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Evaluation of the relationship between renal function and renal volume-vascular indices using 3D power Doppler ultrasound

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ABSTRACT

Purpose: To investigate the relationship between renal function and total renal volume-vascular indices using 3D power Doppler ultrasound (3DPDUS).

Materials and methods: One hundred six patients with hypertensive proteinuric nephropathy (HPN) (49 male, 57 female) and 65 healthy controls (32 male, 33 female) were evaluated prospectively using 3DPDUS. Total renal volume (RV), vascularization index (VI), flow index (FI) and vascularization flow index (VFI) were calculated using Virtual Organ Computer-aided Analysis (VOCAL). The estimated glomerular filtration rates (GFRs) of the patients with HPN and the control group were calculated. The patients with HPN were divided into two groups on the basis of GFR, normal (≥90) or reduced (<90). Differences between groups were compared using ANOVA. Correlations between GFR, renal volume and vascular indices were analyzed using Pearson's correlation analysis. Significance was set at $p < 0.05$.

Results: The mean total RV, VI, FI and VFI values in the reduced GFR, normal GFR and control groups were RV (ml): 234.7, 280.7 and 294.6; VI: 17.6, 27.6 and 46.8; FI: 79.1, 88.7 and 93.9 and VFI: 7.1, 12.7 and 23.8. There were statistically significant differences between the groups ($p < 0.001$). Total RVs and vascular indices exhibited significant correlations with estimated GFR ($r = 0.53–0.59$, $p < 0.001$)

Conclusion: Three-dimensional power Doppler ultrasound is a reliable predictive technique in renal function analysis.

1. Introduction

Estimated glomerular filtration rate (GFR) calculated from serum creatinine concentration is the most commonly used index for the evaluation of overall renal function [1]. However, calculating estimated GFR depends on body mass index and age and cannot be applied to evaluate split renal function [2]. Because of the limitations of blood tests, the question of using different imaging methods in the assessment of renal function has now arisen.

Renal length measurement is generally used for the evaluation of chronic renal impairment [3]. However, renal volume is a more accurate predictor of the functional capacity of the kidney [4–8]. Imaging methods for evaluation of renal volume may become an important tool for the assessment of chronic renal diseases, kidney transplantation and follow-up of transplant kidneys. A number of reports [4,6,9–12] have described the relation between renal function and renal volume using CT or MRI, but these techniques have associated problems of cost, use of contrast material and exposure to ionizing radiation in CT. Furthermore, only one study has investigated the relation between renal function determined with GFR and renal volume determined with three-dimensional (3D) sonography [13]. To the best of our knowledge, the relationship between renal function determined with estimated GFR and renal vascularization determined with 3D power Doppler ultrasound (3DPDUS) has not previously been investigated.

Three-dimensional quantification of blood flow using power Doppler ultrasound with the virtual organ computer-aided Analysis (VOCAL) program, commonly used in the studies of obstetrics and gynecology [14–16], makes it possible to calculate volume and evaluate vascularity. Three vascular indices can be calculated automatically; vascularization index (VI), flow index (FI) and vascularization flow index (VFI) [16]. The aim of this study was to investigate the relationship between renal function and total renal volume-vascular indices using 3DPDUS.

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2. Materials and methods

2.1. Study population

The study was approved by the Institutional Ethics Committee, and all subjects gave informed consent. One hundred six patients with hypertensive proteinuric nephropathy (HPN) (49 male, 57 female) and 65 healthy controls (32 male, 33 female) meeting the study criteria were prospectively evaluated using 3DPDUS between April, 2011, and March, 2013. Subjects with other causes of chronic renal disease, such as diabetes, amyloidosis, glomerular disease or chronic pyelonephritis, or a renal lesion larger than 1 cm in diameter or a greater than 2 cm discrepancy in renal lengths at 2D ultrasound examination ($n = 43$) and subjects with excessive bowel gas ($n = 9$) or who could not hold their breath ($n = 20$) were excluded. Age, sex, body weight (kg), height (m) and serum creatinine level were recorded. Body mass index (BMI) was calculated as weight (kg) divided by the square of the height (m) [17]. Glomerular filtration rates (GFRs) of the patient and control groups were also calculated. Estimated GFR was calculated based on the formulaestimated GFR = 1.86 × (serum creatinine concentration)$^{-1.154}$ × (age)$^{-0.203}$ × (0.742 if female) [1].

Patients with HPN were divided into two groups on the basis of GFR, normal (≥90) or reduced (<90).

2.2. Ultrasound examination

The examinations were performed using Voluson 730 Expert (General Electric, Waukesha, Wisconsin) with a volumetric abdominal probe RAB 2–5 MHz. In order to standardize our evaluation of renal vascularization during systole, identical power Doppler settings were used as follows; pulse repetition frequency, 0.9 kHz; wall motion filter, low I; quality, normal; frequency, low; harmonic frequency, middle; smooth, 5/5, line density, 7; balance gray > 170; artifact on. The highest gain was set initially and then reduced until all artefacts were suppressed. Renal lengths were measured in the coronal plane in the supine position or in the contralateral decubitus position, which was appropriate for optimal visualization of the renal poles. After visualization of maximum length in the longitudinal 2D view, we performed 3D static power Doppler scanning using the widest scanning angle (85°) including the entire kidney (Fig. 1). Three-dimensional power Doppler acquisition was performed separately for each kidney. The acquired volume data were analyzed using the VOCAL program. The outer kidney borders were traced on a fixed axis by the same radiologist. The rotation steps were 30° revealing six sequential kidney sections. When all contours had been drawn, the volume of the kidney was calculated automatically (Fig. 2). Using the histogram facility in the VOCAL software, three indices were obtained; VI, FI and VFI (Fig. 3). VI is the ratio of color voxels to all voxels in the studied volume expressed as a percentage and reflects the density of vessels. FI is the sum of weighted color voxels divided by the number of all color voxels and represents average color intensity. VFI is the sum of weighted color voxels divided by all voxels and reflects vascularization and perfusion [16].

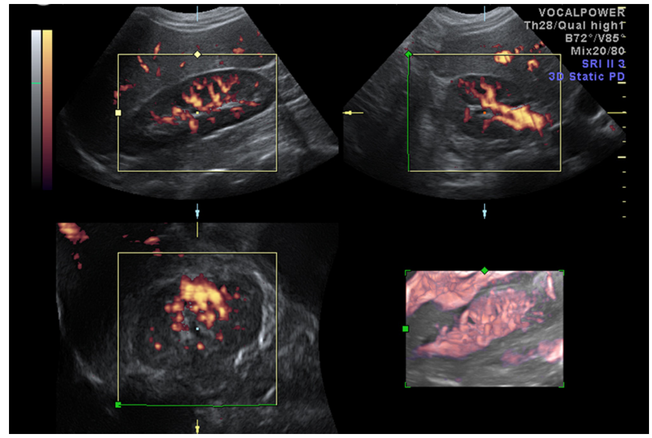

Fig. 1. Sonogram showing 3D power Doppler acquisition in the longitudinal view by 3D power Doppler ultrasound. The power Doppler box positioned to cover the whole kidney. The widest scanning angle (85°) including the entire kidney was used.

2.3. Statistical analysis

The total (sum of the right and left kidneys) renal volume, VI, FI and VFI of the three groups (control, patients with normal GFR and patients with reduced GFR) were compared using one-way ANOVA, and further comparisons were made with Bonferroni or Tamhane's tests as appropriate. Correlation between GFR and renal volume and vascular indices was analyzed using Pearson's correlation analysis. Furthermore, the differences between the right and left kidneys were assessed using paired t-test. A p value <0.05 was considered statistically significant.

3. Results

Fifty-seven of the 106 patients with HPN had normal GFR and the remaining 49 had reduced GFR. The mean ages of the reduced GFR, normal GFR and control groups were 53.5 ± 14.1 years, 34.9 ± 12.7 and 37.9 ± 11.0, respectively. The mean height (cm) and body weight (kg) of the reduced GFR, normal GFR and control groups were 1.67 ± 0.1 m and 1.64 ± 0.1 m, 1.67 ± 0.1 m and 81.8 ± 17.1 kg and 79.1 ± 18.6 kg and 75.4 ± 15.1 kg, respectively. Mean BMI (kg/m^2) values in the reduced GFR, normal GFR and control groups were 29.5 ± 6.2, 29.4 ± 6.9 and 27.1 ± 5.3, respectively. There were no statistically significant differences in terms of mean height, body weight or BMI values between the groups, but there was a significant difference in mean age between the reduced GFR group and the normal GFR and control groups. The demographic characteristics are presented in Table 1.

The mean total RV, VI, FI and VFI values in the reduced GFR, normal GFR and control groups were RV (ml): 234.7, 280.7, 294.6; VI: 17.6, 27.6, 46.8; FI: 79.1, 88.7, 93.9 and VFI: 7.1, 12.7, 23.8, respectively. Statistically significant differences were determined between the groups using one-way ANOVA test ($p < 0.001$ for all pairs) (Table 2). Although the total renal volume of the control group was slightly larger than the normal GFR group, this difference was not statistically significant ($p = 0.5$; Bonferroni post

Table 1
Demographic Characteristics of Study Population ($n = 171$).

	Sex (no.)		Age (y)	Height (m)	Weight (kg)	BMI (kg/m^2)	eGFR (ml/min/1.73 m^2))
	Men	Women					
Reduced GFR (<90)	29	20	53.5 ± 14.1	1.67 ± 0.1	81.8 ± 17.1	29.5 ± 6.2	56.1 ± 26.3
Normal GFR (≥90)	20	37	34.9 ± 12.7	1.64 ± 0.1	79.1 ± 18.6	29.3 ± 6.9	116.3 ± 22.4
Control	32	33	37.9 ± 11.0	1.67 ± 0.1	75.4 ± 15.1	27.1 ± 5.3	136.3 ± 23.5

eGFR: estimated glomerular filtration rate; BMI: body mass index; Values are mean values ± SD (except for sex).

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