Int J Clin Exp Med 2017;10(8):12472-12482
www.ijcem.com /ISSN:1940-5901/IJCEM0052140

*Original Article*

# Characteristics of 24-hour ambulatory blood pressure and its influence on cardiac function in non-dialysis chronic kidney disease patients

Danye Shi[1*], Jingyuan Lu[2*], Aihong Yuan[3], Xudong Xu[1], Chen Yu[3]

*[1]Department of Nephrology, Central Hospital of Minhang District, Shanghai 201199, China; [2]Department of Nephrology, Shanghai Pudong New Area People's Hospital, Shanghai 201299, China; [3]Department of Nephrology, Shanghai Tongji Hospital, Tongji University School of Medicine, Shanghai 200065, China. [*]Equal contributors.*

Received March 3, 2017; Accepted April 11, 2017; Epub August 15, 2017; Published August 30, 2017

**Abstract:** *Objectives*: Concomitant abnormal blood pressure is closely related to the progression of chronic kidney disease (CKD). The characteristics of 24-hour ambulatory blood pressure and the relationship with cardiac function were investigated in non-dialysis CKD patients. Methods: 476 non-dialysis CKD patients were recruited. The 24-hour ambulatory blood pressure was analyzed. Echocardiography and laboratory examinations were also performed in each patient to evaluate cardiac function. Results: The 24-hour average systolic blood pressure (24 h-SBP), 24-hour average diastolic blood pressure (24 h-DBP), 24-hour mean arterial pressure (24 h-MAP), daytime average systolic blood pressure (D-SBP), daytime average diastolic blood pressure(D-DBP), nighttime average systolic blood pressure (N-SBP) and nighttime average diastolic blood pressure (N-DBP) were positively related to left ventricular mass (LVM), left ventricular mass index (LVMI) and amino-terminal pro-brain natriuretic peptide (NT-proBNP) ($P<0.05$) and negatively to left ventricular ejection fraction (LVEF) ($P<0.05$). The 24 h-SBP and N-SBP were positively related to creatine kinase ($P<0.05$), and N-SBP was positively associated with cardiac troponin I(cTnI) ($P<0.05$). The standard deviations of D-SBP, N-SBP and N-DBP were positively related to LVM and LVMI ($P<0.05$), but negatively to LVEF ($P<0.05$). LVEF was significantly affected by blood pressure rhythm, followed by D-SBP. Blood pressure rhythm and serum creatinine affected cTnI with similar extent. Blood pressure, blood pressure rhythm and standard deviation of blood pressure had no significant influence on NT-proBNP. Blood pressure rhythm, D-SBP, serum creatinine and gender affected LVMI, especially the blood pressure rhythm. *Conclusion*: Blood pressure is closely related to the renal and cardiac function of non-dialysis CKD patients. Blood pressure rhythm has significant influence on cardiac function.

**Keywords:** Chronic kidney disease, 24-hour ambulatory blood pressure, cardiac function, clinical study

## Introduction

The kidney is involved in the blood pressure regulation. Thus, most patients with kidney disease usually have concomitant hypertension when the kidney disease of any cause progresses into chronic kidney disease (CKD) [1, 2], while hypertension may further deteriorate the damage to the target organs such as heart, kidney and brain. In recent years, studies have shown that the management of blood pressure plays an important role in delaying the progression of cardiovascular diseases in CKD patients [3, 4]. Currently, little is known about the relationship between 24-hour ambulatory blood pressure and cardiac function in CKD patients. Moreover, studies are often conducted in dialysis patients, and the situation in non-dialysis patients is still unclear [5, 6]. To date, some studies have shown that the blood pressure (BP) and BP rhythm are closely related to the pathogenesis of left ventricular hypertrophy [7, 8], but there are no indicators that can be used to accurately reflect the cardiac function. In addition, the routine laboratory and adjunctive examinations usually fail to identify the early heart injury in CKD patients, and thus the early heart injury is usually neglected. Comprehensive BP control of CKD patients has been one of the challenges that clinicians should face.

In this study, the characteristics of 24-hour ambulatory blood pressure and the relationship between ambulatory blood pressure and cardiac function were investigated in non-dialysis CKD patients, which may be helpful for the early identification of cardiac dysfunction via monitoring BP in CKD patients.

## Materials and methods

### *Diagnostic criteria of 24-hour ambulatory blood pressure monitoring (24 h ABPM)*

Average blood pressure in 24 hours reflects the whole level of pressure in different periods, which were the main basis of hypertension diagnosis with 24 h ABPM. The diagnostic criteria of 24 h ABPM included 24-hour ≥130/80 mmHg, daytime ≥135/85 mmHg, and nighttime ≥120/70 mmHg [9].

### *Subjects*

#### *Inclusion criteria and exclusion criteria*

*Inclusion criteria:* CKD was diagnosed according to the diagnostic criteria for Chronic Kidney Disease in the Clinical Practical Guideline for Chronic Kidney Disease developed by the National Kidney Foundation in 2002 (NKF-K/DOQI) [10]. Patients were aged 18-80 years.

*Exclusion criteria:* 1) patients were receiving treatment with steroids and/or immunosuppressants; 2) patients had acute complications (such as diabetic ketoacidosis), severe infectious diseases, rheumatic diseases, blood diseases, severe respiratory insufficiency, severe liver dysfunction, or severe anemia [hemoglobin (HB)<60 g/L], hypoproteinemia [albumin (Alb)<25 g/L]; 3) patients received hemodialysis or peritoneal dialysis; 4) patients had severe heart diseases: patients had a history of coronary heart disease, severe arrhythmia, hyperthyroidism induced organic heart disease, or severe cardiac dysfunction (NYHA grade III-IV); 5) patients had acute kidney injury; 6) patients had malignancy or were pregnant; 7) patients received kidney transplantation.

### *Patients' characteristics*

#### *Patients and grouping*

This was a cross-sectional study. According to the inclusion and exclusion criteria, non-dialysis CKD patients (n=476) were recruited from the Central Hospital of Minhang District, Shanghai, between August 2014 and December 2015. Antihypertensive drugs used by patients included calcium channel blocker (CCB), beta receptor blocker, alpha receptor blocker, angiotensin converting enzyme inhibitor, AT1 receptor blocker (ARB), diuretics, alpha & beta receptor blocker, CCB & ARB compound, ARB & thiazide diuretic compound, and alpha 2 receptor agonist. Different patients took one or more antihypertensive drugs. They took medicine at 6:30 am, 11:30 am, 4:30 pm, or 20:00 pm. Different patients took medicines for different times everyday.

This study was approved by the Ethics Committee of Central Hospital of Minhang District, Shanghai (2014-08-AJ). The medical record and findings from physical examination (including 24 h ABPM), Cardiac color ultrasound examination and laboratory examination were reviewed by experienced and trained investigators. *Patients were divided into several groups according to different standards:* (1) According to the diagnostic criteria for CKD of NKF-K/DOQI, CKD was divided into stage 1-5 according to the glomerular filtration rate (GFR); (2) BP rhythm: the BP rhythm is usually expressed as the percentage of nighttime BP reduction: percentage of nighttime BP reduction = (mean daytime BP-mean nighttime BP)/mean daytime BP×100%. Dipper BP: nighttime BP reduction ≥10%; non-dipper BP: 0%≤ nighttime BP reduction <10%; reversed dipper BP: nighttime BP reduction <0% [11]. When the systolic blood pressure (SBP) was inconsistent with diastolic blood pressure (DBP), SBP was used [9]. According to the BP rhythm, patients were divided into dipper group, non-dipper group and reversed dipper group.

### *Methods*

#### *General characteristics*

*General characteristics of patients were recorded:* age, gender, height, body weight, primary disease, findings from serum biochemical examination, and symptoms and signs of cardiovascular disease.

### *Measurement of ambulatory BP*

24 h ABPM was measured with Oscar2 non-invasive portable ambulatory blood pressure

monitor (SunTech Medical, USA). In brief, the cuff was fasted on the non-dominant arm of patients (most left arm). Measurement was done once every 30 min from 6:00 am to 22:00 pm and once very 1 h from 22:00 pm to 6:00 am. During the measurement of 24 h ABPM, intense excise should be avoided, but normal daily activity and work were allowable. In the detection of BP, the arm was kept straight and calm. After measurement of 24 h ABPM, the monitor was released, and data were acquired with specific software. BP was delineated [12, 13]. The non-discontinued and effective data of BP should be more than 80% in a day, or measurement was performed again on the second day.

*Heart color ultrasound examination*

IE Elite color doppler ultrasound detector with phased array probes (Philips, USA) was used for examination. The frequency of probe was 1-5 MHz. Examination was done according to the manufacturer's instructions and method recommended by WHO. M ultrasound, dimensional ultrasound, and color Doppler echocardiography was performed in each patient.

Left ventricular mass (LVM) was calculated as follows: LVM (g)=0.8×1.04×[(IVST + LVDd + LVPWT)$^3$-LVDd$^3$] + 0.6. Left ventricular mass index (LVMI) was calculated with Devereux formula [14]: LVMI (g/m$^2$)=LVM/body surface area (BSA); BSA (m$^2$)=0.0061× height (cm) + 0.0128 ×body weight (kg) -0.1529 [15].

Determinations: 1) Normal ranges: left ventricular end-diastolic diameter (LVDd): 39-50 mm; left ventricular end-systolic diameter (LVDs): 20-35 mm; left atrial diameter (LAD): 20-30 mm; interventricular septal thickness (IVST): 6-11 mm; left ventricular posterior wall thickness (LVPWT): 6-11 mm; left ventricular ejection fraction (LVEF): 50%-80%; 2) Left ventricular hypertrophy: LVMI≥130 g/m$^2$ for male; LVMI≥126 g/m$^2$ for female [16].

*Laboratory examinations*

Fasting venous blood (5 ml) was collected in the morning for the detection of creatine kinase (CK) and creatine kinase isoenzyme MB (CK-MB) by using performance rate method with automatic biochemical analyzer (7600, Hitach). Electrochemical luminescence method was used for the measurement of cardiac troponin I (cTnI) (COBAS 1601, Roche) with the autoimmune ECL analyzer. Electrochemical luminescence method was used to detect amino-terminal pro-brain natriuretic peptide (NT-proBNP) with VITROS 5600 automated immunoassay analyzer (Johnson). Detection ranges: serum CK: 25-130 U/L; serum CK-MB: 0-24 U/L; serum cTnI: <0.12 ng/mL for healthy controls; 0.12-0.5 ng/mL for heart injury patients, >0.5 ng/mL for acute myocardial infarction patients. NT-proBNP: 0-125 pg/mL.

Routine blood test and detection of kidney and liver function, blood glucose, blood lipids, Parathyroid hormone, serum calcium (Ca) and serum phosphorus (P) were performed with automatic biochemical analyzer (7600, Hitachi). GFR was calculated with modified MDRD formula [17].

*Statistical analysis*

Statistical analysis was performed with SPSS version 19.0. Continuous variables are expressed as mean ± standard deviation. Categorical variables are expressed as percentage (N; %). Comparisons were conducted with one way analysis of variance among groups, followed by SNK method between two groups. Counting data were compared with chi square test. Correlation was evaluated with linear correlation analysis. Once data did not conform to the normal distribution, linear correlation analysis was performed after transformation into data with normal distribution. The factors affected (LVEF, NT-proBNP, cTnI and LVMI) were analyzed with multivariate linear regression analysis. A value of $P$<0.05 was considered statistically significant.

## Results

*Patients' characteristics*

A total of 476 patients were recruited into the present study. There were 237 males (49.79%) and 239 females (50.21%). The mean age was 62.34 ± 13.53 years. Stage 1 CKD was found in 157 patients, stage 2 in 123, stage 3 in 91, stage 4 in 58 and stage 5 in 47. In addition, there were 104 patients in dipper BP group, 230 patients in non-dipper BP group and 142 patients in reversed dipper BP group.

There were no significant differences in the body mass index (BMI), fasting plasma glucose

**Table 1.** General characteristics of patients in different groups ($\bar{x} \pm s$)

| Variables | Stage 1 (n=157) | Stage 2 (n=123) | Stage 3 (n=91) | Stage 4 (n=58) | Stage 5 (n=47) | *F* or $\chi^2$ | *P* |
|---|---|---|---|---|---|---|---|
| Male | 79 (50.3%) | 64 (52%) | 43 (47.3%) | 30 (51.7%) | 21 (44.7%) | | |
| Smoking | 46 (29.3%) | 31 (25.2%) | 22 (24.2%) | 15 (25.9%) | 11 (23.4%) | 1.227 | 0.874 |
| Drinking | 18 (11.5%) | 19 (15.4%) | 15 (16.5%) | 5 (8.6%) | 1 (2.1%) | 8.002 | 0.091 |
| BMI (kg/m$^2$) | 24.76 ± 3.29 | 25.06 ± 3.30$^{e}$ | 25.14 ± 4.09$^{e}$ | 25.50 ± 3.95$^{e}$ | 23.81 ± 3.69$^{b,c,d}$ | 1.719 | 0.145 |
| HB (g/L) | 132.45 ± 15.76$^{b,c,d,e}$ | 127.80 ± 16.49$^{a,c,d,e}$ | 120.36 ± 15.502$^{a,b,d,e}$ | 100.31 ± 10.532$^{a,b,c,e}$ | 93.47 ± 12.74$^{a,b,c,d}$ | 95.154 | 0.000 |
| Alb (g/L) | 40.05 ± 4.54$^{e}$ | 39.46 ± 3.96$^{e}$ | 38.88 ± 3.96 | 38.24 ± 13.40 | 36.66 ± 6.65$^{a,b}$ | 3.065 | 0.016 |
| UA (μmol/L) | 314.34 ± 88.92$^{b,c,d,e}$ | 402.14 ± 104.03$^{a,c,d,e}$ | 453.14 ± 87.06$^{a,b,d,e}$ | 500.19 ± 101.22$^{a,b,c}$ | 513.15 ± 119.49$^{a,b,c}$ | 67.795 | 0.000 |
| PTH (pg/ml) | 38.25 ± 12.97$^{b,c,d,e}$ | 52.54 ± 14.13$^{a,c,d,e}$ | 65.11 ± 20.15$^{a,b,d,e}$ | 117.62 ± 55.79$^{a,b,c,e}$ | 158.76 ± 103.49$^{a,b,c,d}$ | 108.668 | 0.000 |
| Ca (mmol/L) | 2.20 ± 0.11$^{c,d,e}$ | 2.19 ± 0.10$^{c,d,e}$ | 2.14 ± 0.12$^{a,b,d,e}$ | 2.04 ± 0.10$^{a,b,c}$ | 2.107 ± 0.19$^{a,b,c}$ | 26.291 | 0.000 |
| P (mmol/L) | 1.08 ± 0.17$^{c,d,e}$ | 1.10 ± 0.15$^{c,e}$ | 1.43 ± 2.1$^{a,b}$ | 1.38 ± 0.30$^{a}$ | 1.50 ± 0.35$^{a,b}$ | 3.95 | 0.004 |
| FPG (mmol/L) | 5.44 ± 1.77 | 5.46 ± 1.83 | 5.66 ± 1.63 | 5.75 ± 2.08 | 5.5 ± 1.27 | 0.523 | 0.719 |
| HbA1c (%) | 6.3 ± 1.28$^{c}$ | 6.4 ± 1.43 | 6.65 ± 1.24$^{a}$ | 6.62 ± 1.51 | 6.22 ± 1.11 | 1.598 | 0.174 |
| TC (mmol/L) | 4.52 ± 0.98 | 4.48 ± 0.98 | 4.59 ± 1.13 | 4.45 ± 0.96 | 4.55 ± 1.08 | 0.252 | 0.908 |
| TG (mmol/L) | 1.91 ± 1.50 | 1.74 ± 1.11$^{c}$ | 2.58 ± 5.74$^{b}$ | 1.69 ± 0.92 | 1.85 ± 1.31 | 1.516 | 0.196 |
| HDL-ch (mmol/L) | 1.15 ± 0.30 | 1.12 ± 0.28 | 1.08 ± 0.30 | 1.09 ± 0.39 | 1.07 ± 0.32 | 0.995 | 0.410 |
| LDL-ch (mmol/L) | 4.40 ± 20.87 | 2.7 ± 0.79 | 2.81 ± 0.98 | 2.71 ± 0.77 | 2.64 ± 0.89 | 0.512 | 0.727 |
| ALP (U/L) | 79.60 ± 21.89$^{c,e}$ | 85.73 ± 32.73 | 88.43 ± 27.66$^{a}$ | 84.40 ± 23.42 | 89.94 ± 32.56$^{a}$ | 2.244 | 0.063 |

Note: body mass index (BMI); hemoglobin (HB); albumin (Alb); uric acid (UA); parathyroid hormone (PTH); calcium (Ca); phosphorus (P); fasting plasma glucose (FPG); hemoglobin A1C (HbA1c); total cholesterol (TC); triglyceride (TG); high-density lipoprotein cholesterol (HDL-ch); low-density lipoprotein cholesterol (LDL-ch); alkaline phosphatase (ALP). $^{a}P<0.05$ vs stage1; $^{b}P<0.05$ vs stage 2; $^{c}P<0.05$ vs stage 3; $^{d}P<0.05$ vs stage 4; $^{e}P<0.05$ vs stage 5.

(FPG), hemoglobinA1c (HbA1c), alkaline phosphatase, total cholesterol, triglyceride, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, history of smoking, and history of drinking among patients with CKD at different stages. Significant differences were observed in the HB, serum Alb, serum uric acid (UA), serum parathyroid hormone (PTH), serum calcium (Ca) and serum phosphorus (P) among patients with CKD at different stages (P<0.05). The HB reduced gradually with the progression of CKD (P<0.05); serum Alb reduced gradually and significant difference in Alb was found between stage 1/2 and stage 5 CKD (P<0.05). Serum UA increased gradually and significant difference was observed between two groups except between stage 4 and stage 5 CKD (P<0.05). Serum PTH increased gradually, and significant difference was observed between any two groups (P<0.05). Serum Ca decreased gradually, significant difference was observed between stage 1/2 and stage 3-5 (P<0.05), and there was no marked difference between stage 1 and stage 2 CKD as well as between stage 4 and stage 5 CKD (P>0.05). Serum P increased gradually, significant difference was observed between stage 1/2 and stage 3/5 CKD (P<0.05), and there was no marked difference between stage 1 and stage 2 CKD as well as among patients with stage 3-5 CKD (P>0.05) (**Table 1**).

*24 h ABPM*

The mean 24-hour average systolic blood pressure (24 h-SBP), 24-hour average diastolic blood pressure (24 h-DBP), 24-hour mean arterial pressure (24 h-MAP), daytime average systolic blood pressure (D-SBP), daytime average diastolic blood pressure (D-DBP), nighttime average systolic blood pressure (N-SBP) and nighttime average diastolic blood pressure (N-DBP) increased gradually with the progression of stage 1 CKD to stage 5 CKD. There were no marked differences in the 24 h-SBP, D-SBP and N-SBP between stage 4 and stage 5 CKD (P>0.05) as well as in 24 h-DBP, 24 h-MAP, D-DBP, D-SBP and N-DBP between stage 3 and stage 4 CKD (P>0.05), but significant differences were observed in other parameters among patients with CKD at different stages (P<0.05) (**Table 2**).

There were marked differences in the standard deviations of D-SBP, D-DBP, N-SBP and N-DBP among patients with CKD at different stages (P<0.05). There were no significant differences in the standard deviations of 24 h-SBP and 24 h-DBP among them. The mean standard deviation of D-SBP and N-SBP increased gradually with the deterioration of kidney function, and the mean standard deviation of D-SBP in stage 1 CKD patients was significantly lower than in

**Table 2.** Parameters of 24 h ABPM in patients of different groups ($\bar{x} \pm s$)

| Variables | Stage 1 (n=157) | Stage 2 (n=123) | Stage 3 (n=90) | Stage 4 (n=58) | Stage 5 (n=47) | $F$ or $\chi^2$ | $P$ |
|---|---|---|---|---|---|---|---|
| 24 h-SBP (mmHg) | 122.34 ± 12.75[b,c,d,e] | 133.61 ± 15.38[a,c,d,e] | 144.38 ± 17.01[a,b,d,e] | 149.4 ± 16.44[a,b,c] | 152.94 ± 15.65[a,b,c] | 66.348 | 0.000 |
| 24 h-DBP (mmHg) | 72.34 ± 9.42[b,c,d,e] | 77.25 ± 11.01[a,c,d,e] | 80.84 ± 10.61[a,b,e] | 81.88 ± 12.06[a,b,e] | 86.4 ± 12.07[a,b,c,d] | 21.898 | 0.000 |
| 24 h-MAP (mmHg) | 88.98 ± 9.76[b,c,d,e] | 96.22 ± 11.29[a,c,d,e] | 101.77 ± 11.64[a,b,e] | 104.35 ± 11.85[a,b,e] | 108.96 ± 12.26[a,b,c,d] | 45.201 | 0.000 |
| D-SBP (mmHg) | 124.72 ± 12.82[b,c,d,e] | 134.89 ± 15.43[a,c,d,e] | 145.04 ± 16.61[a,b,e] | 148.9 ± 16.39[a,b] | 151.89 ± 16.6[a,b,c] | 53.382 | 0.000 |
| D-DBP (mmHg) | 74.27 ± 9.84[b,c,d,e] | 78.3 ± 11.44[a,c,d,e] | 81.71 ± 10.67[a,b,e] | 82.22 ± 11.88[a,b,e] | 86.89 ± 12.38[a,b,c,d] | 16.217 | 0.000 |
| N-SBP (mmHg) | 116.41 ± 14.01[b,c,d,e] | 130.15 ± 17.99[a,c,d,e] | 142.41 ± 19.97[a,b,d,e] | 150.76 ± 19.01[a,b,c] | 155.19 ± 17.21[a,b,c] | 78.708 | 0.000 |
| N-DBP (mmHg) | 67.73 ± 9.34[b,c,d,e] | 74.36 ± 11.65[a,c,d,e] | 78.48 ± 11.65[a,b,e] | 81.16 ± 13.59[a,b,e] | 85.83 ± 12.72[a,b,c,d] | 33.520 | 0.000 |
| SD of 24 h-SBP | 13.87 ± 13.19 | 14.18 ± 3.77 | 15.10 ± 4.00 | 16.25 ± 4.19 | 16.17 ± 4.35 | 1.448 | 0.217 |
| SD of 24 h-DBP | 10.41 ± 3.29 | 10.58 ± 2.88 | 17.92 ± 65.68 | 11.32 ± 3.03 | 10.65 ± 2.84 | 1.187 | 0.316 |
| SD of D-SBP | 12.41 ± 7.81[c,d,e] | 12.97 ± 3.93[c,d,e] | 14.56 ± 4.41[a,b] | 15.58 ± 4.66[a,b] | 14.84 ± 4.70[a] | 5.003 | 0.001 |
| SD of D-DBP | 9.49 ± 3.51[d] | 9.76 ± 2.88[d] | 10.33 ± 3.03[d] | 12.53 ± 13.89[a,b,c,e] | 9.91 ± 3.10[d] | 3.251 | 0.012 |
| SD of N-SBP | 11.36 ± 4.56 [b,c,d,e] | 14.1 ± 6.38[a] | 13.86 ± 5.51[a] | 14.82 ± 5.86[a] | 15.63 ± 5.50[a] | 8.892 | 0.000 |

Note: 24-hour average systolic blood pressure (24 h-SBP); 24-hour average diastolic blood pressure (24 h-DBP); 24-hour mean arterial pressure (24 h-MAP); daytime average systolic blood pressure (D-SBP); daytime average diastolic blood pressure (D-DBP); nighttime average systolic blood pressure (N-SBP) and nighttime average diastolic blood pressure (N-DBP); standard deviation (SD). [a]$P$<0.05 vs stage 1; [b]$P$<0.05 vs stage 2; [c]$P$<0.05 vs stage 3; [d]$P$<0.05 vs stage 4; [e]$P$<0.05 vs stage 5.

**Table 3.** BP rhythm in patients with CKD at different stages

| | Stage 1 (n=157) | Stage 2 (n=123) | Stage 3 (n=90) | Stage 4 (n=58) | Stage 5 (n=47) |
|---|---|---|---|---|---|
| Dipper BP | 60 (38.22%) | 26 (21.14%) | 10 (10.99%) | 4 (6.90%) | 4 (8.51%) |
| Non-dipper BP | 82 (52.23%) | 61 (49.59%) | 50 (54.95%) | 24 (41.38%) | 13 (27.66%) |
| Reversed dipper BP | 15 (9.55%) | 36 (29.27%) | 31 (34.07%) | 30 (51.72%) | 30 (63.83%) |

Note: blood pressure (BP).

stage 3-5 CKD patients (P<0.05). The standard deviation of N-SBP in stage 1 CKD patients was markedly lower than in stage 2-5 CKD patients (P<0.05) (**Table 2**).

The BP rhythm became abnormal with the deterioration of kidney function. The proportion of patients with dipper BP was 38.2%, 21.1%, 11.0%, 6.9% and 8.5% in patients with CKD at stage 1-5 respectively; the proportion of patients with non-dipper BP was 52.2%, 49.6%, 54.9%, 41.4% and 27.7% in patients with CKD at stage 1-5 respectively; the proportion of patients with reversed dipper BP was 9.6%, 29.3%, 34.1%, 51.7% and 63.8% in patients with CKD at stage 1-5 respectively. The proportion of dipper BP decreased, but that of reversed dipper BP increased with the deterioration of kidney function, and significant difference was observed among groups ($\chi^2$=77.29, $P$<0.05) (**Table 3**).

*Cardiac function of patients in different groups*

Significant differences were observed in the LVDd, LVDs, LAD, LVPWT, IVST, LVM, LVMI, LVEF, CK, cTnI and NT-proBNP of patients with CKD at different stages (P<0.05), but no significant difference was found in CK-MB. The mean LVDd, LVDs, LAD, LVPWT, IVST, LVM, LVMI, CK, cTnI and NT-proBNP increased gradually, but the mean LVEF reduced gradually with the deterioration of CKD. The mean LVDd, LAD, LVPWT, IVST, LVM, LVMI and NT-proBNP in patients with stage 1 and 2 CKD were significantly lower than in those with stage 4 and 5 CKD (P<0.05). The mean LVDs, CK and cTnI in patients with stage 1 CKD were significantly lower than in those with stage 5 CKD (P<0.05). The mean LVEF in stage 1 and 2 CKD patients were significantly higher than in those with stage 4 and 5 CKD (P<0.05) (**Table 4**).

*Correlation between 24-hour ambulatory blood pressure and cardiac function in non-dialysis CKD patients*

24 h-SBP was positively related to LVDd, LVDs, LAD, LVPWT, IVST, LVM, LVMI, CK and NT-proBNP (P<0.05), but negatively to LVEF ($P$<0.05). 24 h-DBP was positively related to LVDd, LVDs, LAD, LVPWT, IVST, LVM, LVMI and NT-proBNP ($P$<0.05) but negatively to LVEF ($P$<0.05). 24 h MAP was positively related to LVDd, LVDs, LAD, LVPWT, IVST, LVM, LVMI and NT-proBNP ($P$<0.05), but negatively to LVEF ($P$<0.05).

**Table 4.** Cardiac function of patients in different groups ($\bar{x} \pm s$)

| Variables | Stage 1 (n=57) | Stage 2 (n=43) | Stage 3 (n=32) | Stage 4 (n=29) | Stage 5 (n=25) | $F$ or $\chi^2$ | $P$ |
|---|---|---|---|---|---|---|---|
| LVDd (mm) | 44.22 ± 3.57[d,e] | 44.5 ± 3.72[d,e] | 44.91 ± 3.59[e] | 46.21 ± 5.71[a,b] | 46.66 ± 3.97[a,b,c] | 5.352 | 0.000 |
| LVDs (mm) | 26.96 ± 3.32[e] | 26.67 ± 3.25[d,e] | 27.53 ± 3.4 | 28.03 ± 5.7[b] | 28.7 ± 3.87[a,b] | 3.487 | 0.008 |
| LAD (mm) | 37.14 ± 4.38[c,d,e] | 37.37 ± 4.51[d,e] | 38.51 ± 4.25[a,e] | 39.36 ± 5.08[a,b] | 40.81 ± 4.06[a,b,c] | 8.349 | 0.000 |
| LVPWT (mm) | 9.08 ± 0.95[b,c,d,e] | 9.51 ± 0.97[c,d,e] | 9.88 ± 1.76[a,b,e] | 9.93 ± 1.14[a,b,e] | 10.79 ± 1.27[a,b,c,d] | 21.089 | 0.000 |
| IVST (mm) | 9.46 ± 1.07[b,c,d,e] | 10.07 ± 1.28[a,d,e] | 10.32 ± 1.23[a,e] | 10.53 ± 1.3[a,b,e] | 11.49 ± 1.49[a,b,c,d] | 28.106 | 0.000 |
| LVEF | 0.65 ± 0.03 [b,c,d,e] | 0.64 ± 0.03[a,c,d,e] | 0.63 ± 0.03[a,b,d] | 0.61 ± 0.06[a,b,c] | 0.62 ± 0.04[a,b] | 18.300 | 0.000 |
| CK (U/L) | 86.7 ± 61.1[e] | 97.24 ± 63.06[e] | 99.05 ± 62.22[e] | 111.12 ± 68.44[e] | 179.28 ± 262.81[a,b,c,d] | 7.852 | .000 |
| CK-MB (U/L) | 12.52 ± 11.76 | 12.41 ± 6.28 | 13.36 ± 7.41 | 12.24 ± 5.47 | 15 ± 14.53 | .836 | .503 |
| cTnI (ng/mL) | 0.02 ± 0.02[d,e] | 0.02 ± 0.01[d,e] | 0.03 ± 0.05 | 0.04 ± 0.12[a,b] | 0.04 ± 0.04[a,b] | 3.691 | .006 |
| NT-proBNP (pg/mL) | 125.13 ± 205.14[d,e] | 233.64 ± 425.03[d,e] | 430.92 ± 902.08[e] | 1085.31 ± 1893.71[a,b,e] | 3238.13 ± 5889.43[a,b,c,d] | 24.436 | .000 |
| LVM (g) | 136.31 ± 33.09[b,c,d,e] | 148.32 ± 34.3[a,d,e] | 156.1 ± 47.03[a,e] | 168.93 ± 48.84[a,b,e] | 191.62 ± 46.9[a,b,cd] | 20.712 | .000 |
| LVMI (g/m$^2$) | 74.19 ± 16.97[b,c,d,e] | 80.07 ± 17.42[a,d,e] | 85.92 ± 22.75[a,b,e] | 90.82 ± 22.41[a,b,e] | 106.6 ± 22.52[a,b,c,d] | 28.532 | .000 |

Notes: left ventricular end-diastolic diameter (LVDd); left ventricular end-systolic diameter (LVDs); left atrial diameter (LAD); left ventricular posterior wall thickness (LVPWT); interventricular septal thickness (IVST); left ventricular ejection fraction (LEVF); creatine kinase (CK); creatine kinase isoenzyme MB (CK-MB); cardiac troponin I (cTnI); amino-terminal pro-brain natriuretic peptide (NT-proBNP); left ventricular mass (LVM); left ventricular mass index (LVMI). [a]$P$<0.05 vs stage 1; [b]$P$<0.05 vs stage 2; [c]$P$<0.05 vs stage 3; [d]$P$<0.05 vs stage 4; [e]$P$<0.05 vs stage 5.

**Table 5.** Correlation between blood pressure and cardiac color ultrasonography

| Variables | | LVDd (mm) | LVDs (mm) | LAD (mm) | LVPWT (mm) | IVST (mm) | LVEF | LVM (g) | LVMI (g/m$^2$) |
|---|---|---|---|---|---|---|---|---|---|
| 24 h-SBP | $r$ | 0.223** | 0.192** | 0.288** | 0.416** | 0.508** | -0.310** | 0.419** | 0.427** |
| | $P$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 24 h-DBP | $r$ | 0.207** | 0.207** | 0.155** | 0.324** | 0.360** | -0.212** | 0.347** | 0.309** |
| | $P$ | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 24 h MAP | $r$ | 0.236** | 0.218** | 0.242** | 0.394** | 0.458** | -0.280** | 0.410** | 0.393** |
| | $P$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| D-SBP | $r$ | 0.196** | 0.171** | 0.265** | 0.386** | 0.476** | -0.251** | 0.385** | 0.385** |
| | $P$ | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| D-DBP | $r$ | 0.186** | 0.193** | 0.132** | 0.298** | 0.323** | -0.155** | 0.318** | 0.274** |
| | $P$ | 0.000 | 0.000 | 0.004 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| N-SBP | $r$ | 0.252** | 0.211** | 0.311** | 0.438** | 0.540** | -0.401** | 0.448** | 0.479** |
| | $P$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| N-DBP | $r$ | 0.248** | 0.235** | 0.199** | 0.360** | 0.421** | -0.329** | 0.398** | 0.387** |
| | $P$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| SD of 24 h-SBP | $r$ | -0.028 | -0.012 | 0.109* | 0.055 | 0.104* | -0.041 | 0.036 | 0.031 |
| | $P$ | 0.538 | 0.793 | 0.018 | 0.231 | 0.024 | 0.370 | 0.429 | 0.502 |
| SD of 24 h-DBP | $r$ | -0.009 | -0.024 | 0.020 | 0.021 | 0.039 | -0.011 | 0.012 | 0.000 |
| | $P$ | 0.837 | 0.608 | 0.666 | 0.653 | 0.396 | 0.809 | 0.793 | 0.997 |
| SD of D-SBP | $r$ | 0.017 | 0.032 | 0.113* | 0.153** | 0.177** | -0.123** | 0.106* | 0.111* |
| | $P$ | 0.708 | 0.491 | 0.013 | 0.001 | 0.000 | 0.007 | 0.021 | 0.016 |
| SD of D-DBP | $r$ | 0.010 | 0.018 | 0.052 | 0.088 | 0.088 | -0.069 | 0.060 | 0.040 |
| | $P$ | 0.833 | 0.695 | 0.257 | 0.055 | 0.055 | 0.134 | 0.194 | 0.386 |
| SD of N-SBP | $r$ | 0.086 | 0.048 | 0.158** | 0.179** | 0.252** | -0.134** | 0.198** | 0.184** |
| | $P$ | 0.061 | 0.291 | 0.001 | 0.000 | 0.000 | 0.003 | 0.000 | 0.000 |
| SD of N-DBP | $r$ | 0.072 | 0.109* | 0.132* | 0.108* | 0.142** | -0.149** | 0.131** | 0.105* |
| | $P$ | 0.115 | 0.017 | 0.004 | 0.018 | 0.002 | 0.001 | 0.004 | 0.021 |

Note: 24-hour average systolic blood pressure (24 h-SBP); 24-hour average diastolic blood pressure (24 h-DBP); 24-hour mean arterial pressure (24 h-MAP); daytime average systolic blood pressure (D-SBP); daytime average diastolic blood pressure (D-DBP); nighttime average systolic blood pressure (N-SBP) and nighttime average diastolic blood pressure (N-DBP); standard deviation (SD); left ventricular end-diastolic diameter (LVDd); left ventricular end-systolic diameter (LVDs); left atrial diameter (LAD); left ventricular posterior wall thickness (LVPWT); interventricular septal thickness (IVST); left ventricular ejection fraction (LVEF); left ventricular mass (LVM); left ventricular mass index (LVMI). *P<0.05; **P<0.001.

**Table 6.** Correlation between blood pressure and serum CK, CK-MB, cTNI and NT-proBNP

| Variables | | CK (u/L) | CK-MB (u/L) | cTNI (ng/mL) | NT-proBNP (pg/mL) |
|---|---|---|---|---|---|
| 24 h-SBP | *r* | 0.109* | 0.005 | 0.087 | 0.195** |
| | *P* | 0.018 | 0.921 | 0.058 | 0.000 |
| 24 h-DBP | *r* | 0.043 | -0.036 | -0.005 | 0.118* |
| | *P* | 0.352 | 0.432 | 0.916 | 0.010 |
| 24 h MAP | *r* | 0.082 | -0.024 | 0.040 | 0.165** |
| | *P* | 0.073 | 0.605 | 0.384 | 0.000 |
| D-SBP | *r* | 0.084 | 0.000 | 0.063 | 0.178** |
| | *P* | 0.068 | 0.999 | 0.171 | 0.000 |
| D-DBP | *r* | 0.021 | -0.033 | -0.026 | 0.100* |
| | *P* | 0.643 | 0.472 | 0.578 | 0.029 |
| N-SBP | *r* | 0.136** | 0.015 | 0.135** | 0.211** |
| | *P* | 0.003 | 0.744 | 0.003 | 0.000 |
| N-DBP | *r* | 0.086 | -0.031 | 0.051 | 0.149** |
| | *P* | 0.061 | 0.498 | 0.268 | 0.001 |
| SD of 24 h-SBP | *r* | 0.018 | -0.007 | -0.009 | 0.039 |
| | *P* | 0.694 | 0.875 | 0.850 | 0.394 |
| SD of 24 h-DBP | *r* | -0.020 | -0.024 | -0.019 | -0.013 |
| | *P* | 0.663 | 0.604 | 0.679 | 0.781 |
| SD of D-SBP | *r* | 0.014 | 0.054 | -0.018 | 0.074 |
| | *P* | 0.759 | 0.238 | 0.693 | 0.107 |
| SD of D-DBP | *r* | 0.022 | 0.081 | 0.088 | 0.086 |
| | *P* | 0.636 | 0.076 | 0.056 | 0.061 |
| SD of N-SBP | *r* | -0.005 | 0.009 | 0.017 | 0.054 |
| | *P* | 0.905 | 0.850 | 0.710 | 0.243 |
| SD of N-DBP | *r* | 0.061 | 0.033 | 0.007 | -0.030 |
| | *P* | 0.185 | 0.473 | 0.887 | 0.512 |

Note: 24-hour average systolic blood pressure (24 h-SBP); 24-hour average diastolic blood pressure (24 h-DBP); 24-hour mean arterial pressure (24 h-MAP); daytime average systolic blood pressure (D-SBP); daytime average diastolic blood pressure (D-DBP); nighttime average systolic blood pressure (N-SBP); nighttime average diastolic blood pressure (N-DBP); standard deviation (SD); creatine kinase (CK); creatine kinase isoenzyme MB (CK-MB); cardiac troponin I (cTnI); amino-terminal pro-brain natriuretic peptide (NT-proBNP). *P<0.05; **P<0.001.

D-SBP was positively related to LVDd, LVDs, LAD, LVPWT, IVST, LVM, LVMI and NT-proBNP (*P*<0.05), but negatively to LVEF (*P*<0.05). D-DBP was positively related to LVDd, LVDs, LAD, LVPWT, IVST, LVM, LVMI and NT-proBNP (P<0.05), but negatively to LVEF (*P*<0.05). N-SBP was positively related to LVDd, LVDs, LAD, LVPWT, IVST, LVM, LVMI, CK, NT-proBNP and cTnI (P<0.05), but negatively to LVEF (*P*<0.05). N-DBP was positively related to LVDd, LVDs, LAD, LVPWT, IVST, LVM, LVMI and NT-proBNP (P<0.05), but negatively to LVEF (*P*<0.05). Standard deviation of 24 h-SBP was positively related to LAD and IVST (*r*=0.109 and 0.104, *P*<0.05). Standard deviation of 24 h-DBP had no relationship with above variables (P>0.05). Standard deviation of D-SBP was positively related to LAD, LVPWT, IVST, LVM and LVMI (*P*<0.05), but negatively associated with LVEF (P<0.05). Standard deviation of D-DBP had no relationship with above variables (P>0.05). Standard deviation of N-SBP was positively related to LAD, LVPWT, IVST, LVM and LVMI (P<0.05), but negatively to LVEF (P<0.05). Standard deviation of N-DBP was positively related to LVDs, LAD, LVPWT, IVST, LVM and LVMI (P<0.05), but negatively to LVEF (P<0.05). Above results are shown in **Tables 5** and **6**.

*Correlation between BP rhythm and cardiac function*

Patients were divided into dipper BP group, non-dipper BP group and reversed dipper BP group. Analysis of variance showed significant differences in the mean LVDd, LVDs, LAD, LVPWT, IVST, LVM, LVMI, LVEF, CK, cTnI and NT-proBNP among three groups (P<0.05), but there was no marked difference in CK-MB (P>0.05). The mean LVEF was the highest in dipper BP group and lowest in reversed dipper BP group; the mean LVPWT, IVST, LVM and LVMI were the highest in reversed dipper BP group and lowest in dipper BP group; the mean LVDd, LVDs, LAD, cTnI and NT-proBNP in reversed dipper BP group were significantly higher than in non-dipper BP group and dipper BP group, but there were no marked differences between later two groups; the mean CK in reversed dipper group was markedly higher than in dipper BP group, but there was no significant difference between non-dipper BP group and reversed dipper BP group and between non-dipper BP group and dipper BP group (**Table 7**).

*Multivariate linear regression analysis of cTnI, NT-proBNP, LVMI and LVEF*

cTnI, NT-proBNP, LVMI and LVEF were used as dependent variables, and independent variables included 24 h-SBP, 24 h-DBP, 24 h-MAP, D-SBP, D-DBP, N-SBP, N-DBP, standard deviation (SD) of 24 h-SBP, SD of 24 h-DBP, SD of D-SBP, SD of D-DBP, SD of N-SBP, SD of N-DBP, BP rhythm, CKD stage, serum urea nitrogen,

**Table 7.** Correlation between BP rhythm and cardiac function

| Variables | Dipper (n=123) | Non-dipper (n=91) | Reversed dipper (n=58) | *F* or $\chi^2$ | *P* |
|---|---|---|---|---|---|
| LVDd (mm) | 43.86 ± 3.37 | 44.45 ± 3.54 | 46.42 ± 4.79[a,b] | 15.798 | .000 |
| LVDs (mm) | 26.55 ± 3.06 | 26.86 ± 3.01 | 28.55 ± 4.93[a,b] | 11.893 | .000 |
| LAD (mm) | 36.92 ± 3.99 | 37.69 ± 4.65 | 39.61 ± 4.54[a,b] | 12.571 | .000 |
| LVPWT (mm) | 9.02 ± 1.01 | 9.52 ± 1.05[a] | 10.22 ± 1.59[a,b] | 30.003 | .000 |
| IVST (mm) | 9.37 ± 1.23 | 10.04 ± 1.2[a] | 10.78 ± 1.39[a,b] | 38.399 | .000 |
| LVEF | 0.66 ± 0.03 | 0.64 ± 0.02[a] | 0.61 ± 0.05[a,b] | 75.849 | .000 |
| CK (u/L) | 81.33 ± 84.54 | 102.42 ± 96.22 | 122.85 ± 125.58[a] | 4.863 | .008 |
| CK-MB (u/L) | 12.28 ± 5.99 | 12.61 ± 8.49 | 13.7 ± 12.69 | .832 | .436 |
| cTnI (ng/mL) | 0.02 ± 0.01 | 0.02 ± 0.01 | 0.04 ± 0.09[a,b] | 8.332 | .000 |
| NT-proBNP (pg/mL) | 154.1 ± 531.97 | 540.14 ± 2636.81 | 1144.22 ± 2083.66[a,b] | 6.665 | .001 |
| LVM (g) | 133.15 ± 33.83 | 147.64 ± 34.13[a] | 174.99 ± 52.03[a,b] | 35.846 | .000 |
| LVMI ($g/m^2$) | 70.63 ± 15.83 | 81.07 ± 16.13[a] | 95.78 ± 26.47[a,b] | 51.302 | .000 |

Note: left ventricular end-diastolic diameter (LVDd); left ventricular end-systolic diameter (LVDs); left atrial diameter (LAD); left ventricular posterior wall thickness (LVPWT); interventricular septal thickness (IVST); left ventricular ejection fraction (LVEF); creatine kinase (CK); creatine kinase isoenzyme MB (CK-MB); cardiac troponin I (cTnI); amino-terminal pro-brain natriuretic peptide (NT-proBNP); left ventricular mass (LVM); left ventricular mass index (LVMI). [a]P<0.05 vs dipper BP group; [b]P<0.05 vs non-dipper BP group.

**Table 8.** cTnI, NT-proBNP, LVMI and LVEF served as dependent variables

| Dependent variables | Independent variables | *β* | *SE* | *B'* | *t* | *P* |
|---|---|---|---|---|---|---|
| LVEF | (constant) | 0.719 | 0.012 | | 58.523 | 0.000 |
| | BP rhythm (Dipper, non-dipper and reversed dipper) | -0.022 | 0.002 | -0.427 | -9.972 | 0.000 |
| | D-SBP | 0.000 | 0.000 | -0.112 | -2.403 | 0.017 |
| | CKD stage | -0.003 | 0.001 | -0.107 | -2.143 | 0.033 |
| NT-proBNP | (constant) | -3379.898 | 1840.292 | | -1.837 | 0.067 |
| | Creatinine | 2.732 | 0.970 | 0.186 | 2.815 | 0.005 |
| | PTH | 11.718 | 2.545 | 0.295 | 4.605 | 0.000 |
| | Ca | 2856.165 | 796.582 | 0.171 | 3.586 | 0.000 |
| | BMI | -64.974 | 24.748 | -0.106 | -2.625 | 0.009 |
| | HB | -14.431 | 5.695 | -0.133 | -2.534 | 0.012 |
| cTnI | (constant) | -.001 | 0.007 | | -0.199 | 0.842 |
| | Creatinine | 4.292E-5 | 0.000 | 0.128 | 2.704 | 0.007 |
| | BP rhythm (Dipper, non-dipper and reversed dipper) | 0.009 | 0.003 | 0.123 | 2.612 | 0.009 |
| LVMI | (constant) | 33.663 | 7.089 | | 4.748 | 0.000 |
| | Creatinine | 0.039 | .006 | 0.267 | 6.273 | 0.000 |
| | BP rhythm (Dipper, non-dipper and reversed dipper) | 9.461 | 1.187 | 0.311 | 7.971 | 0.000 |
| | Gender | -6.432 | 1.620 | -0.148 | -3.971 | 0.000 |
| | D-SBP | 0.244 | 0.049 | 0.204 | 4.958 | 0.000 |

Notes: left ventricular ejection fraction (LVEF); amino-terminal pro-brain natriuretic peptide (NT-proBNP); cardiac troponin I (cTnI); left ventricular mass index (LVMI); blood pressure (BP); daytime average systolic blood pressure (D-SBP); chronic kidney disease (CKD); parathyroid hormone (PTH); calcium (Ca); body mass index (BMI); hemoglobin (HB).

serum creatinine, serum uric acid, BMI, FPG, HbA1c, serum alkaline phosphatase, serum cholesterol, triglyceride, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, serum PTH, serum Ca and serum P. Multivariate linear regression analysis was performed among these factors. Results showed 1) BP rhythm, D-SBP and CKD stage had significant influence on LVEF, especially the BP rhythm and D-SBP; 2) BP rhythm and serum

creatinine had significant influence on cTnI with comparable extent; 3) BP, BP rhythm and SD of BP had no influence on NT-proBNP; 4) BP rhythm, D-SBP, serum creatinine and gender had significant influence on LVMI, especially the BP rhythm (**Table 8**).

## Discussion

Studies on dynamic measurement of BP have shown that the damage of hypertension to target organs is closely related to the BP, BP rhythm and BP variability. In this retrospective study, the characteristics of 24-hour ambulatory blood pressure as well as the relationship between BP and cardiac function were investigated in 476 non-dialysis CKD inpatients, and of note, the serum CK, CK-MB, cTnI and NT-proBNP were also detected in these patients.

### *BP and its variability in non-dialysis patients with CKD at different stages*

For CKD patients, CKD may cause increase in BP [18] and the increased BP is also a potent factor causing CKD progression. Studies have revealed that CKD patients usually have elevated BP and increased BP variability, which are closely related to the kidney function [19]. These were consistent with our findings in this study. Kidney is one of the major target organs of BP, and the elevated BP and increased BP variability may cause damage to the function and structure of the kidney, which then worsen the elevated BP, resulting in a vicious cycle. Thus, to control the BP and its variability is crucial for the renoprotection.

### *BP rhythm of non-dialysis patients with CKD at different stages*

When compared with simple hypertension patients, the incidence of abnormal BP rhythm is relatively high in CKD patients, the nighttime mean SBP in CKD patients is higher than in non-CKD patients, and the circadian reductions in SBP and DBP in CKD patients are also significantly lower than in non-CKD patients [20, 21]. Our study indicated that the incidence of abnormal BP rhythm increased significantly with the deterioration of kidney function in CKD patients, which may be explained as follows: 1) The reduced GFR in CKD patients affects the excretion of sodium in the kidney and thus the BP is more sensitive to sodium intake, which is characterized by the abnormal BP rhythm and increase in BP variability. This has been confirmed in clinical trials [22, 23]. 2) In the case of CKD, the kidney is in a state of ischemia and the endothelin increases significantly. The increase in endothelin may not only increase BP, but also alter the BP rhythm [24]. 3) The renin-angiotensin-aldosterone system (RAAS) activation may cause the contraction or spasm of renal artery, leading to the increase in BP [25]. Studies also reveal that RAAS activation may also result in the abnormal BP rhythm [26]. 4) In the case of CKD, the kidney injury may induce the activation of sympathetic nervous system. On this condition, the renal artery is under high pressure, leading to the increase in renal artery resistance and subsequent elevation of BP [27]. In addition, the activated sympathetic nervous system may also activate RAAS, further affecting BP rhythm. Thus, it is recommended to regularly monitor the 24-h BP in patients with kidney diseases, which is helpful for the early identification and early treatment of kidney diseases.

### *Cardiac function in non-dialysis patients with CKD at different stages*

Kidney diseases may result in change in cardiac function. The damage to cardiac structure is characterized by left ventricular hypertrophy (LVH), which refers to the increase in left ventricular area, not the increase in the number of cardiac myocyte [28]. Our results showed the mean LVM, LVMI, CK, cTnI and NT-proBNP in patients with stage 1 and 2 CKD were significantly lower than in patients with stage 4 and 5 CKD, the mean LVEF in patients with stage 1 and 2 CKD patients was markedly higher than those in patients with stage 4 and 5 CKD. There was no marked difference in CK-MB among these patients. These findings were consistent with those reported by Mathew et al [29]. In addition, the serum CK, CK-MB, cTnI and NT-proBNP were also detected in patients with CKD at different stages, and results indicated that regular heart color Doppler ultrasound examination was necessary for patients with kidney diseases. In addition, our results also revealed the clinical importance of serum CK, cTnI and NT-proBNP in CKD at different stages.

*Association of BP, BP variability and BP rhythm with cardiac function in non-dialysis CKD patients*

Our results showed 24 h-SBP and N-SBP were related to CK; N-SBP was related to cTnI, standard deviations of daytime SBP, nighttime SBP and nighttime DBP were independently related to LVM, LVMI and LVEF; BP rhythm was associated with LVM, LVMI, CK, cTnI and NT-proBNP. This suggests that BP affects cardiac function and BP variability and BP rhythm are also closely related to cardiac function. Multivariate linear regression analysis showed BP rhythm, D-SBP, and CKD stage had significant influence on LVEF, especially the BP rhythm and D-SBP. In addition, BP rhythm and serum creatinine also affected cTnI with similar extent. BP, BP rhythm and standard deviation of BP had no significant infleunce on NT-proBNP. BP rhythm and D-SBP had significant influence on LVMI, especially the BP rhythm. These findings indicate that BP rhythm and D-SBP may significantly affect the cardiac function, especially the BP rhythm. The mean LVMI was the largest in reversed dipper BP group, mean LVEF the lowest in reversed dipper BP group, and mean cTnI the highest in reversed dipper BP group. This suggests that reversed dipper BP rhythm has the greatest influence on the cardiac function in CKD patients without dialysis. As compared with study conducted by Gong et al [30], this study further investigated serum CK, CK-MB, cTnI and NT-proBNP in non-dialysis patients with CKD at different stages. Our results revealed that the reversed dipper BP rhythm and high BP are easy to not only cause LVH, but result in myocardial injury and left ventricular dysfunction.

## Conclusions

Thus, in the management of BP in CKD patients, clinicians should not only pay attention to the BP control, but also restore the normal BP rhythm, which may delay the deterioration of kidney function, inhibit the damage to cardiac function and improve the prognosis of CKD.

## Disclosure of conflict of interest

None.

**Address correspondence to:** Aihong Yuan and Chen Yu, Department of Nephrology, Shanghai Tongji Hospital, Tongji University School of Medicine, Shanghai 200065, China. E-mail: yuanah@tongji.edu.cn (AHY); yuchen@tongji.edu.cn (CY)

## References

[1] Anderson AH, Yang W, Townsend RR, Pan Q, Chertow GM, Kusek JW, Charleston J, He J, Kallem R, Lash JP, Miller ER 3rd, Rahman M, Steigerwalt S, Weir M, Wright JT Jr and Feldman HI. Time-updated systolic blood pressure and the progression of chronic kidney disease: a cohort study. Ann Intern Med 2015; 162: 258-265.

[2] Zhang J, Zhang AH, Chen SY, Cheng LT, He L, Fan MH and Wang T. The prevalence and influencing factors in chronic kidney disease patients with hypertension. Chin J Hypertens 2010; 18: 855-860.

[3] de Beus E, Bots ML, van Zuilen AD, Wetzels JF and Blankestijn PJ. Prevalence of apparent therapy-resistant hypertension and its effect on outcome in patients with chronic kidney disease. Hypertension 2015; 66: 998-1005.

[4] Li KL, Wang RX, Dai M, Lu J, Xue J and Yang XJ. Antihypertensive treatment improves left ventricular diastolic function in patients with chronic kidney disease. Exp Ther Med 2015; 9: 1702-1708.

[5] Lertdumrongluk P, Streja E, Rhee CM, Sim JJ, Gillen D, Kovesdy CP and Kalantar-Zadeh K. Changes in pulse pressure during hemodialysis treatment and survival in maintenance dialysis patients. Clin J Am Soc Nephrol 2015; 10: 1179-1191.

[6] Shafi T, Zager PG, Sozio SM, Grams ME, Jaar BG, Christenson RH, Boulware LE, Parekh RS, Powe NR and Coresh J. Troponin I and NT-proBNP and the association of systolic blood pressure with outcomes in incident hemodialysis patients: the choices for healthy outcomes in caring for ESRD (CHOICE) study. Am J Kidney Dis 2014; 64: 443-451.

[7] Wang C, Zhang J, Liu X, Li CC, Ye ZC, Peng H and Lou TQ. Features of ambulatory blood pressure in 540 patients with chronic kidney disease. Chin J Nephrol 2013; 29: 11-15.

[8] Gupta D, Chaturvedi S, Chandy S and Agarwal I. Role of 24-h ambulatory blood pressure monitoring in children with chronic kidney disease. Indian J Nephrol 2015; 25: 355-361.

[9] Writing Group of 2010 Chinese Guidelines for the Management of Hypertension. 2010 Chinese guidelines for the management of hypertension. Chin J Hypertens 2011; 19: 701-743.

[10] National Kidney Foundation. K/DOQI clinical practice guidelines for chronic kidney disease: evaluation, classification, and stratification. Am J Kidney Dis 2002; 39: S1-266.

[11] Wang C, Zhang J, Liu X, Li C, Ye Z, Peng H, Chen Z and Lou T. Reversed dipper blood-pressure pattern is closely related to severe renal and cardiovascular damage in patients with chronic kidney disease. PLoS One 2013; 8: e55419.
[12] Li Y. Essentials of 2014 European society of hypertension practice guidelines for ambulatory blood pressure monitoring. Chin J Hypertens 2015; 23: 215-216.
[13] Wang W, Zhang WZ, Sun NL, Lin JX, Chen LY, Wu KG, Zhu DL, Wu ZS and Liu LS. Chinese guideline for the measurement of blood pressure. Chin J Hypertens 2011; 19: 1101-1115.
[14] Peng B, Xu T, Wang NS and Sheng XH. Impact of hemodialysis combined with hemodiafiltration on cardiac structure and function in maintenance hemodialysis patients with diabetic nephropathy. Chin J Integ Trad West Nephrol 2014; 15: 129-133.
[15] Stevenson PH. Height-weight-surface formula for the estimation of surface area in Chinese subjects. Chin J Physiol 1937; 3: 327-330.
[16] Fu XG, Tang YL, Wang YH and Qin JW. Changes in B-type natriuretic peptide precursor, cystatin C and aldosterone and their clinical significance in hypertensive patients with left ventricular hypertrophy. Shandong Med 2014; 54: 65-66.
[17] Chinese eGFR Investigation Collaboration. Modification and evaluation of MDRD estimating equation for Chinese patients with chronic kidney disease. Chin J Nephrol 2006; 22: 589-595.
[18] Muntner P, Anderson A, Charleston J, Chen Z, Ford V, Makos G, O'Connor A, Perumal K, Rahman M, Steigerwalt S, Teal V, Townsend R, Weir M and Wright JT Jr. Hypertension awareness, treatment, and control in adults with CKD: results from the chronic renal insufficiency cohort (CRIC) study. Am J Kidney Dis 2010; 55: 441-451.
[19] Tanner RM, Shimbo D, Dreisbach AW, Carson AP, Fox ER and Muntner P. Association between 24-hour blood pressure variability and chronic kidney disease: a cross-sectional analysis of African Americans participating in the Jackson heart study. BMC Nephrol 2015; 16: 84.
[20] Hermida RC, Smolensky MH, Ayala DE, Fernandez JR, Moya A, Crespo JJ, Mojon A, Rios MT, Fabbian F and Portaluppi F. Abnormalities in chronic kidney disease of ambulatory blood pressure 24 h patterning and normalization by bedtime hypertension chronotherapy. Nephrol Dial Transplant 2014; 29: 1160-1167.
[21] Mojon A, Ayala DE, Pineiro L, Otero A, Crespo JJ, Moya A, Boveda J, de Lis JP, Fernandez JR and Hermida RC. Comparison of ambulatory blood pressure parameters of hypertensive patients with and without chronic kidney disease. Chronobiol Int 2013; 30: 145-158.
[22] de Brito-Ashurst I, Perry L, Sanders TA, Thomas JE, Dobbie H, Varagunam M and Yaqoob MM. The role of salt intake and salt sensitivity in the management of hypertension in south Asian people with chronic kidney disease: a randomised controlled trial. Heart 2013; 99: 1256-1260.
[23] McMahon EJ, Bauer JD, Hawley CM, Isbel NM, Stowasser M, Johnson DW and Campbell KL. A randomized trial of dietary sodium restriction in CKD. J Am Soc Nephrol 2013; 24: 2096-2103.
[24] Dhaun N, Moorhouse R, MacIntyre IM, Melville V, Oosthuyzen W, Kimmitt RA, Brown KE, Kennedy ED, Goddard J and Webb DJ. Diurnal variation in blood pressure and arterial stiffness in chronic kidney disease: the role of endothelin-1. Hypertension 2014; 64: 296-304.
[25] Cao JX, Zhang LP, Gao CL and Jia JY. Pathophysiological function of activiated renal renin-angiotensin system in hypertension and kidney disease. Chin J Clin Pharmacol Therap 2009; 14: 1436-1440.
[26] Braga AN, da Silva Lemos M, da Silva JR, Fontes WR and dos Santos RA. Effects of angiotensins on day-night fluctuations and stress-induced changes in blood pressure. Am J Physiol Regul Integr Comp Physiol 2002; 282: R1663-1671.
[27] Jordan J. Sympathetic genes, baroreflexes, and hypertension. Clin Auton Res 2004; 14: 358-359.
[28] Bayauli MP, Lepira FB, Kayembe PK and M'Buyamba-Kabangu JR. Left ventricular hypertrophy and geometry in type 2 diabetes patients with chronic kidney disease. An echocardiographic study. Cardiovasc J Afr 2012; 23: 73-77.
[29] Mathew J, Katz R, St John Sutton M, Dixit S, Gerstenfeld EP, Ghio S, Gold MR, Linde C, Shlipak MG and Deo R. Chronic kidney disease and cardiac remodelling in patients with mild heart failure: results from the resynchronization reverses remodeling in systolic left ventricular dysfunction (REVERSE) study. Eur J Heart Fail 2012; 14: 1420-1428.
[30] Gong WY, Zhang J, Peng H, Liu X, Lou TQ and Wang C. Influence of reversed dipper blood pressure pattern on target organ damage in patients with chronic kidney disease. Chin J Nephrol 2014; 30: 907-911.