

Normal values of native T1 / T2 maps and ventricular function in Cardiac Magnetic Resonance Imaging in 3T scanner

Valores normales de los mapas de T1 nativo / T2 y de la función ventricular en resonancia magnética cardiaca en un equipo de 3T

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Summary

Background: T1 and T2 maps are useful sequences in cardiac magnetic resonance (CMR) for the detection of myocardial alterations. Normal values of native T1 maps depend on multiple factors, so each center must establish its own normal values. CMR is the reference imaging technique in the quantification of ventricular function, however, current studies are generally based on European and US Caucasian population. ***Objective:*** To establish the normal reference values of native T1 and T2 maps and ventricular function in healthy individuals in a 3T MRI scanner. ***Methods:*** Cross-sectional study in healthy individuals between 20 and 80 years old in Medellín who underwent CMR in 3T scanner. Native T1 and T2 map sequences and ventricular function were obtained. Mean values, standard deviation and 95% confidence interval were estimated for each age group and sex. Interobserver and intraobserver agreement was evaluated. ***Results:*** 64 healthy individuals (32 women) with a mean age of 47 years (SD: 15.1) were included. The mean native T1 value was 1177 ms ± 43.19 ms and T2 map value was 38.9 ms ± 2.66. Native T1 values increase with age in both sexes, and were higher in females. Most ventricular function values were higher in men and decreased with age in both sexes. Intra- and interobserver agreement was good. ***Conclusion:*** Normal values of native T1 and T2 maps and ventricular function in healthy individuals from Medellín are presented, with good intra- and interobserver agreement.

Resumen

Antecedentes: Los mapas de T1 y T2 son secuencias útiles en la resonancia magnética cardiaca (RMC) para la detección de alteraciones miocárdicas. Los valores normales de los mapas de T1 nativo dependen de múltiples factores, por tal motivo cada centro debe establecer sus propios valores normales. La RMC es la técnica de imagen de referencia en la cuantificación de la función ventricular; sin embargo, los estudios actuales están basados generalmente en población caucásica europea y de Estados Unidos. ***Objetivo:*** Establecer los valores de referencia normales de los mapas T1 nativo y T2 y de la función ventricular en individuos sanos en un equipo de RM 3T. ***Método:*** Estudio transversal en individuos sanos entre 20 y 80 años de edad a quienes se les practicó RMC en un equipo de 3T. Se obtuvieron secuencias de mapas de T1 nativo y T2 y función ventricular. Se estimaron valores promedio, desviación estándar e intervalo de confianza del 95%, para cada grupo de edad y sexo. Se evaluó la concordancia interobservador e intraobservador. ***Resultados:*** Se incluyeron 64 individuos sanos (32 mujeres) con una edad promedio de 47 años (DE: 15,1). La media del valor del T1 nativo fue de 1.177 ms ± 43,19 ms y del valor del mapa de T2 fue 38,9 ms ± 2,66. Los valores de T1 nativo aumentan con la edad en ambos sexos, y fueron mayores en las mujeres. La mayoría de los valores de función ventricular fueron más altos en los hombres y disminuyeron con la edad en ambos sexos. La concordancia intra e interobservador fue buena. ***Conclusión:*** Se presentan los valores normales de los mapas de T1 nativo y mapas T2 y de la función ventricular en individuos sanos, con una buena concordancia intra e interobservador.

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Introduction

Cardiac magnetic resonance imaging (CMR) is the gold-standard imaging technique for noninvasively quantifying global ventricular function and characterizing myocardial tissue, with an increasingly significant impact on diagnosis, prognosis, and therapeutic decision-making for patients with cardiomyopathy.

Accurate quantification of left ventricular (LV) function is key to clinical decision-making in cardiology. Left ventricular end-systolic volumes (LVESV) and end-diastolic volumes (LVEDV) reflect adverse myocardial remodeling. Left ventricular mass (LVM) is an independent prognostic marker in individuals with and without cardiovascular disease. Left ventricular ejection fraction (LVEF) provides an estimate of left ventricular systolic function and is critical for many important clinical decisions, such as cardiac resynchronization therapy, valvular interventions, and the treatment of heart failure syndromes.

T1 and T2 parametric maps are sequences that have been incorporated into CMR studies in recent years (1, 2). These sequences are becoming increasingly available in clinical practice (3). T1 and T2 maps are acquired during multiple apneas in the diastolic phase of the cardiac cycle, and the results are displayed as color maps, in which the color of each pixel represents a T1 or T2 value.

Compared with normal myocardium, native T1 mapping values (which are obtained without the administration of intravenous contrast) in patients with cardiomyopathies are mildly to moderately increased in the presence of myocardial fibrosis or edema, and to a greater extent in patients with amyloidosis (3–6). Meanwhile, in Anderson-Fabry disease and in conditions involving myocardial iron overload, these values are decreased (3, 7, 8). Furthermore, T2 maps can detect myocardial edema, for example, in acute myocardial infarction and in acute inflammatory and infectious processes (3, 9). In transplant recipients, T2 maps can detect edema in diffuse inflammatory processes of the myocardium due to transplant rejection, even in the early stages (10).

A key aspect of quantifying native T1 and T2 maps is knowing the normal reference values for each healthcare facility, as these values depend on multiple factors such as the MRI scanner brand, magnetic field strength (1.5T or 3T), the study population, and the type of sequence used. Most studies have published normal reference values for native T1 and T2 maps using 1.5-T scanners. However, in recent years, 3-T scanners have been increasingly used for CMR, and studies reporting normal reference values for T1 maps are scarce; none have been conducted in a Colombian population.

The international consensus on myocardial mapping using CMR (3) emphasizes the importance of establishing normal reference values at each center. In healthy subjects, myocardial tissue has a very homogeneous composition and, therefore, exhibits highly uniform magnetic properties; as a result, the native T1 and T2 map values for normal myocardium are highly reproducible and show relatively narrow ranges when acquired under the same conditions. Reference ranges should be generated from datasets acquired, processed, and analyzed in the same manner as the intended application at each center, with the upper and lower limits of normal defined by the mean plus and minus two standard deviations of the normal data, respectively. According to the international consensus on CMR myocardial mapping (3), the required precision of the local reference interval depends on the proposed clinical application: for scenarios involving small-magnitude biological changes—for example, the diagnosis of diffuse myocardial fibrosis—high precision is required for the quantification of native T1 maps; for example, reference ranges derived from more than 50 healthy subjects.

Normal reference values for global ventricular function are currently available for 1.5- and 3-T MRI systems in healthy subjects using short-axis SSFP (Steady-State Free Precession) images. It has been demonstrated that parameters related to left ventricular (LV) volume and function do not vary with field strength or scanner brand (11–13). It should also be noted that current reference studies for quantifying ventricular function are based, for the most part, on European and U.S. Caucasian populations, which means that the accuracy of the values generated from this quantification cannot be precisely applied to other populations. Populations of Latin American origin, such as Colombians, have generally been underrepresented or not represented at all in most large clinical studies. The aim of this study is to establish normal reference values for native T1 and T2 maps and for ventricular function in healthy individuals from the Colombian population using a 3T MRI scanner. Accurate knowledge of normal values is necessary for the diagnosis of cardiomyopathies.

Materials and Methods

A cross-sectional study of healthy individuals who were invited and recruited to undergo CMR without intravenous contrast on a 3T scanner (Siemens Skyra) at a diagnostic imaging center in Medellín between August 2018 and February 2021. The data were stored in the institution's PACS (Picture Archiving and Communication System), and postprocessing was performed using the CVI cardiovascular imaging software (Circle CVI CMR 42, release 5.9.3-1130).

The study included healthy individuals aged 20 to 80 years who had no cardiovascular symptoms at the time of the study and no history of heart disease (congenital, valvular, or cardiomyopathy). This was verified upon enrollment in the study via a questionnaire and confirmed using cine sequences obtained after the CMR sequences were acquired, ensuring that there were no structural or functional cardiac abnormalities.

Participants were excluded if, upon enrollment, they reported pregnancy, hypertension, diabetes mellitus, collagen disease, a history of chemotherapy for any type of tumor, severe hyperlipidemia, renal failure, systemic diseases (amyloidosis, sarcoidosis, lymphoma, tuberculosis, Chagas disease), autoimmune diseases, or if they were high-performance athletes.

The sample size was determined based on the international consensus on mapping (3)—which recommends using 50 or more CMRs from healthy patients—divided and distributed as follows: in the 20–39 age group (11 women and 13 men), the 40–59 age group (11 women and 9 men), and the 60–80 age group (10 women and 10 men).

CMR images were acquired using a 3-T scanner (Skyra, Siemens Healthcare, Erlangen, Germany). Acquisition was performed with the patient in the supine position using a 30-channel cardiac coil. Longitudinal, four-chamber, three-chamber, and two-chamber Steady-State Free Precession (SSFP) cine sequences were performed, in addition to short-axis sequences of the ventricles to assess ventricular function—which reflects current clinical standards for the quantification of ventricular function. In the native T1 maps, three short-axis images were acquired: basal, mid-chamber, and apical. The MOLLI (Modified Look-Locker Inversion-recovery) T1 mapping sequence was used. Postprocessing was performed using cardiovascular imaging software (Circle cvi CMR 42, release 5.9.3-1130) to analyze biventricular function and native T1 and T2 map values of the left ventricle.

The images were analyzed individually and independently by two radiologists specializing in cardiac imaging with more than 10 years of experience. Furthermore, while blinded to patient information and analyzing the images in random order, each specialist recalculated the native T1 map values to assess validity and accuracy through inter- and intra-observer agreement.

Ventricular function (VF) parameters were determined by semi-automatically tracing the epicardial and endocardial borders during the telediastole and telesystole cardiac phases in short-axis cine MRI sequences; the tracing included the papillary muscles within the myocardial mass (Figure 1).

The images were evaluated to identify motion artifacts (cardiac or respiratory) in order to exclude myocardial segments showing focal, diffuse, or band-like abnormalities. The map values were calculated by delineating a region of interest (ROI) on the short-axis view of the interventricular septum where myocardial thickness was greatest, excluding blood pools and epicardial fat to avoid false results (Figure 2).

Ventricular function parameters and native T1 and T2 maps were described using the mean and standard deviation (SD), and normal values were estimated using the 95% confidence interval (95% CI) for the mean. All variables followed a normal distribution according to the Kolmogorov-Smirnov test; therefore, comparisons by sex were performed using Student's t-test.

To estimate the confidence intervals in the graphs relating age-indexed ventricular function parameters (in years), local regression (LOESS) was used because no linear relationship was found between these variables. Inter- and intra-observer agreement was analyzed using the Bland-Altman plot, and Student's t-test was used to confirm the absence of bias in the radiologists' assessments of T1 maps.

SPSS 22.0 and R 4.013 were used. A two-sided p-value less than 0.05 was considered statistically significant.

This study was approved by the Health Research Ethics Committee of the Universidad Pontificia Bolivariana on September 14, 2020 (Minutes 19 of 2020) and by Cedimed. All participants provided informed consent prior to enrollment in the study.

Results

A total of 64 CMR studies were performed on healthy individuals between the ages of 20 and 80, who were distributed proportionally by sex and age group. No adverse events were reported at the time of image acquisition. All MRI scans were performed using an appropriate technique and were free of artifacts.

The mean age was 47.0 (SD: 15.1) and was similar across genders. The mean native T1 map value for the entire sample was 1,177 ms (SD 43.19), and the 95% CI was 1,092–1,261. When analyzed by sex, the T1 mapping value was found to be higher in women (1.184; 95% CI: 1.084–1.284 ms) than in men (1.169; 95% CI: 1.105–1.233 ms), with no statistically significant difference (Table 1). This higher value was observed across all age groups (Figure 3).

Table 1. Comparison of ventricular function, native T1 map, and T2 map by sex in healthy individuals from Medellín

Characteristic*	Women *n*=32	Men *n*=32	*p*-value
Age (years)	47.6 ± 15.24	46.3 ± 15.10	0.737
LV end-diastolic volume (mL)	92.6 ± 15.45	134.4 ± 23.97	<0.001
LV end-systolic volume (mL)	24.9 ± 7.25	42.4 ± 10.83	<0.001
LV stroke volume (mL)	67.4 ± 11.58	91.9 ± 15.74	<0.001
LV ejection fraction (%)	73.3 ± 5.74	68.6 ± 4.26	0.001
Myocardial mass (g)	79.3 ± 11.97	123.9 ± 19.49	<0.001
LV end-diastolic volume index (mL/m^2)	56.2 ± 6.81	71.3 ± 10.83	<0.001
LV end-systolic volume index (mL/m^2)	15.1 ± 4.18	22.5 ± 5.64	<0.001
LV stroke volume index (mL/m^2)	41.1 ± 5.13	48.8 ± 6.53	<0.001
Myocardial mass index (g/m^2)	48.2 ± 5.16	65.9 ± 9.16	<0.001
Right Ventricular End-Diastolic Volume (mL)	95.9 ± 17.92	149.8 ± 28.91	<0.001
Right Ventricular End-Systolic Volume (mL)	31.0 ± 8.66	54.1 ± 13.58	<0.001
Right Ventricular Stroke Volume (mL)	64.9 ± 13.05	95.0 ± 18.20	<0.001
Right Ventricular Ejection Fraction (%)	67.8 ± 6.47	63.9 ± 4.74	0.009
Right Ventricular End-Diastolic Volume Index (mL/m^2)	58.1 ± 8.11	79.4 ± 12.81	<0.001
Right Ventricular End-Systolic Volume Index (mL/m^2)	18.8 ± 4.94	28.6 ± 6.54	<0.001
Right Ventricular Stroke Volume/Output, Index (mL/m^2)	39.3 ± 5.86	50.5 ± 8.41	<0.001
Native T1 Map (ms)	1,184.5 ± 51.01	1,169.4 ± 32.74	0.164
T2 Map (ms)	39.5 ± 2.95	38.2 ± 2.19	0.053

*All values are presented as mean ± standard deviation. LV: left ventricle; RV: right ventricle; Index: value adjusted for the patient's body surface area; ms: milliseconds.

For the T2 maps, a mean of 38.9 ms (95% CI: 38.2–39.5 ms) was obtained. In women, T2 map values (39.5 ms ± 2.95) were higher than in men (38.2 ms ± 2.19), with no statistically significant difference (p = 0.053) (Table 2). This trend was consistent across all age groups (Figure 4).

Values for LV function parameters (ventricular volumes) and LV mass were higher in men, with a statistically significant difference (Table 1). In contrast, the left ventricular ejection fraction was higher in women, at 73.3% compared to 68.64% in men (p = 0.001) (Table 1).

When analyzing LV function by age, it was observed that the values decrease as age increases (Figure 5, panels a–c). Furthermore, LV values remain higher in men than in women across the different

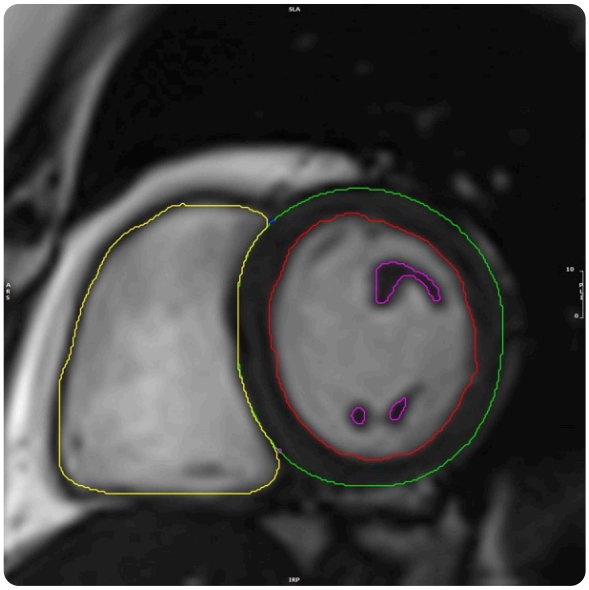


Figure 1. Assessment of ventricular function. Telediastolic short-axis images using the SSFP sequence. The epicardial (green) and endocardial (red) contours defined for the left ventricle and the endocardial (yellow) contours defined for the right ventricle are shown.

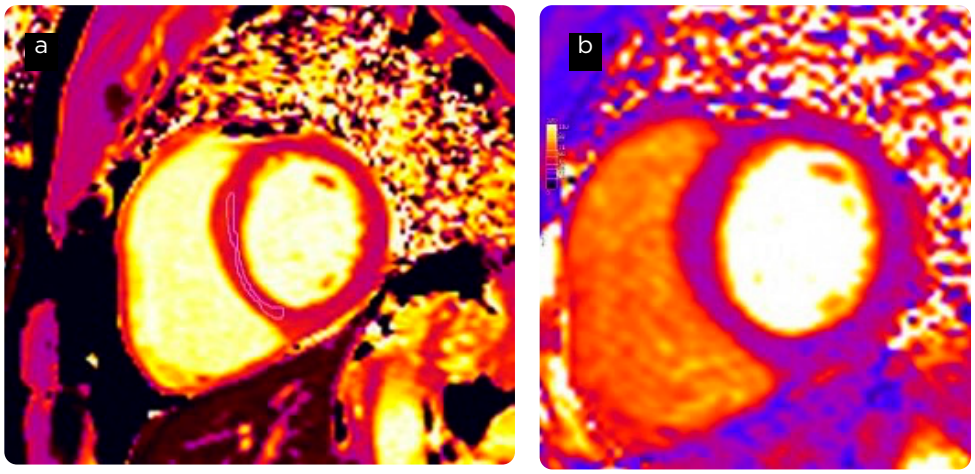


Figure 2. Native T1 and T2 maps. a) MOLLI T1 map sequence from a healthy individual (with a normal T1 time of 1,176 milliseconds [ms]), measured by placing the ROI on the interventricular septum without including the blood pool. b) T2 mapping sequence of a healthy individual (with a normal T2 time: 38 ms).

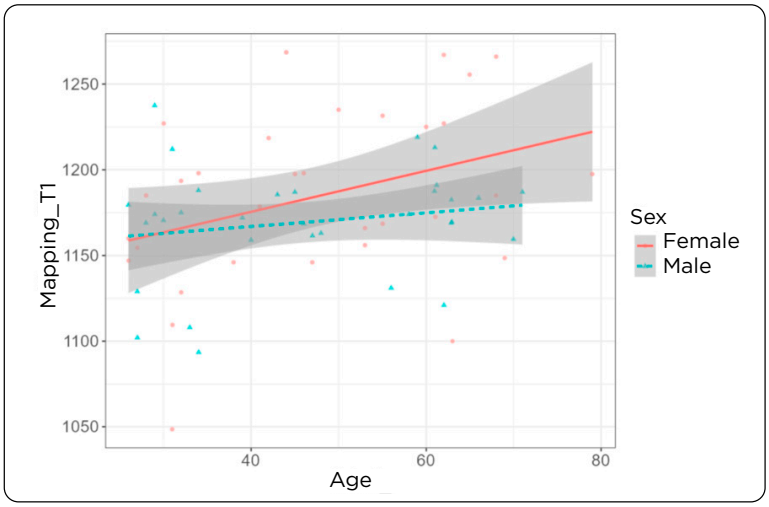


Figure 3. Native T1 map by sex and age. Native T1 map values are plotted against age, stratified by sex.

age groups, except for the ejection fraction, where this relationship is reversed (Tables 2 and 3). LV myocardial mass is lower in the 60–80-year-old age group.

To establish normal values for T1 maps by age and sex, validity was assessed by estimating interobserver agreement between two radiologists, as well as intra-observer agreement for each radiologist, using Bland-Altman plots (Figure 6). It was found that the average bias between the two radiologists in measuring the T1 maps did not show significant differences (2.32 ms; 95% CI: -1.71, 6.36; p=0.30), and more than 95% of the measurements fell within the limits of agreement (Figure 6a).

Table 2. Left ventricular function parameters by age and sex in healthy individuals from Medellín (2018–2021)*

Parameter	Sex / Age (years)					
	Men			Women		
	20-39	40-59	60-80	20-39	40-59	60-80
EDV (mL)	144.2 ± 26.85 [129.6; 158.8]	136.9 ± 17.89 [125.2; 148.6]	119.2 ± 18.16 [107.9; 130.4]	99.2 ± 16.99 [89.1; 109.2]	95.9 ± 9.09 [90.5; 101.2]	81.7 ± 14.56 [72.7; 90.7]
ESV (mL	46.1 ± 11.80 [39.7; 52.5]	41.6 ± 6.86 [37.2; 46.1]	38.2 ± 11.70 [31.0; 45.5]	29.4 ± 7.60 [24.9; 33.9]	23.8 ± 5.11 [20.8; 26.9]	21.1 ± 6.74 [16.9; 25.2]
BV/O (mL)	98.1 ± 17.40 [88.7; 107.6]	95.2 ± 12.97 [86.8; 103.7]	80.9 ± 9.93 [74.8; 87.1]	69.8 ± 12.33 [62.5; 77.1]	71.1 ± 8.11 [66.3; 75.9]	60.8 ± 12.13 [53.2; 68.3]
LVEF (%)	68.2 ± 4.08 [66.0; 70.4]	69.7 ± 3.00 [67.7; 71.6]	68.3 ± 5.56 [64.8; 71.7]	70.5 ± 5.39 [67.3; 73.7]	75.2 ± 4.24 [72.7; 77.7]	74.2 ± 6.79 [70.0; 78.4]
MM (g)	124.0 ± 21.38 [112.4; 135.6]	131.4 ± 15.75 [121.1; 141.7]	117.0 ± 19.19 [105.1; 128.8]	79.3 ± 14.38 [70.8; 87.8]	80.5 ± 7.73 [75.9; 85.1]	78.0 ± 13.92 [69.3; 86.6]
VEDIV (mL/m^2)	76.2 ± 9.83 [70.9; 81.6]	70.1 ± 9.55 [63.9; 76.4]	65.8 ± 11.15 [58.9; 72.7]	60.3 ± 6.57 [56.4; 64.2]	57.0 ± 5.00 [54.1; 60.0]	50.7 ± 5.37 [47.4; 54.0]
VESIV (mL/m^2)	24.3 ± 4.98 [21.6; 27.0]	21.4 ± 3.99 [18.8; 24.0]	21.3 ± 7.39 [16.7; 25.9]	17.8 ± 4.03 [15.4; 20.2]	14.2 ± 2.85 [12.5; 15.9]	13.1 ± 4.29 [10.4; 15.7]
BV/IO (mL/m^2)	52.2 ± 6.18 [48.8; 55.5]	48.7 ± 6.36 [44.6; 52.9]	44.6 ± 4.90 [41.5; 47.6]	42.5 ± 5.48 [39.2; 45.7]	42.9 ± 4.14 [40.4; 45.3]	37.5 ± 4.25 [34.9; 40.2]
MMX (g/m^2)	65.8 ± 9.35 [60.7; 70.9]	67.3 ± 7.95 [62.1; 72.5]	64.6 ± 10.60 [58.0; 71.2]	48.1 ± 4.87 [45.2; 51.0]	48.1 ± 5.21 [45.0; 51.2]	48.5 ± 5.93 [44.8; 52.1]

* Values represent the mean, standard deviation, and 95% confidence interval for the mean value. LV: left ventricle; RV: right ventricle; EDV: End-diastolic volume; ESV: End-systolic volume; BV/O: beat volume/output; LVEF %: left ventricular ejection fraction; MM: myocardial mass; VEDIV: indexed ventricular end-diastolic volume; VESIV: indexed ventricular end-systolic volume; BV/IO: indexed ventricular beat volume/output; MMX: indexed myocardial mass. Index: value adjusted according to the patient's body surface area.

Table 3. Right ventricular function parameters by age and sex in healthy individuals from Medellín (2018–2021)*

Parameter	Sex / Age (years)					
	Men			Women		
	20-39	40-59	60-80	20-39	40-59	60-80
BV/O (mL)	60.9 ± 14.43 [53.1; 68.7]	54.0 ± 12.49 [45.8; 62.1]	45.3 ± 8.12 [40.3; 50.3]	36.5 ± 7.65 [31.9; 41.0]	26.7 ± 6.69 [22.8; 30.7]	29.6 ± 9.10 [23.9; 35.2]
BV/O (mL)	102.0 ± 20.93 [90.6; 113.4]	99.4 ± 15.36 [89.4; 109.4]	81.9 ± 8.10 [76.8; 86.9]	67.2 ± 12.63 [59.7; 74.6]	69.2 ± 11.54 [62.4; 76.0]	57.6 ± 13.15 [49.5; 65.8]
LVEF (%)	62.7 ± 4.96 [60.0; 65.4]	64.9 ± 5.48 [61.3; 68.4]	64.6 ± 3.82 [62.2; 67.0]	64.7 ± 6.10 [61.1; 68.3]	72.3 ± 4.15 [69.9; 74.8]	66.1 ± 6.60 [62.0; 70.1]
VEDIV (mL/m^2)	87.1 ± 12.95 [80.1; 94.2]	78.4 ± 10.36 [71.6; 85.1]	70.3 ± 8.21 [65.3; 75.4]	63.1 ± 6.48 [59.3; 67.0]	57.0 ± 8.77 [51.8; 62.2]	53.9 ± 6.49 [49.9; 57.9]
VESIV (mL/m^2)	32.2 ± 6.84 [28.5; 35.9]	27.6 ± 6.00 [23.6; 31.5]	25.0 ± 4.27 [22.3; 27.6]	22.3 ± 4.44 [19.6; 24.9]	15.9 ± 3.87 [13.6; 18.2]	18.3 ± 4.52 [15.5; 21.1]
BV/IO (mL/m^2)	54.2 ± 9.52 [49.0; 59.3]	50.8 ± 7.23 [46.1; 55.5]	45.3 ± 5.26 [42.1; 48.6]	40.9 ± 5.47 [37.7; 44.1]	41.1 ± 5.82 [37.6; 44.5]	35.6 ± 5.04 [32.5; 38.8]

*Values represent the mean, standard deviation, and 95% confidence interval for the mean value. LV: left ventricle; RV: right ventricle; EDV: end-diastolic volume; ESV: end-systolic volume; BV/O: beat volume/output; LVEF %: left ventricular ejection fraction; MM: myocardial mass; VEDIV: indexed ventricular end-diastolic volume; VESIV: indexed ventricular end-systolic volume; BV/IO: indexed ventricular beat volume/output; MMX: indexed myocardial mass. Index: value adjusted according to the patient's body surface area.

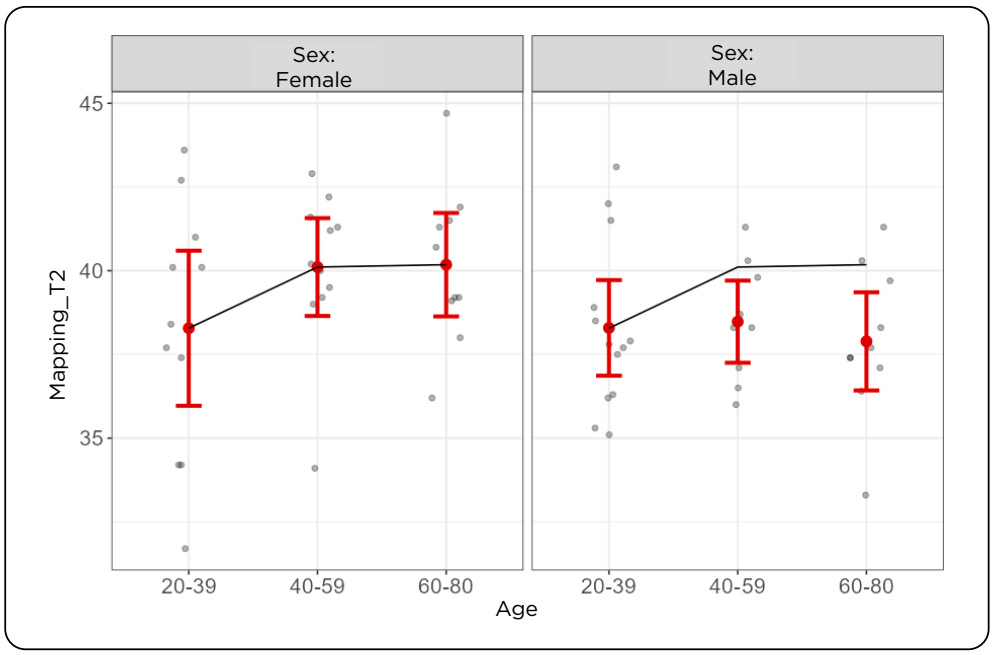


Figure 4. T2 maps by sex and age. The figure shows the mean T2 values with their 95% confidence intervals, broken down by age and sex.

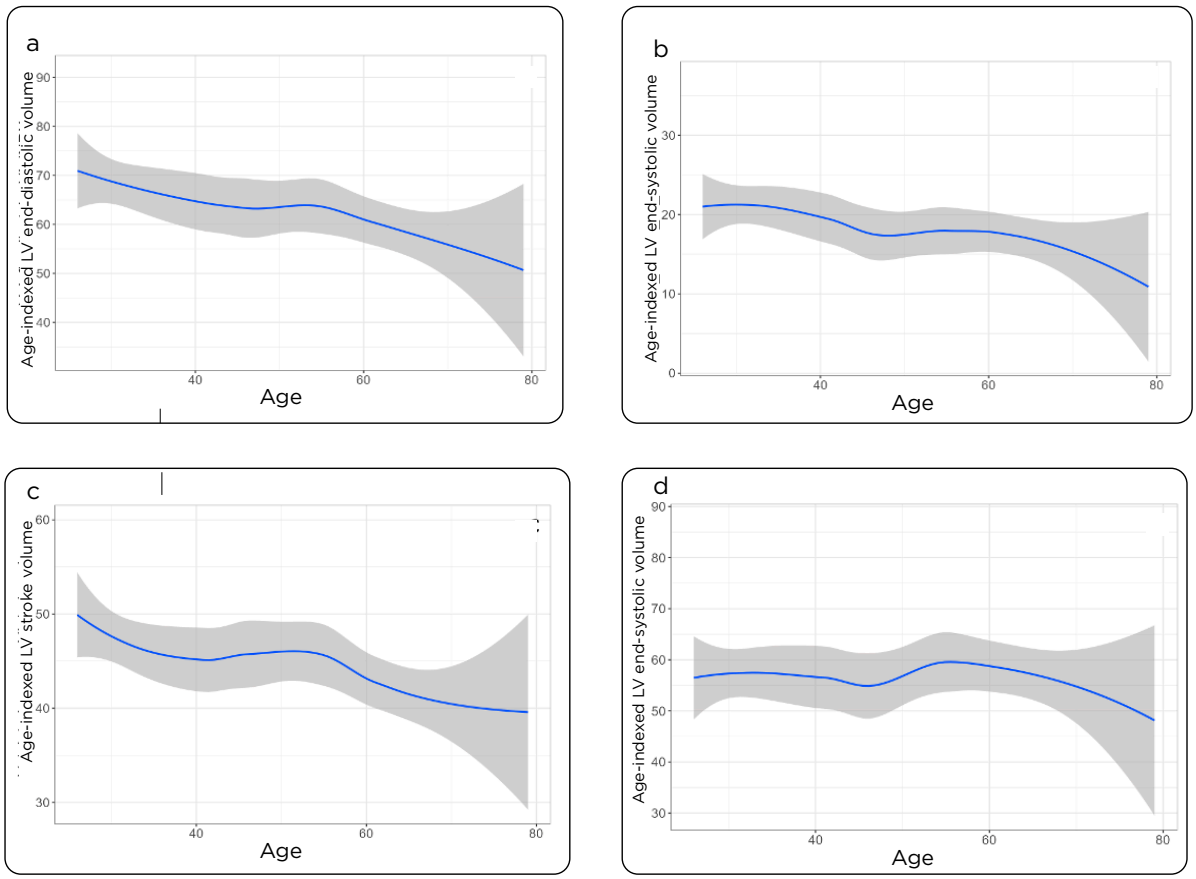


Figure 5. Age-indexed ventricular function parameters. Shows left ventricular (LV) function values and LV myocardial mass. a) Age-indexed LV end-diastolic volume. b) Age-indexed LV end-systolic volume. c) Age-indexed LV stroke volume. d) Age-indexed LV myocardial mass.

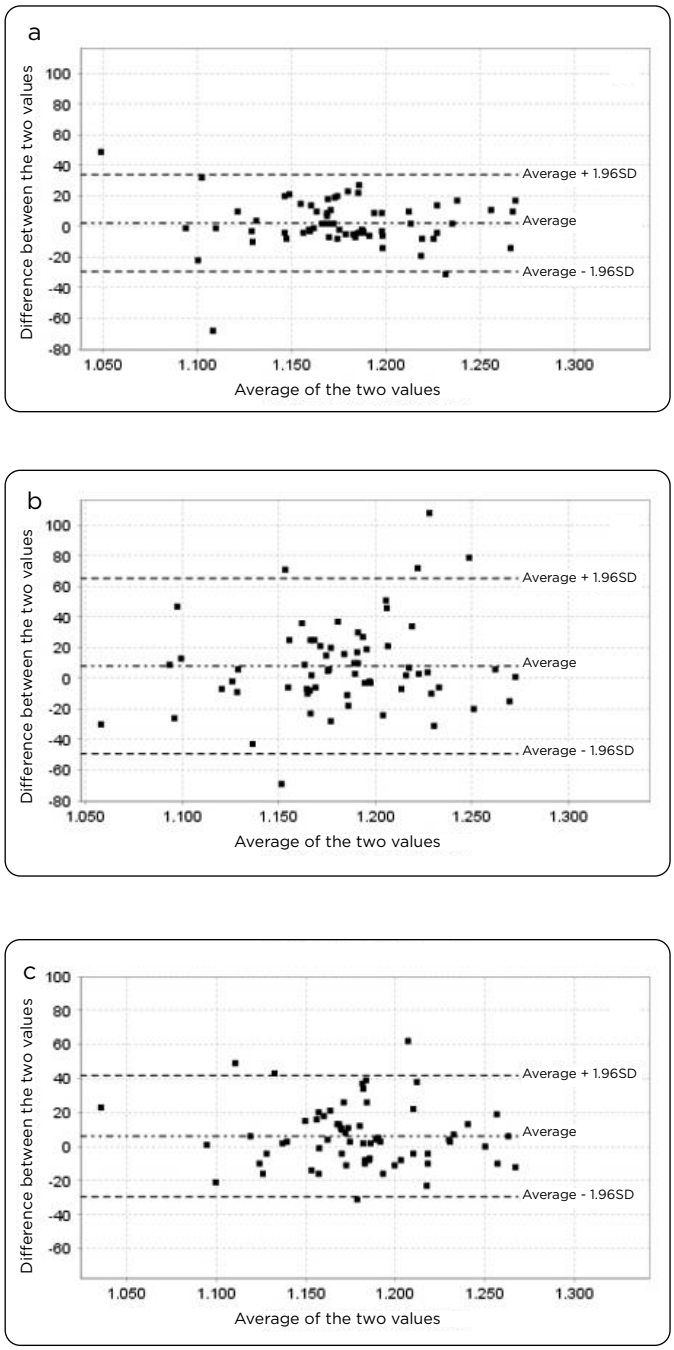


Figure 6. Inter- and intra-observer agreement in the interpretation of native T1 maps in healthy individuals from Medellín (2018–2021). Inter-observer precision is shown in panel a, and intra-observer precision for each radiologist is shown in panels b–c. SD: standard deviation.

Discussion

This is the first study in Colombia to analyze the normal values of native T1 and T2 maps and VF in healthy individuals using a 3T MRI scanner.

We found a mean native T1 value for the entire sample of healthy individuals of 1,177 ms (SD 43.19 and 95% CI 1,092–1,261). These values are similar to those reported in the literature for 3T MRI scanners. Gottbrecht et al. (14) conducted a meta-analysis aimed at understanding the degree of variability among studies reporting measurements of native T1 maps in healthy adults. Of 120 published articles (n = 5,541 patients), 62 used a 3T MRI scanner; of these, 28 were performed with Siemens 3T equipment. In the latter group, a pooled mean native T1 map value of 1.192 ms (95% CI 1.171–1.214) was found (14), similar to the results described here of a native T1 value of 1.177 ms (95% CI 1.166–1.187). On the other hand, Von Knobelsdorff-Brenkenhoff et al. (15) obtained normal native T1 map values on a 3T scanner (Magnetom Verio, Siemens) in 60 healthy individuals (30 men) in Germany, using a native T1 mapping sequence (Modified Look-Locker Inversion Recovery [MOLLI]), and found native T1 values of 1.158 ms (95% CI 1.074–1.250), which are slightly lower than the findings of this study. Roy et al. (16)—75 healthy individuals, 36 women—and Granitz et al. (1) —58 healthy individuals, 33 women—reported a mean native T1 value for the entire sample of 1,162 ms (SD 80) and 1,183 ms (SD 37.5), respectively, both using a 3T scanner; when compared with the results of this study, these values show no statistically significant difference (p = 0.106).

In this study, an analysis of the behavior of native T1 maps in relation to age and sex revealed that native T1 values increase with age in women, for whom this value is consistently higher than in men across all age groups; however, this difference was not statistically significant. These results are similar to those published by Roy et al., who reported native T1 map (MOLLI) values of 1,194 ms (SD 48) for women and 1,128 (SD 103) for men, with values consistently higher in women (16).

The normal absolute values for native T1 maps in this study are similar to those reported in previous studies conducted under similar conditions (3T scanner, MOLLI sequence, and Siemens brand) and, therefore, serve as a fundamental reference framework for interpreting studies on myocardial tissue characterization. However, as described in recent publications by Razzaq et al. (17) and Kranzusch et al. (18), reporting T1 map results in absolute values does not allow for a direct comparison of results from examinations performed at institutions with equipment of different tesla strengths and brands, due to variability resulting from their hardware and software. These authors recommend using z-scores (standard deviations) to report the results of native T1 and myocardial T2 maps, in order to eliminate variation in absolute quantitative mapping results across different MRI systems and field strengths, provided that sequences from the MOLLI family are used in the studies being compared. Specifically, Razzaq et al. (17) documented in their study significant improvements in agreement between scanners of different brands and tesla ratings regarding native T1 and T2 map values when comparing z-score values rather than absolute values, with good agreement among the resulting T1 and T2 z-score values. Furthermore, no significant variability was observed among the scanner-specific paired samples for the z-score mapping data, whereas there were significant differences in the absolute T1 and T2 values between scanners. If, in the present study, the absolute and z-score values of the native T1 maps (mean: 1.177 ms, SD 43.19 / 2SD 86.38, normal T1 values: 1.090–1.263 ms) and T2 maps (mean: 38.9 ms, SD 2.57 / 2SD 5.14, normal T2 values: 33.76–44.04 ms), they are similar to those obtained by Razzaq et al. (17) using the same scanner and sequence as those used in the present study (Siemens Skyra 3-T and MOLLI sequence), T1 maps (mean: 1,210 ms SD 31 / 2SD 62, normal T1 values: 1,148–1,272 ms) and T2 maps (mean: 41 ms SD

2.5 / 2SD 5, normal T2 values: 36–46 ms). These results support the notion of a positive effect when expressing T1 and T2 map results as z-scores in clinical settings.

This study found that native T1 maps are a valid and accurate tool with adequate inter- and intra-observer agreement. Furthermore, intra-observer agreement for each radiologist indicated that the average bias was zero (p=0.2) in both cases, and there was no proportional bias, even though 8% of the data points fell outside the agreement limits for Radiologist 1. These results indicate that the interpretation of T1 mapping is operator-independent. These findings are comparable to those reported in the study by Kai Lin et al. (19), who demonstrated good reproducibility. Furthermore, Aus dem Siepen et al. found T1 mapping values that were stable over time in healthy patients, with baseline T1 maps of 1,017 ± 24 ms versus follow-up values of 1,015 ± 21 ms (p = 0.6) (20).

As expected, differences related to sex and age were observed in cardiac volumes and left ventricular mass. Higher ventricular volumes and left ventricular mass were found in men, which is consistent with other studies that have established reference values in healthy populations within a similar age range. Granitz et al. (1) analyzed 60 healthy volunteers (mean age 40.1 years ± 13.7, 33 women) using 3-T and 1.5-T MRI scanners and found that the left ventricular myocardial mass index (58.6 ± 5.9 g/m² in women and 72.5 ± 9.6 g/m² in men), left ventricular end-diastolic volume (123.0 mL ± 23.2 in women) and systolic volumes (43.2 mL ± 13.6, women) were lower in women, unlike left ventricular ejection fraction (LVEF), which was lower in men (60.0% ± 6.6 vs. 65.6% ± 5.8; p = 0.001). Alfakih et al. (21) evaluated 60 healthy individuals (30 men) using a 1.5-T MRI scanner (Philips Intera CV MRI system) and found that the EDV index values for the left ventricle (men = 82.3 mL/m² ± 14.7, women = 77.7 mL/m² ± 10.8) and the EDV index for the right ventricle (men = 86.2 mL/m² ± 14.1, women = 75.2 mL/m² ± 13.8) were higher in men, while the ejection fraction was higher in women (men = 65.5% ± 4.1, women = 67.1% ± 4.6). Other studies in English and Belgian populations reported findings with similar trends (16, 22). Maceira et al. studied 120 healthy patients aged 20 to 79 years (60 women) whose left ventricular ejection fraction was measured by CMR using a 1.5-T scanner. As in the present study (Figure 5), Maceira et al. (22) observed that ventricular volume values and left ventricular mass are influenced by age, with a tendency toward a progressive decrease in EF values as age advances. In the study documented here, the ejection fraction in the female population is higher than that found by Maceira et al., and the group showing the greatest difference was that of women aged 40–59 (22). These results are also consistent with a recent international study by Raisi-Estabragh et al. (23), which included 9,088 healthy individuals and found that ventricular cavity volumes were larger in men than in women, even after adjustment for body surface area, with a downward trend in ventricular volumes with advancing age and a corresponding reduction in measures of ventricular function.

Table 4. Comparison of absolute and indexed right and left ventricular volumes, ejection fraction, and left ventricular mass between the Medellín cohort and the cohorts from the studies by Kael-Boehm et al. (24) and Macedo et al. (25) in women and men

Women			
Parameter	**Medellín. 2024 (*n*: 32/ Medellín/20-80 years)**	**Kael-Boehm. 2015. meta-analysis (*n*: 105/Europe/20-80 years) (24)**	**Macedo. Brazil. 2013 (*n*: 53/3 centers in Brazil/ages 20-80) (25)**
LV EDV mL	92.6 (61.7-123.5) 2DE 30.9	132 (86-178) 2DE 46	114.4 (62.4-166.4) 2DE 52
LV ESV mL	24.9 (10.4-39.4) 2DE 14.5	44 (22-66) 2DE 22	40.1 (5.1-75.1) 2DE 35
LV BV mL	67.4 (44.2-90.5) 2DE 23.16	87 (57-117) 2DE 30	
LV mass g	79.3 (55.3-103.2) 2DE 23.94	98 (56-140) 2DE 42	74.8 (34.6-115) 2DE 40.2
LVEF %	73.3 (61.8-84.7) 2DE 11.48	67 (57-77) 2DE 10	66.1 (53.1-79.1) 2DE 13
LV EDIV mL/m²	56.2 (42.5-69.8) 2DE 13.62	76 (56-96) 2DE 20	68.5 (34.6-102.1) 2DE 33.6
LV ESIV mL/m²	15.1 (6.7-23.4) 2DE 8.36	24 (14-34) 2DE 10	24 (1.4-46.6) 2DE 22.6
LV BV mL/m²	41.1 (30.8-51.3) 2DE 10.26	52 (38-66) 2DE 14	
LV Mass g/m²	48.2 (37.8-58.5) 2DE 10.32	61 (41-81) 2DE 20	44.6 (21.2-68) 2DE 23.4
RV EDV mL	95.9 (60.0-131.7) 2DE 35.84	139 (77-201) 2DE 62	115 (63-167) 2DE 52
RV FFS mL	31.0 (13.6-48.3) 2DE 17.32	54 (24-84) 2DE 30	45.4 (16.8-74) 2DE 28.6
RV BV mL	64.9 (38.8-91.0) 2DE 26.1	84 (48-120) 2DE 36	
RVEF	67.8 (54.8-80.7) 2DE 12.94	61 (51-71) 2DE 10	61 (45.4-76.6) 2DE 15.6
RV EDEF mL/m²	58.1 (41.8-74.3) 2DE 16.22	80 (48-112) 2DE 32	68.6 (38.2-99) 2DE 30.4
RV ESIV mL/m²	18.8 (8.9-28.6) 2DE 9.88	32 (12-52) 2DE 20	27.1 (10.1-44.1) 2DE 17
RV BVI mL/m²	39.3 (27.5-51.0) 2DE 11.72	53 (35-71) 2DE 18	

Men			
Parameter	Medellín. 2024 (*n*: 32/ Medellín/20-80 years)	Kael-Boehm. 2015. meta-analysis (*n*: 105/ Europe/20-80 years) (24)	Macedo. Brazil. 2013 (*n*: 53/3 centers in Brazil/ages 20-80) (25)
LV EDV mL	134.4 (86.4-182.3) 2DE 47.94	160 (106-214) 2DE 54	142 (98.6-185.4) 2DE 43.4
LV ESV mL	42.4 (20.7-64.0) 2DE 21.66	54 (26-82) 2DE 28	50.1 (21.9-78.3) 2DE 28.2
LV IV mL	91.9 (60.5.2-123.3) 2DE 31.4	108 (72-144) 2DE 36	
LV mass g	123.9 (84.9-162.88) 2DE 38.98	134 (92-176) 2DE 42	115.2 (63.2-167.2) 2DE 52
LVEF %	68.6 (60.0-77.1) 2DE 8.52	67 (57-77) 2DE 10	64.9 (52.7-77.1) 2DE 12.2
LV EDIV mL/m^2	71.3 (49.6-92.9) 2DE 21.66	81 (57-105) 2DE 24	74.2 (48-100.4) 2DE 26.2
LV ESIV mL/m^2	22.5 (11.22-33.7) 2DE 11.28	26 (14-38) 2DE 12	26.3 (11.7-40.9) 2DE 14.6
LV BVI mL/m^2	48.8 (35.7-61.8) 2DE 13.06	54 (42-66) 2DE 12	
LV mass g/m^2	65.9 (47.5-84.2) 2DE 18.32	67 (49-85) 2DE 18	59.8 (36.4-83.2) 2DE 23.4
RV EDV mL	149.8 (91.9-207.6) 2DE 57.82	184 (118-250) 2DE 66	149 (81.4-216.6) 2DE 67.6
RV ESV mL	54.1 (26.9-81.2) 2DE 27.16	79 (41-117) 2DE 38	64.1 (25.5-102.7) 2DE 38.6
RV BV mL	95.0 (58.6-131.4) 2DE 36.4	106 (68--144) 2DE 38	
RVEF %	63.9 (54.4-73.38) 2DE 9.48	62 (52-72) 2DE 10	57.1 (42.9-71.3) 2DE 14.2
RV EDIV diastolic volume mL/m^2	79.4 (53.7-105.0) 2DE 25.62	91 (61-121) 2DE 30	77 (44.2-109.8) 2DE 32.8
RV ESIV mL/m^2	28.6 (15.5-41.6) 2DE 13.08	39 (19-59) 2DE 20	33.4 (15.4-51.4) 2DE 18
RV BVI mL/m^2	50.5 (33.6-67.3) 2DE 16.82	57 (41-73) 2DE 16	

EDV: end-diastolic volume; ESV: end-systolic volume; BV: beat volume; LVEF: left ventricular ejection fraction; RVEF: right ventricular ejection fraction.

A key finding of this study is that the absolute and indexed values of ventricular volumes in the cohort of healthy individuals are lower than those reported in previous studies, as shown in Table 4, which compares normal values with two studies: a literature review by Kael-Boehm et al. (24) of studies conducted in a European Caucasian population and another by Macedo et al. (25) in a Brazilian population. These two studies were selected because, in those studies—as in the present one—image post-processing was used in which the papillary muscles are included in the left ventricular mass rather than in the ventricular volume. As described in a 2021 meta-analysis by Raisi-Estabragh et al. (26), the main potential sources of variability in normal values across different publications on the subject are: 1) characteristics of the study population (age, sex, ethnicity); 2) image analysis (post-processing software brand and version, segmentation method, and inclusion or exclusion of the papillary muscles from the ventricular myocardial mass); 3) CMR protocol; and 4) characteristics of the scanner used (tesla strength, brand, etc.); the first two are the primary sources of variability. After analyzing all the factors described, it is believed that the most likely cause of the difference in ventricular volumes may be differences in the racial characteristics of the populations studied. Except for the present study and that of Macedo et al. (25) in Brazil, there are no known published studies on normal reference values for CMR in Latin American populations. Most publications on this subject are based on studies of European and North American Caucasian populations. Raisi-Estabragh et al. (23), in a study published in 2024 that included the largest number of healthy individuals (9,088), sought to minimize racial biases by including populations from various countries and ethnic groups (Caucasians, people of African descent, Chinese, South Asians, and others); however, the Latin American population was not included. Natori et al. (27) analyzed 800 patients (400 men) aged 45 to 84 and found that, for men, there were no significant differences in most VI parameters among white Americans, African Americans, and Hispanics. However, left ventricular end-diastolic volume (LVEDV), left ventricular end-systolic volume (LVESV), and myocardial mass differed between Asians and other ethnic groups ($p < 0.05$). In this study, the representation of Hispanics was very limited, and only Hispanics residing in the United States were included. As shown in Table 4, the ventricular volume values in the present study are lower than those found in the study by Macedo et al. in Brazil; however, it is important to consider that the proportions of different ethnic groups (mixed-race, African descent, white, indigenous, etc.) differ greatly between Colombia and Brazil and may explain the differences observed.

Limitations

This study included only a healthy population from Medellín, so its findings cannot be generalized to Colombia or the Latin American population. Furthermore, a limited number of healthy individuals were included; although this was sufficient to establish normal reference values for native T1 and T2 maps, it is insufficient to define reference values for ventricular function parameters for the Colombian population.

Conclusion

This study reports, for the first time in Colombia, normal values for native T1 maps (MOLLI sequence), T2 maps, and ventricular function in healthy individuals from Medellín using a 3-T MRI scanner. The normal values for native T1 and T2 maps and ventricular function varied with age and sex in a manner similar to that reported in the literature. Native T1 maps were found to be a valid and accurate tool with adequate inter- and intra-observer agreement. A relevant finding

is that the absolute and indexed values of ventricular volumes in the cohort of healthy individuals in this study are lower than those reported in previous studies, which have typically been conducted in European and American Caucasian populations; it would be highly valuable to conduct a multicenter study in Colombia and Latin America to define their own normal ranges in order to improve the interpretation of MRA studies in this population.

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