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# Evaluation of Right Ventricular Functions and Pulmonary Artery Distensibility in Patients with Pulmonary Hypertension Using Cardiac Magnetic Resonance Imaging

## Pulmoner Hipertansiyonlu Hastalarda Kardiyak Manyetik Rezonans Görüntüleme Kullanılarak Sağ Ventriküler Fonksiyonlarının ve Pulmoner Arter Distensibilitesinin Değerlendirilmesi

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## ABSTRACT

**Objective:** Pulmonary hypertension (PHT) is a chronic progressive disease characterized by an abnormal blood pressure increase in the pulmonary circulation. This study aimed to measure right ventricular volume and functions and pulmonary artery distensibility, which are important in the follow-up and prognosis of PHT, and to compare right ventricular measures between echocardiography and cardiac magnetic resonance imaging (CMRI).

**Materials and Methods:** Seventeen patients who were diagnosed with PHT with right heart catheterization between January 2014 and August 2019 were included. Following echocardiography, right ventricular ejection fraction, end-diastolic volume, end-systolic volume, and myocardial mass values were measured by CMRI in 12 patients. Similarly, the pulmonary artery pressure (PAP) was calculated through echocardiography and pulmonary artery distensibility through CMRI.

**Results:** No significant difference was found between the measurements of the right ventricular volume and functions obtained from CMRI images and those from echocardiography. Distensibility decreased with an increase in PAP, and a curvilinear ratio was found between the two values.

**Conclusion:** In the diagnoses and follow-up of patients with PHT, CMRI can be used as an alternative to echocardiography.

**Keywords:** Cardiac MRI, pulmonary hypertension, right ventricular function, pulmonary artery distensibility

## ÖZ

**Amaç:** Pulmoner hipertansiyon (PHT), pulmoner dolaşımda anormal kan basıncı artışı ile karakterize kronik, ilerleyici bir hastalıktır. Bu çalışmada, PHT'nin takibi ve prognozunda önemli olan sağ ventrikül hacmi ve fonksiyonları ile pulmoner arter distensibilitesini kardiyak manyetik rezonans görüntüleme (MRG) ile ölçmeyi ve sağ ventrikül ölçümlerini ekokardiyografi sonuçları ile karşılaştırmayı amaçlamıştır.

**Gereç ve Yöntem:** Ocak 2014 ile Ağustos 2019 tarihleri arasında sağ kalp kateterizasyonu ile PHT tanısı alan 17 hasta çalışmaya dahil edildi. Ekokardiyografiyi takiben 12 hastada sağ ventrikül ejeksiyon fraksiyonu, diyastol sonu hacmi, sistol sonu hacim ve miyokardiyal kitle değerleri kardiyak MRG ile ölçüldü. Benzer şekilde, pulmoner arter basıncı (PAP) ekokardiyografi ile ve pulmoner arter distensibilitesi MRG yoluyla hesaplandı.

**Bulgular:** Sağ ventrikül fonksiyon ve hacmi ölçümlerinde MRI görüntülerinden elde edilen ile ekokardiyografiden elde edilen ölçümler arasında anlamlı fark bulunmadı.Distensibilite, pılmoner arter basıncındaki artışla azaldı ve iki değer arasında eğrisel bir oran bulundu.

**Sonuç:** PHT'li hastaların tanı ve takibinde kardiyak MRG ekokardiyografiye alternatif olarak kullanılabilir.

**Anahtar Kelimeler:** Kardiyak MRG, pulmoner hipertansiyon, sağ ventrikül fonksiyonu, pulmoner arter distensibilitesi

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## INTRODUCTION

Pulmonary hypertension (PHT) is a chronic progressive disease characterized by an abnormal blood pressure increase in the pulmonary circulation, resulting in chronic right heart failure and death (1, 2). After the diagnosis, the cardiac volume and functions should be assessed to determine prognosis and treatment. Increased wall rigidity of the pulmonary artery (PA) leads to a higher right ventricular afterload, resulting in more vascular damage (3-5). Therefore, the measurement of PA distensibility (PAD) provides important information on the mortality of the disease (6, 7).

Transthoracic Doppler echocardiography is the first imaging modality used in patients with PHT to evaluate right ventricular structures and functions (8-10). This method is widely available and feasible, but it has the significant disadvantage of being dependent on the user and acoustic window. Right-heart catheterization is the gold standard method for PHT. Some different prognostic values can be determined from right heart catheterization, such as pulmonary vascular resistance and right atrial pressure. Nevertheless, it is an invasive test that carries real mortality and morbidity risks; thus, it cannot be repeated for the follow-up of patients (6, 11).

With the development of technology during the past decade, the role of cardiac magnetic resonance imaging (CMRI) in the evaluation of cardiac diseases has increased. Right heart function and structure can be easily assessed by the gold standard CMRI without the disadvantages of alternative imaging modalities (12, 13). Using contiguous cine images, right ventricular myocardial mass (MM), end-diastolic volume (EDV), end-systolic volume (ESV), and right and left ventricular ejection fraction (EF) measurements can be obtained. In addition, the mean area of the PA can be measured to determine the grade of vascular stiffness (14, 15).

In this study, we aimed to investigate the role of CMRI in evaluating the right heart volume and functions and PAD in patients with PHT and to compare the results with echocardiographic findings.

## MATERIALS AND METHODS

### Study Selections

We prospectively evaluated 17 consecutive patients who were diagnosed with PHT and underwent right heart catheterization between January 2014 and July 2019. Right heart catheterization was performed without sedation by dedicated cardiologists. Echocardiography followed by CMRI was performed within 48 h after right heart catheterization. Two female patients with claustrophobia and three patients (two female) with respiratory distress withdrew from the study. Twelve Caucasian patients (eight women) aged 25–42 (average, 33) years were included in the study. Of these patients, two had idiopathic PHT, one had PHT due to left heart disease, five had chronic thromboembolic PHT, and four had PHT due to an unknown mechanism.

The study was approved by the medical ethics committee (Atatürk University Research Hospital, B.30.2.ATA.0.01.00/70) and written informed consent was obtained from all patients.

### Echocardiographic Evaluation

Echocardiographic studies were performed by two cardiologists using a Vivid e9 (GE Vingmed, Horten, Norway) device with a 3.5-MHz-frequency transducer with the patients in the left lateral decubitus position. On apical four-chamber views, the right ventricular volume and function and PA pressure (PAP) were determined by the drawing systolic and diastolic endocardial borders. The average evaluation time was 17 min.

### MRI Analysis

After echocardiography, all patients underwent CMRI study in a 3-T MRI device (Magnetom Skyra Healthcare, Berlin, Germany) without any change in clinical status or treatment. On prescreening, patients were assessed for contraindications to MRI, contrast agent allergies, and acute cardiovascular events and symptoms. Anesthesia was not needed in any patient, and oxygen was provided for all patients.

Cine-MRI images (two chambers, four chambers, short axis, and right two chambers) were obtained using gradient-echo sequences and steady-state free precession (SSFP) sequences after the localizer views were used to assess wall movements and right ventricular volume and functions. Furthermore, from the right ventricular outflow tract planes, a set of 2–3 transverse short-axis views of the main PA were imaged using SSFP. These images were used to measure the mean systolic and diastolic mean PA area during the cardiac cycle to determine PAD (mPAD=(systolic area–diastolic area)/systolic area) (Figure 1). The parameters of the cine-MRI sequence were as follows: repetition time, 36.1 msn; echo time, 1.3 msn; slice thickness, 8.0 mm, and gap, 2.0 mm. The field of view values were chosen as appropriate according to the patient's physical characteristics and heart position. Shots were taken with electrocardiography triggering while the patient was breathing in. The screening of all 12 patients was successfully completed.

Measurements of the right ventricular EF, volume, and mass and mean PA areas were performed by two radiologists blinded to the echocardiographic results using a

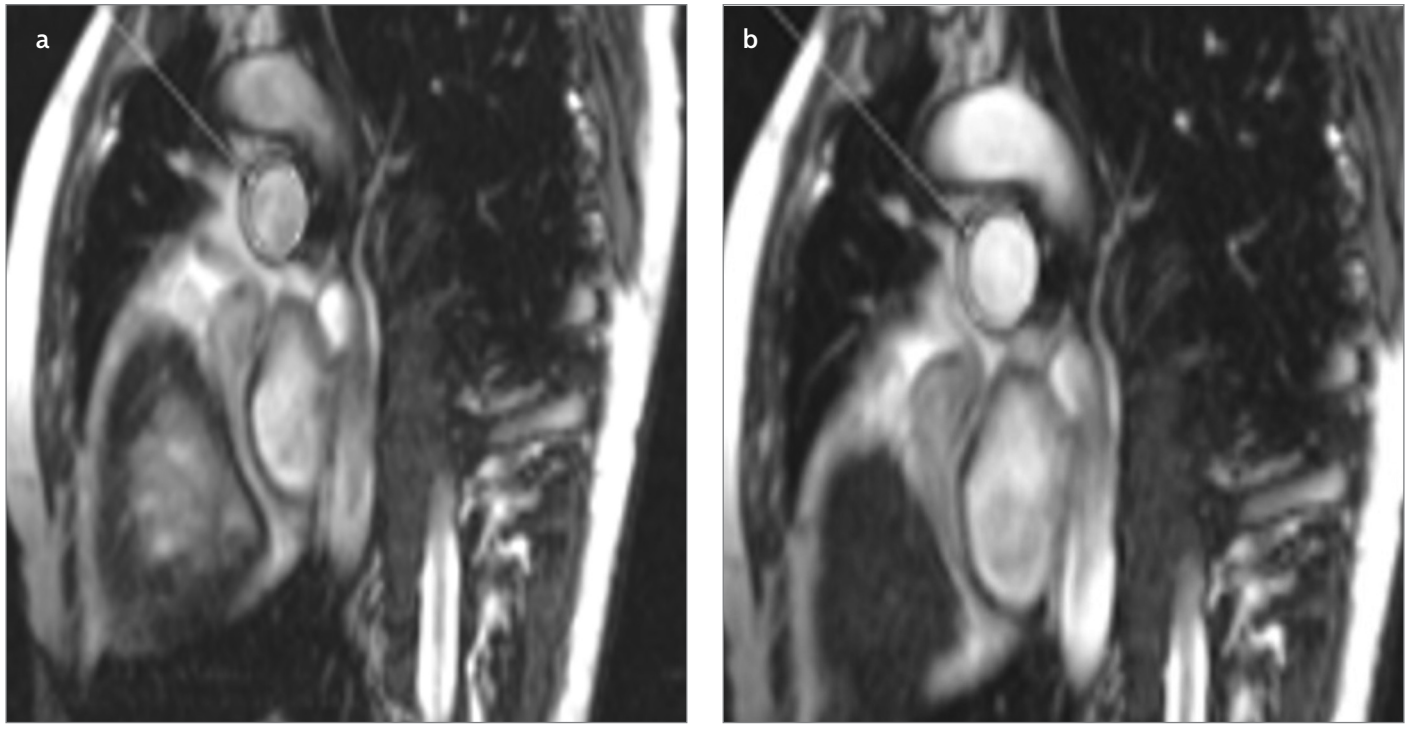


**Figure 1. a, b.** Short-axis view of the mean pulmonary artery in a patient with pulmonary hypertension. End-diastolic image (steady-state free-precession magnetic resonance imaging technique) (a) and end-systolic image (b).

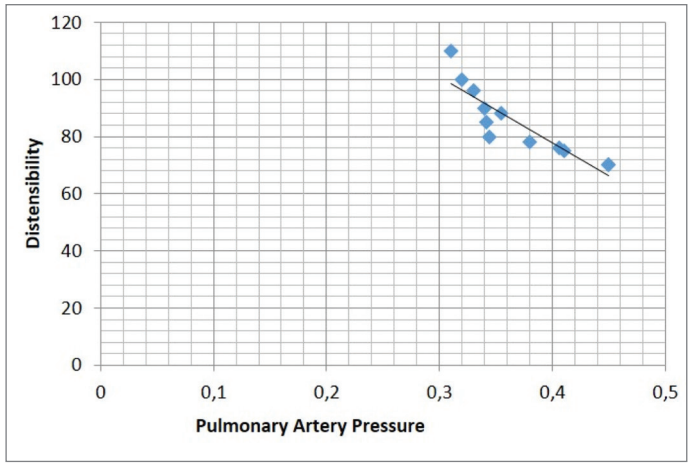


**Figure 2.** Relationship between pulmonary artery distensibility and pressure.

dedicated workstation (Syngo Via Console, software version 2.0; Siemens AG Medical Solutions, Germany).

### Statistical Analysis

Data obtained were analyzed statistically using MedCalc ver. 12 software (Medcalc; Ostend, Belgium). Descriptive statistics are given as median (minimum–maximum) or mean ± standard deviation. Categorical variables are stated as frequencies and percentages. According to the assessment of conformity to a normal distribution with the Kolmogorov–Smirnov and Shapiro–Wilk tests, continuous variables were compared with nonparametric tests or parametric tests. Spearman and Pearson correlation analyses were used to evaluate the relationship between the measurements by CMRI and echocardiography. A value of $p<0.05$ was accepted as statistically significant.

## RESULTS

The right ventricular EF, EDV, ESV, and MM values obtained from 12 patients with PHT using CMRI and echocardiography are presented in Table 1.

No significant difference was found between the right ventricular EF obtained by CMRI and echocardiography according to the paired correlation test, which revealed a high correlation ($p<0.01$, $r=0.996$). In addition, EDV, ESV, and MM values obtained from CMRI and echocardiography showed a good correlation ($r=0.820$, $r=0.998$, and $r=0.996$, respectively).

Distensibility and echo-measured PAP values of the 12 patients who underwent PAD measurements using CMRI are presented in Table 2. PAD values decreased with increasing PAP (Figure 2).

## DISCUSSION

PHT is a disease that has an extremely poor prognosis. Right ventricular volume and functions should be correctly measured to demonstrate disease progression, identify the best treatment, and evaluate the patient's response to treatment (6). Echocardiography is the preferred imaging method in PHT, and this method is easily

**Table 1.** The right ventricular EF, EDV, ESV and MM values of 12 patients using echocardiography and CMRI

| | Echocardiography | | | CMRI | | |
|---|---|---|---|---|---|---|
| **Parameters** | **Min.** | **Max.** | **Mean** | **Min.** | **Max.** | **Mean** |
| Ejection Fraction (%) | 10 | 35 | 22.6±8.5 | 10.7 | 35.7 | 23.8±8.4 |
| End-diastolic volume (ml) | 70 | 150 | 105.5±30.6 | 68.7 | 152.3 | 106.4±31.1 |
| End-systolic volume (ml) | 45 | 120 | 79±27.7 | 47.6 | 122.7 | 81.6±28.9 |
| Myocardial mass (ml) | 12 | 130 | 71.4±41.4 | 13.1 | 121.3 | 72.9±40.9 |

**Table 2.** Pulmonary artery distensibility and pressure values of the patients.

| Patient | Distensibility | Systolic Pressure (mmHg) |
|---|---|---|
| 1 | 0.344 | 80 |
| 2 | 0.410 | 75 |
| 3 | 0.355 | 88 |
| 4 | 0.380 | 78 |
| 5 | 0.342 | 85 |
| 6 | 0.310 | 110 |
| 7 | 0.340 | 90 |
| 8 | 0.450 | 70 |
| 9 | 0.450 | 70 |
| 10 | 0.330 | 96 |
| 11 | 0.320 | 100 |
| 12 | 0.406 | 76 |

accessible and reusable and has lower cost than MRI. However, an objective assessment cannot be made with this method, as it provides insufficient data in patients with comorbidities, such as obesity or anatomical variations (6, 16).

The use of CMRI is rapidly increasing because it is noninvasive, has high spatial and temporal resolution despite the absence of radiation, provides better soft tissue contrast, and allows the assessment of myocardial viability. CMRI provides not only functional but also comprehensive information on heart diseases caused by neighboring pathologies. Therefore, it contributes to the identification of the etiology of PHT (13, 15).

This study showed no significant difference in right ventricular parameters between CMRI and echocardiography. Previous CMRI studies of the right ventricle reported similar results. For example, one study concluded that CMRI was the ideal imaging method in assessing right ventricular volume and functions in patients with congenital heart disease. In that study, measurement of the right ventricular EF, EDV, and ESV by three- and two-dimensional echocardiography showed good correlation compared with the CMRI measurement (17). The best correlation between these values was between the EF measurements (r=0.71). In our study, we found that the best correlations were in the EF measurements, which produced similar values in both imaging modalities (r=0.998). The differences in the correlation values between the two studies may be related to the sample size and previous authors' inclusion of trabecula in the ventricular cavity for the measurements.

Normally, pulmonary circulation has low pressure and high distensibility. Increased pressure in patients with PHT leads to an increase in the maximal and minimal areas of the PA, resulting in reduced vessel flexibility. Proximal artery branches make a major contribution to total vascular resistance. For this reason, pulmonary vascular bed compliance in PHT is largely determined by the compliance of proximal vessels. PA rigidity can be calculated through the measurement of distensibility. Distensibility decreases in patients with PHT compared with controls, and this decrease has an important relationship with the increase in PAP. The change in distensibility is an important prognostic indicator for assessing mortality (18-20). Dyer et al. (21) and Gan et al. (3) showed a curvilinear proportionality between PAP and PAD. However, the data distribution revealed that PAP was not the only determinant of distensibility. Increased PAP also leads to vascular remodeling, such as thickening of the vessel wall. Similarly, in our study, we found an inverse ratio between PAP and PAD.

Recent studies have shown a relationship between pulmonary arterial stiffness and the course of pulmonary arterial hypertension. Ray et al. presented CMRI successfully measured PA pulsatility in the diagnosis of early PAH (22). Swift et al. showed that the findings of the right ventricular structure in CMRI are independent predictors of the clinical course of PAH (23). Toll et al. reported that strain analysis with CMRI was successful in demonstrating diastolic dysfunction in PAH (24). All these findings show that CMRI has an important role in the diagnosis and follow-up of PAH as shown in our study.

This study has certain limitations. First, the number of patients was small. A larger case series is needed to opti-

mally compare echocardiography and CMRI techniques in measuring cardiac parameters that are important in the follow-up. Second, patients with dyspnea have difficulty holding their breath during relatively long imaging. Lastly, we were unable to perform scans in patients with claustrophobia.

In conclusion, CMRI is the best diagnostic, noninvasive, and reliable method in patients with PHT. It can be used in the evaluation of both right ventricular functions, as the gold standard, and PAD. Although echocardiography is a widely available method, the use of CMRI to evaluate treatment and prognosis during the follow-up of patients with PHT can provide very useful data.

**Ethics Committee Approval:** Ethics committee approval was received for this study from the ethics committee of Atatürk University Research Hospital Clinical Research (09.04.2015/2015/B.30.2.ATA.0.01.00/70).

**Informed Consent:** Written informed consent was obtained from the patients who participated in this study.

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

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