http://dx.doi.org/10.4250/jcu.2015.23.3.158
pISSN 1975-4612/ eISSN 2005-9655

www.kse-jcu.org

ORIGINAL ARTICLE J CARDIOVASC ULTRASOUND 2015;23(3):158-172

NORMAL ECHOCARDIOGRAPHIC MEASUREMENTS IN A KOREAN POPULATION STUDY: PART I. CARDIAC CHAMBER AND GREAT ARTERY EVALUATION

JIN-OH CHOI, MD[1], MI-SEUNG SHIN, MD[2], MI-JEONG KIM, MD[3], HAE OK JUNG, MD[4], JEONG RANG PARK, MD[5], IL SUK SOHN, MD[6], HYUNGSEOP KIM, MD[7], SEONG-MI PARK, MD[8], NAM JIN YOO, MD[9], JUNG HYUN CHOI, MD[10], HYUNG-KWAN KIM, MD[11], GOO-YEONG CHO, MD[12], MI-RAE LEE, MD[13], JIN-SUN PARK, MD[14], CHI YOUNG SHIM, MD[15], DAE-HEE KIM, MD[16], DAE-HEE SHIN, MD[17]*, GIL JA SHIN, MD[18], SUNG HEE SHIN, MD[19], KYE HUN KIM, MD[20], JAE-HYEONG PARK, MD[21], SANG YEUB LEE, MD[22], WOO-SHIK KIM, MD[23], AND SEUNG WOO PARK, MD[1]

[1]DIVISION OF CARDIOLOGY, DEPARTMENT OF MEDICINE, SAMSUNG MEDICAL CENTER, SUNGKYUNKWAN UNIVERSITY SCHOOL OF MEDICINE, SEOUL, KOREA; [2]DIVISION OF CARDIOLOGY, DEPARTMENT OF INTERNAL MEDICINE, GIL HOSPITAL, GACHON UNIVERSITY OF MEDICINE AND SCIENCE, INCHEON, KOREA; [3]DIVISION OF CARDIOLOGY, DEPARTMENT OF INTERNAL MEDICINE, INCHEON ST. MARY'S HOSPITAL, COLLEGE OF MEDICINE, THE CATHOLIC UNIVERSITY OF KOREA, INCHEON, KOREA; [4]DEPARTMENT OF INTERNAL MEDICINE, SEOUL ST. MARY'S HOSPITAL, COLLEGE OF MEDICINE, THE CATHOLIC UNIVERSITY OF KOREA, SEOUL, KOREA; [5]DIVISION OF CARDIOLOGY, DEPARTMENT OF INTERNAL MEDICINE, GYEONGSANG NATIONAL UNIVERSITY HOSPITAL, GYEONGSANG NATIONAL UNIVERSITY SCHOOL OF MEDICINE, JINJU, KOREA; [6]DEPARTMENT OF CARDIOLOGY, KYUNG HEE UNIVERSITY SCHOOL OF MEDICINE, KYUNG HEE UNIVERSITY HOSPITAL AT GANGDONG, SEOUL, KOREA; [7]DIVISION OF CARDIOLOGY, KEIMYUNG UNIVERSITY DONGSAN MEDICAL CENTER, DAEGU, KOREA; [8]DIVISION OF CARDIOLOGY, DEPARTMENT OF INTERNAL MEDICINE, KOREA UNIVERSITY COLLEGE OF MEDICINE, SEOUL, KOREA; [9]DEPARTMENT OF INTERNAL MEDICINE, WONKWANG UNIVERSITY HOSPITAL, INSTITUTE OF WONKWANG MEDICAL SCIENCE, IKSAN, KOREA; [10]DEPARTMENT OF INTERNAL MEDICINE, DIVISION OF CARDIOLOGY, PUSAN NATIONAL UNIVERSITY SCHOOL OF MEDICINE, BUSAN, KOREA; [11]DIVISION OF CARDIOLOGY, DEPARTMENT OF INTERNAL MEDICINE, CARDIOVASCULAR CENTER, SEOUL NATIONAL UNIVERSITY COLLEGE OF MEDICINE, SEOUL, KOREA; [12]DIVISION OF CARDIOLOGY, DEPARTMENT OF INTERNAL MEDICINE, SEOUL NATIONAL UNIVERSITY AND CARDIOVASCULAR CENTER, SEOUL NATIONAL UNIVERSITY BUNDANG HOSPITAL, SEONGNAM, KOREA; [13]DIVISION OF CARDIOLOGY, DEPARTMENT OF MEDICINE, SAMSUNG CHANGWON HOSPITAL, SUNGKYUNKWAN UNIVERSITY SCHOOL OF MEDICINE, CHANGWON, KOREA; [14]DEPARTMENT OF CARDIOLOGY, AJOU UNIVERSITY SCHOOL OF MEDICINE, SUWON, KOREA; [15]DIVISION OF CARDIOLOGY, SEVERANCE CARDIOVASCULAR HOSPITAL, YONSEI UNIVERSITY COLLEGE OF MEDICINE, SEOUL, KOREA; [16]DEPARTMENT OF CARDIOLOGY, ASAN MEDICAL CENTER, UNIVERSITY OF ULSAN COLLEGE OF MEDICINE, SEOUL, KOREA; [17]DIVISION OF CARDIOLOGY, GANGNEUNG ASAN HOSPITAL, UNIVERSITY OF ULSAN COLLEGE OF MEDICINE, GANGNEUNG, KOREA; [18]DIVISION OF CARDIOLOGY, DEPARTMENT OF INTERNAL MEDICINE, EWHA WOMANS UNIVERSITY SCHOOL OF MEDICINE, SEOUL, KOREA; [19]DIVISION OF CARDIOLOGY, DEPARTMENT OF INTERNAL MEDICINE, INHA UNIVERSITY COLLEGE OF MEDICINE, INCHEON, KOREA; [20]DEPARTMENT OF CARDIOLOGY, CHONNAM NATIONAL UNIVERSITY HOSPITAL, GWANGJU, KOREA; [21]DIVISION OF CARDIOLOGY, DEPARTMENT OF INTERNAL MEDICINE, CHUNGNAM NATIONAL UNIVERSITY HOSPITAL, CHUNGNAM NATIONAL UNIVERSITY SCHOOL OF MEDICINE, DAEJEON, KOREA; [22]DIVISION OF CARDIOLOGY, DEPARTMENT OF INTERNAL MEDICINE, CHUNGBUK NATIONAL UNIVERSITY SCHOOL OF MEDICINE, CHEONGJU, KOREA; [23]CARDIOVASCULAR CENTER, DEPARTMENT OF INTERNAL MEDICINE, KYUNG HEE UNIVERSITY MEDICAL CENTER, SEOUL, KOREA

BACKGROUND: Measurement of the cardiac chamber is essential, and current guidelines recommend measuring and reporting values for both sides of the cardiac chamber during echocardiographic evaluation. Normal echocardiographic reference values have been suggested previously, but detailed information about right-sided chambers and values according to gender was not included.
METHODS: This is a prospective multicenter (23 centers) study evaluating normal Korean adult subjects using comprehensive echocardiography. We included normal adult subjects (age; 20–79 years old) who had no significant cardiac disorders or illnesses,

• *Dae-Hee Shin currently works in the Incheon St. Mary's Hospital, College of Medicine, The Catholic University of Korea, Incheon, Korea.
• Received: June 25, 2015 • Revised: August 26, 2015 • Accepted: August 26, 2015
• Address for Correspondence: Seung Woo Park, Division of Cardiology, Department of Medicine, Heart Vascular Stroke Center, Samsung Medical Center, Sungkyunkwan University School of Medicine, 81 Irwon-ro, Gangnam-gu, Seoul 06351, Korea
Tel: +82-2-3410-3419, Fax: +82-2-3410-3849, E-mail: parksmc@gmail.com

such as hypertension or diabetes, which could affect cardiac structure and function. We measured the cardiac chamber including both right and left ventricles as well as atria according to current echocardiography guidelines and compared values according to gender and age groups.

Results: A total of 1003 subjects were evaluated and the mean age was 48 ± 16 years. Left ventricular (LV) dimensions increased, but LV volume decreased in older subjects. Right ventricular (RV) area decreased in women and older subjects, and the RV long-axis dimension showed a similar trend. Left atrial (LA) volume increased in men but there were no differences in LA volume index between men and women. The dimension of great arteries increased in men and older subjects.

Conclusion: Since there were considerable differences between men and women and in the different age groups, and the trends differed significantly between different echo variables, normal echocardiographic cutoff values should be differentially applied based on age and gender.

KEY WORDS: Echocardiography · Normal population · Reference value.

Introduction

Echocardiography has been referred to as the single most important study in patients with cardiovascular disorders, as it provides comprehensive information about cardiac function and hemodynamic parameters.[1] Recently, there were improvements in echocardiographic techniques including higher resolution with harmonic imaging and better information about cardiac structure, function, and prognostic values became available.[2][3] Current echocardiographic guidelines recommend that physicians measure and provide detailed information on both right- and left-sided cardiac chambers when evaluating patients.[4][5] Although there are reports on normal echocardiographic data, reference values for cardiac structure and function may be influenced by physical characteristics of the target population.[6-8] Therefore, reference values from one population cannot be extrapolated to other populations.

Previously, normal echocardiographic reference values in Korea were defined in a multicenter prospective study.[9] Although reference values were provided according to age group, gender differences were not investigated. Furthermore, detailed information about right-sided cardiac chambers and tissue Doppler imaging for diastolic function was not provided.

In this regard, we performed the Normal echOcaRdiographic Measurements in KoreAn popuLation (NORMAL) study, which was a multicenter prospective study performed from January 2011 to March 2014 to establish normal reference values for echocardiography in a Korean population. We sought to provide two-dimensional (2D) and M-mode measurement values (Doppler and tissue Doppler variables will be reported in part II of the NORMAL study) for normal echocardiography, including both left and right-sided cardiac chambers and great arteries according to age and gender groups.

Methods

Study populations

The NORMAL study was a prospective nationwide multicenter (23 centers) study evaluating normal Korean adult subjects using comprehensive echocardiography. We included normal adult subjects (age; 20–79 years old) who had no significant cardiac disorders or clinical illnesses that might affect cardiac structure and function, such as hypertension and diabetes. We also excluded subjects if a structural or functional abnormality on the cardiac valve or cardiac chamber was evident during echocardiographic examination. All study patients agreed to provide their information for research purposes and the study protocol was approved by the Institutional Review Board of each institute. Written informed consent was waived.

Echocardiography

Echocardiographic images were acquired and measured at each institute. They were stored in DICOM format and electronically transferred to the Echocardiographic Core laboratory (ECL) in Samsung Medical Center. Final measurements and analysis were performed in ECL with a dedicated software package (EchoPAC, GE Medical Systems, Horten, Norway).

Echocardiographic measurements were performed according to the American Society of Echocardiography guidelines.[5][10][11] All echo variables were measured in three cardiac cycles and average values were taken. Briefly, M-mode echocardiography was performed on parasternal views. Left ventricular (LV) end-diastolic dimension (LVEDD), interventricular septal wall thickness (IVST), LV posterior wall thickness (LVPWT), and the dimension of the aortic root were measured at end-diastole. The LV end-systolic dimension (LVESD) and left atrial (LA) anteroposterior dimension were measured at end-systole. LVEDD and LVESD were indexed to body surface area (BSA). LV ejection fraction (LVEF) was calculated using linear method using following formula; $LVEF (\%) = (LVEDD^2 - LVESD^2) / LVEDD^2 \times 100 (\%)$. An M-mode echocardiogram of the right ventricular (RV) free wall was also obtained on a subcostal view to measure RV end-diastolic free wall thickness. Tricuspid annular plane systolic excursion (TAPSE) was measured by placing the M-mode cursor line along the movement of the tricuspid annulus during an M-mode echocardiogram on an apical 4-chamber view.

LV dimensions (LVEDD and LVESD) and LV wall thickness (IVST and LVPWT) were also measured on 2D images using parasternal views. LV volumes and ejection fraction were measured using the biplane Simpson's method on apical 4-chamber and 2-chamber views. LV end-diastolic and end-systolic volume (LVEDV and LVESV) were measured and indexed to BSA. The LV long-axis dimension was also measured, and the sphericity index was calculated as the LV short-axis dimension (LVEDD) divided by the LV long-axis dimension. LV mass (LVM) was calculated using a linear method using both measurement values from M-mode and 2D images as follows: LVM (gm) = 0.8 × {1.04 × [(IVST + LVEDD + LVPWT)^3 - LVEDD^3]} + 0.6 (gm). LVM was also indexed to BSA. Relative wall thickness (RWT) was calculated as follows: RWT = 2 × LVPWT / LVEDD.

The basal and mid RV short-axis dimension and the RV long-axis dimension were measured in the RV-focused apical 4-chamber view at end-diastole (Fig. 1A and B). RV end-diastolic and end-systolic area (RVEDA and RVESA) were also measured in the RV-focused apical 4-chamber view (Fig. 1C and D), and RV fractional area change (RVFAC) was calculated as follows: RVFAC (%) = (RVEDA - RVESA) / RVEDA × 100 (%). Proximal and distal RV outflow tract dimensions were measured on the parasternal short-axis view.

The LA anteroposterior dimension was measured on parasternal views, and transverse and longitudinal dimensions were measured on an apical 4-chamber view at end-systole. LA volume was calculated using both the ellipsoid method and the area-length method and indexed to BSA. Right atrial (RA) transverse and longitudinal dimensions as well as RA area were measured on an apical 4-chamber view.

Images for aortic root measurement were acquired on a zoomed parasternal long-axis view and dimensions of the aortic annulus, the sinus of Valsalva, the sinotubular junction, and the proximal ascending aorta were measured at end-diastole using leading edge to leading edge techniques. The main pulmonary artery was measured at end-diastole on a parasternal short-axis view.

STATISTICAL ANALYSIS

Data are expressed as mean ± standard deviation and 95% confidence intervals (CIs) are provided for continuous variables. The independent t-test was used to compare mean values between men and women, and a one-way analysis of variance test was performed to evaluate whether mean values differed based on age groups. Pearson's method was used to evaluate significant correlations among clinical and measurement variables. To evaluate the intra- and interobserver variability, 50 cases were randomly selected and intraclass correlation coefficients (ICC) were calculated. One researcher repeated measurements at least 2 weeks after the first measurements for intraobserver

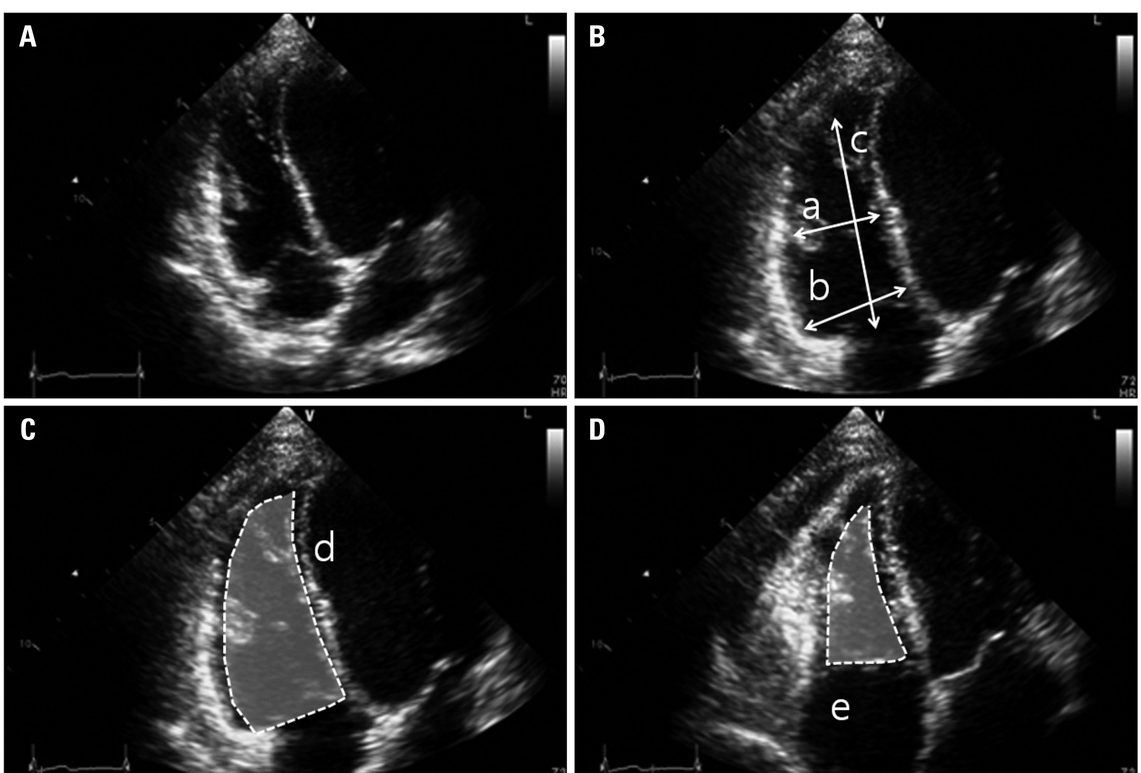

Fig. 1. Measurement of right ventricular (RV) dimension and RV fractional area change in focused RV view. After obtaining RV focused view (A), mid (a), basal (b), and longitudinal RV dimensions (c) are measured at end-diastolic period (B). In the same view, RV end-diastolic area (d) and RV end-systolic area (e) are measured and RV fractional area change are calculated as (d - e) / d × 100% (C and D).

variability testing, and another researcher who was blinded to the first measurement value performed measurements to evaluate interobserver variability. p values < 0.05 were considered statistically significant. All statistical analyses were performed using SPSS Statistics version 21 (SPSS Inc., Chicago, IL, USA).

Results

Clinical characteristics of study patients

A total of 1003 normal subjects from 23 centers were evaluated in the current study. Demographic and clinical data are provided in Table 1 according to gender and in Supplementary Table 1 according to gender and age. The mean age was 48 ± 16 years in both men and women. Physical findings such as weight, height, BSA, and body mass index were significantly higher in men compared to women ($p < 0.0001$ for all variables). Similarly, systolic and diastolic blood pressures in men were slightly higher than those in women, but all values were within normal limits. There was no significant difference in heart rate between men and women. BSA decreased with age in both men and women. While older men had a lower body mass index than younger men, body mass index was increased in older women compared to younger women. Systolic blood pressure increased with age in both men and women, and this trend was stronger in women.

M-mode echocardiographic data

M-mode variables according to gender groups and according to age and gender groups are presented in Table 2 and Supplementary Table 2, respectively. There were significant differences in M-mode variables between men and women, except in TAPSE. LVEDD was not significantly different according to age in men, though it increased with age in women. However, indexed LVEDD and LVESD were greater in women compared to men and indexed LVEDD was increased with age in both men and women. Likewise, indexed LVESD increased with age in women but no significant differences were noted according

Table 1. Demographic and clinical findings of study patients according to gender

Variables	Men		Women		Total		p
	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI	
Number	487		516		1003		
Age (year)	48 ± 16	17–79	48 ± 16	18–79	48 ± 16	18–79	0.9659
Weight (kg)	69 ± 9	50–87	56 ± 7	41–70	62 ± 11	41–83	< 0.0001
Height (cm)	170 ± 7	157–184	158 ± 6	147–169	164 ± 9	147–181	< 0.0001
BSA (m^2)	1.79 ± 0.14	1.51–2.07	1.55 ± 0.11	1.34–1.77	1.67 ± 0.17	1.33–2.01	< 0.0001
BMI (kg/m^2)	23.7 ± 2.6	18.6–28.7	22.3 ± 2.8	16.9–27.8	23.0 ± 2.8	17.6–28.4	< 0.0001
SBP (mm Hg)	123 ± 12	99–146	118 ± 13	93–142	120 ± 13	95–145	< 0.0001
DBP (mm Hg)	75 ± 9	58–93	72 ± 10	53–91	73 ± 9	55–92	< 0.0001
Heart rate (bpm)	68 ± 10	49–87	69 ± 9	51–86	68 ± 9	50–86	0.0635

BSA: body surface area, BMI: body mass index, SBP: systolic blood pressure, DBP: diastolic blood pressure, SD: standard deviation, CI: confidence interval

Table 2. M-mode variables according to gender

Variables	Men		Women		Total		p
	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI	
LVEDD (mm)	50.5 ± 3.3	44.0–57.0	47.4 ± 3.3	41.0–53.9	48.9 ± 3.6	41.8–56.1	< 0.0001
LVESD (mm)	30.9 ± 2.9	25.3–36.5	28.7 ± 2.8	23.3–34.1	29.8 ± 3	23.9–35.7	< 0.0001
LVEDD index (mm/m^2)	28.3 ± 2.2	23.9–32.7	30.6 ± 2.5	25.7–35.5	29.5 ± 2.6	24.3–34.6	< 0.0001
LVESD index (mm/m^2)	17.3 ± 1.7	13.9–20.7	18.5 ± 1.9	14.8–22.2	17.9 ± 1.9	14.2–21.6	< 0.0001
LVEF (%) by linear method	62.4 ± 4.6	53.3–71.5	63.3 ± 4.3	54.8–71.8	62.9 ± 4.5	54.1–71.7	0.0023
IVSWT (mm)	8.2 ± 1.1	6.3–10.2	7.4 ± 0.9	5.7–9.1	7.8 ± 1	5.9–9.8	< 0.0001
LVPWT (mm)	8.2 ± 0.9	6.5–9.9	7.4 ± 0.8	5.8–9.0	7.8 ± 0.9	6–9.6	< 0.0001
LA AP diameter (mm)	36.1 ± 3.9	28.5–43.6	33.6 ± 4.0	25.7–41.5	34.8 ± 4.1	26.7–42.9	< 0.0001
Aortic root diameter (mm)	32.2 ± 3.0	26.4–38.1	28.7 ± 2.8	23.2–34.3	30.4 ± 3.4	23.8–37.1	< 0.0001
RV end-diastolic free wall thickness (mm)	4.2 ± 0.9	2.5–6.0	4.0 ± 0.8	2.4–5.6	4.1 ± 0.9	2.4–5.8	< 0.0001
TAPSE (mm)	22.6 ± 3.2	16.3–29.0	22.3 ± 3.1	16.3–28.3	22.5 ± 3.1	16.3–28.6	0.0898

LVEDD: left ventricular end-diastolic dimension, LVESD: left ventricular end-systolic dimension, LVEF: left ventricular ejection fraction, IVSWT: interventricular septal wall thickness, LVPWT: left ventricular posterior wall thickness, LA: left atrium, AP: anteroposterior, RV: right ventricular, TAPSE: tricuspid annular plane systolic excursion, SD: standard deviation, CI: confidence interval to age in men. LV wall thicknesses and LA anteroposterior dimension increased with age in both men and women. However, there was no significant change in RV end-diastolic free wall thickness according to age in both gender groups. TAPSE was significantly reduced only in elderly women (71 to 80 years old).

2D MEASUREMENT DATA ON CARDIAC CHAMBERS: VENTRICLES

Measurement values of the LV and RV using 2D echocardiography according to gender groups and according to age and gender groups are presented in Table 3 and Supplementary Table 3, respectively. Every variable regarding the dimension and wall thickness of both ventricles was significantly larger and thicker in men compared to women. Measurement values of LVEDD, LVESD and their indexed values showed similar trends compared with those from M-mode. The LVEDV and LVESV indices were also greater in men than in women. Interestingly, LVEF and the sphericity index, as well as RVFAC, were significantly higher in women. The LV short-axis dimension decreased with age in men and slightly increased in older women. However, the LV long-axis dimension was significantly decreased with age in both gender groups. Interestingly, LV volumes significantly decreased with age in both groups, which was not observed in the mean values of LV short-axis dimensions. LV long-axis dimension was significantly correlated with height in both men and women (r = 0.508, $p < 0.0001$ in men and r = 0.434, $p < 0.0001$ in women). Interestingly, the LV long-axis dimension was more significantly correlated with LVEDV in both men and women (r = 0.638, $p < 0.0001$ in men and r = 0.578, $p < 0.0001$ in women) than the LV short-axis dimension was (r = 0.528, $p < 0.0001$ in men and r = 0.511, $p < 0.0001$ in women). Similar trends according to age and gender were noted in RV short-axis dimensions, long-axis dimensions, and RV areas in apical 4-chamber views.

2D MEASUREMENT DATA ON CARDIAC CHAMBERS: ATRIA

Measurement values of the LA and RA using 2D echocardiography according to gender groups and according to age and gender groups are presented in Table 4 and Supplementary Table 4, respectively. Every echo variable related to LA and RA size in men was significantly larger than those in women. However, the mean values of indexed LA volume measured using both ellipsoidal and area-length were not significantly different between men and women. Mean values of LA volume by the area-length method were significantly higher than those

Table 3. Measurement values of the left and right ventricles by 2D imaging according to gender

Variables	Men		Women		Total		p
	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI	
LVEDD (mm)	49.1 ± 3.3	42.5–55.7	46.5 ± 3.2	40.2–52.7	47.7 ± 3.5	40.8–54.7	< 0.0001
LVESD (mm)	30.5 ± 3.1	24.4–36.6	28.6 ± 3.0	22.8–34.5	29.5 ± 3.2	23.3–35.8	< 0.0001
LVEDD index (mm/m^2)	27.5 ± 2.3	22.9–32.0	30.0 ± 2.4	25.3–34.6	28.8 ± 2.7	23.6–34.0	< 0.0001
LVESD index (mm/m^2)	17.1 ± 1.9	13.4–20.7	18.5 ± 2.0	14.5–22.4	17.8 ± 2.1	13.7–21.8	< 0.0001
LVEF (%) by linear method	61.3 ± 5.1	51.2–71.3	61.9 ± 5.5	51.1–72.7	61.6 ± 5.3	51.1–72.0	0.0634
IVSWT (mm)	8.1 ± 1.0	6.1–10.1	7.3 ± 0.9	5.5–9.1	7.7 ± 1.0	5.7–9.7	< 0.0001
LVPWT (mm)	8.0 ± 0.9	6.2–9.9	7.3 ± 0.9	5.4–9.1	7.6 ± 1.0	5.7–9.6	< 0.0001
LVEDV (mL)	113 ± 22	70–156	92 ± 16	59–124	102 ± 22	59–145	< 0.0001
LVESV (mL)	43 ± 11	22–63	34 ± 8	17–50	38 ± 11	17–58	< 0.0001
LVEDV index (mL/m^2)	63 ± 11	42–83	59 ± 9	40–77	61 ± 10	41–81	< 0.0001
LVESV index (mL/m^2)	23.6 ± 5.2	13.4–33.9	21.6 ± 5.0	11.7–31.4	22.6 ± 5.2	12.3–32.8	< 0.0001
LVEF (%) by volumetric method	62.6 ± 4.5	53.6–71.5	63.5 ± 4.8	54.1–72.9	63.1 ± 4.7	53.8–72.3	0.0014
LV long-axis dimension (mm)	88 ± 6	76–100	81 ± 6	70–92	84 ± 7	71–98	< 0.0001
Sphericity index	0.56 ± 0.05	0.47–0.65	0.58 ± 0.05	0.48–0.68	0.57 ± 0.05	0.48–0.67	< 0.0001
RV end-diastolic area (cm^2)	17.3 ± 3.3	10.9–23.8	14.3 ± 2.7	9.0–19.7	15.8 ± 3.4	9.2–22.4	< 0.0001
RV end-systolic area (cm^2)	9.3 ± 2.2	5.0–13.6	7.4 ± 1.7	4.1–10.7	8.3 ± 2.2	4.1–12.6	< 0.0001
RVFAC (%)	46 ± 6	34–59	48 ± 6	36–60	47 ± 6	35–60	< 0.0001
Basal RVD (mm)	35.4 ± 3.7	28.1–42.8	32.6 ± 3.6	25.6–39.7	34.0 ± 3.9	26.3–41.7	< 0.0001
Mid RVD (mm)	27.1 ± 3.7	19.8–34.4	24.7 ± 3.3	18.1–31.2	25.8 ± 3.7	18.5–33.1	< 0.0001
RV long-axis dimension (mm)	70 ± 9	52–89	64 ± 9	46–82	67 ± 10	48–86	< 0.0001
Proximal RVOT dimension (mm)	29.7 ± 4.3	21.3–38.1	27.0 ± 4.0	19.1–34.8	28.3 ± 4.4	19.7–36.9	< 0.0001
Distal RVOT dimension (mm)	23.5 ± 3.1	17.4–29.6	22.2 ± 2.8	16.6–27.8	22.8 ± 3.0	16.9–28.8	< 0.0001

LV: left ventricular, LVEDD: LV end-diastolic dimension, LVESD: LV end-systolic dimension, LVEF: LV ejection fraction, IVSWT: interventricular septal wall thickness, LVPWT: LV posterior wall thickness, LVEDV: LV end-diastolic volume, LVESV: LV end-systolic volume, RV: right ventricular, RVFAC: RV fractional area change, RVD: RV dimension, RVOT: RV outflow tract, 2D: two-dimensional, SD: standard deviation, CI: confidence interval measured by the ellipsoid method. Echocardiographic variables related to LA size significantly increased with age only in women, and those variables were not significantly different according to age in men, except the LA anteroposterior dimension. However, the LA volume index increased with age in both men and women.

2D measurement data on great vessels

Measurement values of the aortic root and the main pulmonary artery using 2D echocardiography according to gender groups and according to age and gender groups are presented in Table 5 and Supplementary Table 5, respectively. Every echocardiographic variable regarding both the aortic root and the main pulmonary artery was greater in men than in women, and increased with age in both men and women.

LVM and RWT

LVM, LVM index, and RWT calculated using both M-mode and 2D measurement values according to age and gender groups are presented in Table 6 and Supplementary Table 6, respectively. Both LVM and LVM index were significantly greater in men than in women. RWT was significantly greater in men com-

Table 4. Measurement values of the left and right atria by 2D imaging according to gender

Variables	Men		Women		Total		*p*
	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI	
LA area (cm^2) at A4C	16.3 ± 2.7	11.1–21.6	15.3 ± 2.7	9.9–20.6	15.8 ± 2.8	10.4–21.2	< 0.0001
LA area (cm^2) at A2C	16.4 ± 2.6	11.3–21.6	15.1 ± 2.7	9.7–20.5	15.7 ± 2.8	10.3–21.2	< 0.0001
LA longitudinal dimension (cm)	4.7 ± 0.5	3.8–5.6	4.6 ± 0.5	3.6–5.6	4.6 ± 0.5	3.7–5.6	0.0001
LA transverse dimension (mm)	38.7 ± 4.0	30.9–46.5	37.2 ± 3.9	29.6–44.8	37.9 ± 4.0	30.1–45.8	< 0.0001
LA AP dimension (mm)	34.7 ± 4.2	26.5–43.0	32.5 ± 4.0	24.7–40.4	33.6 ± 4.3	25.3–41.9	< 0.0001
LA volume (mL) by EM	33 ± 8	17–50	29 ± 8	14–45	31 ± 8	15–48	< 0.0001
LA volume index (mL/m^2) by EM	18.7 ± 4.5	9.9–27.5	18.9 ± 5.0	9.2–28.7	18.8 ± 4.7	9.5–28.1	0.4217
LA volume (mL) by ALM	49 ± 11	27–70	43 ± 11	22–64	46 ± 11	24–68	< 0.0001
LA volume index (mL/m^2) by ALM	27.2 ± 5.9	15.7–38.8	27.6 ± 6.7	14.5–40.8	27.5 ± 6.3	15.1–39.8	0.3241
RA transverse dimension (mm)	36.4 ± 4.1	28.4–44.4	33.2 ± 3.5	26.3–40.1	34.7 ± 4.1	26.7–42.8	< 0.0001
RA longitudinal dimension (mm)	46.5 ± 4.6	37.5–55.5	43.9 ± 4.8	34.6–53.3	45.2 ± 4.9	35.7–54.7	< 0.0001
RA area (cm^2)	14.2 ± 2.3	9.7–18.8	12.3 ± 2.2	8.0–16.7	13.3 ± 2.4	8.5–18.1	< 0.0001

LA: left atrial, A4C: apical 4-chamber view, A2C: apical 2-chamber view, AP: anteroposterior, EM: ellipsoid method, ALM: area-length method, RA: right atrial, 2D: two-dimensional, SD: standard deviation, CI: confidence interval

Table 5. Measurements of the aortic root and main pulmonary artery by 2D imaging according to gender

Variables	Men		Women		Total		*p*
	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI	
Aortic annulus (mm)	21.3 ± 1.8	17.8–24.8	19.4 ± 1.6	16.3–22.6	20.3 ± 1.9	16.5–24.1	< 0.0001
Sinus of Valsalva (mm)	33.5 ± 3.2	27.2–39.8	30.1 ± 3.0	24.2–36.0	31.8 ± 3.5	24.8–38.7	< 0.0001
ST junction (mm)	27.3 ± 2.7	21.9–32.6	24.9 ± 2.7	19.6–30.2	26.0 ± 3.0	20.2–31.9	< 0.0001
Tubular portion of ascending aorta (mm)	30.7 ± 3.7	23.5–38.0	29.1 ± 4.0	21.1–37.0	29.9 ± 4.0	22.1–37.6	< 0.0001
Main pulmonary artery (mm)	23.5 ± 3.3	17.0–30.0	23.0 ± 3.1	16.8–29.1	23.2 ± 3.2	16.9–29.6	0.0086

ST: sinotubular, 2D: two-dimensional, SD: standard deviation, CI: confidence interval

Table 6. LVM and relative wall thickness according to gender

Variables	Men		Women		Total		*p*
	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI	
LVM (gm) by M-mode	144 ± 28	90–199	114 ± 24	67–161	129 ± 30	70–187	< 0.0001
LVMI (gm/m^2) by M-mode	80 ± 14	53–108	73 ± 15	45–102	77 ± 15	48–106	< 0.0001
LVM (gm) by 2D	134 ± 25	85–184	107 ± 23	63–152	120 ± 28	66–174	< 0.0001
LVMI (gm/m^2) by 2D	75 ± 13	49–100	69 ± 14	42–96	72 ± 14	45–99	< 0.0001
RWT by M-mode	0.32 ± 0.04	0.26–0.39	0.31 ± 0.03	0.24–0.38	0.32 ± 0.04	0.25–0.39	< 0.0001
RWT by 2D	0.33 ± 0.04	0.25–0.41	0.31 ± 0.04	0.23–0.39	0.32 ± 0.04	0.24–0.40	< 0.0001

LVM: left ventricular mass, LVMI: LVM index, RWT: relative wall thickness, 2D: two-dimensional, SD: standard deviation, CI: confidence interval pared to women as well. LVM index and RWT increased according to age in both men and women. Interestingly, the difference in RWT between men and women was more evident in young patients (age < 50 years).

Intra- and interobserver variability

ICCs for both intra- and interobserver variability testing are presented in Supplementary Table 7. For intraobserver variability, ICCs for echo variables were above 0.8, except that of the RV end-diastolic free wall thickness (ICC = 0.723, 95% CI = 0.535–0.843) and the RWT calculated from 2D measurement (ICC = 0.790, 95% CI = 0.639–0.883). For interobserver variability, ICCs of echocardiographic variables were above 0.8 except for RV end-diastolic free wall thickness (ICC = 0.521, 95% CI = 0.165–0.738), LVPWT (ICC = 0.712, 95% CI = 0.479–0.845), LVEF (ICC = 0.764, 95% CI = 0.372–0.898), and RVFAC (ICC = 0.611, 95% CI = 0.332–0.773).

Discussion

This study provided normal reference measurement values of cardiac chambers and great arteries for comprehensive echocardiographic evaluation according to age and gender using data from the NORMAL study, which prospectively evaluated 1003 normal Korean patients from 23 nationwide centers. Briefly, most of cardiac chamber dimension and volume were greater in men compared to women and ventricular chamber size of both RV and LV were decrease according to age in both men and women. When indexed to BSA, LV volume indices were still larger in men compared to women, but indexed LV dimensions were usually greater in women and elderly populations. Interestingly, LA volumes were greater in men compared to women but, when indexed to BSA, difference according to sex was no longer evident. However, both LA volume and LA volume index increased with age in both men and women.

As previously noted, there were considerable differences in chamber size between men and women and according to age.[6-8)12)] Although our current data were very similar with those from other populations, the effect of age on normal values showed slightly different trends in this study.[13-15)] For example, there were differential effects of age on LV short-axis dimension (LVEDD) between men and women, whereas the LV long-axis dimension was similarly affected by age in both men and women. These differences might be partly due to unique physical characteristics of the Korean population according to age and gender.[16)] The Korean economy has developed very quickly since 1960, and there are many differences in physical features and the incidence of metabolic syndrome between the young and elderly generations.[17)] In our data, younger subjects were taller than older subjects, and young men were heavier than elderly men, as expected. However, young ladies were lighter in weight than elderly women. Therefore, these physical characteristics might change when the young generation replaces those of middle age and the latter replace elderly subjects.

The effect of age on LV volume could not be offset by adjusting for BSA, as previously reported in other populations.[14)15)] The effect of aging on LV volumes seems closely related with the LV long-axis dimension, considering that the LV long-axis dimension is more strongly correlated with LVEDV than the LV short-axis dimension. As there were only weak correlations between LV short- and long-axis dimensions, the greater effect of LV long-axis dimension on LV volume and its correlation with height might explain the trends of decreasing LV volumes along with age in both men and women.

As previously noted, RV size and function were very difficult to evaluate, especially in cases with a poor echo window.[18)] In our data, reproducibility was relatively low for several RV variables, such as RV free wall thickness and RVFAC. In this regard, when interpreting RV variables, meticulous care should be used to determine whether the measurement value was adequately acquired. Nevertheless, our data was consistent with prior studies and confirms that RV dimensions as well as RV area are significantly affected by age and gender.[14)15)19)20)]

Gender differences in LA volume were significantly reduced when LA volume was adjusted with BSA, as descried previously.[15)] In other words, LA volume might be more influenced by body size than gender. However, the effect of age on LA volume in a normal population was controversial and differs among populations.[14)15)] Our data were similar to those from a Chinese population, in that the LA volume index significantly increased with age in both men and women. However, European data did not show any difference in LA volume, even after adjustment for BSA.[15)]

Kou et al.[15)] suggested that normal range of the LA volume index, which stands as 16–34 mL/m^2 in the current guidelines, was slightly low. Our study supports this assertion. In addition, LA volume as measured by the area-length method was significantly larger than the LA volume measured by Simpson's method or the ellipsoid method. Therefore, when LA volume or volume index is reported, the exact method should be clarified.

Effects of age and gender on the great arteries were consistent with previous studies, and the size of the aortic root and the main pulmonary artery as well as the proximal and distal RV outflow tract dimension increased with age in both men and women.[14)] LVM index and RWT were also significantly affected by age in both men and women. Interestingly, RWT in younger women (age < 50 years) was significantly lower than RWT in men, but these became similar after the age of 50. This might be consistent with findings that cardiovascular risks of postmenopausal women exceeded the risks of men of the same age.[21)22)]

Several limitations of this study should be acknowledged. First, we included only normal Korean subjects in the NORMAL study, and our data might not be applicable to other populations. Second, our NORMAL study did not include three-dimensional (3D) echocardiography data and we could not provide reference values for 3D echocardiography. The next limitation was that patients with significant disease, such as hypertension and diabetes, were excluded based on past medical histories obtained from the study subjects, and results of blood sampling and/or other clinical tests were not obtained. Therefore, patients with preclinical hypertension or subclinical coronary artery disease might be included in the current study. However, their effects on the structure of the heart are unlikely to be significant.

In conclusion, we provided normal reference values for echocardiographic measurements of the cardiac chambers and great arteries from the NORMAL study. As these values change considerably with age and gender, these should be considered when evaluating cardiac function and structure by echocardiography. Since physical characteristics of the Korean population change continuously, a new study for echocardiographic reference values, including 3D data, may be needed in the future.

• Acknowledgements
NORMAL study was supported by a research fund from Korean Society of Echocardiography.

References

1. Wolk MJ, Bailey SR, Doherty JU, Douglas PS, Hendel RC, Kramer CM, Min JK, Patel MR, Rosenbaum L, Shaw LJ, Stainback RF, Allen JM; American College of Cardiology Foundation Appropriate Use Criteria Task Force. *ACCF/AHA/ASE/ASNC/HFSA/HRS/SCAI/SCCT/SCMR/STS 2013 multimodality appropriate use criteria for the detection and risk assessment of stable ischemic heart disease: a report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force, American Heart Association, American Society of Echocardiography, American Society of Nuclear Cardiology, Heart Failure Society of America, Heart Rhythm Society, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance, and Society of Thoracic Surgeons. J Am Coll Cardiol 2014;63:380-406.*
2. Nagueh SF, Quiñones MA. *Important advances in technology: echocardiography. Methodist Debakey Cardiovasc J 2014;10:146-51.*
3. Maekawa E, Inomata T, Watanabe I, Yanagisawa T, Mizutani T, Shinagawa H, Koitabashi T, Takeuchi I, Tokita N, Inoue Y, Izumi T. *Prognostic significance of right ventricular dimension on acute decompensation in chronic left-sided heart failure. Int Heart J 2011;52:119-26.*
4. Rudski LG, Lai WW, Afilalo J, Hua L, Handschumacher MD, Chandrasekaran K, Solomon SD, Louie EK, Schiller NB. *Guidelines for the echocardiographic assessment of the right heart in adults: a report from the American Society of Echocardiography endorsed by the European Association of Echocardiography, a registered branch of the European Society of Cardiology, and the Canadian Society of Echocardiography. J Am Soc Echocardiogr 2010;23:685-713; quiz 786-8.*
5. Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, Flachskampf FA, Foster E, Goldstein SA, Kuznetsova T, Lancellotti P, Muraru D, Picard MH, Rietzschel ER, Rudski L, Spencer KT, Tsang W, Voigt JU. *Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. J Am Soc Echocardiogr 2015;28:1-39.e14.*
6. Salton CJ, Chuang ML, O'Donnell CJ, Kupka MJ, Larson MG, Kissinger KV, Edelman RR, Levy D, Manning WJ. *Gender differences and normal left ventricular anatomy in an adult population free of hypertension. A cardiovascular magnetic resonance study of the Framingham Heart Study Offspring cohort. J Am Coll Cardiol 2002;39:1055-60.*
7. Daimon M, Watanabe H, Abe Y, Hirata K, Hozumi T, Ishii K, Ito H, Iwakura K, Izumi C, Matsuzaki M, Minagoe S, Abe H, Murata K, Nakatani S, Negishi K, Yoshida K, Tanabe K, Tanaka N, Tokai K, Yoshikawa J; JAMP Study Investigators. *Normal values of echocardiographic parameters in relation to age in a healthy Japanese population: the JAMP study. Circ J 2008;72:1859-66.*
8. Dewey FE, Rosenthal D, Murphy DJ Jr, Froelicher VF, Ashley EA. *Does size matter? Clinical applications of scaling cardiac size and function for body size. Circulation 2008;117:2279-87.*
9. Park SW. *Multicenter trial for estimation of normal values of echocardiographic indices in Korea. Korean Circ J 2000;30:373-82.*
10. Lang RM, Bierig M, Devereux RB, Flachskampf FA, Foster E, Pellikka PA, Picard MH, Roman MJ, Seward J, Shanewise JS, Solomon SD, Spencer KT, Sutton MS, Stewart WJ; Chamber Quantification Writing Group; American Society of Echocardiography's Guidelines and Standards Committee; European Association of Echocardiography. *Recommendations for chamber quantification: a report from the American Society of Echocardiography's Guidelines and Standards Committee and the Chamber Quantification Writing Group, developed in conjunction with the European Association of Echocardiography, a branch of the European Society of Cardiology. J Am Soc Echocardiogr 2005;18:1440-63.*
11. Nagueh SF, Appleton CP, Gillebert TC, Marino PN, Oh JK, Smiseth OA, Waggoner AD, Flachskampf FA, Pellikka PA, Evangelisa A. *Recommendations for the evaluation of left ventricular diastolic function by echocardiography. Eur J Echocardiogr 2009;10:165-93.*
12. Son MK, Chang SA, Kwak JH, Lim HJ, Park SJ, Choi JO, Lee SC, Park SW, Kim DK, Oh JK. *Comparative measurement of aortic root by transthoracic echocardiography in normal Korean population based on two different guidelines. Cardiovasc Ultrasound 2013;11:28.*
13. Echocardiographic Normal Ranges Meta-Analysis of the Left Heart Collaboration. *Ethnic-Specific Normative Reference Values for Echocardiographic LA and LV Size, LV Mass, and Systolic Function: The EchoNoRMAL Study. JACC Cardiovasc Imaging 2015;8:656-65.*
14. Yao GH, Deng Y, Liu Y, Xu MJ, Zhang C, Deng YB, Ren WD, Li ZA, Tang H, Zhang QB, Mu YM, Fang LG, Zhang M, Yin LX, Zhang Y; Echocardiographic Measurements in Normal Chinese Adults (EMINCA) Study Investigators. *Echocardiographic measurements in normal chinese adults focusing on cardiac chambers and great arteries: a prospective, nationwide, and multicenter study. J Am Soc Echocardiogr 2015;28:570-9.*
15. Kou S, Caballero L, Dulgheru R, Voilliot D, De Sousa C, Kacharava G, Athanassopoulos GD, Barone D, Baroni M, Cardim N, Gomez De Diego JJ, Hagendorff A, Henri C, Hristova K, Lopez T, Magne J, De La Morena G, Popescu BA, Penicka M, Ozyigit T, Rodrigo Carbonero JD, Salustri A, Van De Veire N, Von Bardeleben RS, Vinereanu D, Voigt JU, Zamorano JL, Donal E, Lang RM, Badano LP, Lancellotti P. *Echocardiographic reference ranges for normal cardiac chamber size: results from the NORRE study. Eur Heart J Cardiovasc Imaging 2014;15:680-90.*
16. Park SJ, Kang HT, Nam CM, Park BJ, Linton JA, Lee YJ. *Sex differences in the relationship between socioeconomic status and metabolic syndrome: the Korean National Health and Nutrition Examination Survey. Diabetes Res Clin Pract 2012;96:400-6.*
17. Lim S, Shin H, Song JH, Kwak SH, Kang SM, Won Yoon J, Choi SH, Cho SI, Park KS, Lee HK, Jang HC, Koh KK. *Increasing prevalence of metabolic syndrome in Korea: the Korean National Health and Nutrition Examination Survey for 1998-2007. Diabetes Care 2011;34:1323-8.*
18. Oldershaw P, Bishop A. *The difficulties of assessing right ventricular function. Br Heart J 1995;74:99-100.*
19. Kawut SM, Lima JA, Barr RG, Chahal H, Jain A, Tandri H, Praestgaard A, Bagiella E, Kizer JR, Johnson WC, Kronmal RA, Bluemke

DA. *Sex and race differences in right ventricular structure and function: the multi-ethnic study of atherosclerosis-right ventricle study. Circulation 2011; 123:2542-51.*

20. Maffessanti F, Muraru D, Esposito R, Gripari P, Ermacora D, Santoro C, Tamborini G, Galderisi M, Pepi M, Badano LP. *Age-, body size-, and sex-specific reference values for right ventricular volumes and ejection fraction by three-dimensional echocardiography: a multicenter echocardiographic study in 507 healthy volunteers. Circ Cardiovasc Imaging 2013;6:700-10.*
21. Lloyd-Jones D, Adams R, Carnethon M, De Simone G, Ferguson TB, Flegal K, Ford E, Furie K, Go A, Greenlund K, Haase N, Hailpern S, Ho M, Howard V, Kissela B, Kittner S, Lackland D, Lisabeth L, Marelli A, McDermott M, Meigs J, Mozaffarian D, Nichol G, O'Donnell C, Roger V, Rosamond W, Sacco R, Sorlie P, Stafford R, Steinberger J, Thom T, Wasserthiel-Smoller S, Wong N, Wylie-Rosett J, Hong Y; American Heart Association Statistics Committee and Stroke Statistics Subcommittee. *Heart disease and stroke statistics--2009 update: a report from the American Heart Association Statistics Committee and Stroke Statistics Subcommittee. Circulation 2009;119:480-6.*
22. Lloyd-Jones DM, Evans JC, Levy D. *Hypertension in adults across the age spectrum: current outcomes and control in the community. JAMA 2005; 294:466-72.*

Supplementary Table 1. Demographic and clinical findings according to age and gender

Age groups	Men (mean ± SD)						p*	Women (mean ± SD)						p*
	21–30	31–40	41–50	51–60	61–70	71–80		21–30	31–40	41–50	51–60	61–70	71–80	
Number	87	88	88	94	89	41		87	86	98	112	87	46	
Age (year)	26 ± 3	36 ± 3	46 ± 3	55 ± 3	66 ± 3	74 ± 2	< 0.0001	25 ± 3	36 ± 3	46 ± 3	55 ± 3	65 ± 3	74 ± 2	< 0.0001
Weight (kg)	70 ± 10	74 ± 11	71 ± 8	68 ± 8	65 ± 8	61 ± 7	< 0.0001	54 ± 8	55 ± 7	56 ± 7	57 ± 7	56 ± 7	55 ± 8	0.2046
Height (cm)	174 ± 6	174 ± 6	172 ± 6	169 ± 5	166 ± 6	163 ± 7	< 0.0001	162 ± 5	160 ± 4	159 ± 5	157 ± 5	155 ± 6	154 ± 5	< 0.0001
BSA (m^2)	1.83 ± 0.14	1.88 ± 0.14	1.83 ± 0.13	1.78 ± 0.12	1.72 ± 0.11	1.65 ± 0.12	< 0.0001	1.56 ± 0.12	1.56 ± 0.1	1.57 ± 0.11	1.56 ± 0.10	1.54 ± 0.11	1.52 ± 0.11	0.1036
BMI (kg/m^2)	22.9 ± 2.7	24.3 ± 2.9	24.0 ± 2.4	23.8 ± 2.4	23.6 ± 2.3	22.9 ± 2.1	0.0029	20.7 ± 2.9	21.6 ± 2.5	22.3 ± 2.2	23.2 ± 2.7	23.3 ± 2.6	23.1 ± 2.9	< 0.0001
SBP (mm Hg)	120 ± 10	123 ± 10	123 ± 12	123 ± 12	123 ± 14	128 ± 14	0.0469	111 ± 10	112 ± 12	117 ± 12	121 ± 13	122 ± 13	124 ± 10	< 0.0001
DBP (mm Hg)	74 ± 8	77 ± 8	76 ± 9	74 ± 10	75 ± 9	75 ± 10	0.3003	68 ± 8	68 ± 10	73 ± 11	74 ± 9	73 ± 9	72 ± 10	< 0.0001
Heart rate (bpm)	69 ± 9	69 ± 11	67 ± 8	66 ± 10	67 ± 9	68 ± 11	0.1835	71 ± 9	70 ± 9	71 ± 9	67 ± 8	66 ± 8	70 ± 8	< 0.0001

*p value from analysis of variance test in each gender. BSA: body surface area, BMI: body mass index, SBP: systolic blood pressure, DBP: diastolic blood pressure, SD: standard deviation

Supplementary Table 2. M-mode variables according to age and gender

Age groups	Men (mean ± SD)						p*	Women (mean ± SD)						p*
	21–30	31–40	41–50	51–60	61–70	71–80		21–30	31–40	41–50	51–60	61–70	71–80	
LVEDD (mm)	50.3 ± 3.4	50.9 ± 3.5	50.9 ± 3.2	51.0 ± 3.2	49.8 ± 3.2	49.8 ± 3.3	0.0519	46.0 ± 3.1	46.7 ± 2.8	47.5 ± 3.4	48.1 ± 3.3	48.5 ± 3.1	47.6 ± 3.3	< 0.0001
LVESD (mm)	31.4 ± 2.6	31.7 ± 3.0	31.4 ± 2.9	30.8 ± 2.9	30.0 ± 2.8	29.5 ± 2.2	< 0.0001	28.4 ± 2.4	28.7 ± 2.5	29.0 ± 2.7	29.0 ± 3.0	28.7 ± 3.0	27.9 ± 2.9	0.1740
LVEDD index (mm/m^2)	27.5 ± 2.0	27.1 ± 1.8	28.0 ± 2.1	28.8 ± 2.3	29.0 ± 2.1	30.2 ± 2.3	< 0.0001	29.5 ± 2.2	29.9 ± 2.0	30.4 ± 2.3	31.0 ± 2.5	31.6 ± 2.5	31.5 ± 2.8	< 0.0001
LVESD index (mm/m^2)	17.2 ± 1.6	16.9 ± 1.6	17.2 ± 1.8	17.4 ± 1.9	17.5 ± 1.6	17.9 ± 1.7	0.0251	18.2 ± 1.7	18.4 ± 1.6	18.6 ± 1.8	18.7 ± 2.1	18.7 ± 2.0	18.5 ± 2.2	0.5652
LVEF (%) by linear method	60.8 ± 4.1	61.2 ± 4.4	61.9 ± 4.6	63.5 ± 4.9	63.5 ± 4.5	64.6 ± 4.3	< 0.0001	61.8 ± 3.9	62.1 ± 4.1	62.7 ± 3.9	63.6 ± 4.4	65.0 ± 4.3	65.6 ± 4.3	< 0.0001
IVSWT (mm)	8.1 ± 0.9	8.1 ± 1.0	8.1 ± 1.0	8.3 ± 1.1	8.5 ± 1.0	8.5 ± 0.8	0.0058	6.9 ± 0.6	7.1 ± 0.8	7.3 ± 0.8	7.6 ± 0.8	8.0 ± 0.9	8.1 ± 0.8	< 0.0001
LVPWT (mm)	8.0 ± 0.8	8.1 ± 0.9	8.0 ± 0.9	8.2 ± 0.8	8.5 ± 0.8	8.5 ± 0.8	0.0004	6.8 ± 0.6	7.0 ± 0.7	7.3 ± 0.7	7.5 ± 0.8	7.9 ± 0.7	8.1 ± 0.6	< 0.0001
LA AP diameter (mm)	33.6 ± 3.7	35.6 ± 3.7	35.7 ± 3.3	37.2 ± 3.5	37.6 ± 3.9	37.1 ± 3.8	< 0.0001	30.6 ± 2.8	31.6 ± 3.2	33.2 ± 3.4	34.5 ± 3.1	36.0 ± 4.0	37.5 ± 4.2	< 0.0001
Aortic root diameter (mm)	30.5 ± 2.2	31.3 ± 2.6	32.3 ± 3.1	32.9 ± 2.7	33.6 ± 3.1	33.3 ± 3.1	< 0.0001	26.3 ± 2.0	27.4 ± 2.1	28.8 ± 2.3	29.5 ± 2.6	30.2 ± 2.6	31.2 ± 3.0	< 0.0001
RV end-diastolic free wall thickness (mm)	4.1 ± 0.9	4.3 ± 0.8	4.2 ± 0.9	4.2 ± 1.0	4.4 ± 0.9	4.2 ± 0.7	0.4648	3.8 ± 0.8	3.9 ± 0.8	4.1 ± 0.8	4.0 ± 0.8	4.0 ± 0.8	4.2 ± 0.9	0.0664
TAPSE (mm)	22.8 ± 3.2	22.6 ± 3.2	22.6 ± 3.5	22.8 ± 3.1	22.7 ± 3.3	22.2 ± 2.9	0.9666	22.0 ± 2.4	22.2 ± 3.0	23.0 ± 2.9	22.7 ± 3.3	22.0 ± 3.1	21.2 ± 3.5	0.0098

*p value from analysis of variance test in each gender. LVEDD: left ventricular end-diastolic dimension, LVESD: left ventricular end-systolic dimension, LVEF: left ventricular ejection fraction, IVSWT: interventricular septal wall thickness, LVPWT: left ventricular posterior wall thickness, LA: left atrium, AP: anteroposterior, RV: right ventricular, TAPSE: tricuspid annular plane systolic excursion, SD: standard deviation

Supplementary Table 3. Measurement values of left and right ventricle by 2D imaging according to age and gender

Age groups	Men (mean ± SD)						p*	Women (mean ± SD)						p*
	21–30	31–40	41–50	51–60	61–70	71–80		21–30	31–40	41–50	51–60	61–70	71–80	
LVEDD (mm)	49.6 ± 3.4	49.6 ± 3.3	49.4 ± 3.4	49.0 ± 3.2	48.3 ± 3.6	48.4 ± 2.8	0.0617	45.9 ± 2.8	46.0 ± 2.9	46.4 ± 2.9	46.9 ± 3.6	47.1 ± 3.3	46.2 ± 3.4	0.0358
LVESD (mm)	31.5 ± 2.9	31.1 ± 2.9	31.1 ± 2.7	30.3 ± 3.0	29.3 ± 3.7	29.1 ± 2.1	< 0.0001	28.7 ± 2.8	29.0 ± 2.6	28.8 ± 2.9	28.5 ± 3.5	28.4 ± 2.9	28.0 ± 3.0	0.4919
LVEDD index (mm/m^2)	27.2 ± 2.3	26.4 ± 2.0	27.1 ± 2.3	27.7 ± 2.3	28.1 ± 2.1	29.4 ± 2.1	< 0.0001	29.5 ± 2.2	29.4 ± 1.8	29.7 ± 2.1	30.2 ± 2.7	30.7 ± 2.5	30.5 ± 2.7	0.0004
LVESD index (mm/m^2)	17.3 ± 1.9	16.6 ± 1.6	17.1 ± 1.8	17.1 ± 2.0	17.0 ± 2.1	17.7 ± 1.7	0.0465	18.4 ± 2.0	18.6 ± 1.8	18.5 ± 1.9	18.4 ± 2.3	18.5 ± 2.0	18.5 ± 2.3	0.9931
LVEF (%) by linear method	59.4 ± 4.9	60.5 ± 4.5	60.2 ± 4.7	61.6 ± 4.9	63.3 ± 5.5	63.7 ± 5.0	< 0.0001	60.7 ± 5.0	60.2 ± 5.1	61.3 ± 5.3	62.9 ± 6.0	63.5 ± 5.3	63.2 ± 5.2	< 0.0001
IVSWT (mm)	8.0 ± 1.0	8.0 ± 1.0	7.9 ± 1.0	8.3 ± 1.1	8.3 ± 0.9	8.2 ± 1.1	0.0370	6.7 ± 0.7	6.9 ± 0.8	7.1 ± 0.7	7.5 ± 0.8	7.8 ± 0.8	8.0 ± 0.9	< 0.0001
LVPWT (mm)	7.8 ± 1.0	7.9 ± 0.8	8.0 ± 1.0	8.2 ± 0.8	8.2 ± 0.8	8.3 ± 1.1	0.0048	6.7 ± 0.7	6.8 ± 0.9	7.1 ± 0.7	7.4 ± 0.9	7.7 ± 0.9	8.0 ± 1.0	< 0.0001
LVEDV (mL)	124 ± 21	124 ± 23	113 ± 19	110 ± 17	101 ± 20	100 ± 16	< 0.0001	96 ± 16	95 ± 14	93 ± 17	91 ± 17	88 ± 16	82 ± 15	< 0.0001
LVESV (mL)	48 ± 10	48 ± 10	43 ± 10	41 ± 9	36 ± 9	36 ± 7	< 0.0001	36 ± 9	35 ± 7	34 ± 8	34 ± 9	32 ± 8	29 ± 7	< 0.0001
LVEDV index (mL/m^2)	67 ± 10	66 ± 11	62 ± 10	62 ± 10	58 ± 11	61 ± 9	< 0.0001	61 ± 9	60 ± 8	59 ± 10	59 ± 10	57 ± 9	54 ± 10	0.0009
LVESV index (mL/m^2)	26.0 ± 4.8	25.4 ± 4.9	23.7 ± 5.1	22.8 ± 5.3	21.1 ± 5.1	22.1 ± 4.0	< 0.0001	23.2 ± 5.0	22.4 ± 4.2	21.5 ± 4.9	21.6 ± 5.5	20.6 ± 4.4	19.1 ± 5.1	0.0001
LVEF (%) by volumetric method	61.5 ± 4.4	61.4 ± 3.7	62.0 ± 4.6	63.3 ± 4.8	64.0 ± 4.9	63.4 ± 4.2	0.0002	62.3 ± 4.8	63.0 ± 4.7	64 ± 4.1	63.4 ± 5.0	63.9 ± 4.9	65.2 ± 5.3	0.0205
LV long-axis dimension (mm)	91 ± 6	91 ± 6	88 ± 5	88 ± 5	84 ± 5	83 ± 4	< 0.0001	84 ± 6	82 ± 5	82 ± 5	80 ± 5	78 ± 5	77 ± 5	< 0.0001
Sphericity index	0.55 ± 0.05	0.55 ± 0.04	0.56 ± 0.04	0.56 ± 0.04	0.58 ± 0.04	0.58 ± 0.04	< 0.0001	0.55 ± 0.04	0.56 ± 0.04	0.57 ± 0.04	0.59 ± 0.05	0.60 ± 0.04	0.60 ± 0.05	< 0.0001
RV end-diastolic area (cm^2)	18.5 ± 3.4	18.4 ± 3.5	16.9 ± 3.0	17.1 ± 3.0	16.3 ± 3.1	16.2 ± 3.1	< 0.0001	15.7 ± 3.0	14.3 ± 2.7	14 ± 2.4	13.8 ± 2.5	14.4 ± 2.9	13.8 ± 2.4	< 0.0001
RV end-systolic area (cm^2)	10.1 ± 2.0	10.1 ± 2.4	9.0 ± 2.1	9.0 ± 2.0	8.8 ± 2.1	8.7 ± 2.1	< 0.0001	8.1 ± 1.6	7.4 ± 1.7	7.2 ± 1.6	7.2 ± 1.6	7.4 ± 1.9	7.4 ± 1.6	0.0074
RVFAC (%)	46 ± 6	46 ± 5	47 ± 8	48 ± 7	46 ± 6	46 ± 7	0.2337	48 ± 7	48 ± 6	49 ± 5	48 ± 6	49 ± 7	47 ± 7	0.2763
Basal RVD (mm)	36.1 ± 3.9	36.0 ± 3.6	35.0 ± 3.3	35.6 ± 3.4	34.7 ± 4.4	35.0 ± 3.8	0.0583	32.7 ± 3.5	32.4 ± 3.5	32.2 ± 3.9	32.7 ± 3.1	33.3 ± 3.9	32.6 ± 3.6	0.4121
Mid RVD (mm)	27.7 ± 3.6	28.3 ± 3.8	27.2 ± 3.8	26.5 ± 3.5	26.2 ± 3.8	26.3 ± 3.2	0.0008	25.5 ± 3.4	24.6 ± 3.0	24.2 ± 3.3	24.3 ± 3.2	24.8 ± 3.4	24.9 ± 4.0	0.0894
RV long-axis dimension (mm)	73 ± 9	72 ± 10	70 ± 8	69 ± 10	67 ± 9	67 ± 9	0.0002	67 ± 10	64 ± 9	64 ± 8	63 ± 9	63 ± 9	61 ± 8	0.0142
Proximal RVOT dimension (mm)	28.0 ± 4.2	28.9 ± 3.9	29.2 ± 4.5	31.1 ± 4.0	30.6 ± 3.7	31.0 ± 5.0	< 0.0001	24.6 ± 4.0	26.5 ± 3.4	27.1 ± 3.6	27.6 ± 3.7	28.3 ± 4.4	28.1 ± 3.7	< 0.0001
Distal RVOT dimension (mm)	22.3 ± 2.7	23.8 ± 3.2	23.3 ± 3.1	23.4 ± 3.1	24.2 ± 2.8	25.2 ± 3.5	< 0.0001	21.1 ± 2.4	21.1 ± 2.2	21.6 ± 2.6	22.9 ± 2.9	23.5 ± 2.9	23.4 ± 2.9	< 0.0001

*p value from analysis of variance test in each gender. LV: left ventricular, LVEDD: LV end-diastolic dimension, LVESD: LV end-systolic dimension, LVEF: LV ejection fraction, IVSWT: interventricular septal wall thickness, LVPWT: LV posterior wall thickness, LVEDV: LV end-diastolic volume, LVESV: LV end-systolic volume, RV: right ventricular, RVFAC: RV fractional area change, RVD: RV dimension, RVOT: RV outflow tract, 2D: two-dimensional, SD: standard deviation

Supplementary Table 4. Measurement values of left and right atrium by 2D imaging according to age and gender

Age groups	Men (mean ± SD)						p*	Women (mean ± SD)						p*
	21–30	31–40	41–50	51–60	61–70	71–80		21–30	31–40	41–50	51–60	61–70	71–80	
LA area (cm^2) at A4C	16.3 ± 2.5	16.4 ± 2.9	16.2 ± 2.5	16.6 ± 3.1	16.3 ± 2.6	16.1 ± 2.7	0.9468	14.2 ± 2.1	14.5 ± 2.5	15.1 ± 2.8	15.6 ± 2.4	15.9 ± 2.8	16.8 ± 3.4	< 0.0001
LA area (cm^2) at A2C	15.9 ± 2.4	15.9 ± 2.7	16.5 ± 2.5	17.1 ± 2.8	16.7 ± 2.7	16.5 ± 2.6	0.0161	13.4 ± 2.3	14.4 ± 2.0	14.9 ± 2.8	15.4 ± 2.7	16.4 ± 2.6	16.5 ± 3.0	< 0.0001
LA longitudinal dimension (cm)	4.6 ± 0.4	4.7 ± 0.5	4.7 ± 0.4	4.8 ± 0.5	4.7 ± 0.5	4.7 ± 0.4	0.0982	4.3 ± 0.5	4.5 ± 0.5	4.6 ± 0.5	4.7 ± 0.5	4.8 ± 0.5	4.8 ± 0.5	< 0.0001
LA transverse dimension (mm)	38.9 ± 3.6	38.3 ± 4.1	38.8 ± 3.9	38.8 ± 4.2	38.8 ± 4.0	38.5 ± 4.1	0.9071	36.5 ± 3.4	36.8 ± 4.0	36.7 ± 3.8	37.5 ± 4.0	37.7 ± 3.9	38.7 ± 4.1	0.0186
LA AP dimension (mm)	33.1 ± 4.2	34.7 ± 4.5	34.2 ± 3.7	35.6 ± 3.7	35.5 ± 4.5	35.8 ± 4.3	0.0002	30.2 ± 3.0	31.2 ± 3.5	32.2 ± 3.8	33.3 ± 3.7	34.2 ± 4.1	35.1 ± 4.5	< 0.0001
LA volume (mL) by EM	48 ± 10	48 ± 11	48 ± 10	51 ± 12	50 ± 11	48 ± 11	0.4943	38 ± 8	40 ± 8	42 ± 11	44 ± 10	47 ± 11	49 ± 15	< 0.0001
LA volume index (mL/m^2) by EM	26.3 ± 4.9	25.3 ± 5.4	26.5 ± 4.9	28.5 ± 6.8	28.8 ± 6.1	28.9 ± 6.2	< 0.0001	24.4 ± 4.9	25.6 ± 4.9	27.1 ± 6.9	28.3 ± 6.7	30.2 ± 6.1	32.4 ± 8.6	< 0.0001
LA volume (mL) by ALM	31 ± 7	33 ± 8	33 ± 7	35 ± 9	34 ± 9	35 ± 9	0.0213	25 ± 6	27 ± 6	29 ± 8	31 ± 7	33 ± 9	35 ± 10	< 0.0001
LA volume index (mL/m^2) by ALM	16.9 ± 3.5	17.3 ± 4.0	18.1 ± 3.7	19.8 ± 4.9	19.9 ± 4.7	21.0 ± 5.0	< 0.0001	15.8 ± 3.4	17.3 ± 3.7	18.2 ± 4.5	19.7 ± 4.6	21.2 ± 5.2	22.9 ± 5.8	< 0.0001
RA transverse dimension (mm)	36.9 ± 4.1	37.3 ± 3.7	36.5 ± 4.4	36.0 ± 4.1	35.4 ± 3.9	36.2 ± 4.2	0.0302	33.4 ± 3.2	33.3 ± 3.3	33.0 ± 3.9	33.3 ± 3.8	33.5 ± 3.4	32.1 ± 3.1	0.3165
RA longitudinal dimension (mm)	45.4 ± 4.3	46.8 ± 5.0	46.1 ± 4.7	47.2 ± 4.6	46.9 ± 4.4	46.8 ± 4.5	0.1451	41.6 ± 3.9	42.7 ± 4.7	43.8 ± 4.4	45.0 ± 4.4	45.4 ± 5.2	45.5 ± 5.2	< 0.0001
RA area (cm^2)	14.1 ± 2.3	14.7 ± 2.5	14.0 ± 2.1	14.4 ± 2.3	13.9 ± 2.3	14.4 ± 2.3	0.1889	11.6 ± 1.9	12.0 ± 2.1	12.2 ± 2.3	12.7 ± 2.2	13.0 ± 2.4	12.6 ± 2.0	0.0006

*p value from analysis of variance test in each gender. LA: left atrial, A4C: apical 4-chamber view, A2C: apical 2-chamber view, AP: anteroposterior, EM: ellipsoid method, ALM: area-length method, RA: right atrial, 2D: two-dimensional, SD: standard deviation

Supplementary Table 5. Measurement values of aortic root and main pulmonary artery by 2D imaging according to age and gender

Age groups	Men (mean ± SD)						p*	Women (mean ± SD)						p*
	21–30	31–40	41–50	51–60	61–70	71–80		21–30	31–40	41–50	51–60	61–70	71–80	
Aortic annulus (mm)	21.3 ± 1.8	21.4 ± 1.9	21.5 ± 2.1	21.3 ± 1.7	20.9 ± 1.5	21.4 ± 1.8	0.4085	18.9 ± 1.5	19.1 ± 1.8	19.3 ± 1.5	19.5 ± 1.5	20.1 ± 1.5	19.5 ± 1.8	0.0001
Sinus of Valsalva (mm)	31.2 ± 3.0	32.7 ± 2.6	33.7 ± 3.2	34.0 ± 2.9	35.1 ± 3.1	35.0 ± 3.1	< 0.0001	27.8 ± 2.4	28.7 ± 2.4	29.9 ± 2.5	30.7 ± 2.7	32.0 ± 2.6	32.4 ± 2.8	< 0.0001
ST junction (mm)	24.9 ± 2.3	26.9 ± 2.0	27.5 ± 2.6	27.9 ± 2.5	28.5 ± 2.8	28.3 ± 2.6	< 0.0001	22.7 ± 2.2	23.8 ± 2.4	24.8 ± 2.3	25.7 ± 2.5	26.4 ± 2.4	26.5 ± 2.7	< 0.0001
Tubular portion of ascending aorta (mm)	27.0 ± 2.3	29.6 ± 3.0	30.5 ± 2.9	31.6 ± 2.7	33.6 ± 3.3	33.5 ± 4.0	< 0.0001	25.0 ± 2.1	26.2 ± 2.5	29.0 ± 2.9	30.6 ± 3.4	32.3 ± 3.1	32.6 ± 3.9	< 0.0001
Main pulmonary artery (mm)	22.4 ± 3.4	23.5 ± 3.0	23.3 ± 3.2	23.0 ± 3.0	24.5 ± 3.5	25.5 ± 3.2	< 0.0001	21.4 ± 2.6	22.2 ± 2.8	22.6 ± 2.7	23.2 ± 2.9	24.4 ± 3.5	24.6 ± 3.2	< 0.0001

*p value from analysis of variance test in each gender. ST: sinotubular, 2D: two-dimensional, SD: standard deviation

Supplementary Table 6. LVM and relative wall thickness according to age and gender

Age groups	Men (mean ± SD)						p*	Women (mean ± SD)						p*
	21–30	31–40	41–50	51–60	61–70	71–80		21–30	31–40	41–50	51–60	61–70	71–80	
LVM (gm) by M-mode	139 ± 27	144 ± 31	143 ± 29	147 ± 27	147 ± 26	147 ± 24	0.4356	97 ± 17	104 ± 20	111 ± 22	120 ± 23	129 ± 23	128 ± 21	< 0.0001
LVMI (gm/m^2) by M-mode	76 ± 12	76 ± 13	78 ± 14	83 ± 15	85 ± 14	89 ± 13	< 0.0001	62 ± 9	66 ± 11	71 ± 13	77 ± 14	84 ± 14	84 ± 12	< 0.0001
LVM (gm) by 2D	133 ± 27	134 ± 26	133 ± 27	137 ± 23	134 ± 24	135 ± 25	0.9202	95 ± 17	98 ± 20	104 ± 19	112 ± 23	119 ± 23	121 ± 24	< 0.0001
LVMI (gm/m^2) by 2D	72 ± 12	71 ± 12	73 ± 14	77 ± 12	78 ± 13	82 ± 14	< 0.0001	61 ± 10	62 ± 10	67 ± 11	72 ± 14	77 ± 14	79 ± 15	< 0.0001
RWT by M-mode	0.32 ± 0.03	0.32 ± 0.03	0.32 ± 0.03	0.32 ± 0.04	0.34 ± 0.04	0.34 ± 0.04	< 0.0001	0.30 ± 0.03	0.30 ± 0.03	0.31 ± 0.03	0.31 ± 0.03	0.33 ± 0.03	0.34 ± 0.04	< 0.0001
RWT by 2D	0.32 ± 0.04	0.32 ± 0.03	0.32 ± 0.04	0.34 ± 0.04	0.34 ± 0.04	0.35 ± 0.05	< 0.0001	0.29 ± 0.03	0.30 ± 0.04	0.31 ± 0.03	0.32 ± 0.04	0.33 ± 0.04	0.35 ± 0.04	< 0.0001

*p value from analysis of variance test in each gender. LVM: left ventricular mass, LVMI: LVM index, RWT: relative wall thickness, 2D: two-dimensional, SD: standard deviation

Supplementary Table 7. Intra- and interobserver variability data

	Intraobserver variability		Interobserver variability	
	ICC	95% CI	ICC	95% CI
M-mode measurements				
LVEDD (mm)	0.990	0.982–0.995	0.981	0.964–0.990
LVESD (mm)	0.983	0.955–0.993	0.938	0.675–0.978
IVSWT (mm)	0.970	0.944–0.984	0.906	0.831–0.949
LVPWT (mm)	0.958	0.922–0.978	0.866	0.758–0.927
LA AP diameter (mm)	0.986	0.974–0.993	0.956	0.901–0.978
Aortic root diameter (mm)	0.970	0.945–0.984	0.968	0.938–0.984
RV end-diastolic free wall thickness (mm)	0.723	0.535–0.843	0.521	0.165–0.738
TAPSE (mm)	0.931	0.875–0.963	0.913	0.841–0.953
2D measurements				
Ventricles				
LVEDD (mm)	0.934	0.879–0.965	0.940	0.889–0.968
LVESD (mm)	0.954	0.914–0.975	0.921	0.850–0.958
IVSWT (mm)	0.922	0.840–0.960	0.860	0.740–0.925
LVPWT (mm)	0.884	0.792–0.937	0.712	0.479–0.845
LVEDV (mL)	0.973	0.915–0.989	0.958	0.911–0.979
LVESV (mL)	0.948	0.851–0.977	0.901	0.631–0.962
LVEDV index (mL/m^2)	0.945	0.862–0.975	0.838	0.715–0.911
LVESV index (mL/m^2)	0.914	0.789–0.960	0.824	0.669–0.906
LVEF (%)	0.807	0.655–0.895	0.764	0.372–0.898
LV long-axis dimension (mm)	0.954	0.915–0.975	0.866	0.606–0.943
Sphericity index	0.926	0.865–0.960	0.873	0.707–0.940
RV end-diastolic area (cm^2)	0.957	0.921–0.977	0.884	0.791–0.937
RV end-systolic area (cm^2)	0.964	0.934–0.981	0.883	0.790–0.937
RVFAC (%)	0.804	0.661–0.891	0.611	0.371–0.774
Basal RVD (mm)	0.875	0.777–0.932	0.897	0.806–0.946
Mid RVD (mm)	0.930	0.870–0.963	0.823	0.665–0.907
RV long-axis dimension (mm)	0.962	0.925–0.981	0.891	0.772–0.945
Proximal RVOT dimension (mm)	0.979	0.961–0.989	0.959	0.925–0.978
Distal RVOT dimension (mm)	0.927	0.868–0.961	0.878	0.781–0.933
Atrium				
LA area (cm^2) at A4C	0.936	0.882–0.966	0.889	0.798–0.940
LA area (cm^2) at A2C	0.955	0.917–0.976	0.896	0.806–0.945
LA longitudinal dimension (cm)	0.886	0.795–0.938	0.832	0.698–0.909
LA transverse dimension (mm)	0.969	0.942–0.983	0.911	0.839–0.952
LA AP dimension (mm)	0.958	0.923–0.978	0.870	0.506–0.951
LA volume (mL) by EM	0.966	0.937–0.982	0.932	0.870–0.964
LA volume index (mL/m^2) by EM	0.966	0.937–0.982	0.924	0.854–0.960
LA volume (mL) by ALM	0.972	0.948–0.985	0.913	0.727–0.964
LA volume index (mL/m^2) by ALM	0.963	0.932–0.980	0.899	0.689–0.958
RA transverse dimension (mm)	0.907	0.832–0.949	0.863	0.673–0.936
RA longitudinal dimension (mm)	0.938	0.886–0.967	0.908	0.834–0.951
RA area (cm^2)	0.940	0.890–0.968	0.932	0.874–0.963
Great vessels				
Aortic annulus (mm)	0.902	0.823–0.947	0.866	0.761–0.927
Sinus of Valsalva (mm)	0.969	0.942–0.983	0.961	0.922–0.980
ST junction (mm)	0.944	0.897–0.970	0.871	0.724–0.936

Supplementary Table 7. Intra- and interobserver variability data (continued)

	Intraobserver variability		Interobserver variability	
	ICC	95% CI	ICC	95% CI
Tubular portion of ascending aorta (mm)	0.979	0.960–0.989	0.972	0.948–0.985
Main pulmonary artery (mm)	0.941	0.891–0.968	0.883	0.790–0.937
LVM and RWT				
LVM (gm) by M-mode	0.992	0.986–0.996	0.962	0.930–0.980
LVMI (gm/m^2) by M-mode	0.987	0.976–0.993	0.939	0.889–0.967
LVM (gm) by 2D	0.975	0.939–0.988	0.936	0.859–0.969
LVMI (gm/m^2) by 2D	0.954	0.896–0.978	0.884	0.753–0.942
RWT by M-mode	0.930	0.872–0.962	0.787	0.624–0.883
RWT by 2D	0.790	0.639–0.883	0.600	0.332–0.773

ICC: intraclass correlation coefficient, LV: left ventricular, LVEDD: LV end-diastolic dimension, LVESD: LV end-systolic dimension, IVSWT: interventricular septal wall thickness, LVPWT: LV posterior wall thickness, LA: left atrial, AP: anteroposterior, TAPSE: tricuspid annular plane systolic excursion, LVEDV: LV end-diastolic volume, LVESV: LV end-systolic volume, LVEF: LV ejection fraction, RV: right ventricular, RVFAC: RV fractional area change, RVD: RV dimension, RVOT: RV outflow tract, A4C: apical 4-chamber view, A2C: apical 2-chamber view, EM: ellipsoid method, ALM: area length method, RA: right atrial, ST: sinotubular, LVM: LV mass, RWT: relative wall thickness, LVMI: LVM index, 2D: two-dimensional, CI: confidence interval