

# Association between central aortic pulsatility and glomerular filtration rate in patients with coronary artery disease

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## ABSTRACT

**Objective:** Aortic stiffness and chronic kidney disease share common risk factors. Increased aortic stiffness is a predictor of lower estimated glomerular filtration rate (eGFR) at lower levels of renal functions. We aimed to investigate the association between invasively measured central aortic pulsatility (AP) as an indicator of aortic stiffness and eGFR in a population with coronary artery disease and without overt renal disease.

**Methods:** This study had a cross-sectional design. Data were retrospectively collected. We evaluated 72 patients (44 males and 28 females; mean age 59.0±10.3 years) with coronary artery disease. eGFR was calculated with dividing the Cockcroft–Gault formula by body surface area. Direct measurements of aortic blood pressures were utilized to calculate pulse pressure and AP. Multiple linear regression analysis was performed to test the relationship between eGFR and AP, independent from potential confounders.

**Results:** eGFR was significantly correlated with age ( $r=0.489$ ,  $p<0.001$ ), body surface area ( $r=0.324$ ,  $p=0.006$ ), weight ( $r=0.323$ ,  $p=0.006$ ), aortic pulse pressure ( $r=-0.371$ ,  $p=0.001$ ), and AP ( $r=-0.469$ ,  $p<0.001$ ). In multiple linear regression analysis, AP was independently associated with eGFR ( $p=0.035$ ), beside the age and body surface area. An AP cut-off level of  $>0.71$  had 84% sensitivity and 72% specificity in predicting eGFR of  $<90$  mL/min per 1.72 m<sup>2</sup> (receiver–operating characteristic area under curve: 0.851, 95% CI: 0.760–0.942,  $p<0.001$ ).

**Conclusion:** We found an independent relationship between invasively measured AP and eGFR in patients with coronary artery disease. Moreover, a higher AP may predict lower eGFR. These results may be utilized to predict eGFR from AP during invasive procedures.

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**Keywords:** pulsatility, aortic stiffness, glomerular filtration rate, atherosclerosis

## Introduction

The association between chronic kidney disease and aortic stiffness has been known for decades (1, 2). Many clinical studies intending to elucidate the interaction between aortic stiffness and renal function have been conducted in individuals with both normal and impaired glomerular filtration rate. This interaction is mutual, and deterioration in aortic stiffness or renal functions may eventually affect the other. Aortic stiffness may increase with a decrease in renal functions as a result of complex metabolic and vascular changes. Moreover, with an increase in aortic stiffness, pulsatile pressures generated by ventricular ejection are transmitted to microvascular systems such as glomeruli without dampening. With the loss of the dampening effect of the aorta, glomeruli are prone to potential deleterious effects of pulsatile pressures, which may result in a permanent decline in the glomerular filtration rate. Current data suggest that this interaction is even valid in patients with normal or mildly impaired renal function (3, 4). Con-

trary to these findings, in a cross-sectional study, Fesler et al. (5) demonstrated no association between glomerular filtration rate and aortic stiffness (evaluated by carotid–femoral pulse wave velocity) in normal individuals. Thus, uncertainties concerning the interaction between renal function and aortic stiffness still persist in patients with normal or near normal renal functions.

Several modalities such as distensibility coefficient, augmentation index, and aortic pulse wave velocity have been evaluated for aortic stiffness assessment. Aortic pulse wave velocity is widely utilized for measuring aortic stiffness. It provides an opportunity for the non-invasive assessment of aortic stiffness. Current guidelines recommend the evaluation of large artery stiffness for the risk stratification of a target population (6). Aortic pulsatility (AP), or in other words fractional pulse pressure derived from the direct measurement of aortic systolic and diastolic blood pressures, is an invasive modality for aortic stiffness assessment. Although this modality is not feasible for bulk community scanning, it is easy to measure and does not involve

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additional costs for patients undergoing invasive catheterization with other indications.

In this context we aimed 1) to investigate the possible association between aortic stiffness evaluated by invasively measured central AP and estimated glomerular filtration rate (eGFR) in a real-life patient population with coronary artery disease and without overt renal disease, 2) to provide additional data concerning the validity of AP in the assessment of aortic stiffness and renal function in patients undergoing invasive procedures, and 3) to provide preliminary data for future studies related to the prognostic value of invasive AP in procedures related to the deterioration of kidney function such as contrast-induced nephropathy.

## Methods

### Study design and population

This study had a cross-sectional design. Data were retrospectively collected. The primary aim of the study was to investigate the association between AP and eGFR. A total sample size of 67 achieved an 85% power to detect an inverse correlation  $r = -0.35$  between AP and eGFR measurements with a significance level (alpha) of 0.05. The coefficient of correlation  $-0.35$  was taken from both pilot study and our clinical study. Sample size estimation was performed using the G\*Power (Franz Faul, Universitat Kiel, Germany) version 3.0.10 software.

We evaluated 72 patients (44 males and 28 females; mean age  $59.0 \pm 10.3$  years, range 39–77 years) with manifest coronary artery disease who underwent invasive blood pressure measurement during cardiac catheterization at the level of the ascending aorta at Türkiye Yüksek İhtisas Hospital between May 2010 and May 2011. Cardiac catheterization was performed after overnight fasting. Aortic blood pressure measurements were obtained from the ascending aorta with a well-calibrated sensitive pressure device (0.014-inch pressure monitoring guide wire; PrimeWire, Volcano, San Diego, California, USA). Patients who had at least one coronary artery with more than 50% stenosis were included in the study. Those with left ventricular severe systolic dysfunction (left ventricular ejection fraction  $<35\%$ ), severe valvular disease, presence of one kidney, stage 4 and 5 chronic kidney disease or history of renal dialysis at any time, atrial fibrillation, aortic coarctation, recent drug use such as trimethoprim or nonsteroidal anti-inflammatory drugs interfering with creatinine excretion were excluded from the study. All patients gave written informed consent before catheterization, and the local ethics committee approved the study protocol. A blood sample was taken from every patient after overnight fasting. Serum lipid, fasting plasma glucose, and serum creatinine levels were recorded. Diabetes was defined as a fasting plasma glucose level of  $\geq 126$  mg/dL or treatment with a hypoglycemic medication. Hyperlipidemia was defined as fasting serum LDL cholesterol level of  $\geq 100$  mg/dL or being treated with lipid-lowering drugs. The presence of hypertension was defined as blood pressure of  $\geq 140/90$  mm Hg or the use of an antihypertensive medication.

### Anthropometric measurement

The height and weight of the patients were measured in the metric system, and body mass index and body surface area were calculated from these measurements. Body mass index was calculated by dividing weight in kilograms by height in meters squared. Body surface area was calculated by a computer program according to the equation postulated by DuBois. The DuBois formula is as follows: body surface area  $= 0.007184 \times \text{weight } 0.425 \text{ (kg)} \times \text{height } 0.725 \text{ (cm)}$  (7).

### Assessment of renal function

Serum creatinine levels were measured from blood samples obtained on the procedure day, before catheterization. The estimated creatinine clearance of each patient was calculated according to the Cockcroft–Gault formula:  $[(140 - \text{age (years)}) \times \text{body weight (kg)}] / [(\text{serum creatinine (mg/dL)}) \times (\text{weight (kg)} / 72)]$  (0.85 if female) (8). eGFR was calculated by dividing estimated creatinine clearance by body surface area.

### Measurement of aortic blood pressure parameters

Hemodynamic assessments including systolic and diastolic blood pressures of the ascending aorta were measured during catheterization for each patient. Pressure tracings were obtained with a 0.014-inch pressure monitoring guide wire. The average of three pressure measurements was used for calculations to minimize the effect of blood pressure fluctuations during catheterization. The mean aortic blood pressure was calculated as  $1/3$  systolic +  $2/3$  diastolic blood pressure. AP was calculated as the ratio of aortic pulse pressure (aortic systolic blood pressure – aortic diastolic blood pressure) to mean aortic pressure.

### Statistical analysis

Data analysis was performed using SPSS for Windows, version 11.5 (SPSS Inc., Chicago, IL, United States). Whether the distributions of continuous variables were normal or not was determined by Kolmogorov–Smirnov test. Continuous variables were shown as mean  $\pm$  SD or median (min–max); the number of cases and (%) were used for categorical data. The patients were initially divided into two subgroups on the basis of the median value of AP. While the mean differences between the groups were compared by Student's t-test, Mann–Whitney U test was applied for comparing the medians. Nominal data were analyzed by Pearson's chi-square test. The study population was also grouped according to the quartiles of the glomerular filtration rate (GFR) distribution (73.95, 96.62, and 110.55 mL/min per  $1.72 \text{ m}^2$ ). Whether the mean differences in AP among the quartiles of GFR were statistically significant or not was evaluated by one-way ANOVA. When the p-value from one-way ANOVA is statistically significant, post hoc Tukey's HSD test was used to determine which quartile differ from which others. Adjustment for age and gender were conducted by the analysis of covariance (ANCOVA). Log-transformation was applied for non-normally distributed variables in ANCOVA. The degrees of association between continuous variables were evaluated by Pearson's or

**Table 1. Clinical, biochemical, and anthropometric characteristics of the overall study population and of the two groups with AP above ( $\geq 0.71$ ) and below ( $< 0.71$ ) the median value**

	All patients n=72	AP<0.71 n=36	AP $\geq 0.71$ n=36	P*	P-value adjusted for age and gender
Age, years	59.1 $\pm$ 10.3	51.9 $\pm$ 7.6	66.2 $\pm$ 7.4	<b>&lt;0.001</b>	–
Male-no. (%)	44 (61.1)	30 (83.3)	14 (38.9)	<b>&lt;0.001</b>	–
Body mass index, kg/m <sup>2</sup>	28.5 $\pm$ 4.7	28.6 $\pm$ 4.1	28.4 $\pm$ 5.2	0.854	0.112
Diabetes mellitus-no. (%)	22 (30.6)	9 (25.0)	13 (36.1)	0.306	–
Hypertension-no. (%)	44 (61.1)	19 (52.8)	25 (69.4)	0.147	–
Hyperlipidemia-no. (%)	58 (80.6)	34 (94.4)	24 (66.7)	<b>0.003</b>	–
Total cholesterol, mg/dL	192.6 $\pm$ 48.5	196.7 $\pm$ 43.3	188.4 $\pm$ 53.4	0.470	0.489
LDL, mg/dL	121.0 $\pm$ 41.5	119.4 $\pm$ 44.0	122.6 $\pm$ 39.4	0.747	0.797
HDL, mg/dL	42.6 $\pm$ 15.3	37.0 $\pm$ 9.3	48.1 $\pm$ 18.0	<b>0.002</b>	0.597
Triglyceride, mg/dL	148.5 (55–442)	178 (55–442)	133 (57–398)	<b>0.026</b>	0.892
Fasting blood glucose, mg/dL	103 (65–398)	101 (65–398)	108 (71–301)	0.125	0.199
Body surface area, m <sup>2</sup>	1.87 $\pm$ 0.2	1.93 $\pm$ 0.2	1.82 $\pm$ 0.2	<b>0.015</b>	0.874
Creatinine, mg/dL	0.87 (0.50–2.00)	0.83 (0.50–2.00)	0.89 (0.54–1.30)	0.413	<b>0.011</b>
eGFR, mL/min per 1.72 m <sup>2</sup>	94.1 $\pm$ 25.4	108.1 $\pm$ 22.7	80.2 $\pm$ 19.8	<b>&lt;0.001</b>	<b>&lt;0.001</b>
ASP, mm Hg	143.4 $\pm$ 27.4	129.4 $\pm$ 22.4	157.4 $\pm$ 24.8	<b>&lt;0.001</b>	0.051
ADP, mm Hg	74.3 $\pm$ 13.4	76.1 $\pm$ 12.1	72.5 $\pm$ 14.5	0.258	0.109
APS, mm Hg	69.1 $\pm$ 21.3	53.3 $\pm$ 14.0	84.9 $\pm$ 14.5	<b>&lt;0.001</b>	<b>&lt;0.001</b>
Aortic pulsatility	0.71 $\pm$ 0.19	0.56 $\pm$ 0.11	0.85 $\pm$ 0.13	–	–

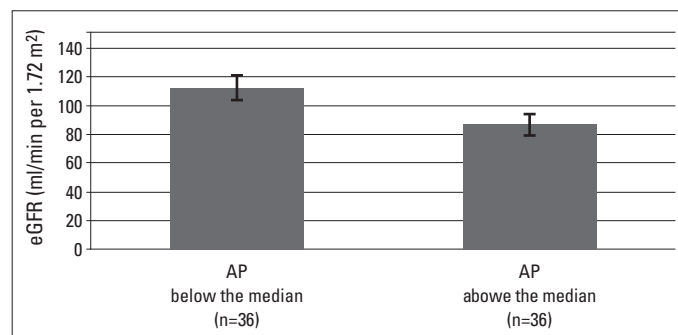
ADP - aortic diastolic pressure; AP - aortic pulsatility; APS - aortic pulse pressure; ASP - aortic systolic pressure; eGFR - estimated glomerular filtration rate; HDL - high-density lipoprotein; LDL - low-density lipoprotein. \* - Student's t-test, otherwise, Mann-Whitney U test, and nominal data were analyzed by Pearson's chi-square test

Spearman's correlation analysis where applicable. Multiple linear regression analysis was performed to test the relationships between eGFR and AP, independent from potential confounders. Any variable whose univariable test had a p-value of  $< 0.05$  was accepted as a candidate for the multivariable model. The multiple regression models were initially built considering eGFR to be a dependent variable, whereas age, gender, surface area, aortic pulse pressure, and AP were independent variables. The coefficient of regression, 95% confidence interval, and t-statistic for each independent variable were also calculated. Receiver-operating characteristic (ROC) curve analysis was used to determine the cut-off level of the fractional pulse pressure in association with impaired eGFR. A p-value of  $< 0.05$  was considered to be statistically significant.

## Results

Seventy-two patients, 28 females (38.9%) and 44 males (61.1%), were included in this study. All patients had at least one coronary artery lesion with more than 50% luminal narrowing. The median value of AP for the entire population was 0.71. No patient was in stage IV or V chronic kidney disease according to eGFR. For descriptive purpose, Table 1 shows the clinical, biochemical, and anthropometric characteristics of the overall study population and of the two groups with AP above ( $\geq 0.71$ ) and below ( $< 0.71$ ) the median value. In the above-median group (AP $\geq 0.71$ ), age, HDL

cholesterol level, aortic systolic blood pressure, and aortic pulse pressure were higher compared with those in the below-median group. Patients with AP above the median had lower values of triglycerides, body surface area, and eGFR than those with AP below the median. Male ratio and hyperlipidemia prevalence were lower in patients with AP above the median. After adjustment for age and gender, aortic pulse pressure was significantly higher and eGFR was significantly lower in patients with AP above the median. Figure 1 depicts eGFR according to the two groups, AP above and below the median value, after adjusting for age and gender.



**Figure 1. Estimated glomerular filtration rate in coronary artery disease patients with aortic pulsatility above and below the median value (0.71). After adjustment for age and sex, this difference was still valid ( $p < 0.001$ ). eGFR - estimated glomerular filtration rate. Groups were compared by Student's t-test**

**Table 2. Clinical, biochemical, and anthropometric characteristics of the overall study population and of the two groups with eGFR above ( $\geq 90$  mL/min per  $1.72 \text{ m}^2$ ) and below ( $< 90$  mL/min per  $1.72 \text{ m}^2$ )**

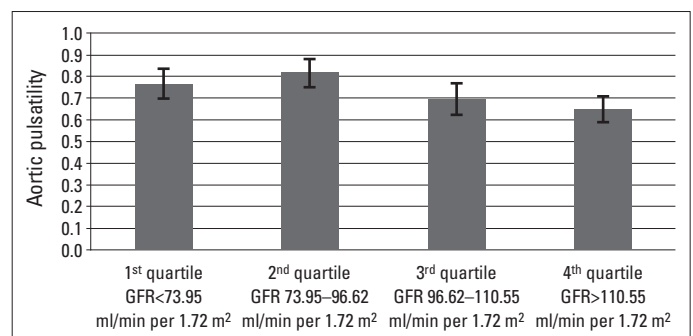
	All patients n=72	eGFR $< 90$ n=31	eGFR $\geq 90$ n=41	P*	P-value adjusted for age and gender
Age, years	59.1 $\pm$ 10.3	64.7 $\pm$ 8.6	54.8 $\pm$ 9.6	<b>&lt;0.001</b>	–
Male-no. (%)	44 (61.1)	14 (45.2)	30 (73.2)	<b>0.016</b>	–
Body mass index, kg/m <sup>2</sup>	28.5 $\pm$ 4.7	27.9 $\pm$ 4.2	29.0 $\pm$ 5.0	0.314	<b>0.049</b>
Diabetes mellitus-no. (%)	22 (30.6)	12 (38.7)	10 (24.4)	0.192	–
Hypertension-no. (%)	44 (61.1)	17 (54.8)	27 (65.9)	0.342	–
Hyperlipidemia-no. (%)	58 (80.6)	23 (74.2)	35 (85.4)	0.236	–
Total cholesterol, mg/dL	192.6 $\pm$ 48.5	191.1 $\pm$ 60.1	193.7 $\pm$ 38.2	0.837	0.983
LDL, mg/dL	121.0 $\pm$ 41.5	123.8 $\pm$ 45.8	118.9 $\pm$ 38.4	0.627	0.855
HDL, mg/dL	42.6 $\pm$ 15.3	45.2 $\pm$ 10.5	40.6 $\pm$ 18.0	0.217	0.363
Triglyceride, mg/dL	148.5 (55–442)	140 (57–398)	152 (55–442)	0.309	0.508
Fasting blood glucose, mg/dL	103 (65–398)	104 (71–301)	103 (65–398)	0.285	0.112
Body surface area, m <sup>2</sup>	1.87 $\pm$ 0.2	1.84 $\pm$ 0.2	1.90 $\pm$ 0.2	0.215	0.783
Creatinine, mg/dL	0.87 (0.50–2.00)	1.00 (0.71–2.00)	0.79 (0.50–1.02)	<b>&lt;0.001</b>	<b>&lt;0.001</b>
eGFR, ml/min per $1.72 \text{ m}^2$	94.1 $\pm$ 25.4	70.9 $\pm$ 12.8	111.7 $\pm$ 17.0	–	–
ASP, mm Hg	143.4 $\pm$ 27.4	147.3 $\pm$ 23.1	140.3 $\pm$ 30.2	0.285	0.132
ADP, mm Hg	74.3 $\pm$ 13.4	70.1 $\pm$ 13.9	77.5 $\pm$ 12.2	<b>0.020</b>	<b>0.004</b>
APS, mm Hg	69.1 $\pm$ 21.3	77.3 $\pm$ 17.3	62.9 $\pm$ 22.1	<b>0.004</b>	0.905
Aortic pulsatility	0.71 $\pm$ 0.19	0.81 $\pm$ 0.19	0.63 $\pm$ 0.14	<b>&lt;0.001</b>	<b>0.013</b>

ADP - aortic diastolic pressure; APS - aortic pulse pressure; ASP - aortic systolic pressure; eGFR - estimated glomerular filtration rate; HDL - high-density lipoprotein; LDL - low-density lipoprotein. \* - Student's t-test, otherwise, Mann-Whitney U test, and nominal data were analyzed by Pearson's chi-square test

Table 2 demonstrates the clinical, biochemical, and anthropometric characteristics of the overall study population and of the two groups with eGFR of  $\geq 90$  and  $< 90$  mL/min per  $1.72 \text{ m}^2$ . In the eGFR  $\geq 90$  mL/min group, age, creatinine, aortic pulse pressure, and AP were significantly lower, whereas male ratio and aortic diastolic blood pressure were significantly higher. After adjustment for age and gender, difference in body mass index, creatinine, aortic diastolic blood pressure, and AP persisted between the two groups.

The study population was also grouped according to the quartiles of the GFR distribution (73.95, 96.62, and 110.55 mL/min per  $1.72 \text{ m}^2$ ). Figure 2 shows AP according to the quartiles of the GFR distribution after adjusting for age and gender. The AP value was significantly lower in the 4<sup>th</sup> quartile than in the 1<sup>st</sup> and 2<sup>nd</sup> quartiles ( $p=0.022$  and  $p=0.001$ ). Additionally, the AP value was significantly lower in the 3<sup>rd</sup> quartile than in the 2<sup>nd</sup> quartile ( $p=0.016$ ).

In correlation analysis, which is summarized in Table 3, eGFR was significantly correlated with age ( $r=0.489$ ,  $p<0.001$ ), body surface area ( $r=0.324$ ,  $p=0.006$ ), weight ( $r=0.323$ ,  $p=0.006$ ), aortic pulse pressure ( $r=-0.371$ ,  $p=0.001$ ), and AP ( $r=-0.469$ ,  $p<0.001$ ). Figure 3 shows the significant inverse correlation between eGFR and AP. On the other hand, creatinine was not significantly correlated with both aortic pulse pressure ( $r=-0.031$ ,  $p=0.799$ ) and AP ( $r=0.078$ ,  $p=0.515$ ). Furthermore, AP was significantly cor-



**Figure 2. Aortic pulsatility with quartiles of estimated glomerular filtration rate after adjusting for age and sex. The 4<sup>th</sup> quartile vs. 1<sup>st</sup> and the 2<sup>nd</sup> quartiles ( $p=0.022$  and  $P=0.001$ ) and the 3<sup>rd</sup> quartile vs. the 2<sup>nd</sup> quartile ( $p=0.016$ ). eGFR-estimated glomerular filtration rate. Adjustment for age and gender was done by analysis of covariance (ANCOVA)**

related with age ( $r=0.62$ ,  $p<0.001$ ), body surface area ( $r=-0.241$ ,  $p=0.041$ ), aortic systolic blood pressure ( $r=0.444$ ,  $p<0.001$ ), aortic diastolic blood pressure ( $r=-0.382$ ,  $p=0.001$ ), and aortic pulse pressure ( $r=0.810$ ,  $p<0.001$ ).

Following the correlation analysis, all factors possibly affecting eGFR were evaluated in the multiple linear regression analysis. Age, gender, aortic pulse pressure, weight, body surface area, and AP were included in the multiple regression model. However, weight and creatinine were excluded from the model due to multiple interrelations between these parameters.

**Table 3. Univariate correlations between aortic pulsatility, estimated glomerular filtration rate, and some demographical and clinical variables in the entire study population**

Variables	AP	P	eGFR	P
Age	0.620	<0.001	0.489	<0.001
ASP	0.444	<0.001	-0.182	0.125
ADP	-0.382	<0.001	-0.217	0.067
APS	0.810	<0.001	-0.371	<0.001
Weight	-0.204	0.086	0.323	0.006
Height	-0.224	0.058	0.225	0.058
Body mass index	-0.075	0.530	0.200	0.093
Body surface area	-0.241	0.041	0.324	0.006
Serum creatinine	0.078	0.515	-0.692	<0.001
Fasting glucose	0.146	0.221	-0.061	0.613
Total cholesterol	0.000	0.999	-0.091	0.447
HDL	0.235	0.047	-0.075	0.531
LDL	0.114	0.339	-0.159	0.183
Triglyceride	-0.256	0.030	0.067	0.575
Aortic pulsatility	–	–	-0.464	<0.001
eGFR	-0.464	<0.001	–	–

ADP - aortic diastolic pressure; AP - aortic pulsatility; APS - aortic pulse pressure; ASP - aortic systolic pressure; eGFR - estimated glomerular filtration rate; HDL - high density lipoprotein; LDL - low density lipoprotein. Pearson's or Spearman's correlation analysis

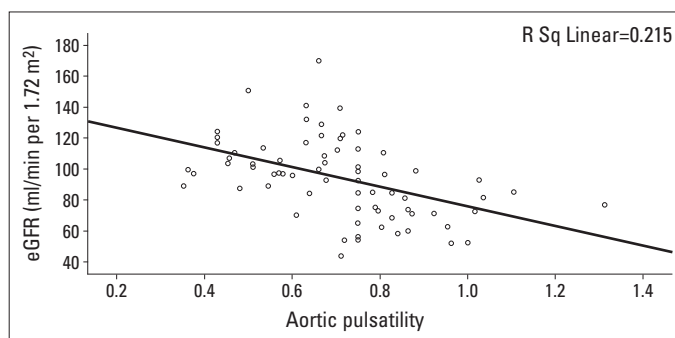
AP was independently associated with eGFR ( $r=0.035$ ), beside creatinine, age, and body surface area (Table 4). An AP cut-off level of  $>0.71$  had 84% sensitivity and 72% specificity in predicting eGFR of  $<90$  mL/min per  $1.72$  m<sup>2</sup> and 97% sensitivity and 20% specificity in predicting eGFR of  $<60$  mL/min per  $1.72$  m<sup>2</sup> (ROC area under curve: 0.851, 95% CI: 0.760–0.942,  $p<0.001$ ) (Figure 4).

### Discussion

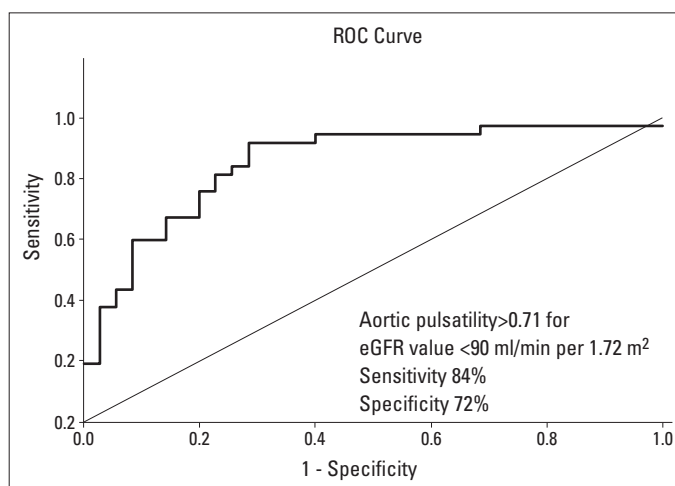
In this study, we found that AP or in other words fractional pulse pressure, an invasively measured aortic stiffness surrogate, is independently and inversely associated with eGFR. This study presented supportive data for the correlation between aortic stiffness and normal, mildly, or moderately impaired eGFR. Additionally, this study suggested the utility of fractional pulse pressure as a predictor of eGFR.

**Table 4. Results of multiple linear regression analysis**

Independent variables	Coefficient of regression ( $\beta$ )	95% confidence interval		t-statistics	P
		Lower bound	Upper bound		
Age	-0.867	-1.588	-0.145	-2.398	0.019
Male factor	-5.965	-18.748	6.818	-0.932	0.355
Body surface area	24.673	-4.091	53.438	1.713	0.091
Aortic pulse pressure	0.201	-0.241	0.643	0.908	0.367
Aortic pulsatility	-51.668	-99.497	-3.838	-2.157	0.035



**Figure 3. Significant inverse correlation between estimated glomerular filtration rate and aortic pulsatility. eGFR-estimated glomerular filtration rate**



**Figure 4. Receiver–operating characteristic curve analysis of aortic pulsatility for predicting estimated glomerular filtration rate. eGFR-estimated glomerular filtration rate**

The evaluation of renal function is crucial in cardiovascular diseases. Measuring the actual GFR is not always feasible or cost effective in daily practice. The estimation of GFR from the serum creatinine level and demographic characteristics by several formulae is widely used in clinical decisions. The validity of the Cockcroft–Gault and Modification of Diet in Renal Disease (MDRD) formulas in estimating GFR was tested in many studies. The MDRD formula loses its accuracy in patients with normal renal function, and a modified Cockcroft–Gault formula considering the body surface area provides a more accurate estimation of GFR (9). Additionally, in a study



conducted in a group of heart failure patient, Zamora et al. (10) concluded that body surface area adjusted by the Cockcroft–Gault formula was the most accurate of the three used eGFR formulae (Cockcroft–Gault formula, MDRD, and the Chronic Kidney Disease Epidemiology Collaboration) for the prediction of prognosis. Our study comprised cardiovascular patients with normal or near normal renal functions, and we used the modified Cockcroft–Gault formula, which is calculated by dividing estimated creatinine clearance by body surface area.

Atherosclerosis and arteriosclerosis share common risk factors. With the stiffening of the aorta, elastic recoil and reservoir capacity decline, resulting in widened pulse pressure and greater pressure fluctuations on vasculature (11). In particular, high flow organs such as the brain and kidneys are more prone to pulsatile hemodynamic load and thus, microvascular injury (12). Thus, the relationship between renal function and aortic stiffness has been evaluated in different patient populations using different modalities such as pulse wave velocity (3), aortic augmentation, augmentation index (13, 14), and renal resistivity index (15). However, the relationship between invasively measured aortic fractional pulse pressure and eGFR has not been previously evaluated.

The aorta, which contains elastin fibers, distends during systole and recoils during diastole and acts like a reservoir throughout the cardiac cycle. Aging and accompanying cardiovascular risk factors such as hypertension, obesity, impaired glucose metabolism, and dyslipidemia precipitate stiffening and loss of elastic properties of the aorta (16). In the presence of constant cardiac function and peripheral vascular resistance, pulse pressure rises and diastolic pressure declines with the decrease of aortic compliance. Dividing pulse pressure by mean arterial pressure theoretically omits the effects of cardiac output and peripheral vascular resistance. Hence, increased pulse pressure relative to mean pressure is an indicator aortic stiffness (17). Previous studies have also demonstrated that fractional pulse pressure is related to coronary artery disease extend (18), coronary artery disease prognosis (19), and bypass graft patency (20). In our study, we used invasively measured fractional pulse pressure as the surrogate of aortic stiffness. Although we used a pressure guide wire for the measurement of aortic blood pressure, a well-calibrated fluid-filled pressure system can be used instead. This method is easy to perform and without additional costs during invasive cardiovascular procedures, and invasively measured pressures are more accurate and reliable than brachial measurements through a sphygmomanometer (21).

In clinical practice, an increasing number of patients is undergoing coronary angiography. Not all these patients are pre-procedurally evaluated for renal functions for many reasons such as emergency setting. Preexisting renal impairment is an important risk factor for procedure-related complications such as contrast-induced nephropathy (22, 23). Taking extra care for the susceptible population might reduce the occurrence of this

complication. Although it will never replace measuring serum creatinine level, the evaluation of central AP during cardiac catheterization would also present additional clues for the renal function status of these patients. In our study, a fractional pulse pressure value of  $<0.71$  would predict eGFR of  $>90$  mL/min per  $1.72$  m<sup>2</sup> with 84% sensitivity and 72% specificity. However, further studies are needed to elucidate this relationship.

## Study limitations

The number of patients and retrospective design are important limitations of our study, and causations discussed above should be considered as hypothetical. Renal impairment was assessed by estimating GFR from serum creatinine level using the modified Cockcroft–Gault formula, which is calculated by dividing estimated creatinine clearance by body surface area. This is an estimation of renal function and is an exact measurement of GFR (e.g., inulin clearance) would differ from the estimated one. Because we expected high eGFR in our study population, using the modified Cockcroft–Gault formula instead of MDRD is more appropriate.

In our study, both aortic pulse pressure and AP were not significantly correlated with creatinine levels contrary to previous findings. As the main aim of our study is to investigate the association between AP and eGFR, we did not adjust our sample size according to creatinine levels. A larger sample size may be needed for the demonstration of a significant association. Although clinicians still continue to use serum creatinine levels as a marker of renal function, eGFR, which incorporates demographic and anthropometric variables, is more reliable.

Additionally, in our study, the association between dyslipidemia parameters and AP may seem to disagree with that in the previous literature. It is important to note that these results were observed in a selected sample of patients with coronary artery disease and that a substantial portion of the population was using statins, which lower LDL and triglyceride and may increase HDL levels; these effects may be faster than the amelioration, if any, of aortic stiffness. It should also be kept in mind that simply elevating HDL or decreasing triglyceride levels may not necessarily for obtaining a clinical benefit. Drug naïve study designs may be necessary to elucidate the full picture.

## Conclusion

In summary, we found an independent relationship between invasively measured aortic fractional pulse pressure and eGFR in patients with manifest coronary artery disease. Also, a higher AP might predict lower eGFR. Further investigations are required to validate these findings.

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**Peer-review:** Externally peer-reviewed.

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