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Altered oscillation of Doppler-derived renal and renal interlobar venous flow velocities in hypertensive and diabetic patients

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Abstract

Background and purpose Flow velocity oscillation rate (FVOR) of the renal interlobar vein has been reported to be decreased in patients with urinary obstruction or diabetic nephropathy, and increased in those with hypertension during pregnancy. To clarify the clinical role of the renal interlobar venous FVOR, we investigated the flow velocity patterns of the renal vessels in patients with hypertension (HT) and/or diabetes (DM).

Methods and results Pulsed-wave Doppler sonography was performed in 34 patients: 15 with HT, 10 with DM, and nine with both HT and DM (HT-DM). Each FVOR of the right and left interlobar veins was closely and positively correlated with the ipsilateral interlobar arterial resistive index (RI), especially in the HT group, but not with the estimated glomerular filtration rate. The right interlobar venous FVOR was decreased in the DM and HT-DM groups compared to the HT group.

Conclusion The renal interlobar venous FVOR is strongly influenced by the arterial RI in HT patients, and is reduced in DM patients without an obvious relationship with diabetic nephropathy. These findings should be noted for the clinical application of renal interlobar venous flow analysis.

Key words: pulsed-wave Doppler sonography, renal interlobar vein, flow velocity oscillation, hypertension, diabetes mellitus

Introduction

Pulsed-wave Doppler sonography is known to be useful for the noninvasive assessment of renal circulation. There have been many reports on the resistive index (RI) of the interlobar artery, revealing its efficacy for predicting the progression of renal function in patients with hypertension [1], diagnosing diabetic nephropathy [2], assessing the prognosis of patients after percutaneous renal artery intervention [3], and detecting acute rejection after renal transplantation [4].

Although the flow velocity of the renal vein and renal interlobar vein can also be readily recorded using Doppler sonography, a smaller number of studies have been done for the renal venous system. Flow velocity measurement of the left renal vein was reported to be useful to diagnose nutcracker syndrome [5-7]. Several previous reports have focused on the flow velocity oscillation rate (FVOR) of the renal interlobar vein, which is calculated as the difference between the maximum and minimum velocities divided by the maximum velocity, and is often termed the “impedance index” by other investigators. It was reported that this index was decreased in patients with urinary obstruction [8, 9], increased in those with hypertensive nephropathy associated with pregnancy [10-12], and reduced in those with early diabetic nephropathy [13]. However, the mechanism and clinical role of the changes in flow pattern in the renal venous system in patients with hypertension (HT) and diabetes mellitus (DM) remain unclear. There has been no comprehensive study on the flow velocities from the renal interlobar vein to the inferior vena cava and their relationships with those of the renal arterial system. Thus, in the present study, we investigated the flow velocity patterns of the renal interlobar vein, renal vein, and inferior vena cava as well as those of the renal arterial system in patients with HT and/or DM to clarify the clinical role and mechanisms of flow abnormalities of the renal venous system induced by HT and DM.

Materials and methods

Study subjects

The study population consisted of 34 patients with HT and/or type II DM who underwent sonographic examination to assess or rule out renal or renovascular abnormalities between October 2015 and June 2016 in Hokkaido University Hospital. They included 20 men and 14 women, and their ages ranged from 24 to 84 years (58.2 ± 15.4 years). HT was defined as repeatedly elevated blood pressure (>140 mmHg at systole or 90 mmHg at diastole) or use of anti-hypertensive medications with a history of HT [14]. DM was defined as hemoglobin A1C $\geq 6.5\%$ or fasting plasma glucose ≥ 126 mg/dL, 2-hour plasma glucose ≥ 200 mg/dL during a 75-g oral glucose tolerance test, or random plasma glucose ≥ 200 mg/dL [15]. The 34 patients were divided into three groups: 15 patients with HT only (HT group), 10 patients with DM only (DM group), and nine patients with both HT and DM (HT-DM group). Patients with acute kidney injury, obstructive uropathy, renal artery stenosis, or cardiac disease were excluded from the study. We could record flow velocities of all the examined vessels in all the subjects involved in this study, and none was excluded because of inadequate recording.

Thirty-nine adult healthy volunteers without any history of HT, DM, renal disease, cardiac disease, or significant systemic diseases served as controls. They included 20 men and 19 women, and their ages ranged from 20 to 47 years (26.6 ± 7.3 years).

All the study subjects agreed to participate in this study with written informed consent before inclusion, and the study protocol was approved by the Research Ethics Committee of Hokkaido University Hospital.

Baseline clinical characteristics

The baseline characteristics of the study subjects, including heart rate, blood pressure, and blood biochemical parameters, were examined on the day of sonographic examination. The estimated glomerular filtration rate (eGFR, mL/min/1.73 m²) was calculated using the following equation:

$$[\text{eGFR}] = 194 \times [\text{serum creatinine (mg/dL)}]^{1.094} \times [\text{age (y)}]^{-0.287} \times [0.739 \text{ when female}].$$

Pulsed-wave Doppler sonography

Sonographic measurements were performed using a LOGIQ E9 ultrasound machine (GE Healthcare, Milwaukee, WI, USA) and a 4-MHz wideband convex probe by a single examiner (Y.K. with 7 years of experience) with the subjects in a supine position.

Pulsed-wave Doppler sonography was performed under the guide of color Doppler imaging with simultaneous electrocardiogram recording (Fig. 1). We recorded the flow velocity waveform of the abdominal aorta, the inferior vena cava, the right and left renal arteries and veins, and the right and left renal interlobar arteries and veins over at least three consecutive cardiac cycles. Breath holding at shallow expiration was used for measurement of the arterial flows, and breath holding at both shallow expiration and shallow inspiration was used for measurement of the venous flow. The Doppler beam was directed to the aorta, the inferior vena cava, and the renal arteries and veins with an incident angle of less than 60 degrees, and an angle correction technique was used for the velocity measurements. For the renal interlobar arteries and veins, the beam was directed as parallel as possible to the vessels under color Doppler guidance, and the flow velocities were recorded without angle correction. We measured the peak systolic flow velocities (PSV, cm/s) and end-diastolic velocities (EDV, cm/s) of the aorta and the right and left renal and renal interlobar arteries and calculated the RI using the following equation:

$$\text{RI} = (\text{PSV} - \text{EDV}) / \text{PSV}.$$

We then measured the maximal velocity (V_{MAX}) and minimal velocity (V_{MIN}) of the inferior

vena cava and the right and left renal and renal interlobar veins during inspiration and expiration, respectively, and calculated the mean value for each vein. The flow velocity oscillation rate (FVOR) was calculated for each mean value using the following equation:

$$\text{FVOR} = (V_{\text{MAX}} - V_{\text{MIN}}) / V_{\text{MAX}}.$$

Statistical analyses

Standard statistical software (SPSS version 23 for Windows; SPSS, Chicago, IL, USA) was used for the statistical analyses. All numerical data were represented as the means +/- standard deviation. Differences among three or four groups were first tested by one-way analysis of variance (ANOVA). When a significant difference was detected, the difference between each pair of individual groups was tested using a Tukey's HSD test. Pearson's linear correlation and regression analysis were used to assess the relationship between two variables. For all statistical tests, a p-value <0.05 was used to indicate significance.

Results

1. Baseline characteristics of the study subjects

Table 1 shows the clinical background of the study subjects classified into four groups—the control, HT, DM, and HT-DM groups—and the differences among the individual groups. Both the age and BMI were significantly greater in the HT, DM, and HT-DM groups than in the control group, but no significant difference was found among the three patient groups. Systolic blood pressure was significantly greater in the HT group than in the control and DM groups, and in the HT-DM group than in the control group. Diastolic blood pressure tended to be greater in the three patient groups than in the controls, but no significant difference was detected between any pair of groups. There were also no significant differences in pulse

pressure among the four groups. Serum creatinine was significantly greater in the HT group than in the control group, and eGFR was significantly reduced in the HT, DM, and HT-DM groups compared to the control group. However, no significant difference was found among the three patient groups either for serum creatinine or eGFR.

2. Difference in the RI of the renal arterial system among groups

Table 2 shows the RI of the abdominal aorta and the renal and renal interlobar arteries of the four groups and the differences among the groups. The RI of the abdominal aorta and the right and left renal arteries did not show any significant differences among the four groups. The RI of the right renal interlobar artery was significantly greater in the HT, DM, and HT-DM groups than in the control group ($P=0.038$, $P=0.016$, and $P=0.014$, respectively), but there was no significant difference among the three patient groups. The RI of the left renal interlobar artery was significantly greater in the DM and HT-DM groups than in the control group ($P<0.001$ and $P=0.003$, respectively), but here again, there was no significant difference among the three patient groups.

3. Difference in FVOR of the renal venous system among groups

Table 2 shows the FVOR of the inferior vena cava and the renal and renal interlobar veins of the four groups and the differences among the groups. The FVOR of the inferior vena cava was significantly lower in the DM and HT-DM groups than in the controls ($P<0.001$ for both). On the whole, the FVOR of the renal and renal interlobar veins tended to be lower in the DM and HT-DM groups compared to the control and HT groups (Fig. 2). The FVOR of the right renal vein was significantly lower in the DM and HT-DM groups than in the control group ($P<0.001$ and $P=0.005$, respectively) and also than in the HT group ($P<0.001$ and $P=0.002$, respectively). The FVOR of the right interlobar vein was significantly lower in the DM and HT-DM groups than in the control group ($P<0.001$ for both), and also lower in the DM groups

than in the HT groups ($P=0.006$). The FVORs of the left renal and left interlobar veins tended to be lower in the DM and HT-DM groups compared to the control and HT groups ($P=0.023$ and $P=0.030$ by one-way ANOVA), without significant differences between the individual groups.

4. Relationship of the arterial RI and venous FVOR to renal function in hypertensive and/or diabetic patients

In the 34 patients with HT or DM, the RI of the abdominal aorta, right and left renal arteries, and left renal interlobar arteries was significantly negatively correlated with eGFR ($r=-0.357$, $P=0.038$; $r=-0.556$, $P=0.001$; $r=-0.463$, $P=0.006$; and $r=-0.358$, $P=0.038$, respectively). However, none of the FVORs of the inferior vena cava, right and left renal vein, and right or left interlobar vein were significantly correlated with eGFR.

5. Relationship among the FVORs of different veins in hypertensive and/or diabetic patients

In the 34 patients with HT or DM, there was an excellent correlation between the RIs of the right and left renal interlobar arteries ($r=0.907$, $P<0.001$), and a good correlation between the FVORs of the right and left renal interlobar veins ($r=0.805$, $P<0.001$) (Fig. 3). The FVOR of the right interlobar vein was well correlated with that of the right renal vein ($r=0.675$, $P<0.001$), but was not significantly correlated with that of the inferior vena cava ($r=0.219$, $P=0.212$). The FVOR of the left interlobar vein was fairly well correlated with the FVOR of the left renal vein ($r=0.584$, $P<0.001$), and more weakly correlated with that of the inferior vena cava ($r=0.440$, $P=0.009$).

6. Relationship between the FVOR of the renal venous system and the interlobar arterial RI in hypertensive and/or diabetic patients

In our 34 patients with hypertension and/or diabetes, the FVOR of the right interlobar vein was significantly positively correlated with the RI of the right interlobar artery ($r=0.584$, $P<0.001$), and the FVOR of the left interlobar vein also was significantly positively correlated with the RI of the left interlobar artery ($r=0.538$, $P<0.001$). In the 15 patients with HT but without DM, there was an excellent correlation between the right interlobar venous FVOR and the right interlobar arterial RI ($r=0.749$, $P=0.001$), and between the left interlobar venous FVOR and the left interlobar arterial RI ($r=0.792$, $P<0.001$), which were, on the whole, surprisingly good and better than the correlations seen in all 34 patients (Fig. 4). In the 15 HT patients, a significant correlation was also observed between the right renal venous FVOR and the right interlobar arterial RI ($r=0.585$, $P=0.022$), and between the left renal venous FVOR and the left interlobar arterial RI ($r=0.521$, $P=0.047$).

7. Relationship between the FVOR of the renal venous system and blood pressure in the hypertensive and/or diabetic patients

In the 34 patients with HT and/or DM, the FVOR of the right and left interlobar veins was significantly positively correlated with systolic blood pressure ($r=0.630$, $P<0.001$ and $r=0.602$, $P<0.001$, respectively), and with pulse pressure ($r=0.807$, $P<0.001$ and $r=0.816$, $P<0.001$). In the 15 patients with HT but without DM, the FVOR of the right and left interlobar veins was significantly positively correlated with systolic blood pressure ($r=0.640$, $P<0.001$ and $r=0.646$, $P<0.001$, respectively) and with pulse pressure ($r=0.796$, $P<0.001$ and $r=0.865$, $P<0.001$), and these correlations were better than the average values for the 34 patients overall (Fig. 5). In the 15 HT patients, a significant correlation was also observed between the right renal venous FVOR and pulse pressure ($r=0.606$, $P=0.017$), and between the left renal venous FVOR and pulse pressure ($r=0.557$, $P=0.031$).

Discussion

The present study demonstrated that the FVOR of the right and left renal interlobar vein, more commonly known as the “impedance index,” was closely and positively correlated with the ipsilateral interlobar arterial RI and the arterial pulse pressure, especially in patients with HT. Contamination of the interlobar venous flow by intrarenal small arterial flows was unlikely, because the renal venous FVOR was also significantly correlated with the ipsilateral interlobar arterial RI and pulse pressure. The renal interlobar FVOR was decreased in patients with DM compared to the normal subjects and HT patients, but did not show any significant correlation with eGFR. Thus, the renal interlobar venous FVOR was strongly influenced by the arterial pulse pressure as well as the renal interlobar arterial RI, and was reduced in DM patients without any apparent relationship with diabetic nephropathy. Therefore, when using FVOR or the “impedance index” for the diagnosis of renal abnormalities such as obstructive uropathy, sufficient attention should be paid to the influence of the arterial hemodynamics and blood glucose level.

Bateman and Cuganesan [8] first reported the abnormality in the renal interlobar venous flow velocity pattern in patients with obstructive nephropathy. They proposed an “impedance index” of the interlobar vein, which represented the degree of oscillation of the venous flow velocity, and they reported that this index was reduced in the acutely obstructed kidney due to an increase in intrarenal pressure compared to the contralateral kidney. We readily accept their conclusion that this index is useful for the diagnosis of obstructive nephropathy, but we do not agree with the naming of the “impedance index,” because we think that this index may be influenced by many factors other than the venous impedance. The renal venous system is connected to the systemic venous system with very large capacitance, and it is also connected to the right heart, which actively draws blood from the venous system and temporarily pushes

blood back to it. If the cause of the intrarenal venous flow abnormality was merely the increased intrarenal venous impedance, the flow pattern would be greatly changed in the renal vein, which is outside of the kidney and should be far more compliant. In the present study, there was a significant similarity in flow pattern between the ipsilateral renal interlobar and renal veins. Our data suggest that the flow velocity oscillation in the renal interlobar vein may depend not only upon the intrarenal venous impedance but also upon the properties and condition of the right heart and systemic venous system and the cyclic oscillation of the intrarenal circulation, which is probably related to arterial pulsation. For this reason, we felt it was appropriate to use the term flow velocity oscillation ratio (FVOR).

While Karabulut et al. [16] reported that the venous waveform in pregnant women showed diminished oscillations, that is, a decrease in FVOR, Bateman et al. [10] reported that FVOR actually increased in seven hypertensive patients in 3rd trimester pregnancy compared to seven normotensive pregnant women who served as controls. They attributed the increase in FVOR to the increased intrarenal venous impedance due to a reduced renal medullary pressure associated with a shift in the pressure natriuresis curve. However, the results of the present study may not contradict theirs since the FVOR may have increased in HT patients with increased pulse pressure and renal interlobar arterial RI. In fact, we think it possible that the data reported by Bateman et al. might simply represent the effect of high pulse pressure on FVOR independently of preeclampsia or hypertensive nephropathy.

In the present study, the renal interlobar FVOR was very closely and positively correlated with the pulse pressure and renal interlobar arterial RI. Although the exact mechanism of this relationship could not be specified in this clinical study, the surprisingly good correlations between the arterial and venous parameters may suggest the presence of a certain robust mechanism within the kidney. Because there are many small arteries and arterioles in the renal

parenchyma, a pulsed-wave Doppler sample volume to record the interlobar venous flow could have included these arterial pulsatile flow signals. However, in the present study, the renal venous FVOR was closely correlated with the ipsilateral interlobar venous FVOR and also significantly correlated with the ipsilateral interlobar arterial RI and pulse pressure. The flow velocity of the renal vein can be readily distinguished from that of the renal artery based on the distinct difference in the flow pattern and direction [17]. The above results suggest that the association of flow pattern between the renal arterial and venous sides shown in this study is present, rather than simply a type of contamination.

The direct transmission of pulse waves between the pulmonary artery and vein is known to occur in the area of cardiology [18], but there has been little evidence for direct pulse wave transmission through the capillary bed of other organs in the systemic circulation. The direct transmission of the arterial pulse wave to the venous system may be particularly unlikely in the kidney, which has a double set of capillary vessels. Intense pulsation of the intrarenal arteries with elevated pulse pressure may cause cyclic fluctuation of the intrarenal pressure, which may compress the intrarenal veins and oscillate the flow speed or volume leading to an increase in the FVOR of the renal venous system. In the area of ophthalmology, spontaneous pulsation of the retinal vein synchronizing with the arterial pulsation has long been recognized. Although still controversial, the most probable mechanism of the retinal venous pulsation may be indirect transmission of the retinal arterial pulsation through the intraocular or cerebrospinal fluid pressure [19, 20]. We suspect that the indirect transmission of the arterial pulsation can also occur in the kidney, which receives a large amount of arterial blood flow, as much as approximately a quarter of cardiac output, within the dense parenchyma covered with a hard capsule.

More recently, Jeong et al. [13] reported that the renal interlobar FVOR was lower in 58

patients with DM with macroscopic proteinuria but without HT compared to 164 healthy control subjects. They speculated that a decrease in FVOR may be a finding of early-stage diabetic nephropathy, and that renal glomerulosclerosis and parenchymal fibrosis caused by diabetic nephropathy might have increased the renal venous impedance, leading to the FVOR reduction. They excluded patients having apparent renal dysfunction with a serum creatinine level ≥ 1.4 mg/dl from their study group, and therefore they did not study the relationship between FVOR and the degree of renal dysfunction. In the present study, no significant relationship was found between the venous FVOR and eGFR in contrast to the significant negative correlation between the arterial RIs and eGFR. We think it unlikely that diabetic patients with relatively mild renal dysfunction have such serious renal parenchymal damage as to extensively restrict the intrarenal venous system. In the present study, the renal interlobar FVOR was decreased in patients with DM, as Jeong et al. also reported, but we could not find any correlation between the FVOR and renal function. Thus, we consider that the FVOR of the renal and renal interlobar veins may reflect an abnormal renal circulation in patients with DM, but may not be a characteristic finding of diabetic nephropathy. We consider that the decrease in FVOR may be induced by an abnormality more commonly seen in DM patients, such as hyperglycemia, dilatation of the afferent arterioles, and contraction of the efferent arterioles, although we could not provide any clear evidence for this point.

In addition, the correlation of the interlobar FVOR to the inferior vena caval FVOR was lower than that to the renal venous FVOR and even that to the interlobar arterial RI in the present study. These results suggest that the cardiac effect on the flow velocity pattern of the renal venous system might not be as strong as that of the local renal circulation abnormality. Nevertheless, the influence of the properties or loading conditions of the right heart and systemic venous system cannot be excluded [21]. These influences of the heart and central

veins on the renal venous system, as well as the renal arteriovenous hemodynamic relationship, may complicate the interpretation of the renal interlobar venous FVOR, and these factors should be noted when applying FVOR clinically for the diagnosis of renal diseases such as obstructive nephropathy and for the evaluation of renal circulation in patients with HT and/or DM.

The present study has several limitations. First, the small number of study subjects might have limited the statistical power of the negative findings (by introducing the possibility of type 2 error), especially in the detection of the individual group differences after ANOVA. Second, the mean age of the control group was significantly younger compared to the other three groups, and this might have been associated with the differences in the renal circulation parameters among the four groups. Third, detailed examination of the right heart function was not performed in this study, and we could not completely exclude the influence of the heart (e.g., right ventricular diastolic dysfunction) on the renal venous system. Finally, we could not provide any direct evidence or supporting literature for our speculation of the mechanisms of the renal venous system flow abnormalities. Further investigation, including animal experiments or rheological simulations, will be required to clarify these mechanisms.

Conclusion

The renal interlobar venous FVOR is strongly influenced by the arterial RI in HT patients, and is reduced in DM patients without an obvious relationship with diabetic nephropathy. These findings should be noted for the clinical application of renal and renal interlobar venous flow analysis.

Ethical statements

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008. Informed consent was obtained from all patients prior to their inclusion in the study.

Conflict of interest

Yusuke Kudo, Taisei Mikami, Mutsumi Nishida, Kazunori Okada, Sanae Kaga, Nobuo Masauzi, Satomi Omotehara, Hitoshi Shibuya, Kaoru Kahata, and Chikara Shimizu do not have any relationship that could lead to a conflict of interest.

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Figure legends

Fig. 1. Pulsed Doppler flow velocity recordings of the aorta (a), right renal artery (b), right renal interlobar artery (c), inferior vena cava (d), right renal vein (e), and right renal interlobar vein (f).

PSV, peak systolic velocity; EDV, end-diastolic velocity.

Fig. 2. Flow velocity oscillation rate (FVOR) in the control, hypertensive (HT), diabetic (DM), and hypertensive and diabetic (HT-DM) groups.

ANOVA, one-way analysis of variance.

Fig. 3. Relationship between the resistive indexes (RI) of the right and left renal interlobar arteries and that between the flow velocity oscillation rates (FVOR) of the right and left renal interlobar veins.

HT, hypertensive group; DM, diabetic group; HT-DM, hypertensive and diabetic group.

Fig. 4. Relationships between the resistive index (RI) of the renal interlobar arteries and the flow velocity oscillation rate (FVOR) of the ipsilateral renal interlobar vein and renal vein in the hypertensive group.

Fig. 5. Relationships between the flow velocity oscillation rate (FVOR) of the renal interlobar vein and renal vein and pulse pressure in the hypertensive group.

Tables

Table 1. Baseline characteristics

Variable	Control n = 39	HT n = 15	DM n = 10	HT-DM n = 9	P-value (ANOVA)
Age (years)	26.6±7.3	56.1±15.8***	53.6±13.8***	65.7±12.7***	<0.001
Male/Female	20/19	8/7	8/2	4/5	0.308
Height (cm)	165.6±7.2	159.5±10.1	167.1±10.1	156.5±6.5*,§	0.004
Weight (kg)	56.1±9.3	62.7±12.1	77.7±18.5*	63.3±14.1	0.010
BMI (kg/m ²)	20.4±2.3	24.6±4.2**	27.5±4.1**	25.6±4.1*	<0.001
BSA (m ²)	1.61±0.15	1.64±0.19	1.86±0.26**,†	1.63±0.19§	0.003
SBP (mmHg)	117±10	143±18***	124±10 ^{††}	132±21*	<0.001
DBP (mmHg)	71±9	81±17	78±8	83±16	0.026
Pulse pressure (mmHg)	46±8	62±26	45±12	50±13	0.164
HR (beats/min)	70±12	65±11	67±11	73±12	0.371
BUN (mg/dL)	12.7±3.0	16.3±5.5	14.3±6.8	18.3±6.4	0.035
Cr (mg/dL)	0.70±0.12	0.85±0.18*	0.90±0.45	0.83±0.23	0.023
eGFR (mL/min/1.73m ²)	100.1±11.8	68.3±21.0***	75.8±20.5*	65.7±19.6**	<0.001

DM, diabetes mellitus; HT, hypertension; BSA, body surface area; SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate; BUN, blood urea nitrogen; Cr, serum creatinine; eGFR, estimated glomerular filtration rate.

Data are shown as the means ± SD.

* P<0.05, ** P<0.01, *** P<0.001 vs. the control group; † P<0.05, †† P<0.01, ††† P<0.001 vs. the HT group; § P<0.05, §§ P<0.01, §§§ P<0.001 vs. the DM group.

Table 2. Flow velocity parameters of the renal and renal interlobar arteries and veins

Variable	Control n = 39	HT n = 15	DM n = 10	HT-DM n = 9	P-value (ANOVA)
RI, abdominal aorta	0.82±0.05	0.85±0.07	0.85±0.04	0.84±0.05	0.659
RI, renal artery					
right	0.66±0.05	0.70±0.10	0.65±0.09	0.70±0.09	0.449
left	0.68±0.07	0.71±0.11	0.68±0.06	0.71±0.07	0.585
RI, interlobar artery					
right	0.58±0.05	0.66±0.10*	0.64±0.05*	0.68±0.07*	<0.001
left	0.57±0.05	0.64±0.11	0.65±0.03***	0.68±0.07**	<0.001
FVOR, inferior vena cava	0.91±0.28	0.72±0.28	0.48±0.19***	0.50±0.14***	<0.001
FVOR, renal vein					
right	0.67±0.14	0.71±0.17	0.45±0.14***,††	0.48±0.09**,††	<0.001
left	0.44±0.12	0.43±0.14	0.32±0.07*	0.37±0.08	0.023
FVOR, interlobar vein					
right	0.55±0.08	0.50±0.11	0.39±0.06***,††	0.42±0.06***	<0.001
left	0.48±0.09	0.50±0.12	0.40±0.07	0.42±0.08	0.030

DM, diabetes mellitus; HT, hypertension; RI, resistive index; FVOR, flow velocity oscillation rate.

Data are shown as the means ± SD.

* P<0.05, ** P<0.01, *** P<0.001 vs. the control group; † P<0.05, †† P<0.01, ††† P<0.001 vs. the HT group; § P<0.05, §§ P<0.01, §§§ P<0.001 vs. the DM group.

Fig.1

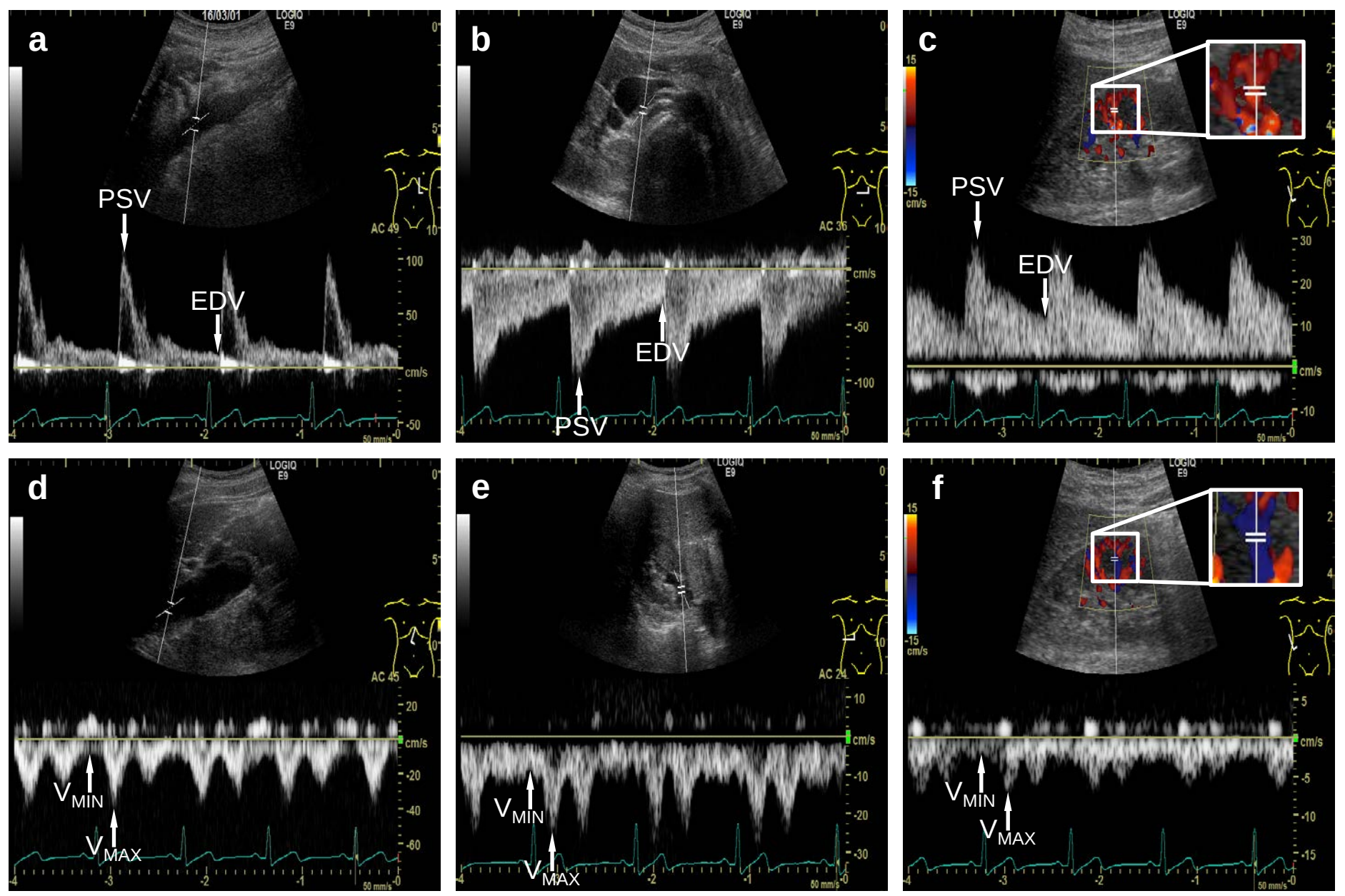


Fig.2

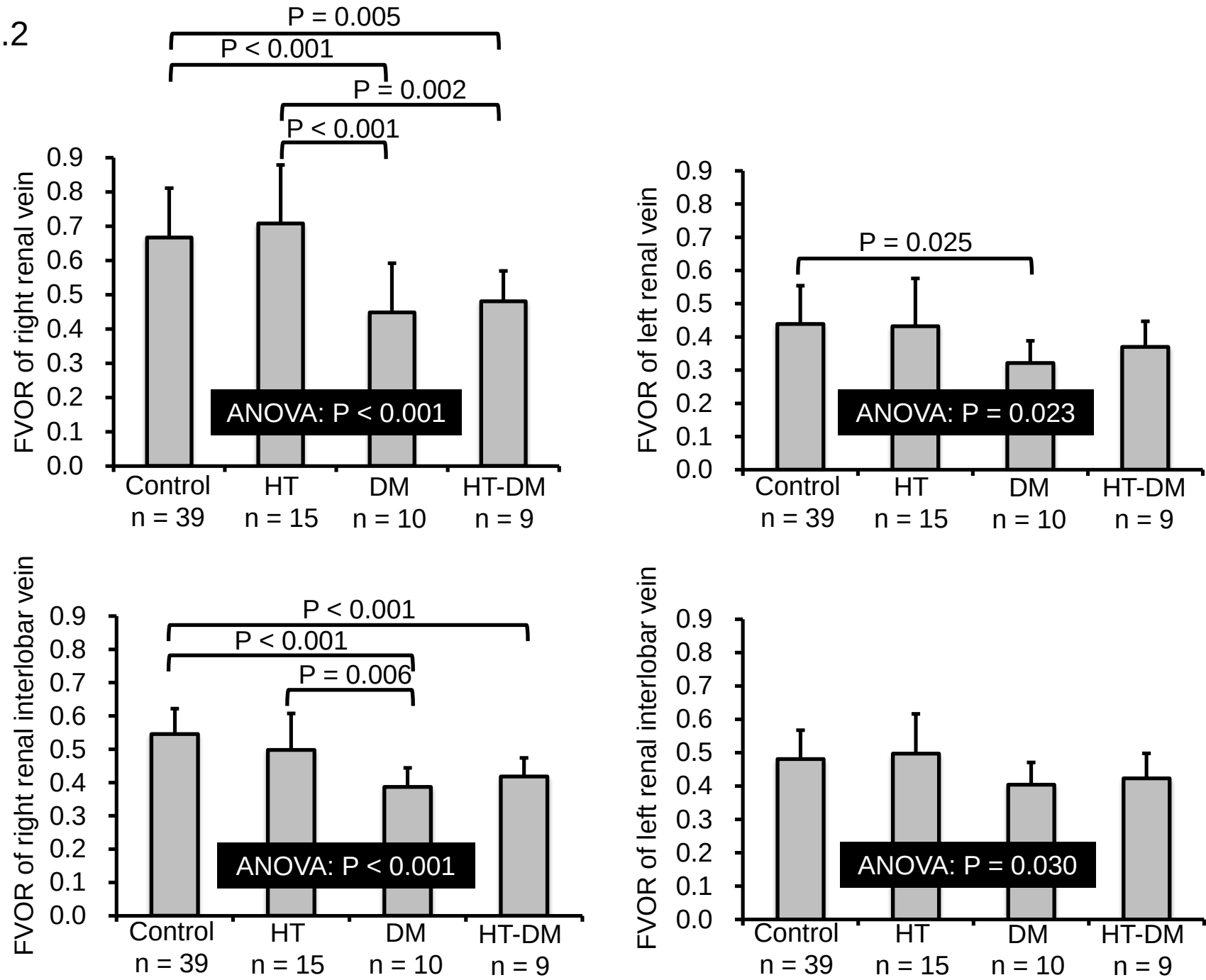


Fig.3

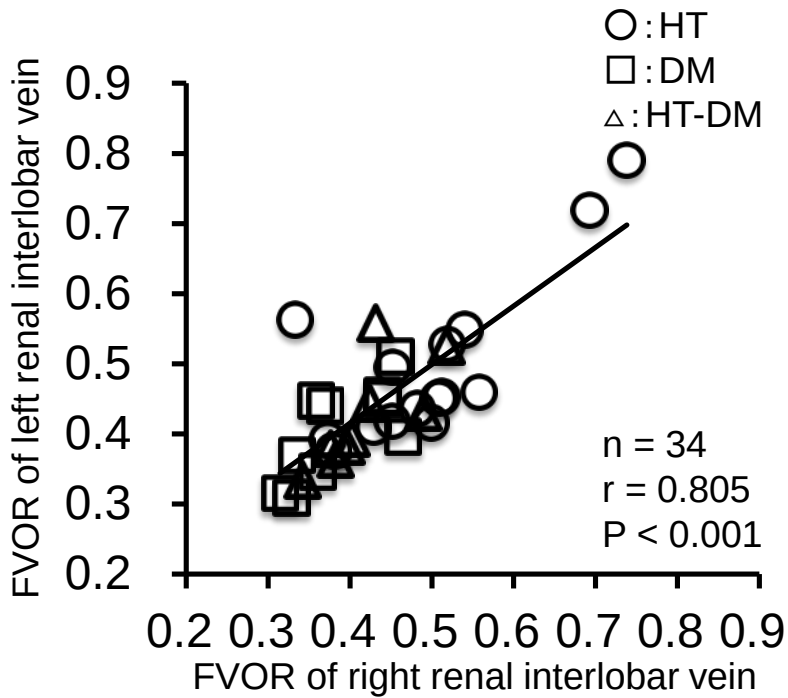
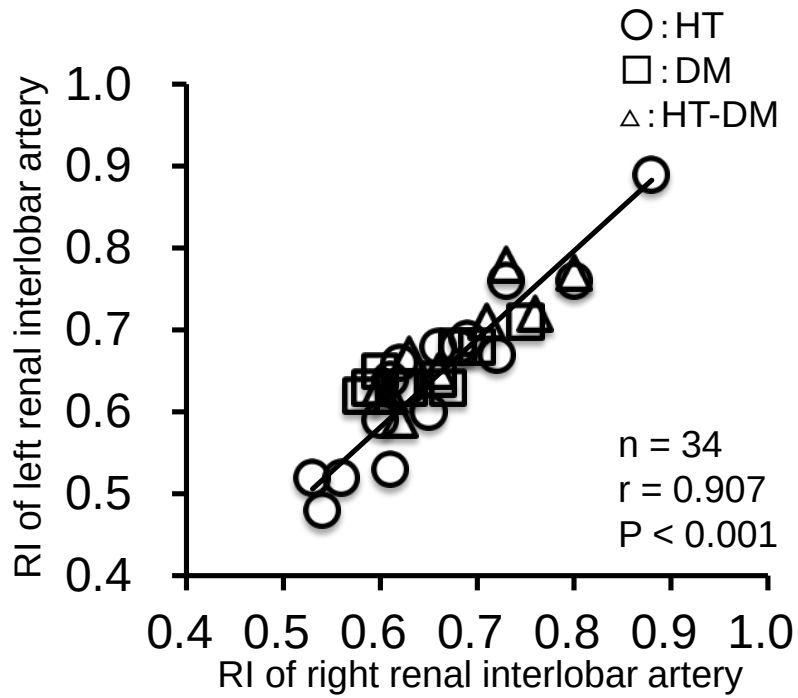


Fig.4

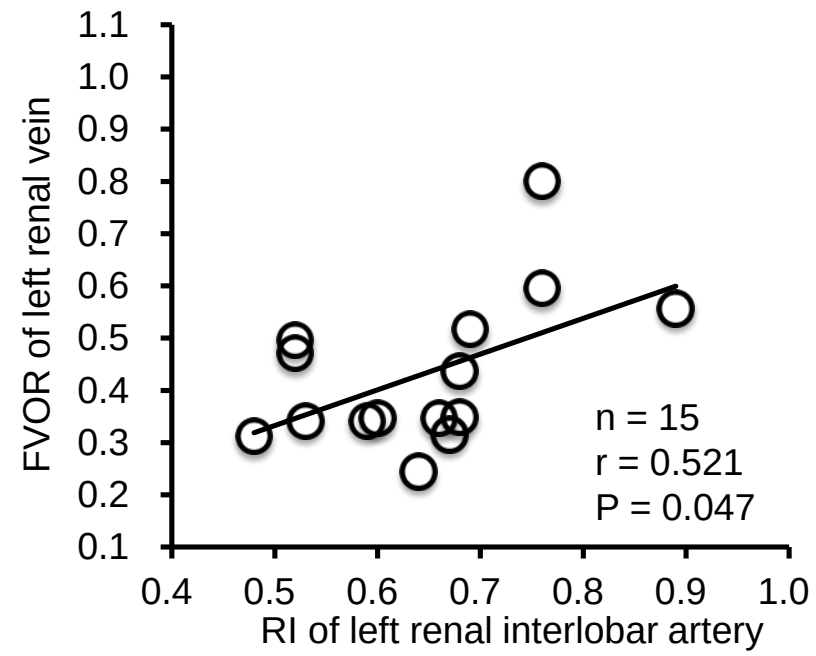
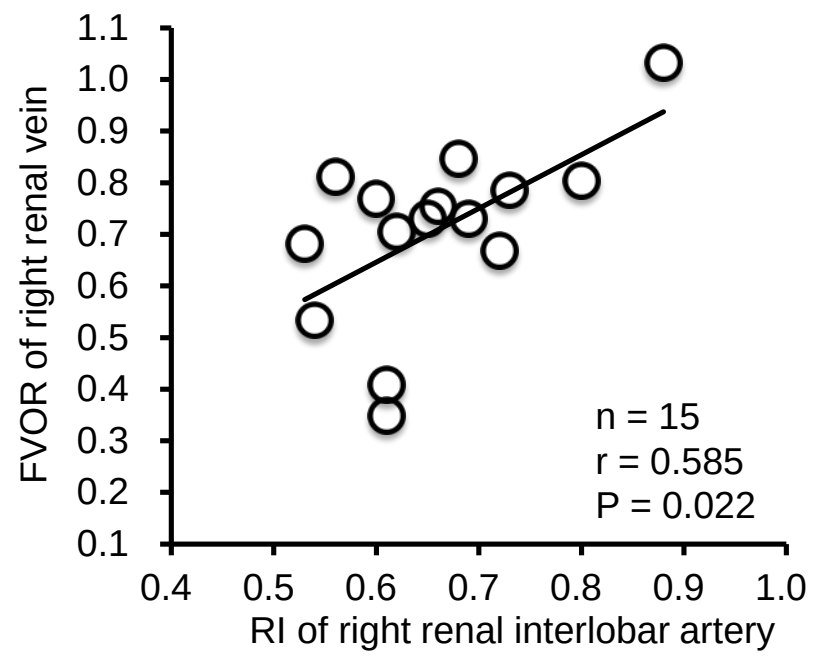
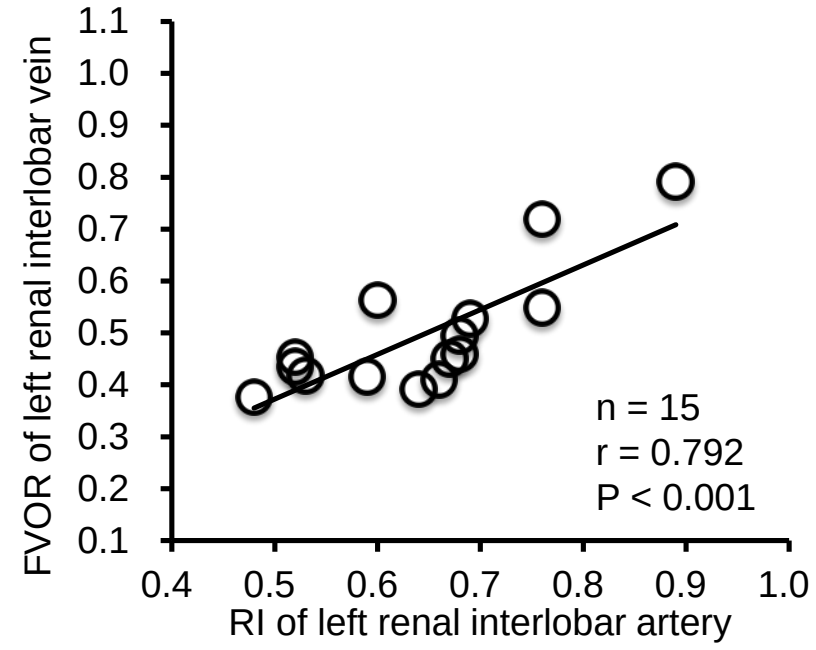
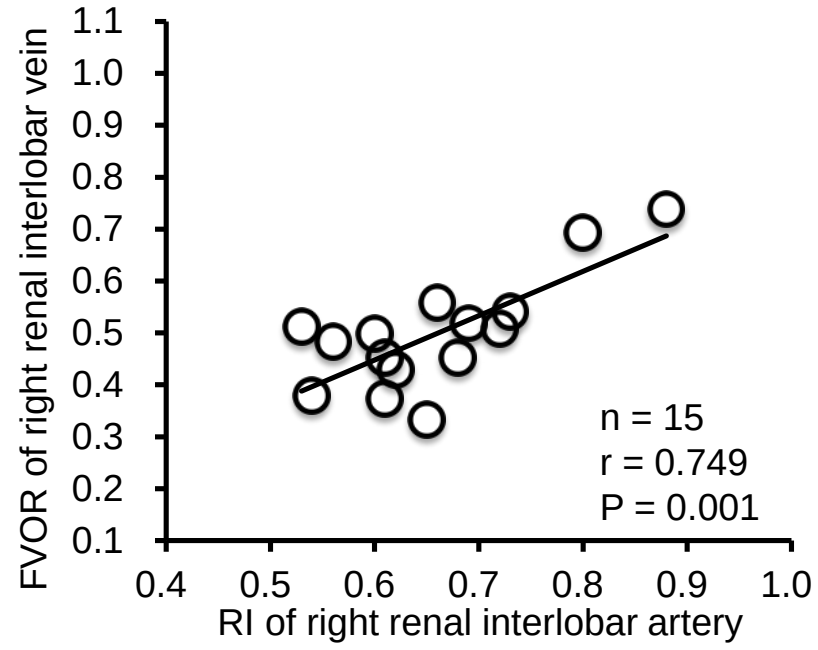


Fig.5

