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# Value of CMR in quantification of paravalvular aortic regurgitation after TAVI

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**Aims** To assess the value of cardiac magnetic resonance (CMR) using phase-contrast velocity mapping for paravalvular aortic regurgitation (PAR) quantification.

**Methods and results** All patients undergoing transcatheter aortic valve implantation (TAVI) in our centre between November 2012 and August 2013, without CMR-contraindication were included. PAR severity was assessed 5 days after TAVI using: transthoracic echocardiography (TTE) and CMR [regurgitant volume (RV), regurgitant fraction (RF)]. Aortic regurgitation (AR) index was obtained during TAVI. Thirty of 51 patients who underwent TAVI were included (COREVALVE, $n = 10$; or EDWARDS SAPIEN XT, $n = 20$). At TTE, PAR was mild in 22, moderate in 3, and severe in 5 patients. Reliable phase-contrast images were acquired at the sino-tubular junction for SAPIEN and at the tubular portion of the ascending aorta for COREVALVE. The reproducibility of CMR was high (coefficient of correlation = 0.99 for intra- and inter-operator variability). At CMR, RV, and RF were significantly ($P < 0.0005$) correlated with AR severity at TTE, with mean RF values at 9.2 ± 7.6% in mild, 20.3 ± 4.2% in moderate, and 46.8 ± 10.8% in severe PAR. A cut-off value of RF < 14% at CMR accurately discriminated mild from moderate/severe (sensitivity: 100%, specificity: 82%). The mean AR index was 29.4 ± 6 for mild and 13.8 ± 5 for moderate/severe PAR. Three patients had a RF > 14% and a low AR index <25 despite a mild PAR at TTE, suggesting an underestimation at TTE.

**Conclusion** CMR is a reproducible, accurate, and reliable method to assess PAR severity. CMR may allow correcting an underestimation at TTE when AR index is doubtful.

**Keywords** aortic regurgitation • aortic stenosis • cardiovascular magnetic resonance • transcatheter aortic valve implantation

## Introduction

Since the publication of the PARTNER Trial results, transcatheter aortic valve implantation (TAVI) has become the treatment of choice for aortic valve stenosis (AS) in inoperable patients, and a valid alternative to conventional surgery [surgical aortic valve replacement (SAVR)] in high-risk patients, with comparable short-term mortality.[1] However, paravalvular aortic regurgitations (PARs) are observed in nearly 70–84% of patients after TAVI, with 15–25% of patients having moderate to severe.[2–4] Moreover, significant PAR is an independent predictor of death after TAVI.[2–4] Even mild PAR was associated with increased late mortality in the PARTNER trial.[5] However, the later result has not been confirmed in the COREVALVE US PIVOTAL study where mild PAR had no impact on long-term mortality after TAVI.[6]

Therefore, accurate quantification of PAR is crucial, but is still a challenge. Transthoracic echocardiography (TTE) is used in routine, as it has been extensively validated for the evaluation of prosthetic aortic valve function after SAVR;[7,8] nevertheless assessment of PAR after TAVI is often difficult and it may explain controversies and diverging results about the real impact of mild PAR.

Other methods to quantify PAR have been proposed but present some limitations as well. The haemodynamic measurement of aortic regurgitation (AR) index allows an assessment of PAR severity but this method still depends on other factors of variability. An AR index <25 has been reported to be an independent factor of mortality at 1 year after TAVI.[9] Cardiac magnetic resonance (CMR) provides a direct quantification of native AR[10,11] with high accuracy and reproducibility by using the technique of phase-contrast velocity mapping.[12,13] However, only few publications have evaluated this

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method to assess PAR.[14–18] According to VARC 2 recommendations, the cut-off value for a mild PAR is a regurgitant fraction (RF) <30%; however, this recommendation is based primarily on the studies concerning native AR.

The primary objective of our study was to evaluate CMR as a method to quantify PAR after TAVI with TTE as the current method of reference, to establish a RF cut-off value to discriminate mild and moderate/severe PAR. Our secondary objective was to use a multi-imaging and haemodynamic approach to better quantify PAR, with the comparison of TTE vs. CMR with AR index as a corrective tool.

# Methods

## Patient population

From November 2012 to August 2013, all patients undergoing TAVI in our centre, either with Medtronic COREVALVE (CV) (Medtronic, Minneapolis, MN, USA) or EDWARDS SAPIEN XT (EDXT) (Edwards Lifesciences, Irvine, CA, USA) were screened for inclusion in this prospective study. Exclusion criteria were a contraindication for CMR [claustrophobia, pacemaker (PM) or implantable cardioverter-defibrillator (ICD), agitation, death] or refusal to write informed consent. Eligibility for TAVI was established on the consensus of a local multidisciplinary 'Heart Team', which included cardiologists, cardiac surgeons, and cardiac anaesthesiologists.

## Devices and procedures

Before TAVI, the aortic annulus dimension and calcifications of aortic root were assessed by transoesophageal echocardiography (TOE), angiography, and multi-slice computed tomography. Patients received either CV or EDXT according to Heart Team preference for each patient. Sizes of transcatheter heart valve (THV) were chosen according to the assessment of the aortic annulus dimensions. TAVI was performed with biplane fluoroscopy under general anaesthesia. Intraprocedural TOE was routinely performed, but procedures were predominantly guided by fluoroscopy. For confirmation of technical success, TOE, aortography, and AR index (according to the following formula: [(DBP – LVEDP)/SBP] × 100) were used.[9] Data of TOE and aortography were not collected.

## Echocardiographic assessment

Echocardiographic studies were performed with a commercially available echocardiographic system (Vivid E9; General Electric Vingmed, Horten, Norway) and 2D transthoracic probe (M5S, General Electric Vingmed, Horten, Norway) by an echocardiographer who did not attend the procedure and who was blinded to the results of the CMR. Loops were recorded and secondary analysed by two independent echocardiographers. Mean transvalvular gradient and aortic area were calculated according to the European recommendations.[19] The PAR was assessed by TTE at Day 5 after TAVI and graded as mild, moderate, or severe using a multiparametric approach. This assessment included analysis of qualitative and semi-quantitative parameters according to the recommendations of the European and American Associations of Echocardiography and the VARC criteria.[7,8,19,20] All views were used for the detection of the regurgitant jets: the parasternal long axis and short axis, the three and five chambers, and the subcostal. A number of jets and extent were assessed in parasternal long and short axes and three and five chambers. The jet width was measured just below the apical border of the THV. The circumferential extent (%) of the PAR was assessed in the parasternal short axis. Valve structure and motion, and Doppler parameters [CW-Doppler of PAR, holodiastolic flow reversal in descending aorta, PW-Doppler in left ventricular outflow tract (LVOT)] were evaluated. Doppler measurements were realized as the average of at least three cycles in patients with sinus rhythm or five cycles in those with atrial fibrillation. In case of discordance between different echocardiographic parameters, the final grading of PAR was taken after assessing and interpreting all parameters. As the majority of authors who have investigated the TTE vs. CMR assessment of PAR,[14,17,18,21] the quantifications of RV and RF were not included in the analysis.

## Cardiac magnetic resonance

After taking into consideration, the safety and use conditions under which the Medtronic CV and the EDXT can be scanned, all imaging was performed on a 1.5 T MR scanner (Symphony TIM, Siemens, Erlangen, Germany, with a 12-element phased array cardiac coil) at Day 5 after TAVI. A standard electrocardiogram-gated CMR method was used. Cine steady-state free precession sequences were acquired on long-axis 2-chamber, 4-chamber, and short-axis views to cover the whole left ventricular. Aortic flow measurements were obtained with a breath-hold flow-encoded fast low-angle shot sequence. Aortic flow measurement was obtained at four different levels (*Figure 1A* and *B*): (1) LVOT, just under the THV; (2) aortic annulus, into the THV; (3) sino-tubular junction (STJ), just above the upper margin of the EDXT, or at the end into the stent for the CV; and (4) tubular portion of the ascending aorta, just above the upper margin of the CV or few millimetres above the EDXT. At each level, imaging planes were placed perpendicular to the aortic flow. Maximum velocity encoding was adapted individually to avoid aliasing. Imaging parameters were repetition time/echo time: 57.55 ms/5.55 ms, slice thickness: 6 mm, field of view: 390 × 250 $mm^2$, matrix size: 256 × 123, voxel size: 3 × 1.5, flow encoding: 250 cm/s, flip angle: 30°, temporal resolution: 57 ms, and four segments. All examinations were transferred to a dedicated workstation and flow was quantified using Siemens Argus™ Flow software (Siemens, Erlangen, Germany). A team including a cardiologist and a radiologist analysed all sequences of cine and flow and controlled the different validation criteria for each levels: (i) agreement between the SV obtained by velocity mapping and by volumes method, (ii) the absence of velocity detection artefact, and (iii) harmonious curve of flow. Only the validated and reliable level was used for the comparison of PAR severity by TTE. Two other operators independently traced the contour of the anatomic structure of interest on the magnitude images at each cine frame for the inter-operator variability. This traced region was matched and applied to the corresponding phase image. The stroke volume (SV) and regurgitant volume (RV) were determined, and RF was calculated as in the previous studies[14–18] by the following formula (*Figure 1C–E*):

$$RF = \frac{RV}{SV} \times 100.$$

One operator re-examined later to determine intra-operator variability.

## Statistical analysis

Data are presented as mean ± SD if normally distributed or as median and interquartile range if not normally distributed. Categorical variables are given as frequencies and percentages. For continuous variables, a Mann–Whitney test was performed for comparison between the two groups. When comparing more than two groups, analysis of variance or

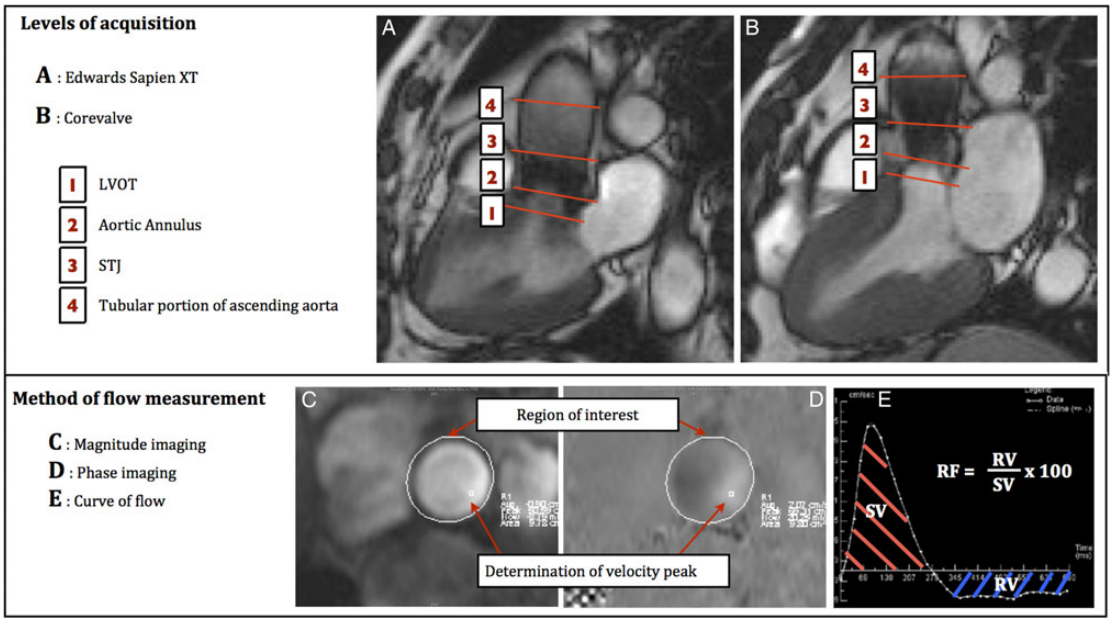


**Figure 1** Method of phase-contrast velocity mapping by CMR. Levels of acquisition of phase-contrast velocity mapping: (*A*) in case of Edwards SAPIEN XT and (*B*) in case of COREVALE. Levels of acquisition through anatomic structure perpendicular to aortic flow: (1) LVOT; (2) aortic annulus; (3) STJ; (4) tubular portion of ascending aorta. Method of flow measurement: (*C*) magnitude phase-contrast imaging—traced of the region of interest and concordance of the traced region on the phase imaging sequence; (*D*) velocity phase imaging, determination of velocity mapping, and peak of velocity and concordance with magnitude imaging; and (*E*) determination of curve of flow during one cardiac cycle, positive flow corresponding to systole and SV, negative flow corresponding to RV. RF is obtained by the division of RV by the SV multiplied by 100.

the Kruskal–Wallis test was used. The cut-off value of the RF for the prediction of a mild PAR was determined in receiver operating characteristic (ROC) curve analysis as maximum sum of sensitivity and specificity to minimize both the number of false-positive and false-negative findings. Statistical significance was assumed when the null hypothesis could be rejected at $P < 0.05$. For the variability test, we used kappa statistic for ordinal variables and intra-class correlation for continuous variables. Bland–Altman analysis was performed to evaluate agreement between the intra- and inter-operator measurements of RF by CMR. Statistical analyses were conducted with R software version 2.14.0 (R Development Core Team (2011). R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0. http://www.R-project.org/) with the packages psy and Epi.

# Results

## Baseline characteristics and procedure

Fifty-one consecutive patients underwent TAVI during the study period. Among these patients, 21 could not undergo CMR and were excluded (*Figure 2A*). The reasons why patients did not benefited of CMR are summarized in *Figure 2B*. TTE and CMR imaging were performed on the same day in the 30 remaining patients, who were included in the present study. Patient's characteristics are summarized in *Table 1*. Eight patients (26.7%) had a history of atrial fibrillation, but only four were in permanent atrial fibrillation.

## Echocardiographic assessment

After TAVI, the mean transvalvular gradient and the mean valvular area were 9.4 ± 3.2 mmHg and 1.3 ± 0.37 $cm^2/m^2$, respectively. PAR was mild in 22 (73.3%) patients, moderate in 3 (10%), and severe in 5 (16.3%) patients. Among moderate and severe PAR, three occurred with CV and five with EDXT. One regurgitant jet was observed in 10 (33.3%) patients, 2 in 18 (60%), and 3 separate jets in 2 patients. Multiple jets were observed in 66% of patients, and more frequently in patients with moderate/severe PAR (8/8) compared with patients with mild PAR (12/22) ($P < 0.029$). No central regurgitation was observed. Two patients (6.7%) were considered as having a very poor echocardiographic images quality.

## CMR assessment of PAR

No clinical adverse event was associated with CMR. All CMR acquisitions that were done at the level of the THV were impaired by severe artefacts (*Figure 3*). These artefacts led to an inharmonious flow curve with false SV, RV, and RF. Levels with artefacts were (i) for EDXT, the annulus aortic level and (ii) for the CV, the annulus aortic level and the STJ level. The reliable level was the STJ for EDXT and the tubular portion of ascending aorta for CV. However, in six patients (three with EDXT and three with CV), the LVOT level presented the validity and reliability criteria. The RV increased significantly ($P < 0.0005$) according to the TTE severity degrees of PAR: 5.5 ± 4.8, 16.7 ± 6.1, and 34.6 ± 22.2 mL for mild, moderate, and severe grades, respectively. The RV difference was significant

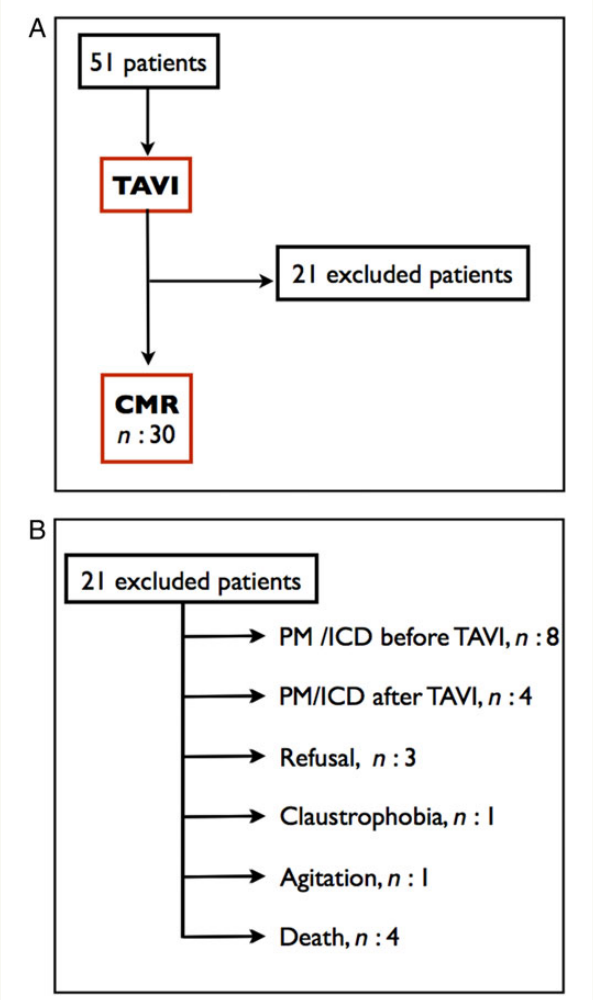


**Figure 2** Inclusion and exclusion of patients. (*A*) Flow chart. Fifty-one patients benefited of TAVI during the study period. (*B*) Excluded patients. Twenty-one patients were excluded due to contraindication to CMR. Thirty patients were finally included. PM/ICD, pacemaker/implantable cardioverter-defibrillator.

between mild and moderate ($P \leq 0.016$) but not between moderate and severe ($P \leq 0.142$) (*Figure 4A*). The RF increased significantly ($P < 0.0005$) with the TTE severity degree of PAR: 9.2 ± 7.6, 20.3 ± 4.2, and 46.8 ± 10.8% for mild, moderate, and severe grades, respectively (*Figure 4B*). In the moderate/severe PAR group, the mean RV and RF were 27.9 ± 19.6 mL and 36.9 ± 16%, respectively. Using a ROC curve (*Figure 5*), the cut-off RF value to discriminate mild from moderate/severe PAR was 14% (sensibility = 100%, specificity = 82%).

## AR index and multi-imaging and haemodynamic approach

Four patients did not have AR index measure for technical reasons (two with mild and two with moderate/severe PAR at TTE). Therefore, 26 patients had a combination of AR index measurement, CMR, and TTE. The mean AR index was significantly different according to PAR severity at TTE: 29.4 ± 6 and 13.8 ± 5 for mild and for moderate/severe, respectively ($P \leq 0.0014$) (*Figure 6*). All patients with significant PAR at TTE had an AR index <25. Among the 20 patients with mild PAR at TTE, 13 had an AR index >25 whereas 7 had an unexpected AR index <25. Of these seven latter patients, four had low RF (<14%) at CMR, suggesting 'a real mild PAR' despite low AR index. The remaining three patients showed a RF >14% at CMR, suggesting the presence of a significant PAR, whereas it had been 'underestimated PAR at TTE assessment' (*Figure 7*). The four patients described as 'real mild PAR' all had a high systemic blood pressure (>140 mmHg). They had a higher mean systemic blood pressure

**Table 1 Characteristics, procedure indication, and echocardiographic parameters of the included patients before TAVI**

| Characteristics | |
|---|---|
| Age | 81.5 ± 7 |
| Men | 14 (46.7) |
| Logistic EuroSCORE (%) | 15.7 ± 9.3 |
| Coronary disease | 14 (46.7) |
| CABG | 3 (10) |
| Peripheral arterial disease | 4 (13.3) |
| Calcified aorta | 5 (16.7) |
| Creatinin serum (μmol/L) | 117.7 ± 103 |
| Kidney transplant | 1 (3.3) |
| Dialysis | 1 (3.3) |
| Ischaemic stroke | 4 (13.3) |
| Pulmonary disease | 7 (23.3) |
| Cirrhosis | 1 (3.3) |
| Diabetes | 9 (30) |
| Hypertension | 19 (63.3) |
| Procedure indication | |
| NYHA | |
| II | 15 (50) |
| III | 13 (43.3) |
| IV | 2 (6.6) |
| Syncope | 2 (6.6) |
| Angina | 6 (20) |
| Previous hospitalization | 9 (30) |
| Previous percutaneous aortic valvuloplasty | 4 (13.3) |
| Echocardiographic parameters | |
| LVEF (%) | 58.5 (9) |
| LVEF <30% | 1 (3.3) |
| Aortic area ($cm^2$) | 0.74 ± 0.16 |
| ($cm^2/m^2$) | 0.42 ± 0.1 |
| Mean gradient (mmHg) | 55 ± 13.4 |
| Aortic regurgitation before TAVI | |
| None | 11 (36.7) |
| Mild | 15 (50) |
| Moderate | 4 (13.3) |
| Severe | 0 (0) |
| Aortic annulus diameter (mm) | 21.5 ± 1.8 |

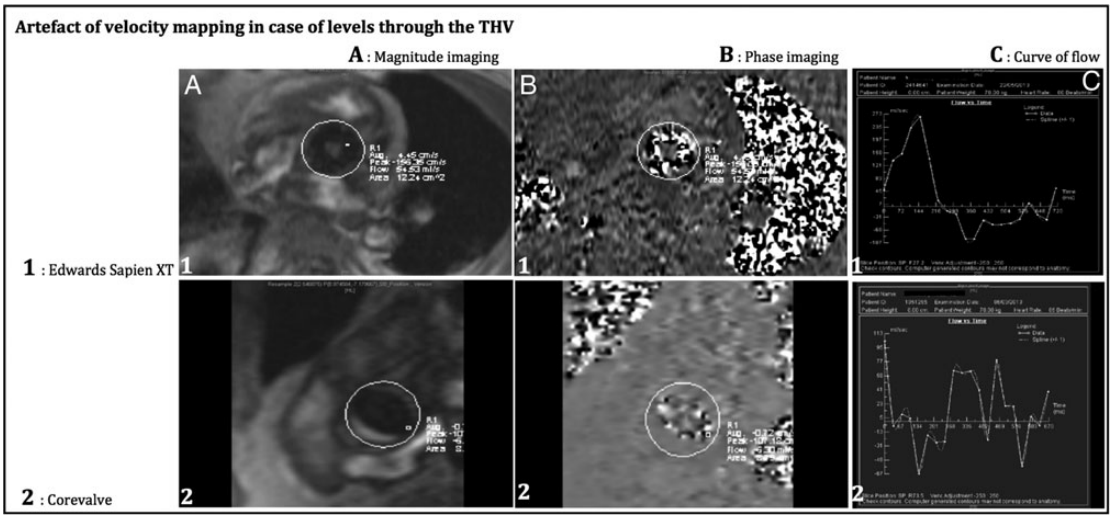


**Figure 3** Artefact of velocity detection in case of levels through the THV. In case of level acquisition through the THV, the velocity mapping presents artefacts due to the detection of peak of velocity flow in the stent of the THV. Levels concerned: (1) for Edwards SAPIEN XT: aortic annulus and (2) for COREVALVE: aortic annulus and STJ. In case of level upper or under the THV, but with a part of stent in the level (default of acquisition), the velocity mapping presents same artefacts. The consequence is an inharmonious and not interpretable curve of flow.

than those described as 'underestimated PAR at TTE' (152 vs. 107; $P = 0.057$), a more elevated mean LVEDP (27.5 vs. 20.7; $P = 0.48$), and a mean higher diastolic blood pressure (58.5 vs. 40, $P = 0.05$). These data explain a worse AR index, however, better than patient with a suspected 'underestimated PAR at TTE' (20.75 vs. 18; $P = 0.4$). Moreover, among the four 'real mild regurgitation', two had a weakly depressed ejection fraction at 50%, and two a grade II mitral regurgitation which may explain in part the high LVEDP. Concerning the RF by CMR, no real variation and no conflicting results, between the first measure and the second measure during the intra- or inter-reproducibility tests, were found. The mean RFs were 5.8% for the 'real mild regurgitation' patients and 24% for the 'suspected underestimation by TTE' patients.

## Variability and reproducibility

Concerning, TTE assessment, $\kappa$ coefficient was 0.78 for intra-operator [95% confidence interval (CI): 0.55–1] and inter-operator [95% CI: 0.54–1) variability. Regarding the CMR RF assessment, intra-class correlation coefficient was 0.99 (95% CI: 0.97–1) for the intra-operator variability and 0.99 (95% CI: 0.97–0.99) for the inter-operator variability (*Figure 8A*). Bland–Altman plots showed a narrower 95% limits of agreement between the two intra-operator measures of RF by CMR (mean bias = 0.2%, 95% limits −4.6 to 5.0) than the measures between the measures of the first and the second operator (mean bias = −1.0%, 95% limits −6.0 to 4.0) (*Figure 8B*).

# Discussion

In this prospective study of 30 patients who underwent TAVI, we found that:

(1) CMR is reliable for the quantification of PAR after TAVI.
(2) A cut-off value of RF of 14% calculated with phase velocity mapping accurately discriminates patients with mild from those with moderate or severe PAR.
(3) In some cases, CMR quantification of RF may correct TTE-underestimation of PAR severity, especially when AR index is doubtful.

## Echocardiography assessment of PAR

TTE is usually adequate to evaluate the performance of surgical aortic prosthesis.[8,19] THV devices are associated with a higher frequency of PAR than SAVR prosthesis.[1,2,5] PAR after TAVI is related to the inherent technical limitation, resulting from incomplete circumferential apposition of THV within the annulus.[3] Several reports have indicated a relation between PAR and long-term mortality,[1,2,5] but the certainty of these findings has been limited by the lack of standardization of methods to assess and quantify PAR. Especially, the impact of mild PAR remains controversial.[5] The echographic approach considers jet anatomy, semi-quantitative Doppler parameters and haemodynamic factors.[7,8,19,20] But the constrained character of the PAR between the stent and the native aortic valve prevents a quantitative measure by the PISA method.[19] The jet of PAR is in majority eccentric and frequently multiple, as it has been noted in almost one-third of the patients in the study. These findings confirm the possibility of errors or approximation with the current semi-quantitative assessment.[14] Other authors have proposed 3D echocardiography methods.[16,19,22] However, Tamborini *et al.*[23] found 10% of limited echocardiographic acoustic window in the population of TAVI patients for the use of 3D. Estimation of RV by TTE may improve the assessment of PAR,[16,19] although the measurements of the left and right outflow tract volumes remain

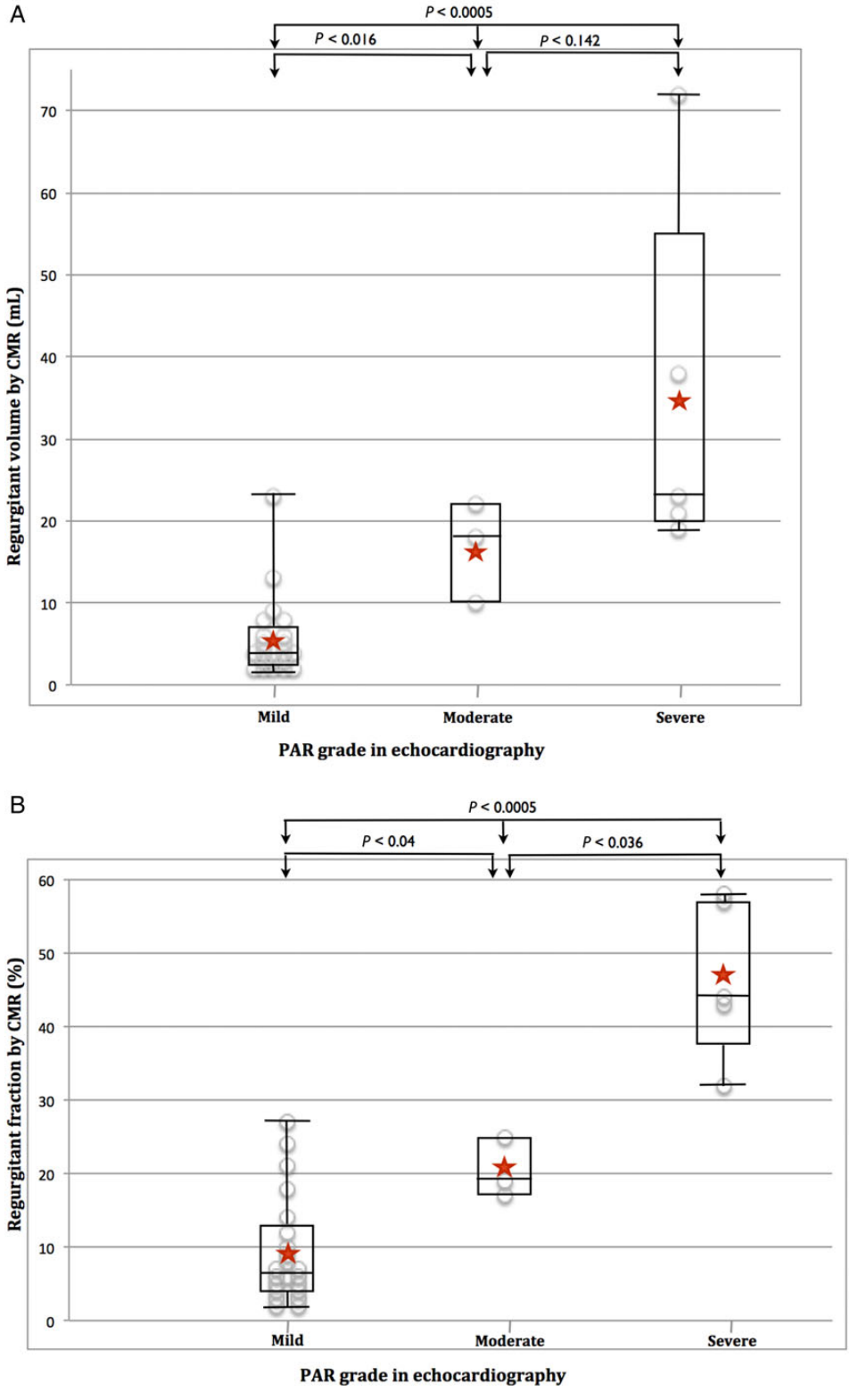


**Figure 4** Quantification by CMR according to the degree of peri-prosthetic aortic regurgitation by TTE. All patients are represented by a grey circle. PARs were graded by TTE at MILD, MODERATE, or SEVERE according to the VARC criteria. Red star represent the mean RV or RF for each groups. (*A*) Quantification of RV. (*B*) Quantification of RF. CMR, cardiac magnetic resonance; TTE, transthoracic echocardiography.

dependent of the risk of errors. Therefore, PAR echographic assessment is usually semi-quantitative and remains dependent of the operator experiences.

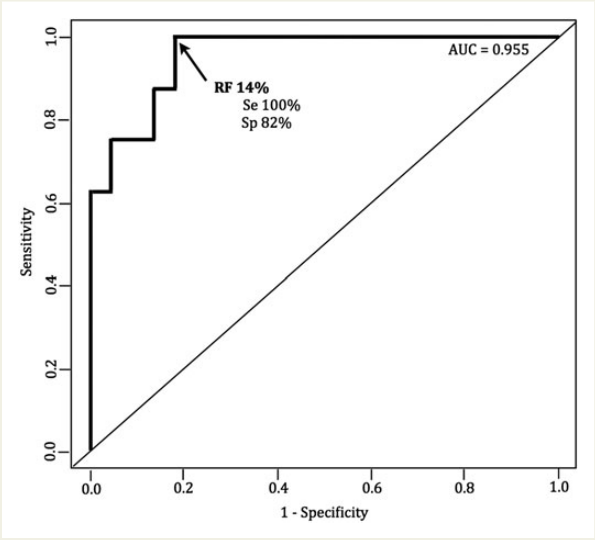


**Figure 5** Cut-off value of RF for discriminate mild to moderate/severe PAR by ROC curve analysis of the cut-off value of RF. RF under 14% discriminate mild PAR with sensitivity (Se) at 100% and specificity (Sp) at 82%. PAR, paravalvular aortic regurgitation; RF, regurgitant fraction.

## CMR assessment of PAR

Quantification technique by CMR uses the velocity-encoded phase-difference.[10] It is an accurate and direct measurement of blood flow velocity and RF in a defined area by the operator.[11,12] This method has been validated *in vitro* and *in vivo* for native AR.[11–13] Several studies with native AR showed a good correlation between CMR, quantitative assessment by echocardiography and prognosis.[10,11,24] Few studies have described the quantification of PAR by CMR in the TAVI setting.[14,15,19] Some authors showed a great potential of CMR in reliably measuring the severity of regurgitation, and an underestimation of PAR in some cases by echocardiography.[14] Recently, the CHOICE trial[25] used CMR in a few patients but the technique and the direct correlation with echocardiographic assessment was not precisely described. CMR appears to be less dependent of image's quality than TTE.[18]

There is seldom information in the literature about the accurate method to use phase-contrast imaging for TAVI. The previous study used only one acquisition in the ascending aorta close to the upper margin of the CV.[14] In our study, four different levels of measure were acquired. The acquisition made through the THV frame leads systematically to false results in flow quantification, with inharmonious curve due to stent detection as peak of velocity.

The most appropriate level for flow quantification was just above the THV upper the margin as it previously described and validated in the previous studies:[14–18] the STJ for EDXT, and the

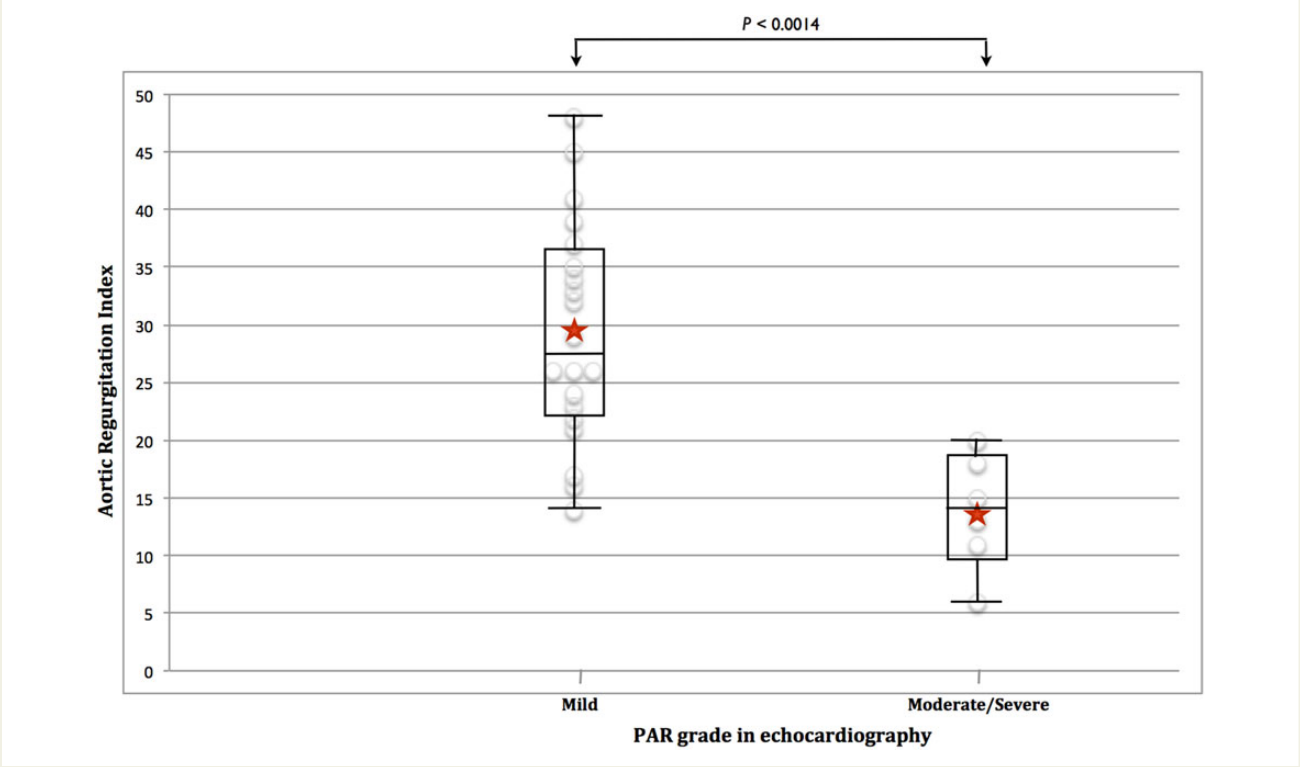


**Figure 6** AR index according to the degree of peri-prosthetic aortic regurgitation by TTE. All patients are represented by a grey circle. PARs were graded by TTE at two groups: MILD and MODERATE/SEVERE according to the VARC criteria. Red star represents the mean AR index for each groups. AR index, aortic regurgitation index; TTE, transthoracic echocardiography.

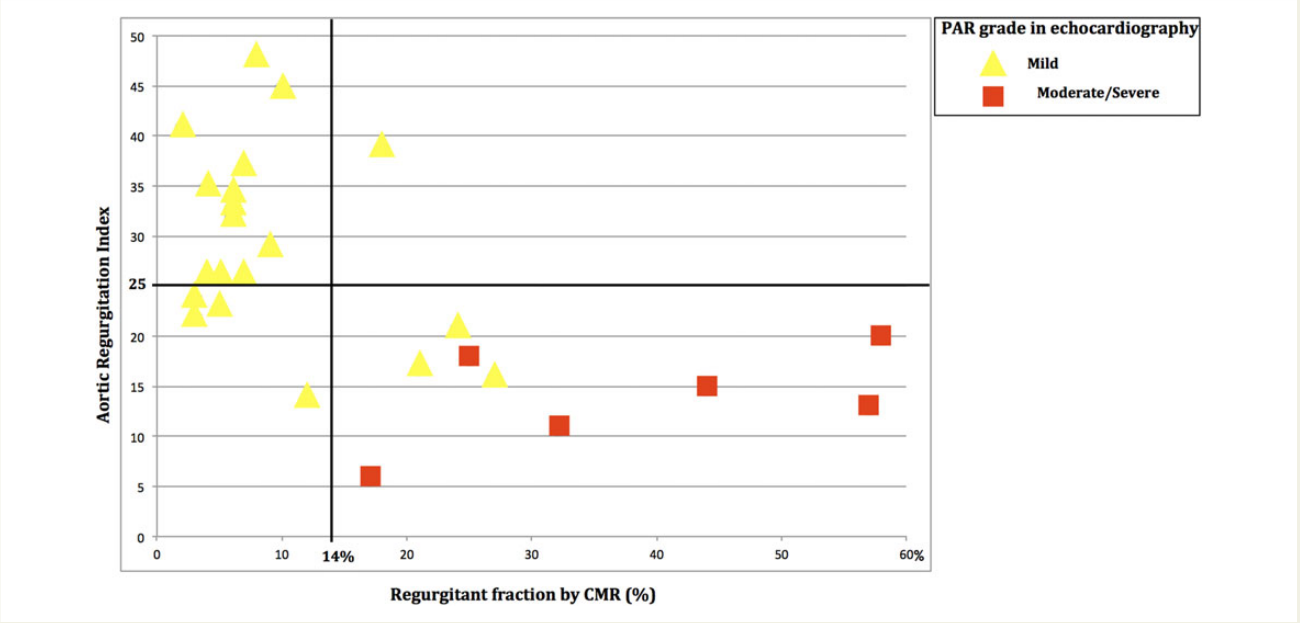


**Figure 7** AR index according to the RF by CMR imaging considering TTE assessment. All patients were represented according to the PAR assessment by haemodynamic AR index, RF calculated by CMR, and TTE assessment in mild or moderate/severe. Cut-off value of RF 14% and AR index 25 were traced. An AR index <25 is in favour of a PAR at least moderate or mild with variability factor. Patients with mild-TTE PAR, AR index <25, and RF >14% had probably a PAR underestimated by TTE.

tubular portion of the ascending aorta for CV. In few cases, the acquisition made just under the THV, at the LVOT level, respected all criteria of validation: (i) agreement between the SV obtained by velocity mapping and by volumes method, (ii) the absence of velocity detection artefact, and (iii) harmonious flow curve. However, this level may be used for PAR assessment if there is no artefact due to the important movements of this anatomic structure during the cardiac cycle. Other studies, as well as *in vitro* study, should take an interest in optimizing the acquisition in case of PAR. Therefore, to assess PAR after TAVI with CMR, the presence of all validation parameters is mandatory.

The assessment of global flow movement through the acquisition level is appropriate to quantify the regurgitant aortic flow as a whole,[10,12] despite the presence of multiple PAR jets.[14] Whereas this global haemodynamic approach is questionable to determine the mechanism of the regurgitation,[10] this approach remains interesting for PAR quantification.[14–16] This CMR method is reproducible with a low inter- and intra-operator variability as it has been previously described for native AR,[13] in our study the reproducibility of the calculation step (trace of area and calculation of the RF) when the level is selected is very high. Moreover, the velocity-encoded phase-difference can be coupled with the analysis of ventricular remodelling. Indeed, different physiopathological LV modifications can be associated to AS:[26] (i) small ventricular cavity with low SV, (ii) normal ventricular cavity, (iii) dilatation of ventricle, or (iv) previous native AR. Depending on the LV morphology and the presence of pre-existing AR, PAR can be differently tolerated. In these circumstances, RF may be the best parameter to evaluate the severity and the consequences of PAR rather than RV.

Compared with VARC 2 recommendations,[7] the RF cut-off value discriminating mild from moderate/severe PAR was different in this study. It may be explained by the fact that the cut-off value <30% was obtained from data about native AR. In our study focusing on PAR after TAVI, the cut-off value was <14%, and might correspond to specific LV morphologies. Moreover, this cut-off value is concordant to others studies in the field.[14,27]

## Global method of assessment of PAR

In some cases, Ribeiro *et al.*[17] and Orwat *et al.*[18] found an underestimation of PAR by TTE. However, this conclusion was only obtained by a direct comparison between TTE and CMR, and by using in Ribeiro study's the CMR as gold standard. Sherif *et al.*[14] compared TTE and CMR with the use of angiography, and found the same risk of underestimation by TTE. Nevertheless, angiography is still a semi-quantitative method and is more at risk of renal failure in TAVI population. Haemodynamic assessment by AR index provides a precise judgement of PAR, but is influenced by other factors of variability.[9] Indeed, the AR index varies with the level of the LVEDP that might be increased by high systemic blood pressure, concomitant diastolic or systolic dysfunction, or mitral regurgitation.[9] In our study in case of discordance between the two imaging methods (TTE and CMR), AR index helped us for discriminate the real severity of the PAR. Because in practice CMR is still not ubiquitously available and adds a cost to an already expansive procedure, CMR should be performed in case of conflicting AR index and TTE assessment. This global and complete multi-imaging and haemodynamic evaluation may allow avoiding cases of PAR underestimation at TTE and may clarify the real impact and the prognosis of mild PAR.

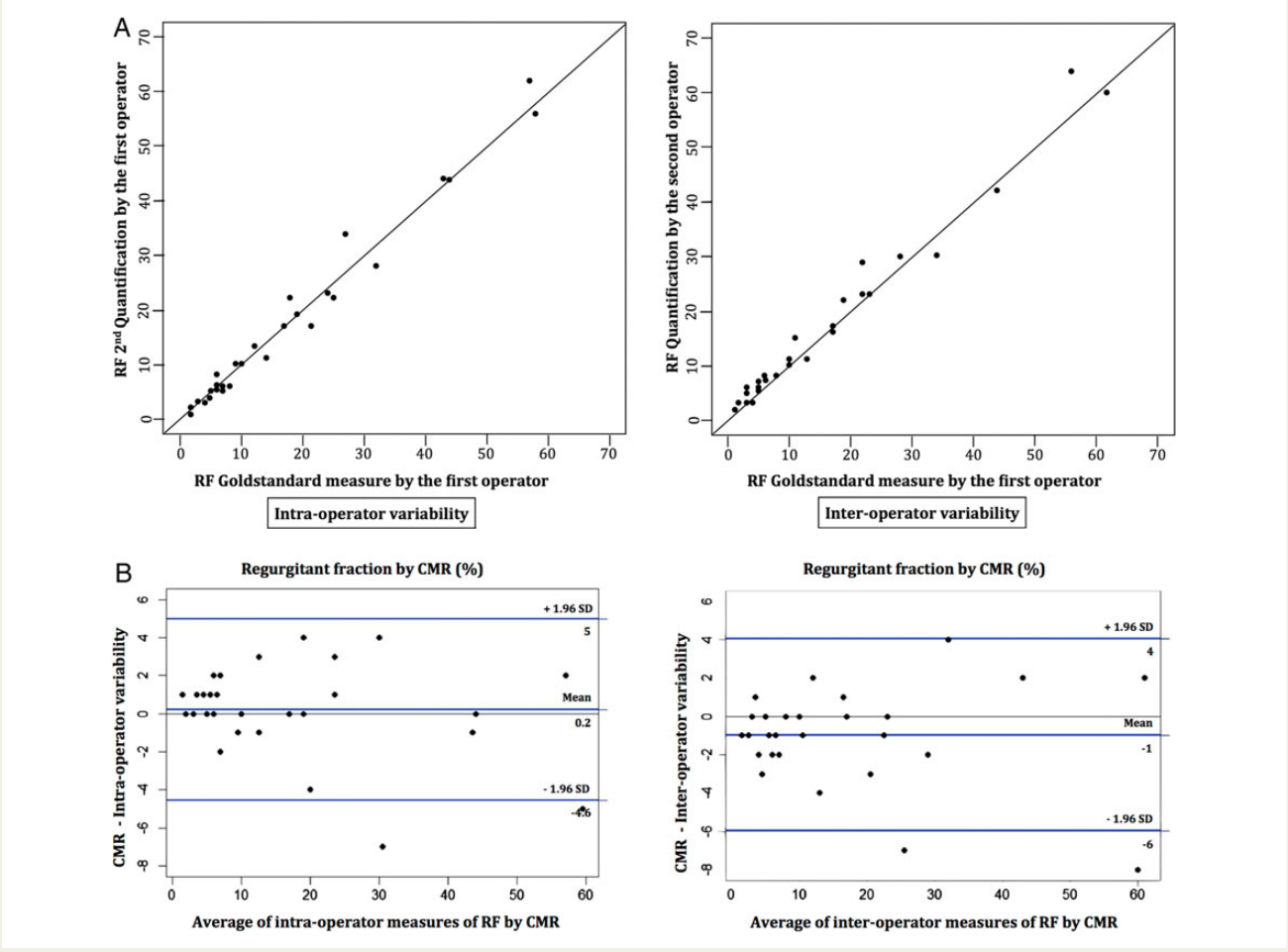


**Figure 8** Variability of the RF calculation by CMR. (*A*) Intra-operator variability and inter-operator variability. (*B*) Bland–Altman plots for the agreement of intra- and inter-operator measures of RF by CMR. CMR, cardiac magnetic resonance; RF, regurgitant fraction.

## Limitations

The main limitation is the absence of an indisputable method of reference for PAR quantification. TTE assessment is used as reference in the first part of the study; even so all parameters are difficult to measure or not very reliable. However, the integrative and multiparameter used method is the one recommended and current.[7,8,19,20] In our study, the reproducibility of CMR only concerned the step of calculation and not the acquisition and the selection of the best level. Otherwise, this is a single-centre study with a small cohort and just small amount of intermediate patients. However, this limit is common with the previous studies, and a greatest prospective cohort is needed to confirm these results, and correlate with a higher statistical power the prognosis to CMR assessment. The use of CMR may be limited by relatively contra-indications as PM/ICD[28]: except the leads implanted <6 weeks which is an absolute contraindication; in the others cases, CMR can be performed but needed a monitoring by qualified personnel; concerning PM CMR compatible, it is necessary to follow the manufacturer's instruction. Claustrophobia and agitation are still a contraindication for CMR. In our study, all CMR studies were well tolerated; however, discomfort, anxiety, and the relatively long duration of the examination may restrict its use in the elderly TAVI population.

## Clinical implications

Because in practice CMR is still not ubiquitously available and adds a cost to an already expansive procedure, CMR should be rather reserved in case of conflicting AR index and TTE assessment. The improvement of PAR quantification by CMR may allow modifying the management of patients identified after CMR as patients with significant PAR, while the TTE suggests only mild PAR, and especially when AR index is doubtful. These patients are exposed to impaired long-term prognosis including mortality and might benefit from post-dilatation or PAR closure with plugs/coils.[29] However, this hypothesis needs to be validated in further clinical studies.

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