fig. 9 3D reconstructed images of renal vascular embolism. **A:** The volume and shape of transplanted kidney were not obviously abnormal. **B:** The color signal of blood flow in entire kidney disappeared completely. Only color signals of internal iliac artery and external iliac vein appeared. The color signals of blood flow into transplanted kidney were not visible. (1: internal iliac artery, 2: external iliac vein).

Fig. 10 The MRA showing that right internal iliac artery interrupted (arrowhead), no vessel was leading to the transplanted kidney, and the transplanted kidney could not be visible.

Discussion

Kidney may have many different complications such as rejection, necrosis of renal tubules, vascular embolism, arteriostenosis, orteriovenous fistula, which may produce changes of renal blood flow. It is of clinical importance that the vasculature of transplanted kidney is monitored accurately after operation of the kidney. To monitor periodically the vasculature of transplanted kidney and to find the pathological changes as soon as possible, we have to use a non-invasive and exact technique of renal blood flow imaging.

There are several techniques of renal blood flow imaging, including ultrasonography, digital subtraction angiography, and magnetic resonance angiography. Among them, ultrasonography has become routine for periodic examination because it is non-invasive, not restricted by contraindication, simple and convenient, and easily repeatable.

Transplanted kidneys, when they are placed under abdominal wall, are superficial and get no or little air. Because of this, they are most appropriate for ultrasonographic examination. The image quality of the transplanted kidneys is superior to kidneys whose positions are normal. The traditional 2D-CDUI monitors the vasculature of the transplanted kidney in 2D views. On the other hand, the 3D-CDUI enables us to display the 3D vasculature ature of a living organ.

The present study has demonstrated that the 3D-CDUI not only could provide the same information of transplant kidney as 2D-CDUI, but also had particular superiority and clinical value.

1) 3D reconstruction of renal blood flow by 3D-CDUI is similar to stereo-anatomy of renal blood vessel. The effect of 3D-CDUI was close to DSA. When reconstructing 3D-CDUI, the 3D images can be observed from any direction, the 3D images can be displayed rotatably in horizontal (or vertical) direction by setting on any angle range. The imaging effect is as if the kidney was observed from the up, down, left, right and around side. There is no need for the examiner to make up and infer the stereoscopic shape of transplant kidney in his/her brain. In comparison with 2D views, 3D images are more visual and stereoscopic, and provide more information of renal blood flow.

2) Images after 3D reconstruction display gray-scale information of renal tissue structure. The color Doppler information of renal blood flow enables us to observe the distribution of blood flow simultaneously and repeatedly. It is easy to see the spatial orientation of renal artery and vein.

3) 3D ultrasonographic imaging is more standard than 2D ultrasonographic imaging and all renal structure and blood flow is displayed in a piece of 3D images. For this reason, the shortcoming of 2D imaging was overcome, and individual difference of ultrasonologists was reduced. 3D-CDUI was useful for repeated examinations.

4) The 3D-CDUI examination of transplanted kidney could be obtained quickly and simply. The time duration for obtaining 2D and 3D imaging was less than five minutes. After the patient was scanned for the 2D images, the images were processed and analyzed off-line at the computer station. This was useful to concentrate our efforts to analyzing the images.

5) Changes of blood flow could be monitored more sensitively by 3D-CDUI than 2D-CDUI. The assessment of renal blood flow by 3D-CDUI was better, compared to 2D-CDUI and RI. The diagnoses of the position of the embolized vasculature was similar to the precision seen in MRA or DSA.

In conclusion, the 3D-CDUI was helpful to improve diagnosis level of ultrasonography by monitoring complications after renal transplantation.

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