Original Article

The impact of anemia on left ventricular function and deformation in patients with essential hypertension: a cardiac magnetic resonance study

Bi-Yue Hu[1,2], Zhi-Gang Yang[1], Si-Shi Tang[3], Xiao-Ling Wen[2], Wei-Feng Yan[1], Shi-Qin Yu[1], Yuan Li[1]^

[1]Department of Radiology, West China Hospital, Sichuan University, Chengdu, China; [2]Department of Radiology, West China School of Public Health and West China Fourth Hospital, Sichuan University, Chengdu, China; [3]Department of Radiology, Chengdu Fifth People's Hospital, Chengdu, China

Contributions: (I) Conception and design: BY Hu, SQ Yu, Y Li; (II) Administrative support: ZG Yang; (III) Provision of study materials or patients: ZG Yang, SS Tang; (IV) Collection and assembly of data: BY Hu, WF Yan, SS Tang, XL Wen; (V) Data analysis and interpretation: BY Hu, ZG Yang, SQ Yu, Y Li; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Yuan Li, MD; Shi-Qin Yu, MD. Department of Radiology, West China Hospital, Sichuan University, 37# Guoxue Xiang, Chengdu 610041, China. Email: dr.liyuan@163.com; yushiqin@wchscu.cn.

Background: Hypertension (HTN) and anemia contribute to left ventricular (LV) hypertrophy and are associated with adverse outcomes. Anemia is often overlooked in patients with HTN, and its combined impact on the heart may be underestimated. The study aims to investigate the additive effects of anemia on LV function and global strains in individuals with essential HTN, utilizing cardiac magnetic resonance (CMR) imaging.

Methods: A total of 238 patients diagnosed with HTN and 67 sex- and age-matched controls who underwent CMR examination were retrospectively included. All HTN patients were divided into two groups: 88 with anemia and 150 without anemia. LV performance was evaluated using CMR including LV function parameters, LV global radial peak strain (GRPS), global circumferential peak strain (GCPS), and global longitudinal peak strain (GLPS). Comparisons among the three groups were conducted using one-way analysis of variance (ANOVA), the Kruskal-Wallis test, or the Chi-squared test. Additionally, multivariable linear regression analysis was performed to investigate factors associated with LV global strains.

Results: The HTN patients with anemia were older and had lower hemoglobin concentration and estimated glomerular filtration rate, and higher indices for LV end-diastolic volume, end-systolic volume, mass index, and mass/volume ratio compared with the control group and HTN without anemia group (all P<0.001). Additionally, the GLPS and GCPS deteriorated progressively from the HTN without anemia group to the HTN with anemia group when compared with the control group (all P<0.001). After adjusting for age, GLPS (−10.40%±0.46% *vs.* −11.95%±0.35%, P=0.008), GCPS (−16.60%±0.52% *vs.* −18.08%±0.39%, P=0.025), and GRPS (28.95%±1.49% *vs.* 32.72%±1.14%, P=0.048) were significantly poorer in HTN patients with anemia compared with those without anemia. Furthermore, multivariate analysis revealed significant independent associations between anemia and GLPS (β =0.308, P=0.002), GCPS (β =0.273, P=0.004), and GRPS (β =−0.142, P=0.021).

Conclusions: Anemia has additive deleterious effects on LV function and global strains in patients with HTN. Regular monitoring and early intervention of anemia might be beneficial for patients with HTN.

Keywords: Hypertension (HTN); anemia; cardiac magnetic resonance (CMR); feature tracking; left ventricular function

^ ORCID: 0000-0003-3681-6186.

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Introduction

Essential hypertension (HTN) escalates the risk of cardiac, cerebral, and renal events (1). The global prevalence of HTN was approximately 1.4 billion in 2010 and is projected to rise to 1.6 billion by 2025 (2). HTN imposes a significant burden on healthcare systems globally and stands as the primary modifiable risk factor for cardiovascular disease (CVD) and overall mortality worldwide (3,4). Anemia affects about one-third of the global population, leading to impaired neurological development, reduced work efficiency, and increased morbidity and mortality (5). Anemia reduces tissue oxygen delivery, prompting a cardiovascular response that can lead to damage, manifesting as cardiac enlargement, left ventricular hypertrophy (LVH), and arterial remodeling (6).

Anemia is a significant risk factor for adverse cardiovascular outcomes in patients with HTN. Chronic anemia increases preload, decreases afterload, and elevates cardiac output, potentially leading to maladaptive LVH, a known risk factor for adverse outcomes and overall mortality (7,8). With aging, the incidence of HTN rises, making elderly patients more susceptible to anemia as a comorbidity. Although both conditions can independently harm the cardiovascular system (6,9,10), their combination can worsen cardiac dysfunction (11). Despite its significance as an independent predictor of mortality in this population (12), anemia is often overlooked, leading to an underestimation of its impact on heart health—particularly concerning cardiac structure and function in patients with HTN.

Cardiac magnetic resonance (CMR) is crucial in cardiology for its unique and intricate imaging techniques, which enables a thorough evaluation by offering precise measurement of LV volumes and function, tissue characterization, and scar quantification (13). CMR is particularly valuable in detecting subtle changes related to HTN, including early myocardial dysfunction using myocardial feature tracking, which may revolutionize LV risk assessment in HTN patients (14). Multiple published studies have indicated a link between anemia and LV diastolic dysfunction in patients with diabetes, chronic kidney disease (CKD), or CVD, yet the findings are inconsistent (15). To our knowledge, no study has utilized CMR feature tracking (CMR-FT) technology to investigate the synergistic effects of HTN and anemia on cardiac function. Therefore, in this study, we employed CMR-FT technology to examine the additional impact of anemia on LV function and strains in patients with HTN, aiming to enhance understanding and management of HTN patients with anemia. We present this article in accordance with the STROBE reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-24-1768/rc).

Methods

Study population

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). Ethical approval for this clinical study was obtained from the Biomedical Research Ethics Committee of West China Hospital, Sichuan University (No. 2019-811). The requirement for informed consent from patients was waived due to the retrospective nature of this study.

From July 2012 to September 2023, we retrospectively enrolled 598 patients diagnosed with essential HTN who had undergone CMR examinations at our institution. These hypertensive patients exhibit cardiovascular symptoms [including heart failure (HF)] and abnormal findings on initial electrocardiogram (ECG) or ultrasound, such as wall thickening. These findings necessitate further investigation for cardiomyopathy. HTN is defined as office systolic blood pressure readings of ≥140 mmHg and/or diastolic blood pressure (DBP) readings of ≥90 mmHg, as outlined in the 2018 European Society of Cardiology and European Society of Hypertension (ESC/ESH) guidelines (16). The diagnostic criteria for anemia were in accordance with the World Health Organization (WHO) guidelines (17). Specifically, individuals (excluding pregnant women) with hemoglobin (Hb) concentrations below 120 g/L for females or 130 g/L for males would be classified as having anemia. The exclusion criteria were as follows: (I) patients with a history of coronary heart disease (myocardial infarction, percutaneous coronary intervention and/or coronary artery bypass grafting), congenital heart diseases, primary or secondary myocardiopathy not caused by HTN, severe aortic or mitral valve diseases, documented surgical procedures for heart diseases, history of chemotherapy

or radiotherapy, and severe renal failure [estimated glomerular filtration rate (eGFR) <30 mL/min/1.73 m^2]; (II) contraindications to CMR or poor CMR image quality; and (III) incomplete key clinical data. The inclusion criteria for the control group were as follows: (I) no history of ECG abnormalities or symptoms of CVD; (II) no history of diseases that could impair cardiac function, such as HTN, type 2 diabetes mellitus, coronary heart disease, cardiomyopathy, valvular heart disease, systemic diseases; and (III) the CMR revealed normal findings. Finally, a total of 238 HTN patients were eligible for this study, including 88 patients with HTN and anemia and 150 patients with HTN but without anemia. A total of 67 age- and sex-matched healthy individuals were selected from our volunteer database to serve as the control group.

Image acquisition

All CMR scans were conducted with patients in the supine position using a 3.0 T whole-body magnetic resonance scanner, either the TrioTim or MAGNETOM Skyra system (Siemens Medical Solutions, Erlangen, Germany). The equipment was outfitted with 32-channel body phased array coils and standard ECG trigger apparatus. Balanced steady-state free precession (b-SSFP) cine images were obtained using a retrospective vector ECG gating method at the end of an inspiratory breath-hold, with 25 frames reconstructed per breath-hold session. Standard short-axis, long-axis two-, three-, and four-chamber cine images were acquired, encompassing the entirety of the LV. The scanning parameters utilized were as follows: repetition time (TR) of 2.81 or 3.4 ms, echo time (TE) of 1.22 ms, flip angle of 40° or 50°, slice thickness of 8 mm, field of view (FOV) of 250×300 or 340×285 mm^2, and matrix of 208×139 or 256×166.

Image analysis

The CMR images were transferred to offline commercial software (Cvi42, v.5.17.2; Circle Cardiovascular Imaging, Calgary, Canada) for analysis by radiologist (B.Y.H.) with over 5 years of CMR experience, who was blinded to the participants' clinical data. In the Short-3D module, the endocardial and epicardial contours of the LV were automatically detected with manual correction during end-diastolic and end-systolic phases on short-axis cine images. Subsequently, morphological and functional parameters were automatically computed, which included LV end-diastolic volume (EDV), end-systolic volume (ESV), stroke volume (SV), ejection fraction (EF), and myocardial mass (M). The papillary muscles and trabeculae were incorporated into the parameters of the LV cavity but excluded from the LVM. Body surface area (BSA) was determined using the Mosteller formula, and the LV volumes and LVM were normalized to BSA [indexed as end-diastolic volume index (EDVI), end-systolic volume index (ESVI), stroke volume index (SVI), and mass index (MI), respectively]. The LV mass/volume ratio (M/V) was calculated by dividing the LVM by the LVEDV. The short- and long-axis four-, three-, and two-chamber cine images were input into the feature tracking module to assess LV myocardial strains (*Figure 1*). The endocardium and epicardium of the LV were automatically detected at end-diastole with manual corrections, ensuring exclusion of papillary muscles and trabeculae, with the LV extent defined in the long-axis views. LV global radial peak strain (GRPS), global circumferential peak strain (GCPS), and global longitudinal peak strain (GLPS) results were automatically generated. For strain analysis, global strain capacity in HTN patients was considered abnormally impaired if the absolute value of any strain parameter was less than or equal to the mean minus two standard deviations (SDs) of the global strain parameter in the control group.

Reproducibility of LV strains

To assess interobserver variability, 30 cases were randomly chosen, and the LV global strains were analyzed independently by two radiologists in a double-blinded fashion. Intraobserver variability was assessed by comparing measurements of the same participants taken by one of the radiologists with a 1-month interval between assessments.

Statistical analysis

All statistical analyses were conducted utilizing SPSS software (version 24.0; IBM Corp., Armonk, NY, USA). The normality of continuous variables was assessed with the Shapiro-Wilk test. Normally distributed data were expressed as means ± SD, whereas non-normally distributed data were presented as medians (interquartile range: 25th to 75th percentile). Categorical data were presented as frequencies (percentages) and compared using the appropriate Chi-squared or Fisher's exact test. The clinical and CMR-derived variables were compared among control participants and HTN patients with and without anemia

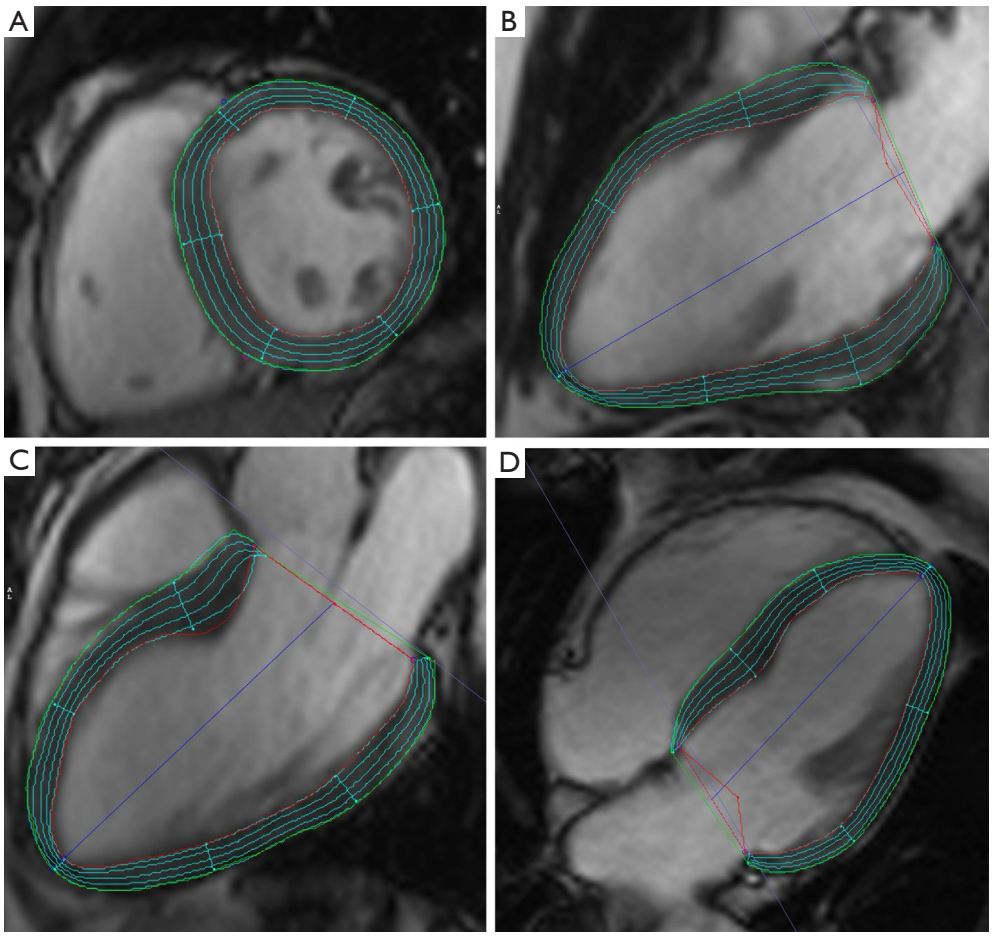

Figure 1 Measurement of LV strains using cardiac magnetic resonance feature tracking. Panel (A) shows the short-axis view, while panels (B-D) display the long-axis 2-, 3-, and 4-chamber views, respectively, at the end-diastole phase. The light blue line denotes the LV myocardium, the red line indicates the endocardium, and the green line represents the epicardium. LV, left ventricular.

using one-way analysis of variance (ANOVA), followed by Bonferroni's post hoc corrections, the Kruskal-Wallis test, or the Chi-squared test (Fisher's exact test) as deemed appropriate. Analysis of covariance was employed to assess the discrepancies in CMR parameters between HTN patients with and without anemia after adjusting for age. Pearson's or Spearman's correlation coefficient was employed to examine relationships between LV global strains, functional parameters, and clinical parameters. The factors influencing LV contractile function were evaluated using linear regression analysis. Variables showing significance (P<0.05) in univariate analysis and demonstrating no collinearity were incorporated into constructing the multivariate models. Intra- and inter-observer variabilities of LV deformation were assessed using the intraclass correlation coefficients (ICCs). Statistical significance was set at a two-tailed P value <0.05.

Results

Baseline characteristics

A total of 305 participants were enrolled in the study, including 67 controls, 88 HTN patients with anemia (32 with mild anemia, 44 with moderate anemia, and 12 with severe anemia), and 150 HTN patients without anemia. Among the three groups, the HTN with anemia group had a higher mean age compared with both the control and HTN without anemia groups. Hb levels (101±17 *vs.* 143±16 *vs.* 150±15 g/L), BSA, and eGFR were significantly lower in the HTN with anemia group compared with the other two groups (all P<0.001). Additionally, BSA and eGFR of the HTN without anemia group were significantly lower than those of the control group. Detailed baseline characteristics are presented in *Table 1*.

Table 1 Baseline characteristics

Variable	Controls (n=67)	HTN without anemia (n=150)	HTN with anemia (n=88)
Demographics			
Age (years)	56.3±10.9	56.5±13.4	63.2±16.4*§
Male	37 (55.2)	86 (57.3)	43 (48.9)
BMI (kg/m^2)	23.15±3.27	24.83±2.98*	22.93±3.20§
BSA (m^2)	1.75±0.24	1.52±0.31*	1.34±0.29*§
Heart rate (beats/min)	69±11	73±14	76±14*
SBP (mmHg)	114±7	139±18*	139±21*
DBP (mmHg)	72±8	87±14*	83±14*
MAP (mmHg)	86±6	104±14*	102±15*
Current smoking	16 (23.9)	39 (26.0)	31 (35.2)
Dyslipidemia	–	33 (22.0)	28 (31.8)
Diabetes	–	31 (20.7)	29 (33.0)
Laboratory data			
Hb (g/L)	150±15	143±16	101±17*§
TG (mmol/L)	1.14 (0.88, 1.50)	1.40 (0.99, 2.04)	1.26 (0.93, 1.98)
TC (mmol/L)	4.34 (3.87, 4.88)	4.31 (3.76, 4.89)	4.09 (3.47, 4.66)
HDL (mmol/L)	1.17 (1.02, 1.41)	1.29 (1.04, 1.50)	1.21 (0.98, 1.53)
LDL (mmol/L)	2.67 (2.23, 3.06)	2.51 (2.05, 2.97)	2.30 (1.76, 2.68)
eGFR (mL/min/1.73 m^2)	105.0 (99.9, 111.4)	91.7 (80.1, 102.2)*	76.9 (51.1, 91.7)*§
Creatinine (μmol/L)	56.0 (50.5, 67.3)	70.4 (61.0, 82.5)*	82.0 (67.8, 110.8)*§
Medications			
ACEI/ARB	–	64 (42.7)	37 (42.0)
Beta-blocker	–	50 (33.3)	28 (31.8)
Calcium channel blocker	–	84 (56.0)	58 (65.9)
Diuretics	–	26 (17.3)	20 (22.7)

Data are presented as mean ± standard deviation, median (Q1, Q3) or number (percentage). *, P<0.05 *vs.* controls; §, P<0.05 *vs.* HTN patients without anemia. HTN, hypertension; BMI, body mass index; BSA, body surface area; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; Hb, hemoglobin; TG, triglycerides; TC, total cholesterol; HDL, high-density lipoprotein; LDL, low-density lipoprotein; eGFR, estimated glomerular filtration rate; ACEI, angiotensin-converting enzyme inhibitor; ARB, angiotensin II receptor blocker.

Characteristics of CMR-derived LV functional, geometric parameters among HTN patients and controls

The HTN with anemia group exhibited significantly higher basic LV geometric and functional parameters, including LVEDV, LVESV, LVSVI, and LVM, compared with both the control group and the HTN without anemia group (all P<0.001). However, there was no significant difference observed between the latter two groups. Furthermore, the LVEDVI, LVESVI, LVMI, and M/V were all significantly increased in the HTN with anemia group when compared with the other two groups (all P<0.001). Detailed information can be found in *Table 2*. In the HTN group without anemia, 41 patients (27%) had impaired LVEF (less than 50%), whereas in the HTN group with anemia,

Table 2 Comparisons of CMR derived LV function and LV global strains findings among controls, HTN patients without anemia and HTN patients with anemia groups

Variable	Controls (n=67)	HTN without anemia (n=150)	HTN with anemia (n=88)
LV function parameters			
LVEDV (mL)	123.9 (112.3, 141.0)	136.4 (115.0, 163.0)*	142.0 (113.5, 179.4)*
LVEDVI (mL/m^2)	71.8 (65.3, 78.3)	91.6 (77.4, 109.3)*	104.6 (82.9, 143.6)*§
LVESV (mL)	46.1 (39.7, 53.3)	56.0 (42.9, 73.8)*	64.3 (48.0, 101.0)*
LVESVI (mL/m^2)	26.8 (22.6, 30.5)	35.1 (28.0, 51.9)*	46.9 (34.1, 78.0)*§
LVSV (mL)	78.5±14.9	76.1±19.1	71.1±21.9*
LVSVI (mL/m^2)	45.2±8.3	50.8±12.1*	53.3±16.1*
LVEF (%)	62.6±4.6	54.8±15.0*	49.5±14.3*§
LVM (g)	72.9 (63.5, 87.0)	95.5 (77.8, 115.5)*	104.9 (85.4, 131.0)*
LVMI (g/m^2)	43.8 (38.5, 50.0)	62.5 (54.4, 72.5)*	75.4 (62.2, 97.4)*§
M/V (g/mL)	0.62±0.12	0.70±0.16*	0.75±0.19*§
Peak strain			
Radial (%)	37.53 (33.72, 42.51)	31.58 (23.83, 40.07)*	27.23 (19.15, 37.97)*
Circumferential (%)	−20.62±2.39	−18.09±4.67*	−16.58±4.94*§
Longitudinal (%)	−15.20±2.36	−11.94±4.18*	−10.41±4.32*§
PSSR			
Radial (s^{-1})	2.23 (1.83, 2.96)	2.05 (1.48, 2.59)	1.64 (1.10, 2.16)*§
Circumferential (s^{-1})	−1.04 (−1.18, −0.92)	−1.05 (−1.19, −0.86)	−0.96 (−1.11, −0.73)*§
Longitudinal (s^{-1})	−0.84 (−0.93, −0.75)	−0.77 (−0.92, −0.52)*	−0.72 (−0.83, −0.46)*
PDSR			
Radial (s^{-1})	−2.09 (−3.17, −1.61)	−1.83 (−2.67, −0.96)	−1.23 (−2.29, −0.55)*§
Circumferential (s^{-1})	0.99 (0.85, 1.21)	0.87 (0.57, 1.04)	0.82 (0.52, 1.01)
Longitudinal (s^{-1})	0.83 (0.71, 1.02)	0.72 (0.54, 0.93)*	0.71 (0.44, 0.88)*

Data are presented as mean ± standard deviation or median (Q1, Q3). *, P<0.05 *vs.* controls. §, P<0.05 *vs.* HTN patients without anemia. "−" indicates the direction of strains (negative). Negative strain means shortening, thinning, and/or contraction, while positive strain means lengthening, thickening, and/or relaxation from end-diastole to end-systole. CMR, cardiovascular magnetic resonance; HTN, hypertension; LV, left ventricular; LVEDV, LV end diastolic volume; LVEDVI, LV end-diastolic volume index; LVESV, LV end systolic volume; LVESVI, LV end-systolic volume index; LVSV, LV stroke volume; LVSVI, LV stroke volume index; LVEF, LV ejection fraction; LVM, LV mass; LVMI, LV mass index; M/V, mass/volume ratio; PSSR, peak systolic strain rate; PDSR, peak diastolic strain rate.

38 patients (43%) had impaired LVEF. After adjusting for age between the HTN patients with and without anemia groups, the former showed higher LVEDVI (118.8±4.4 *vs.* 99.0±3.3 mL/m^2, P<0.001), LVESVI (64.8±4.2 *vs.* 48.5±3.2 mL/m^2, P=0.003), LVSVI (54.4±1.4 *vs.* 50.5±1.1 mL/m^2, P=0.032), LVM (111.9±3.3 *vs.* 98.9±2.5 g, P=0.002), LVMI (84.8±2.5 *vs.* 65.9±1.9 g/m^2, P<0.001), and M/V (0.75±0.02 *vs.* 0.70±0.01 g/mL, P=0.034), but lower LVEF (49.2%±1.6% *vs.* 54.7%±1.2%, P=0.006) (*Table 3*).

Assessment of LV global strains using CMR across the three groups

Figure 2 depicts typical peak strain curves derived from CMR in three different directions for a healthy control, an HTN patient without anemia, and an HTN patient with anemia. Among the three groups, LV GCPS and GLPS exhibited a progressive and significant decline from the control group to HTN patients without anemia and further to HTN

Table 3 Comparisons of CMR data in patients with HTN using analysis of covariance

Variable	HTN without anemia (n=150)	HTN with anemia (n=88)	P value
LV function parameters			
LVEDV (mL)	146.8±4.3	155.9±5.6	0.204
LVEDVI (mL/m^2)	99.0±3.3	118.8±4.4	<0.001
LVESV (mL)	71.8±4.3	83.2±5.6	0.111
LVESVI (mL/m^2)	48.5±3.2	64.8±4.2	0.003*
LVSV (mL)	75.0±1.6	73.1±2.1	0.463
LVSVI (mL/m^2)	50.5±1.1	54.4±1.4	0.032*
LVEF (%)	54.7±1.2	49.2±1.6	0.006*
LVM (g)	98.9±2.5	111.9±3.3	0.002*
LVMI (g/m^2)	65.9±1.9	84.8±2.5	<0.001*
M/V (g/mL)	0.70±0.01	0.75±0.02	0.034*
Peak strain			
Radial (%)	32.72±1.14	28.95±1.49	0.048*
Circumferential (%)	−18.08±0.39	−16.60±0.52	0.025*
Longitudinal (%)	−11.95±0.35	−10.40±0.46	0.008*
PSSR			
Radial (s^{-1})	2.17±0.11	1.69±0.15	0.011*
Circumferential (s^{-1})	−1.02±0.02	−0.96±0.03	0.130
Longitudinal (s^{-1})	−0.68±0.04	−0.67±0.05	0.849
PDSR			
Radial (s^{-1})	−1.53±0.23	−0.68±0.30	0.028*
Circumferential (s^{-1})	0.65±0.05	0.72±0.07	0.467
Longitudinal (s^{-1})	0.69±0.03	0.64±0.04	0.361

Adjustment of age in HTN patients with and without anemia using analysis of covariance. Values are given as mean ± standard error. *, indicates a significance level of <0.05. "−" indicates the direction of strains (negative). Negative strain means shortening, thinning, and/or contraction, while positive strain means lengthening, thickening, and/or relaxation from end-diastole to end-systole. CMR, cardiovascular magnetic resonance; HTN, hypertension; LV, left ventricular; LVEDV, LV end diastolic volume; LVEDVI, LV end-diastolic volume index; LVESV, LV end systolic volume; LVESVI, LV end-systolic volume index; LVSV, LV stroke volume; LVSVI, LV stroke volume index; LVEF, LV ejection fraction; LVM, LV mass; LVMI, LV mass index; M/V, mass/volume ratio; PSSR, peak systolic strain rate; PDSR, peak diastolic strain rate.

patients with anemia. LV GRPS was significantly decreased in both HTN patient groups compared with the control group (P<0.05), whereas there was no significant difference observed between the HTN groups (P=0.085). The GRPS values were 37.53% (33.72–42.51%) in controls, 31.58% (23.83–40.07%) in HTN without anemia, and 27.23% (19.15–37.97%) in HTN with anemia; GCPS values were −20.62%±2.39%, −18.09%±4.67%, and −16.58%±4.94%; GLPS values were −15.20%±2.36%, −11.94%±4.18%, and −10.41%±4.32%, respectively (all P<0.05) (*Table 2*, *Figure 3*). Among hypertensive patients, the number and proportion of individuals with normal LVEF but impaired strain were 8 (3.4%) for radial strain, 10 (4.2%) for circumferential strain, and 25 (10.5%) for longitudinal strain. After adjusting for age, GLPS (−10.40%±0.46% *vs.* −11.95%±0.35%, P=0.008), GCPS (−16.60%±0.52% *vs.* −18.08%±0.39%, P=0.025), and GRPS (28.95%±1.49% *vs.* 32.72%±1.14%, P=0.048) were significantly worse in HTN patients with anemia *vs.* HTN

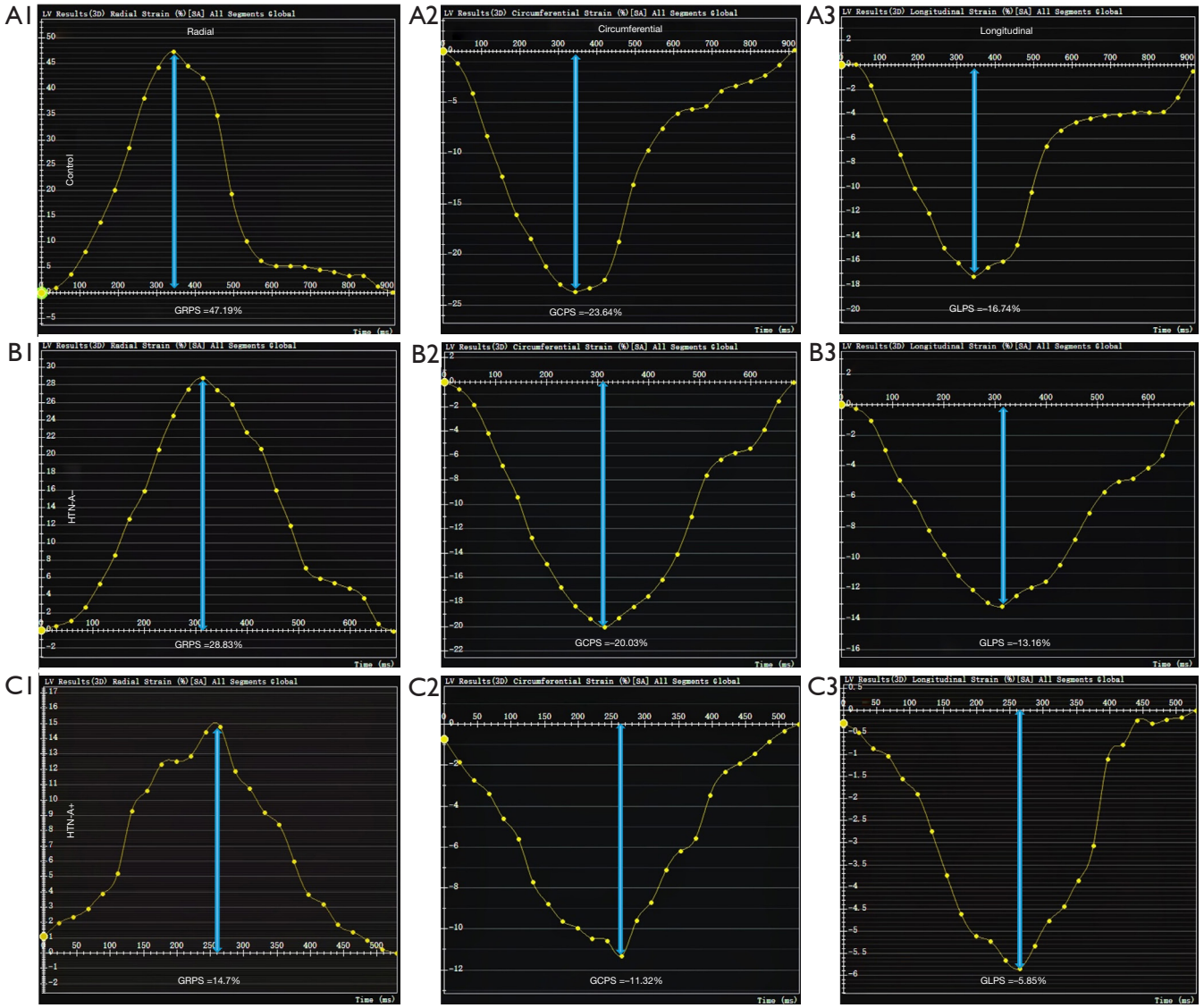

Figure 2 Representative left ventricular global peak strain curves in three directions: (A1-C1) radial, (A2-C2) circumferential, and (A3-C3) longitudinal. Curves are shown for a control subject (A1-A3), an HTN patient without anemia (B1-B3), and an HTN patient with anemia (C1-C3). The blue arrows represent the global peak strain values. GRPS, global radial peak strain; GCPS, global circumferential peak strain; GLPS, global longitudinal peak strain; LV, left ventricular; HTN, hypertension.

patients without anemia (*Table 3*). After adjusting for eGFR, GLPS (–11.88%±0.35% *vs.* –10.52%±0.46%, P=0.020) remained significantly worse in HTN patients with anemia compared to those without anemia (Table S1).

Regarding peak systolic strain rate (PSSR) and peak diastolic strain rate (PDSR), the HTN with anemia group exhibited lower radial PSSR and PDSR and circumferential PSSR compared with the other two groups (all P<0.05). However, there were no significant differences observed between the HTN without anemia group and the control group in these parameters. Additionally, the longitudinal PSSR and PDSR were significantly lower in both HTN patient groups compared with the control group (P<0.05), whereas there was no significant difference observed between the HTN groups. Notably, there was no significant difference in circumferential PDSR among the three groups (*Table 2*). After adjusting for age, the radial PSSR (1.69±0.15 *vs.* 2.17±0.11 s^{-1}, P=0.011) and PDSR (–0.68±0.30 *vs.*

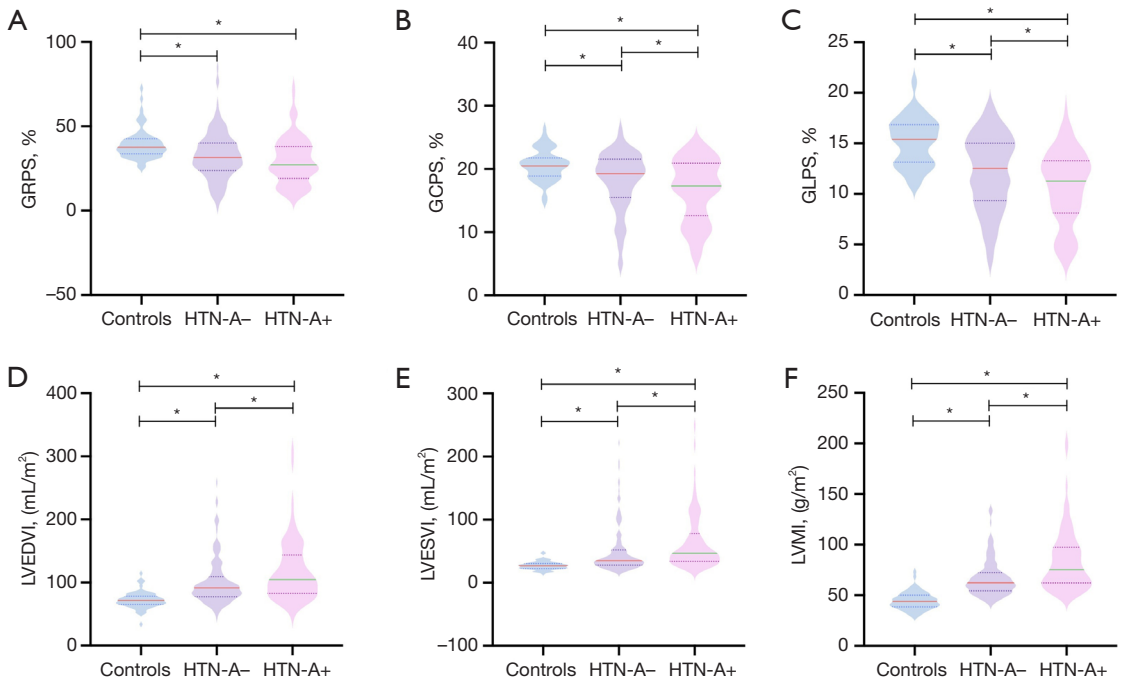

Figure 3 Comparison of LV global peak strains and function parameters across three subgroups. Panel (A) displays radial strain, panel (B) shows circumferential strain, and panel (C) illustrates longitudinal strain. Furthermore, panels (D-F) compare LV function parameters: LVEDVI, LVESVI, and LVMI, respectively. The circumferential and longitudinal peak strain were reported both as absolute values. *, P<0.05. HTN-A–, HTN patients without anemia; HTN-A+, HTN patients with anemia; HTN, hypertension; GRPS, global radial peak strain; GCPS, global circumferential peak strain; GLPS, global longitudinal peak strain; LV, left ventricular; LVEDVI, LV end-diastolic volume index; LVESVI, LV end-systolic volume index; LVMI, LV mass index.

−1.53±0.23 s^{-1}, P=0.028) were still significantly worse in HTN patients with anemia *vs.* HTN patients without anemia (*Table 3*).

Factors influencing LV global strains and functional parameters

Hb demonstrated a significant correlation with LVMI, LVEDVI, LVESVI, LVSVI, GLPS, and GCPS based on correlation analysis (r=−0.356, P<0.001; r=−0.335, P<0.001; r=−0.321, P<0.001; r=−0.260, P<0.001; r=0.187, P=0.001; r=0.113, P<0.05; respectively) (*Figure 4*).

Following univariate linear regression analysis, anemia and triglycerides (TGs) were significantly associated with all three directions of LV global strains (all P<0.05) (Figure S1). Hb and eGFR were significantly associated with GCPS and GLPS (all P<0.05). In addition, DBP was independently related to GRPS (P=0.012) and GLPS (P=0.003), but not with GCPS (P=0.178). Multivariate linear regression analysis indicated that anemia had significant independent associations with GRPS (β =−0.142, P=0.021), GCPS (β =0.273, P=0.004), and GLPS (β =0.308, P=0.002). TG was independently associated with GRPS and GCPS (P<0.05). Moreover, Hb and eGFR were significantly associated with GCPS (all P<0.05). Detailed information is available in *Table 4*.

Intra- and inter-observer variability

The intraobserver and interobserver correlation coefficients were deemed excellent, with ICCs of global peak strains in all three directions exceeding 0.9. Detailed information is provided in Table S2.

Discussion

This study examined the impact of anemia on CMR-derived LV function and deformation in HTN patients, while also identifying independent factors of affecting LV systolic dysfunction. The key findings included the following: (I)

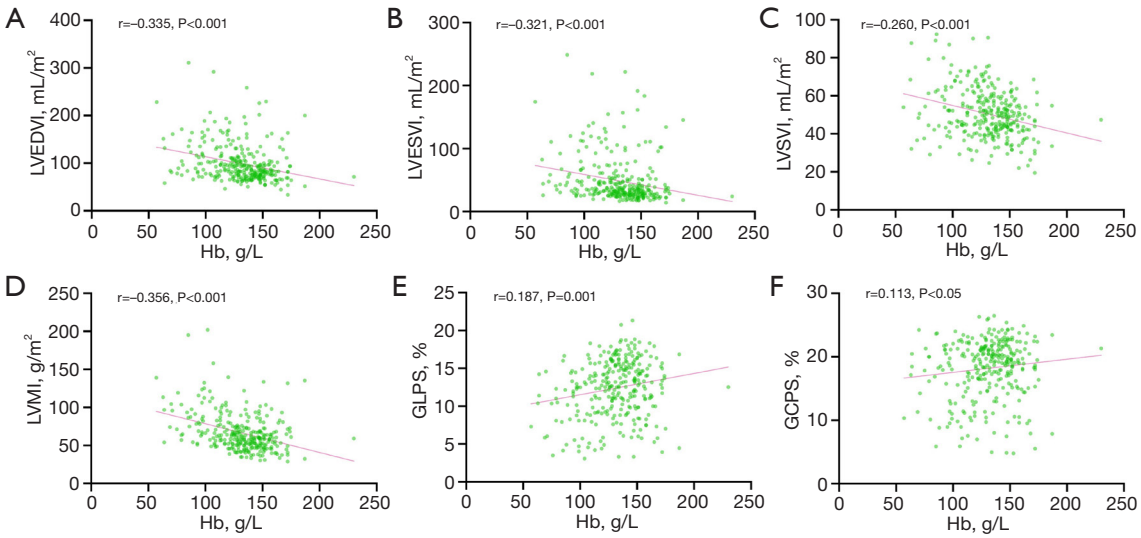

Figure 4 Correlation analysis of hemoglobin with LV function parameters and global strain. Panel (A) illustrates the correlation for the LVEDVI, panel (B) for the LVESVI, panel (C) for the LVSVI, panel (D) for the LVMI, panel (E) for GLPS, and panel (F) for GCPS. The absolute values of circumferential and longitudinal peak strain were analyzed to avoid the influence of directional signs. Hb, hemoglobin; LV, left ventricular; LVEDVI, LV end diastolic volume index; LVESVI, LV end systolic volume index; LVSVI, LV stroke volume index; LVMI, LV mass index; GLPS, global longitudinal peak strain; GCPS, global circumferential peak strain.

Table 4 Univariable and multivariable correlation analysis between clinical parameters and left ventricular global strains in all HTN patients

Variable	GRPS				Abs of GCPS				Abs of GLPS			
	Univariable		Multivariable		Univariable		Multivariable		Univariable		Multivariable	
	β	P value	β	P value	β	P value	β	P value	β	P value	β	P value
Age	0.058	0.312	–	–	−0.046	0.424	–	–	−0.016	0.775	–	–
Sex	−0.108	0.060	–	–	−0.051	0.377	–	–	−0.103	0.072	–	–
Body mass index	0.018	0.755	–	–	0.132	0.021*	−0.186	0.003*	−0.003	0.959	–	–
Heart rate	−0.071	0.218	–	–	−0.082	0.154	–	–	−0.135	0.019*	0.096	0.123
Systolic blood pressure	−0.057	0.324	–	–	0.000	1.000	–	–	−0.138	0.016*	−0.116	0.138
Diastolic blood pressure	−0.144	0.012*	−0.082	0.182	−0.077	0.178	–	–	−0.169	0.003*	0.120	0.133
Hemoglobin	0.080	0.166	–	–	0.113	0.048*	0.215	0.024*	0.186	0.001*	0.115	0.262
Estimated glomerular filtration rate	0.121	0.051	–	–	0.178	0.004*	−0.161	0.011*	0.209	0.001*	−0.090	0.155
Triglycerides	−0.157	0.011*	−0.163	0.008*	−0.018	0.004*	0.178	0.004*	−0.131	0.034*	0.068	0.294
Total cholesterol	−0.004	0.955	–	–	0.023	0.708	–	–	0.082	0.189	–	–
High-density lipoprotein	0.095	0.126	–	–	0.092	0.139	–	–	0.192	0.002*	−0.108	0.095
Low-density lipoprotein	−0.023	0.708	–	–	0.015	0.808	–	–	0.073	0.239	–	–
Anemia	−0.175	0.002*	−0.142	0.021*	0.227	<0.001*	0.273	0.004*	0.271	<0.001*	0.308	0.002*

*, P<0.05. HTN, hypertension; GRPS, global radial peak strain; β, standard regression coefficient; Abs, absolute value; GCPS, global circumferential peak strain; GLPS, global longitudinal peak strain.

HTN patients exhibited poorer LV global strains, poorer LVEF, higher LVMI, and higher M/V compared with the control group. (II) HTN patients with anemia showed the lowest LV global strains, highest LVMI, and highest M/V compared with controls and HTN patients without anemia. (III) Anemia served as an independent factor affecting GLPS, GCPS, and GRPS after adjusting for various factors in this study group.

Our data indicate that HTN patients, both with and without anemia, demonstrated increased LVMI, elevated M/V, decreased LVEF, and impaired LV global strains compared with the control group. These observations align with findings reported in previous studies (18,19). HTN causes increased LVM and LVH, accompanied by interstitial fibrosis marked by type I and III collagen fiber accumulation. The severity of LV remodeling dictates the extent of fibrosis, resulting in increased LV stiffness, ultimately reducing myocardial systolic strain (20). This change can impact ventricular function, electrical activity, and myocardial perfusion, potentially affecting prognosis (21). Elevated LVM is acknowledged as an independent prognosticator for cardiovascular mortality and HF (22). Prolonged HTN can result in HF (23). Furthermore, myocardial strain provides an objective assessment of regional myocardial contractility by evaluating myocardial deformation. LV global strains serve as early and sensitive indicators of LV motion abnormalities (24,25). Our results emphasize that LV damage, particularly for GLPS, can occur due to HTN and anemia, even when LVEF levels appear normal. In patients with HTN, strain parameters demonstrate greater predictive power for adverse outcomes compared with LVEF (26).

Our study demonstrated that HTN patients with anemia exhibited the highest indices of LVEDV, LVM, and M/V. Anemia is associated with increases in LVMI and LVM, both of which are critical indicators for diagnosing LVH. This finding supports the previously established mechanism (27). In response to anemia, the body adapts through both nonhemodynamic and hemodynamic changes to compensate for inadequate oxygen supply. The main nonhemodynamic change is increased erythropoiesis, whereas the key hemodynamic change is elevated cardiac output, resulting from lower afterload, increased preload, and positive inotropic and chronotropic effects (6). Over time, these adaptations lead to cardiac cavity enlargement (increased LVEDV and LVESV) and LVH (increased LVM). This morphological transformation of the heart is termed eccentric hypertrophy (28). Previous research has shown an association between anemia and adverse cardiovascular and renal events in patients with HTN (11). This article further explores how anemia worsens cardiac function in these individuals, potentially leading to poor prognosis. Our study shows that the coexistence of anemia and HTN leads to greater cardiac dysfunction, as evidenced by lower LV function parameters and global strains in HTN patients with anemia compared to other groups. The literature underscores the connection between anemia and HF risk, suggesting that it contributes to adverse cardiac remodeling and reduced function (29). Our findings offer deeper insights into this relationship, indicating a heightened risk of severe LV contractile dysfunction in anemic hypertensive patients.

Normocytic anemia was notably prevalent among HTN patients. Furthermore, inadequate blood pressure management correlated with decreased Hb concentration. These observations imply an elevated cardiovascular risk in uncontrolled HTN (12). However, anemia in HTN patients is frequently underestimated, which may lead to insufficient treatment. Prompt reversal of anemia in patients without obvious heart disease could potentially correct LVH (15,30). Nonetheless, in instances of severe anemia or when coupled with other heart conditions, irreversible damage may ensue, resulting in a deteriorated prognosis (31). Previous research has shown that mild anemia independently elevates cardiovascular and renal risk in high-risk HTN outpatients (11). Thus, upon HTN diagnosis, clinicians and patients should actively address anemia to prevent cardiovascular and renal complications.

This study revealed that anemia was independently linked to LV global strains, possibly attributable to volume overload. The etiology of anemia is multifaceted and diverse. Among HTN patients, numerous studies have focused on CKD, whether it is hypertensive or non-hypertensive (32,33). Renal dysfunction is widespread among HTN patients and correlates with unfavorable prognoses. Impaired eGFR independently predicts anemia in HTN patients (34). Anemia is common in CKD, becoming more frequent as eGFR decreases due to reduced erythropoietin production by the kidneys, activation of the renin-angiotensin-aldosterone system, shortened red blood cell (RBC) lifespan, and iron deficiency (35,36). Additionally, several other risk factors may contribute to Hb reduction, including but not limited to resistance to erythropoietin, hemodilution, loss of RBCs, decreased RBC

longevity, inflammation, and endothelial dysfunction (37). This may help clarify our findings, indicating that anemia is independently associated with LV GLPS when factoring in eGFR. Additionally, our results indicate that HTN patients with anemia were older compared with participants in the other two groups within this study population. Anemia is particularly prevalent among the elderly, with causes ranging from bone marrow failure syndromes to CKD, nutritional deficiencies, and inflammatory conditions such as immunosenescence (38). Therefore, timely monitoring and improvement of Hb levels in HTN patients might be beneficial for enhancing their quality of life and prognosis, warranting further investigation.

Limitations

This study has several limitations. Firstly, most of our patients exhibited mild to moderate anemia, with few cases of severe anemia, thus limiting our ability to explore the effects of varying degrees of anemia severity on cardiac health. Secondly, due to limited technical capabilities in earlier years, a significant proportion of patients in this study did not undergo T1 mapping evaluations. As a result, we lacked sufficient data to analyze LV tissue characterization (such as interstitial fibrosis) using this promising method. Thirdly, as it is a cross-sectional study, the long-term outcomes of HTN patients were not monitored, which could provide valuable insights into the influence of anemia. Lastly, this was an observational and single-center study conducted on a retrospective HTN cohort, which means that selection bias was unavoidable. Future multi-center research will prioritize increasing the sample size to provide a more accurate evaluation of how anemia affects cardiac function. Additionally, longitudinal and prospective studies employing novel CMR scanning techniques should investigate the potential long-term adverse effects of anemia on LV function, deformation, and tissue characterization in patients with HTN.

Conclusions

In patients with HTN, anemia exerts additional harmful impacts on LV function and global strains. Anemia serves as an independent determinant of LV global strains. Heightened awareness of anemia is warranted upon HTN diagnosis, and routine screening coupled with appropriate preventive measures may confer benefits to HTN patients.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). Ethical approval for this clinical study was obtained from the Biomedical Research Ethics Committee of West China Hospital, Sichuan University (No. 2019-811). The requirement for informed consent from patients was waived due to the retrospective nature of this study.

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