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**ORIGINAL PAPER**

# Relationship between the left-to-right ventricular volume ratio and aortic regurgitation severity: an echocardiographic and cardiac magnetic resonance imaging study

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**Aims**

Left ventricular (LV) enlargement in chronic aortic regurgitation (AR) is commonly assessed using diameters and volumes. However, these measures are influenced by body size, sex, and age. The left-to-right ventricular end-diastolic volume ratio (LV/RV ratio), assessed by cardiac magnetic resonance imaging (CMR) and known to remain close to 1 in healthy individuals, could provide a more individualized marker of LV remodeling in chronic AR.

**Methods and results**

This bi-centre study included 258 patients with chronic AR (median age: 55 years, 18% women) who underwent echocardiography (Echo) and CMR. LV and RV volumes were measured from cine-CMR images. Associations between the LV/RV ratio, conventional LV measures, and significant AR, defined as Grades 3–4 on Echo or aortic regurgitant fraction (AR-RegFrac) ≥ 33% on CMR, were analysed using area under the curve (AUC) and logistic regression. The median LV/RV ratio was 1.5 [1.3–1.9], increased with AR severity ($P < 0.001$), and correlated more strongly with AR-RegFrac ($r = 0.67$; $P < 0.001$) than conventional LV measures. The LV/RV ratio identified significant AR with good accuracy (Echo, AUC 0.77; CMR, AUC 0.83). A threshold of 1.5 provided balanced sensitivity and specificity (Se 71–84%, Sp 77–75%), while 1.8 ruled in significant AR with high specificity (Sp 91% for both modalities). The LV/RV ratio did not vary significantly by age or sex and showed consistent performance across subgroups.

**Conclusion**

The LV/RV ratio is a reliable and individualized marker of LV remodeling in chronic AR. These findings support its potential role in clinical assessment and further evaluation in outcome studies.

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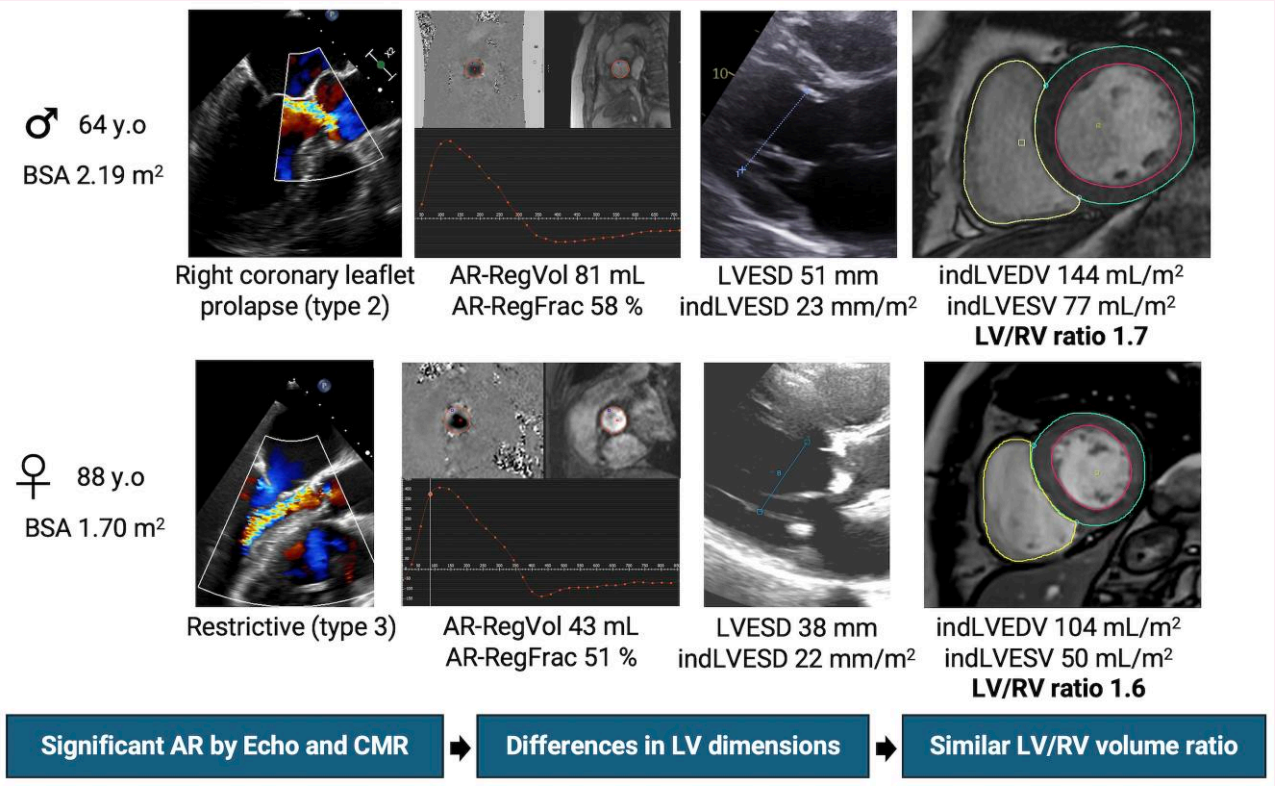
## Graphical Abstract




Example of two patients with significant aortic regurgitation (AR) assessed by echocardiography (Echo) and cardiac magnetic resonance imaging (CMR), but with different left ventricular (LV) dimensions. Despite differences in LV size and aortic regurgitant volume (AR-RegVol), both patients show similar LV/right ventricular (RV) volume ratios, highlighting its ability to account for inter-individual variability. For abbreviations, see *Table 1*.

**Keywords** aortic regurgitation • left ventricular remodeling • cardiac magnetic resonance imaging • left-to-right ventricular volume ratio

# Introduction

Chronic significant aortic regurgitation (AR) increases both preload and afterload, progressively leading to left ventricular (LV) dilation and eccentric hypertrophy.[1] AR severity is graded by transthoracic echocardiography (Echo) according to a multi-parameter, integrative approach, as recommended by the European Association of Cardiovascular Imaging (EACVI).[2,3] This strategy combines semi-quantitative parameters (Doppler colour jet characteristics, diastolic flow reversal in the descending aorta, pressure half-time of the AR jet on continuous-wave Doppler, vena contracta width), and quantitative Doppler measurements [effective regurgitant orifice area (EROA), regurgitant volume (RegVol) and regurgitant fraction (RegFrac) assessed by the proximal isovelocity surface area method]. Each parameter has specific strengths and limitations, and their combined interpretation allows a more robust and reproducible classification of AR severity than reliance on any single measurement.

Monitoring LV remodeling is crucial to assess disease progression in chronic AR. LV end-systolic diameter (LVESD) remains the most commonly used surrogate of adverse remodeling, given its strong association with outcomes and broad availability.[4] However, LV volumes better reflect geometric remodeling and are clinically relevant in chronic AR.[5–7] Yet, LV volumes are influenced by age, sex, and body size—factors unrelated to AR severity—making it difficult to define a single threshold to identify significant AR across patients.[8,9] While sex- and age-specific reference values for LV volumes exist, inter-individual variability remains.[10] Two patients with similar AR severity may have very different LV volumes, depending on their baseline LV size—the expected one without valvular regurgitation. Therefore, using an internal comparator may be more informative.

One such approach could be the ratio of left-to-right ventricular (RV) end-diastolic volumes (LVEDV/RVEDV), or LV/RV volume ratio, measurable by cardiac magnetic resonance imaging (CMR). In healthy individuals, this ratio is close to 1, with minimal variation by age or sex, reflecting biventricular symmetry.[11] This ratio may serve as a patient-specific reference to detect abnormal LV dilation. It has also been proposed as a marker of cardiovascular risk, providing additional value beyond standard LV measures.[11] We hypothesized that the LV/RV volume ratio could provide a more individualized marker of

LV remodeling by comparing LV size to the patient's own RV. The aim of this study was to determine whether the LV/RV volume ratio is more strongly associated with AR severity than conventional LV size measures.

# Methods

## Study population

This study included consecutive patients with chronic AR who underwent both Echo and CMR within a 3-month interval at two tertiary centres (Brussels and Lille) between 2005 and 2023. The study was approved by the institutional review boards of both centres (Brussels, 2016-29FEV076 and 2020-01AVR192; Lille, IRB 00013355). Inclusion criteria were: age ≥ 18 years and at least mild-to-moderate AR (grade ≥ 2+) on Echo. Exclusion criteria were AR-RegVol < 10 mL/beat on CMR, acute AR, concomitant ≥ moderate valvular heart disease, complex congenital heart disease, known cardiomyopathy, chronic pulmonary heart disease, pregnancy, coronary artery disease (>50% stenosis of an epicardial coronary artery or ischaemic myocardial scar), missing relevant Echo or CMR data, contraindications to CMR, prosthetic heart valve, and intracardiac shunt (*Figure 1*).

In each centre, Doppler-Echo and CMR data were prospectively entered into institutional databases and retrospectively pooled for analysis. Clinical data were obtained from electronic health records.

In addition to the study cohort, 100 normal CMR examinations were studied to investigate the LV/RV volume ratio in the absence of AR.

## Echocardiography

All patients had comprehensive Doppler-echocardiographic exams performed using commercially available ultrasound systems by experienced echocardiographers and interpreted locally according to guidelines. LVEDV and LV end-systolic volume (ESV) were measured using the biplane Simpson's method and indexed to body surface area (BSA). LV ejection fraction was calculated as [(EDV − ESV)/EDV]× 100. AR severity was graded according to a multi-parameter integrative approach, as recommended by the EACVI.[2] AR severity was graded as 2+ (mild-to-moderate), 3+ (moderate-to-severe), and 4+ (severe). Significant AR by Echo was defined as either Grade 3+ or 4+, as in clinical practice and surgical cohorts, patients with haemodynamically significant AR are referred for AV surgery according to guidelines.[4,12] Additionally, previous studies have shown a substantial overlap between AR Grades 3+ and 4+.[13–15] AR mechanism was categorized as follows: Type 1, aortic root dilatation; Type 2, excess cusp motion (prolapse, fenestration); and Type 3, cusp retraction, calcification or endocarditis; or indeterminate mechanism.[16]

## Cardiac magnetic resonance imaging

Details regarding the CMR assessment are provided in the Supplementary data online, Methods. CMR studies were performed on clinical scanners and analysed in the context of clinical practice. LV and RV volumes were assessed from contiguous short-axis cine steady-state free precession images covering the entire ventricles, from the valvular planes to the apex. Analyses were performed by experienced operators blinded to the echocardiographic findings. The LV mass, LV and RV volumes were indexed to BSA (calculated using the Mosteller formula). The LV/RV volume ratio was computed as the ratio of LVEDV to RVEDV (Supplementary data online, *Figure S1*). Inter-observer and intra-observer variabilities were assessed. Aortic regurgitant volume (AR-RegVol) was derived from reversal flow during diastole using phase contrast imaging, and the aortic regurgitant fraction (AR-RegFrac) was calculated as AR-RegVol divided by aortic forward flow. Significant AR by CMR was defined as AR-RegFrac ≥ 33%, in accordance with previous studies.[17,18]

## Statistical analysis

Data were analysed with R version 4.4.2 (R Foundation for Statistical Computing, Vienna, Austria) and GraphPad Prism (GraphPad Software, La Jolla, California). Quantitative data are reported as median (25th–75th percentile), while qualitative data are presented as absolute numbers and percentages. Comparisons of continuous variables across AR severity grades were performed using Kruskal–Wallis tests. Pairwise comparisons were conducted using Mann–Whitney *U* tests, with the Benjamini–Hochberg correction. Categorical variables were compared using the $\chi^2$ test or Fisher's exact test, as appropriate. Pearson's correlation coefficient was used to assess the relationship between the LV/RV volume ratio, conventional LV measures, and CMR-assessed AR-RegFrac.

The relationships between conventional LV measures (LVESD, indLVESD, CMR-indLVEDV, CMR-indLVESV) and the LV/RV volume ratio associated with significant AR [either based on Echo (AR Grades 3–4) or CMR (AR-RegFrac ≥ 33%)] were assessed using receiver operating characteristic (ROC) curve analysis.[7,17,18] Areas under the curve (AUCs) and threshold values (optimal, most sensitive, and most specific, based on Youden's index) were reported. Pairwise comparisons of AUCs were performed using the DeLong test. Multivariable logistic regression was used to assess the association of each metric with significant AR, adjusting for age and sex. Odds ratios (ORs) and 95% confidence intervals (CIs) were provided per 1 standard deviation (SD) increase (continuous OR) or dichotomized according to optimal threshold values (categorical OR). Additional analyses were conducted stratified by median age (< or ≥55 years) or sex. Intra- and inter-observer variabilities for the LV/RV volume ratio and indexed LV volumes were evaluated using intraclass correlation coefficient (ICC, single rater/measurement, absolute-agreement, two-way fixed-effects model) and coefficient of variation (CV). All analyses considered a two-tailed *P*-value of <0.05 as statistically significant.

# Results

## Control group

In a control group of 100 normal CMR examinations [median age 49 (25th–75th percentile: 33–61) years, 42% women], indLVEDV and indLVESV significantly differ by age (≥ or <55 years) or sex (all $P \leq 0.001$). Conversely, the median LV/RV volume ratio was of 1 [25th–75th percentile: 0.9–1.1], without significant difference by age or sex (all $P > 0.178$; Supplementary data online, *Figure S2*).

## Baseline characteristics

Of the 258 patients included [median age 55 (25th–75th percentile: 42–67) years], 17% were women. *Table 1* shows the characteristics of the study population, stratified by grades of AR.

## Relationship between the LV/RV volume ratio, conventional LV metrics, and AR severity

The LV/RV volume ratio and conventional LV metrics values differed significantly between AR grades (*Table 1*; *Figure 2*; all $P < 0.004$). The LV/RV volume ratio correlated more strongly with AR-RegFrac ($r = 0.67$; $P < 0.001$) than conventional LV measures (*Figure 3*).

Relations between the LV/RV volume ratio, conventional LV measures, and significant AR were evaluated by ROC curves. When significant AR was based on Echo, the AUCs numerically ranged from 0.60 (0.51–0.69; indLVESD) to 0.77 (0.70–0.83; LV/RV volume ratio; *Figure 3*). When significant AR was based on CMR, the AUCs numerically ranged from 0.64 (0.57–0.71; indLVESD) to 0.83 (0.78–0.88; LV/RV

**Table 1 Clinical and imaging characteristics of the study population according to AR severity grades**

| | All patients $n = 258$ | AR grade 2+ $n = 56$ | AR grade 3+ $n = 88$ | AR grade 4+ $n = 114$ | Overall *P*.value |
|---|---|---|---|---|---|
| Clinical characteristics | | | | | |
| Age (years) | 55 [42;67] | 56 [45;69] | 55 [39;66] | 55 [42;67] | 0.656 |
| Women, *n* (%) | 45 (17%) | 15 (27%) | 18 (21%) | 12 (11%)[a] | **0.021** |
| Body surface area ($m^2$) | 1.93 [1.80;2.08] | 1.91 [1.71;2.03] | 1.92 [1.79;2.06] | 1.97 [1.83;2.14][a] | **0.011** |
| Hypertension, *n* (%) | 128 (50%) | 26 (46%) | 46 (52%) | 56 (49%) | 0.784 |
| Dyslipidaemia, *n* (%) | 80 (31%) | 21 (38%) | 29 (33%) | 30 (26%) | 0.296 |
| Diabetes mellitus, *n* (%) | 14 (5%) | 1 (2%) | 7 (8%) | 6 (5%) | 0.281 |
| Systolic blood pressure (mmHg) | 135 [124;150] | 135 [120;151] | 130 [125;150] | 140 [126;150] | 0.809 |
| Diastolic blood pressure (mmHg) | 70 [60;80] | 70 [60;80] | 70 [61;80] | 67 [60;75] | **0.045** |
| Heart rate (bpm) | 66 [58;75] | 63 [55;70] | 65 [57;75] | 67 [61;75][a] | **0.032** |
| Echocardiographic characteristics | | | | | |
| LVEDD (mm) | 61 [55;67] | 55 [52;60] | 60 [56;64][b] | 65 [61;71][b,c] | **<0.001** |
| LVESD (mm) | 41 [36;47] | 37 [34;41] | 40 [36;45][a] | 45 [39;51][b,c] | **<0.001** |
| indLVEDD ($mm/m^2$) | 32 [29;35] | 29 [27;34] | 32 [30;34] | 33 [31;36][b,d] | **<0.001** |
| indLVESD ($mm/m^2$) | 22 [19;25] | 20 [17;24] | 21 [19;24] | 23 [19;26][a,d] | **0.004** |
| Echo-LVEF (%) | 56 [52;63] | 60 [54;65] | 58 [54;64] | 54 [51;59][a,d] | **<0.001** |
| Aortic valve morphology | | | | | 0.955 |
| Bicuspid, *n* (%) | 111 (43%) | 23 (41%) | 40 (46%) | 48 (42%) | |
| Tricuspid, *n* (%) | 147 (57%) | 33 (59%) | 48 (55%) | 66 (57%) | |
| AR mechanism | | | | | **<0.001** |
| Type 1, *n* (%) | 59 (23%) | 15 (27%) | 21 (24%)[a] | 23 (20%)[a] | |
| Type 2, *n* (%) | 125 (48%) | 11 (20%) | 48 (55%) | 66 (58%) | |
| Type 3, *n* (%) | 61 (24%) | 23 (41%) | 17 (19%) | 21 (18%) | |
| Indeterminate, *n* (%) | 13 (5%) | 7 (13%) | 2 (2%) | 4 (3%) | |
| AR-EROA ($mm^2$) ($n = 225$) | 29 [23;36] | 16 [13;19] | 26 [23;28][b] | 36 [32;44][b,c] | **<0.001** |
| Echo-RegVol (mL) ($n = 223$) | 61 [47;76] | 39 [33;44] | 55 [48;68][b] | 74 [63;93][b,c] | **<0.001** |
| CMR characteristics | | | | | |
| CMR-indLVEDV ($mL/m^2$) | 129 [108;161] | 110 [94.8;127] | 124 [109;154][a] | 153 [116;179][b,c] | **<0.001** |
| CMR-indLVESV ($mL/m^2$) | 60 [47;82] | 48 [38;66] | 58 [47;73][a] | 74 [54;95][b,c] | **<0.001** |
| CMR-indLV mass ($g/m^2$) | 85 [71;100] | 72 [63;85] | 83 [71;92][a] | 92 [79;112][b,c] | **<0.001** |
| CMR-LVEF (%) | 53 [48;58] | 56 [46;61] | 54 [50;58] | 51 [45;56][a,d] | **0.007** |
| CMR-indRVEDV ($mL/m^2$) | 84 [72;97] | 83 [75;92] | 85 [72;101] | 83 [72;95] | 0.383 |
| CMR-indRVESV ($mL/m^2$) | 39 [31;48] | 38 [29;45] | 39 [31;51] | 39 [32;47] | 0.761 |
| CMR-RVEF (%) | 53 [47;60] | 55 [48;61] | 54 [49;58] | 53 [46;60] | 0.794 |
| AR-RegVol (mL) | 43 [25;68] | 21 [15;29] | 37 [25;66][b] | 59 [44;82][b,c] | **<0.001** |
| AR-RegFrac (%) | 36 [24;49] | 23 [18;27] | 35 [26;46][b] | 45 [35;54][b,c] | **<0.001** |
| LV/RV volume ratio | 1.5 [1.3;1.9] | 1.3 [1.2;1.4] | 1.5 [1.3;1.7][b] | 1.8 [1.5;2.1][b,c] | **<0.001** |

EDD, end-diastolic diameter; EDV, end-diastolic volume; EF, ejection fraction; EROA, effective regurgitant orifice area; ESD, end-systolic diameter; ESV, end-systolic volume; ind, indexed to body surface area; LV, left ventricle/ventricular; RegFrac, regurgitant fraction; RegVol, regurgitant volume; RV, right ventricle/ventricular.
[a]$P < 0.05$ individual category vs. AR Grade 2.
[b]$P < 0.001$ individual category vs. AR Grade 2.
[c]$P < 0.001$ individual category vs. AR Grade 3.
[d]$P < 0.05$ individual category vs. AR Grade 3.

volume ratio; *Figure 4*). Pairwise comparisons of AUCs, performed using the DeLong test, are provided in Supplementary data online, *Tables S1* and *S2*.

A threshold of 1.5 for the LV/RV volume ratio showed the best balance between sensitivity and specificity (Echo, Se 71% and Sp 77%; CMR, Se 84% and Sp 75%; *Table 2*). A threshold of 1.8 was associated

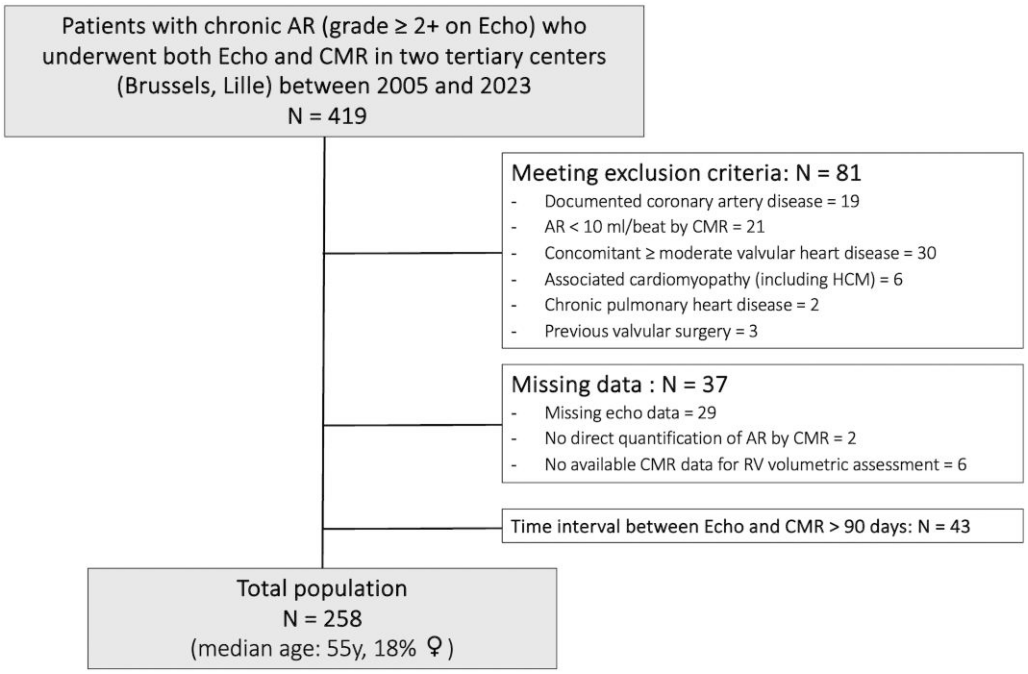



**Figure 1** Flow chart of the study population. HCM, hypertrophic cardiomyopathy; RV, right ventricular.

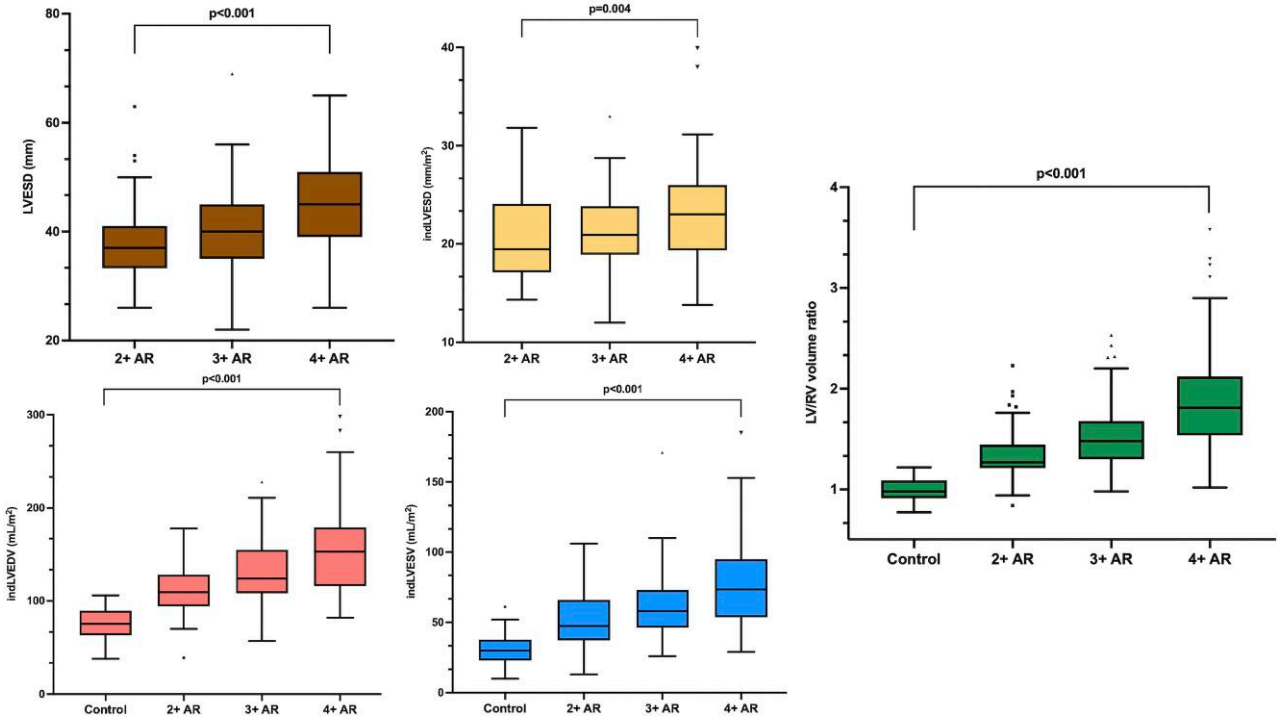



**Figure 2** Relationship between the LV/RV volume ratio, conventional LV measures, and AR grades by Echo. For abbreviations, see *Table 1*.

with high specificity (91% for both Echo and CMR), while a threshold of 1.3 was associated with high sensitivity (Echo, 84%; CMR, 92%; *Table 3*; *Figure 5*).

After adjusting for age and sex, the LV volume ratio and conventional LV measures were associated with the presence of significant AR by Echo or CMR (*Table 4*).

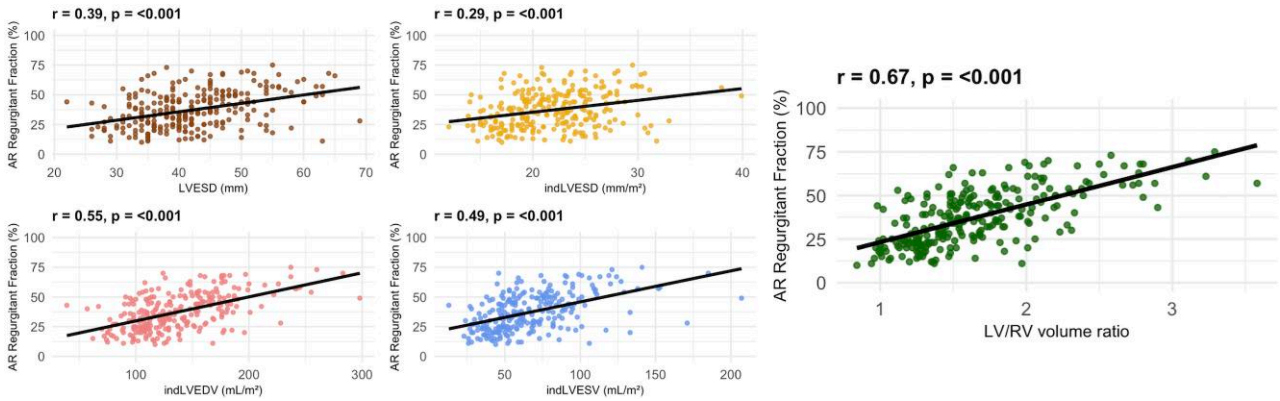



**Figure 3** Relationship between the LV/RV volume ratio, conventional LV measures, and AR regurgitant fraction by CMR. For abbreviations, see *Table 1*.

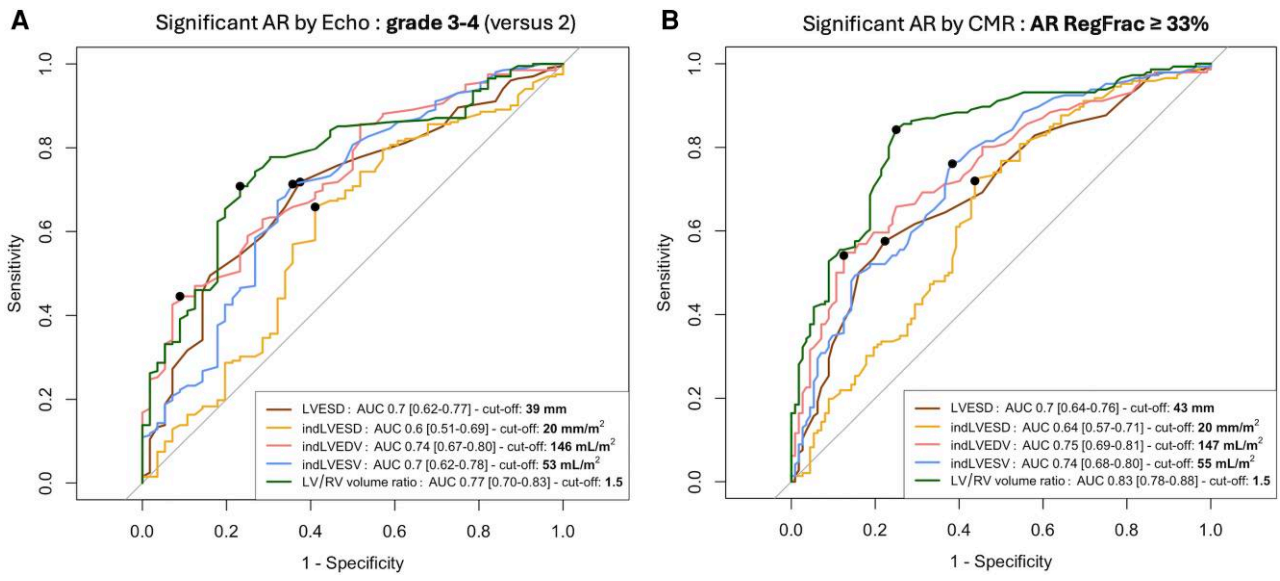



**Figure 4** Relationship between the LV/RV volume ratio, conventional LV measures, and significant AR. ROC curves display the relationship between the LV/RV volume ratio, conventional LV measures, and significant AR by Echo (*A*) or CMR (*B*). For abbreviations, see *Table 1*.

## Relationship between the LV/RV volume ratio, conventional LV metrics, and significant AR according to age and sex

Unlike indexed LV volumes, the LV/RV volume ratio did not significantly differ by age (≥ or <55 years) or sex ($P = 0.350$ and $P = 0.160$, respectively; *Figure 6*). The LV/RV volume ratio showed consistent threshold values across age and sex subgroups (*Tables 3* and *5*).

## Reproducibility

Inter- and intra-observer agreement for the LV/RV volume ratio were excellent [ICC 0.979 (0.748–0.995) and CV 3.7% and ICC 0.99 [0.97–0.996] and CV 2.7%, respectively; Supplementary data online, *Table S3*].

# Discussion

In this bi-centre cohort of patients with at least mild-to-moderate (Grade 2+) chronic AR, we assessed the relationship between the LV/RV volume ratio and AR severity, compared with conventional LV measures (including Echo-absolute and indexed LVESD and CMR-indexed LV volumes). The LV/RV volume ratio showed a stronger correlation with AR severity on Echo and with CMR-based AR-RegFrac than conventional LV parameters. A threshold of 1.5 provided the best balance between sensitivity and specificity to detect significant AR, while a threshold of 1.8 ruled in significant AR. Unlike

**Table 2 Comparison of AUC, optimal cutoff, and diagnostic accuracies of the LV/RV volume ratio and conventional LV measures, associated with significant AR**

| | AUC | Threshold value | Sensitivity (%) | Specificity (%) |
|---|---|---|---|---|
| Significant AR by Echo | | | | |
| LVESD | 0.70 (0.62–0.77) | 39 mm | 72 | 62 |
| indLVESD | 0.60 (0.51–0.69) | 20 mm/m$^2$ | 66 | 59 |
| CMR-indLVEDV | 0.74 (0.67–0.80) | 146 mL/m$^2$ | 45 | 91 |
| CMR-indLVESV | 0.70 (0.62–0.78) | 53 mL/m$^2$ | 71 | 64 |
| LV/RV volume ratio | 0.77 (0.70–0.83) | 1.5 | 71 | 77 |
| | **AUC** | **Threshold value** | **Sensitivity (%)** | **Specificity (%)** |
| Significant AR by CMR | | | | |
| LVESD | 0.70 (0.64– 0.76) | 43 mm | 58 | 78 |
| indLVESD | 0.64 (0.57–0.71) | 20 mm/m$^2$ | 72 | 56 |
| CMR-indLVEDV | 0.75 (0.69– 0.81) | 147 mL/m$^2$ | 54 | 88 |
| CMR-indLVESV | 0.74 (0.68–0.80) | 55 mL/m$^2$ | 76 | 62 |
| LV/RV volume ratio | 0.83 (0.78–0.88) | 1.5 | 84 | 75 |

For abbreviations, see *Table 1*.

**Table 3 Diagnostic performance of the LV/RV volume ratio thresholds for rule in and out significant AR**

| | Significant AR by Echo | | Significant AR by CMR | | |
|---|---|---|---|---|---|
| **Threshold** | **Se (%)** | **Sp (%)** | **Se (%)** | **Sp (%)** | **Prop. of patients above the threshold, *n* (%)** |
| All patients | | | | | |
| 1.3 | 84 | 55 | 92 | 46 | 195 (76%) |
| 1.8 | 37 | 91 | 47 | 91 | 79 (31%) |
| Women | | | | | |
| 1.3 | 80 | 47 | 84 | 38 | 37 (82%) |
| 1.8 | 30 | 93 | 37 | 88 | 10 (22%) |
| Men | | | | | |
| 1.3 | 85 | 59 | 94 | 39 | 163 (77%) |
| 1.8 | 38 | 90 | 49 | 92 | 69 (32%) |
| Age < 55 years | | | | | |
| 1.3 | 80 | 59 | 92 | 54 | 91 (72%) |
| 1.8 | 38 | 93 | 51 | 93 | 40 (31%) |
| Age ≥ 55 years | | | | | |
| 1.3 | 88 | 52 | 80 | 59 | 104 (79%) |
| 1.8 | 35 | 90 | 38 | 93 | 39 (30%) |

Se, sensitivity, Sp, specificity.

indexed LV volumes, the diagnostic performance of the LV/RV volume ratio remained consistent across age and sex subgroups. Overall, these findings suggest that the LV/RV volume ratio may provide a more individualized assessment of adverse LV remodeling in chronic AR, particularly in patients with smaller cardiac size, such as women and older adults (*Graphical Abstract*).

AR severity cannot rely on a single echocardiographic parameter, as no individual marker combines both ease of acquisition and consistent correlation with regurgitation severity across all patients. Therefore, a multiparametric echocardiographic approach is recommended.[2] CMR plays an increasingly important role in the assessment of AR severity. The AR-RegFrac is the primary quantitative parameter, but it may be

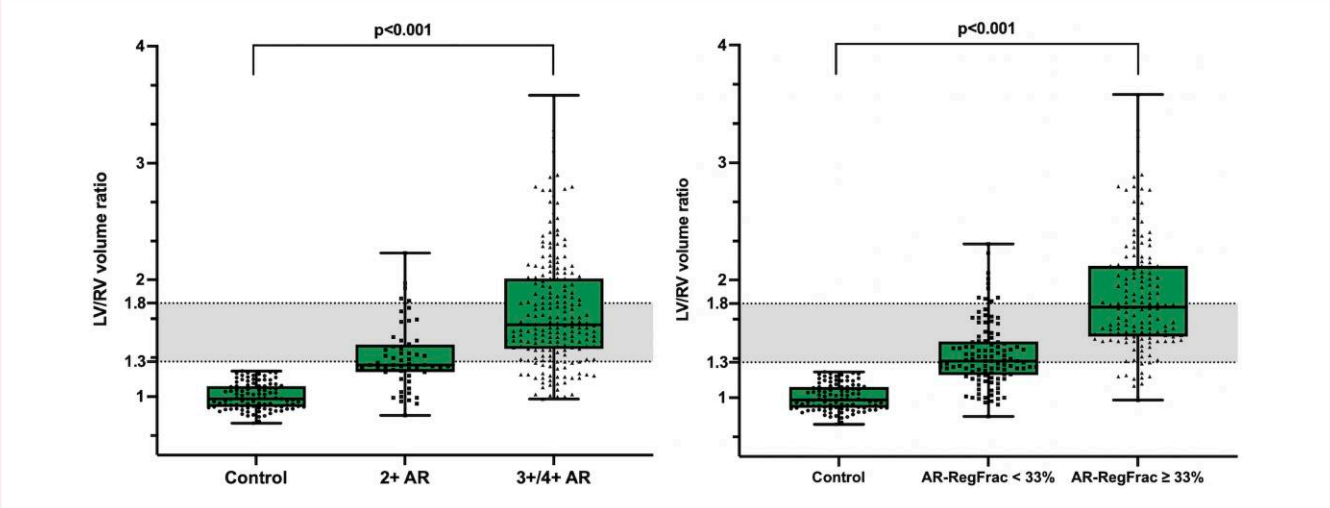



**Figure 5** LV/RV volume ratio according to AR severity, based on AR grade by Echo (left) and AR-RegFrac ≥ 33% vs. AR-RegFrac < 33% (right). Each panel shows individual values with box plots. Dashed lines correspond to LV/RV ratio thresholds of 1.3 and 1.8, associated with low and high probability of significant AR, respectively. The area between these two threshold values represents a diagnostic overlap zone.

**Table 4 Age- and sex-adjusted odds ratio associated with significant AR**

| | Continuous OR | *P*-value | Categorical OR | *P*-value |
|---|---|---|---|---|
| Significant AR by Echo | | | | |
| LVESD | 2.10 (1.43–3.08) | <0.001 | 4.24 (2.28–7.81) | <0.001 |
| indLVESD | 1.50 (1.08–2.09) | 0.016 | 2.76 (1.49–5.13) | 0.001 |
| CMR-indLVEDV | 3.11 (1.95–4.98) | <0.001 | 7.82 (2.93–20.86) | <0.001 |
| CMR-indLVESV | 2.39 (1.51–3.76) | <0.001 | 4.24 (2.24–8.02) | <0.001 |
| LV/RV volume ratio | 4.25 (2.44–7.41) | <0.001 | 7.41 (3.58–15.35) | <0.001 |
| | **Continuous OR** | ***P*-value** | **Categorical OR** | ***P*-value** |
| Significant AR by CMR | | | | |
| LVESD | 2.07 (1.52–2.82) | <0.001 | 4.47 (2.56–7.81) | <0.001 |
| indLVESD | 1.74 (1.31–2.31) | <0.001 | 3.15 (1.85–5.36) | <0.001 |
| CMR-indLVEDV | 3.27 (2.23–4.81) | <0.001 | 9.03 (4.55–7.94) | <0.001 |
| CMR-indLVESV | 2.62 (1.82–3.79) | <0.001 | 4.86 (2.81–8.42) | <0.001 |
| LV/RV volume ratio | 6.28 (3.77–10.47) | <0.001 | 12.1 (6.67–21.97) | <0.001 |

For abbreviations, see *Table 1*. ORs and 95% CIs were provided per 1 SD increase (continuous OR) or dichotomized according to optimal threshold values (categorical OR).

unreliable in patients with arrhythmias, highly eccentric jets, or aortic root dilation. Measurements can also vary depending on technical factors, such as velocity encoding acquisition plane level. In patients without arrhythmia or other significant valvular disease, AR severity can also be assessed by comparing aortic and pulmonary forward stroke volumes, as historically done with radionuclide ventriculography.[19,20] The LV/RV volume ratio reflects this volumetric difference and may serve as a complementary marker of AR severity in clinical practice. In our study, this ratio was strongly associated with AR severity, regardless of the imaging modality used to grade AR.

Echocardiographic LV diameters are easy to obtain, reproducible, and strongly associated with long-term outcomes in patients with chronic AR. However, relying solely on linear measurements may underestimate disease severity, especially in cases of asymmetric, non-concentric LV enlargement. LV volumes show a closer correlation with AR severity and are associated with outcomes.[6,7,21] Yet, cardiac volumes are influenced by age, sex, and body size, irrespective of AR severity, an observation confirmed in our cohort and supported by previous reports.[8,9] As a result, some patients with truly significant chronic AR may have only mildly enlarged LV. Notably, a recent

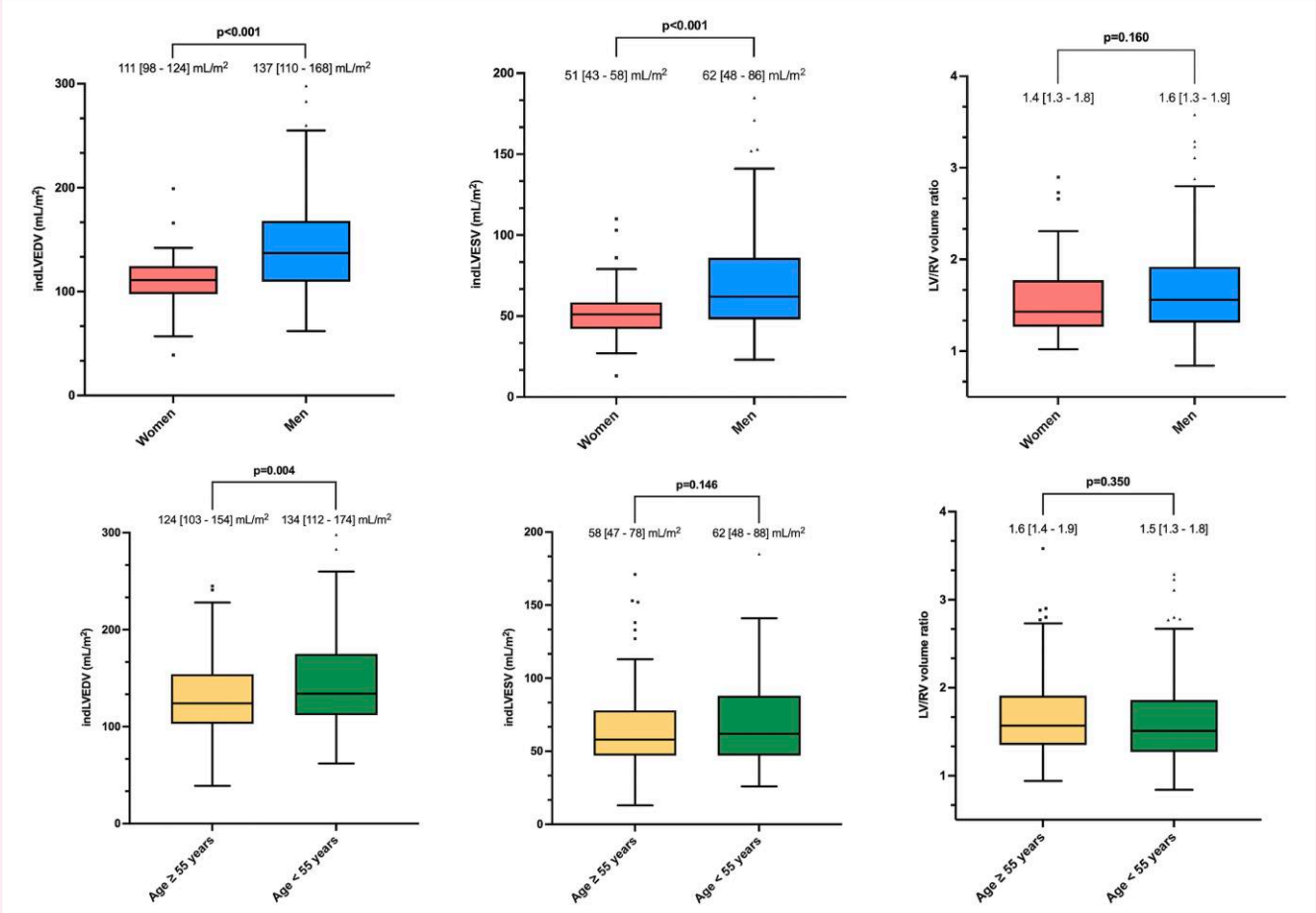



**Figure 6** LV/RV volume ratio and indexed LV volumes according to age and sex. For abbreviations, see *Table 1*.

**Table 5 Comparison of AUC, optimal cutoff, and diagnostic accuracies of the LV/RV volume ratio and indexed LV volumes, associated with significant AR and stratified by age (≥ or <55 years) or sex**

| | AUC | Threshold value | Sensitivity (%) | Specificity (%) |
|---|---|---|---|---|
| CMR-indLVEDV | | | | |
| Women | 0.56 (0.38–0.75) | 127 mL/m$^2$ | 32 | 92 |
| Men | 0.77 (0.71–0.83) | 147 mL/m$^2$ | 61 | 84 |
| Age < 55 years | 0.78 (0.70–0.86) | 146 mL/m$^2$ | 66 | 86 |
| Age ≥ 55 years | 0.74 (0.65–0.83) | 130 mL/m$^2$ | 60 | 79 |
| CMR-indLVESV | | | | |
| Women | 0.63 (0.45–0.81) | 53 mL/m$^2$ | 63 | 73 |
| Men | 0.74 (0.68–0.81) | 74 mL/m$^2$ | 72 | 56 |
| Age < 55 years | 0.76 (0.67– 0.84) | 74 mL/m$^2$ | 59 | 84 |
| Age ≥ 55 years | 0.72 (0.62–0.81) | 52 mL/m$^2$ | 81 | 71 |
| LV/RV volume ratio | | | | |
| Women | 0.70 (0.53–0.86) | 1.6 | 58 | 81 |
| Men | 0.86 (0.80–0.91) | 1.5 | 88 | 78 |
| Age < 55 years | 0.86 (0.79– 0.92) | 1.5 | 86 | 82 |
| Age ≥ 55 years | 0.81 (0.73–0.88) | 1.5 | 81 | 71 |

For abbreviations, see *Table 1*.

phenomapping study described distinct profiles, notably among women and/or older patients, with less LV dilation despite similar AR severity, but a greater symptom burden and higher mortality risk.[22]

The LV/RV volume ratio is physiologically close to 1, regardless of age or sex, as reported in the UK Biobank cohort and confirmed in our own normal reference CMR dataset.[11] The idea of using an 'internal control' has previously been applied to RV assessment in the setting of pulmonary regurgitation after repaired tetralogy of Fallot, pulmonary hypertension, and more recently tricuspid regurgitation.[23–26] We extended this approach to LV assessment, aiming to identify a metric less influenced by physiological variability. We identified a threshold of 1.5 for the LV/RV volume ratio that provided the best balance between sensitivity and specificity to detect significant AR and performed better than conventional LV metrics. Unlike LV volumes, the LV/RV volume ratio showed consistent diagnostic performance across age and sex subgroups, suggesting its usefulness in patients with smaller cardiac dimensions, such as women and older adults.

## Clinical perspectives

The LV/RV volume ratio may provide a patient-specific way to assess LV dilation by referencing an internal control—namely, the RV, which is usually unaffected by AR. This within-patient comparison may better reflect the impact of chronic AR on LV remodeling. It is also easy to apply in clinical practice, as it can be derived from standard CMR volumetric images without the need for advanced techniques. A threshold of 1.8, associated with high specificity, may serve to rule in significant AR and could be useful in the context of CMR, which is typically used as a second-line imaging modality for AR quantification. Conversely, a threshold of 1.3, associated with high sensitivity, may serve to rule out significant AR.

Data on the progression of remodeling in chronic AR are mostly limited to serial measurements of LV diameters.[27] Longitudinal data on LV volume changes in AR remain scarce.[28] As this was a cross-sectional study, we could not evaluate temporal changes. Future longitudinal studies comparing the evolution of the LV/RV ratio with conventional LV measures in conservatively managed patients may provide important insights. Whether this ratio normalizes after AV surgery may also help assess reverse remodeling.

4D-Echo allows accurate and reproducible LV volume measurements in most patients, with close agreement to CMR. Similarly, RV volume assessment by 4D-Echo is feasible; however, its routine use requires specific expertise, excellent quality Echo datasets, and may be limited by the complex geometry of the RV. Whether the LV/RV volume ratio derived from 4D-Echo is clinically relevant in chronic AR warrants further investigation.

Prognostic implications were beyond the scope of this exploratory analysis; therefore, our findings support future investigations into the association between the LV/RV ratio and outcomes in AR.

## Limitations

This study has several limitations. First, it was observational in nature and can only identify associations, not causality. Secondly, there is no universal gold standard for assessing AR severity by Echo. In this study, AR severity was evaluated using a guideline-based, multiparametric approach by experienced cardiologists. The association between the LV/RV volume ratio and AR severity was consistent when severity was defined using CMR AR-RegFrac, supporting its relevance across imaging modalities. Thirdly, the LV/RV ratio may not be reliable in patients with significant RV involvement, either due to advanced AR or other cardiac or pulmonary conditions. Fourthly, the proportion of women was lower in the AR group compared with controls, consistent with most contemporary AR cohorts where men are overrepresented. In addition, LV/RV ratio was similar between sexes in controls. Nevertheless, this imbalance should be considered when interpreting our findings, and larger studies are needed to confirm the clinical relevance of the LV/RV ratio specifically in women. Fifthly, hypertension can influence LV size and myocardial mass; however, data on antihypertensive medication use, adherence, and actual blood pressure control were not available. Finally, our findings may not apply to patients with more than mild-associated valvular disease, in whom biventricular remodeling may result from multiple causes.

# Conclusion

In this cohort of patients with chronic AR, the LV/RV volume ratio was more strongly associated with AR severity than conventional LV measures. A threshold of 1.5 identified significant AR with balanced sensitivity and specificity across Echo and CMR, while a threshold of 1.8 may help rule in significant AR. By referencing an internal, patient-specific control, this ratio may offer a more individualized assessment of LV remodeling, particularly in women and older adults. These results support further investigation into its clinical and prognostic value in chronic AR.

# Supplementary data

Supplementary data are available at *European Heart Journal - Cardiovascular Imaging* online.

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# Author contributions

Alexandre Altes (Conceptualization [lead], Data curation [lead], Formal analysis [lead], Methodology [lead], Writing—original draft [lead]), Vincent Hanet (Data curation [equal], Funding acquisition [lead], Investigation [supporting], Resources [supporting], Writing—review & editing [supporting]), Bérengère Cardot (Conceptualization [equal], Formal analysis [supporting], Investigation [supporting], Writing—review & editing [supporting]), David Vancraeynest (Resources [supporting], Writing—review & editing [supporting]), Agnès Pasquet (Resources [supporting], Writing—review & editing [supporting]), François Delelis (Resources [supporting], Writing—review & editing [supporting]), Achwaq Lebouazda (Investigation [supporting], Writing—review & editing [supporting]), Fanny Tartare (Investigation [supporting], Software [supporting], Writing—review & editing [supporting]), Domitille Tristram (Investigation [supporting], Project administration [supporting], Writing—review & editing [supporting]), Manuel Toledano (Resources [supporting], Writing—review & editing [supporting]), Valentina Silvestri (Resources [supporting], Writing—review & editing [supporting]), Bernhard L Gerber (Methodology [supporting], Project administration [equal], Resources [supporting], Supervision [equal], Validation [supporting], Writing—review & editing [supporting]), and Sylvestre Maréchaux (Conceptualization [supporting], Supervision [lead], Validation [lead], Writing—review & editing [supporting])

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## Data availability

The data that support the results of this study are available from the corresponding author upon reasonable request.

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