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REVIEW

The year 2015–16 in the *European Heart Journal—Cardiovascular Imaging*. Part II

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The multi-modality cardiovascular imaging journal, *European Heart Journal—Cardiovascular Imaging*, was created in 2012. It has gained an impressive impact factor of 5.99 during its first 5 years and is now the most important imaging journal in Europe. The most important studies from the journal's fourth and fifth years will be highlighted in two reports. Part I of the review will focus on studies in myocardial function, myocardial ischaemia, and emerging techniques in cardiovascular imaging and Part II will focus on valvular heart diseases, heart failure, cardiomyopathies, and congenital heart diseases.

Keywords echocardiography • computed tomography • multimodality • PET • cardiomyopathy • congenital heart disease • heart failure • cardiovascular magnetic resonance

Introduction

European Heart Journal—Cardiovascular Imaging has successfully consolidated as a multi-modality journal during its first 5 years. The journal has now an important role as a significant resource for cardiologists, specialists in all imaging modalities, and other physicians working in the field of cardiovascular imaging. The tradition of highlighting the most important studies that were published in the last year is continued.[1,2] In two articles, we will summarize the most important articles from the journal in 2015 and 2016. Part II will focus on cardiomyopathies, congenital heart diseases, valvular heart diseases, and heart failure (HF).

Recommendations from the European Association of Cardiovascular Imaging

One important assignment of *European Heart Journal—Cardiovascular Imaging* is to publish position papers, recommendations, and expert consensus papers from the European Association of Cardiovascular Imaging (EACVI) scientific articles. The journal published 10 recommendations and expert consensus papers in the field of multi-modality imaging, 9 from echocardiography in 2015–16, 1 on cardiovascular magnetic resonance (CMR) and 3 about nuclear imaging and computed tomography (CT).[3–15] These papers are discussed in more detail in Part I.[16]

Cardiomyopathies

Haugaa *et al.*[15] published a comprehensive recommendation paper about multi-modality imaging approach in arrhythmogenic cardiomyopathy. It has also been demonstrated that patients with early-phase arrhythmogenic cardiomyopathy had structural abnormalities with lower right ventricular ejection fraction, increased indexed right ventricle (RV) basal diameter, and pronounced RV-mechanical dispersion in addition to lower % premature ventricular complexes (PVC) by Holter compared with right ventricular outflow tract (RVOT)-ventricular tachycardia patients. These parameters can help

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correct diagnosis in patients with unclear phenotypes and waiting for genotyping.[17]

Haland *et al.*[18] evaluated prognostic value of global longitudinal strain (GLS), strain dispersion by echocardiography and fibrosis by CMR in 150 hypertrophic cardiomyopathy (HCM) patients. They demonstrated that patients with ventricular arrhythmias had reduced longitudinal strain, more mechanical dispersion, and late gadolinium enhanced (LGE) by CMR. Mechanical dispersion was a strong independent predictor of ventricular arrhythmias and was related to the extent of fibrosis. Strain echocardiography may be an important parameter for risk stratifying HCM patients. But, also, in about 1570 HCM patients, Ong *et al.*[19] were able to demonstrate that over one-third of adults evaluated in their HCM clinic demonstrated concomitant pulmonary hypertension, and this was associated with increased mortality except in those with obstructive HCM who underwent septal reduction treatment. Pulmonary hypertension in HCM is therefore an important parameter to be aware of. CMR is also useful in HCMs. Peteiro *et al.*[20] reported in 148 patients with HCM that both wall motion abnormality at exercise echocardiography and perfusion defects and LGE by cardiac MR predicted the occurrence of events such as cardiac failure, stroke, Implantable Cardioverter Defibrillator (ICD) discharge, atrial fibrillation (AF), and syncope.

Several studies evaluated the value of multi-modality imaging in HCM. Indeed, HCM is often characterized by the presence of focal areas of myocardial fibrosis, and the presence of fibrosis has been associated with cardiac dysfunction and with poor outcome, particularly since it may act as substrate for developing ventricular arrhythmias.

CMR was shown to be particularly useful for non-invasive detection of such myocardial fibrosis in HCM. Using echocardiography and CMR, Kim *et al.*[21] evaluated the differences between apical and non-apical forms of HCM in a prospective registry in 350 subjects with HCM. They found that patients with apical HCM had lower LV mass, less LGE, better diastolic function and presented better clinical outcome. Bravo *et al.*[22] evaluated differences in LGE distribution patterns by CMR in HCM on severity of phenotype expression by comparing these patterns to longitudinal strain and myocardial blood flow and flow reserve by N-13 ammonia PET. They compared patients without LGE with intramural LGE, within the hypertrophied segments of LV, and LGE located at the anterior and/or posterior RV insertion points and found that patients with LGE located only at RV insertion points had intermediate phenotype between patients with no LGE and intramural LGE in the LV. Finally, Rodrigues *et al.*[23] evaluated asymmetric hypertrophic patterns in patients with hypertensive disease and found that this was present in 21% of subjects, exclusively in basal or mid septum with frequent presence of LGE, suggesting morphological overlap with HCM.

Amyloidosis has been the subject in several papers and the value of speckle tracking imaging has been highlighted. Patients with wild-type transthyretine amyloidosis (ATTR) are characterized by lower left ventricular ejection fraction (LVEF), LV basal, and LV mid-radial strains compared with patients with ATTR mutated. LVEF and LV radial strain are useful in distinguishing between ATTR wild type (senile) and ATTR mutated when TTR has been proved in biopsy specimens.[24]

Other important studies evaluated the value of CMR in amyloidosis. Indeed, LGE CMR is a highly sensitive technique for detection of amyloid in the heart. Bhatti *et al.*[25] performed an observational retrospective cohort of 251 consecutive patients with multiple myeloma undergoing contrast enhanced CMR between June 2005 and October 2014. They found that LGE suggestive of amyloidosis was present in 30% of patients. Using endomyocardial biopsy as gold standard, LGE-CMR had 100% sensitivity and negative predictive value and respectively 80% and 81% specificity and positive predictive value for diagnosis of amyloidosis. They also evaluated the prognostic value of LGE-CMR in comparison over other clinical parameters for all-cause mortality over a median duration of 28 months and found that history of CAD, increased B-Type Natriuretic Peptide (BNP) level and LGE+ pattern by CMR were independent predictors of mortality and that LGE-CMR had significant additional value to predict survival over clinical history, electrocardiogram (ECG), biomarkers, and transthoracic echocardiography. Mohty *et al.*[26] in 54 patients with confirmed AL amyloidosis showed that left atrial (LA) ejection fraction by CMR is associated with New York Heart Association (NYHA) functional class, Mayo Clinic class, LGE and 2-year mortality.

CMR offers attractive possibilities on tissue characterization in cardiomyopathies and several important papers on these topics were published in the journal in 2015–16.

Foremost, two important studies validated the non-invasive detection of both focal a diffuse myocardial fibrosis by gadolinium enhanced CMR in humans. Iles *et al.*[27] performed a histological validation study and demonstrated excellent correlation of LGE CMR imaging with a threshold signal intensity of 6 standard deviation above reference myocardium with histologically detected replacement fibrosis and of post-contrast T1 mapping with diffuse interstitial fibrosis. In line with these findings, aus dem Siepen *et al.*[28] demonstrated a strong correlation between extracellular volume fraction (ECV) measured by CMR and collagen volume fraction measured by pathology in 24 patients with dilated cardiomyopathy undergoing endomyocardial biopsy.

Putko *et al.*[29] demonstrated the utility of CMR to study LA structure and function in patients with Anderson Fabry disease.

Nadel *et al.*[30] studied 106 patients with biopsy-proven extracardiac sarcoidosis and demonstrated that CMR identified cardiac sarcoidosis involvement and it was an important predictor of survival, predicting 38% event rates of sudden cardiac death and ventricular arrhythmia in patients with vs. only 1.4% in patients without such cardiac involvement. Raimondi *et al.*[31] employed CMR to detect myocardial inflammation by T1 T2 and LGE imaging in children with recently diagnosed dilated cardiomyopathy, and demonstrated that the presence of myocardial inflammation and elevated troponin levels at baseline were the most important two predictors of LV function recovery over a mean follow-up of 24 months. In another study in 210 patients with dilated cardiomyopathy, Buss *et al.*[32] reported that LV longitudinal CMR strain had additional predictive value of survival in addition to NYHA class, BNP, ejection fraction, and standard LGE CMR. CMR can also quantify myocardial iron overload by measuring T2* times. Meloni *et al.*[33] followed patterns of iron accumulation in 259 patients with thalassemia during chelation therapy and demonstrated the ability to monitor the efficacy of this therapy to remove myocardial iron over time.

Differentiation of mild DCM from athletes' heart is often difficult with conventional techniques. Therefore, Mordi *et al.*[34] evaluated the

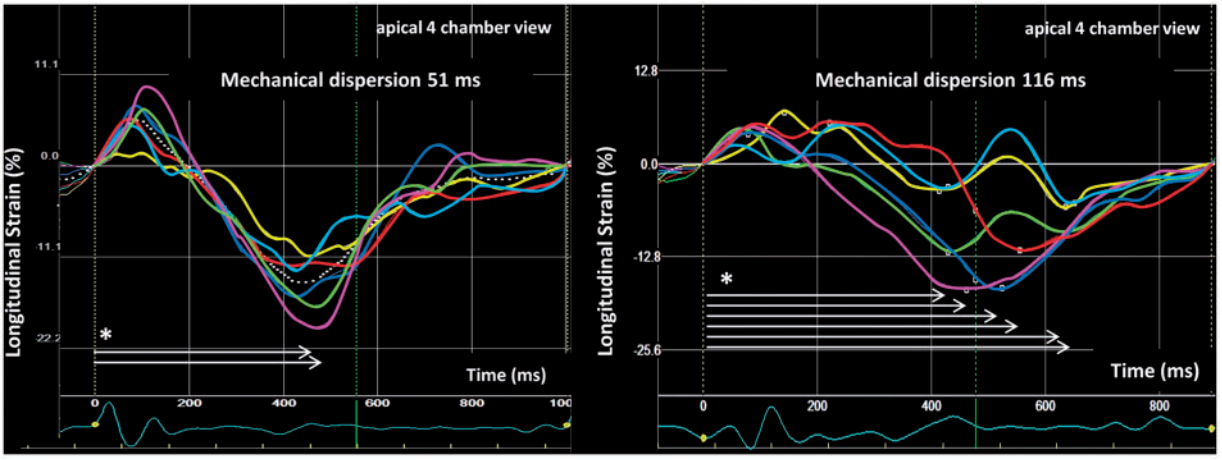

Figure 1 Longitudinal strain curves from apical four-chamber view displaying 6 of the 18 LV segments used to calculate mechanical dispersion at 6 months after CRT. Left panel: patient with mechanical dispersion 51 ms. The patient did not have ventricular arrhythmias during 2-year follow-up. Right panel: patient with mechanical dispersion 116 ms, i.e. severe mechanical dyssynchrony. The patient experienced several sustained ventricular tachycardias. *White arrows indicate time to peak strain (ms). From Hasselberg *et al.*[37]

utility of T1 and T2 mapping in differentiation of athletes and patients with mild DCM. They compared 21 athletes, 16 patients with DCM and preserved ejection fraction, and 21 controls and found that Native T1, ECV, and T2 relaxation times were significantly increased in DCM patients compared with controls and athletes, T1 and T2 mappings are potentially useful tools for differentiating between athlete's heart and patients with early DCM, and could be used whenever differentiation between these two phenotypes using standard imaging techniques is inconclusive.

Duchenne muscular dystrophy and Becker muscular dystrophy (BMD) are X-linked recessive disorders associated with both skeletal myopathy and progressive cardiomyopathy in males. In an important paper by Florian *et al.*,[35] it was demonstrated for the first time that LGE indicating cardiac involvement can also be observed in 65% of female Duchenne and 19% of asymptomatic BMD carriers. Thus, these females demonstrate the same myocardial fibrosis pattern as their male counterparts with overt disease. These findings were however more common in Duchenne than in BMD.

Heart failure

HF syndrome was recently redefined to HF with preserved EF (HFpEF) (LVEF ≥ 50%), HF with reduced EF (LVEF < 40%), and HF with mid-range EF (HFmrEF) (LVEF = 40–49%).[36]

Cardiac resynchronization therapy (CRT) may improve cardiac function and reverse the damaging process of LV remodelling in patients with HF. However, the relatively high non-responder rate to CRT (>30%) poses a great clinical challenge in patient selection. Looking at 170 patients, Hasselberg *et al.*[37] demonstrated that in HF patients with CRT, worse longitudinal function before CRT was an important predictor of fatal outcome during 2 years, independently of CRT response. Mechanical dispersion at 6 months was a strong predictor of ventricular arrhythmias (*Figure 1*). CRT response by reverse remodelling was dependent on improvement of both longitudinal and circumferential function. Also, consecutive HF-patients treated with primary indication for CRT between 2005 and 2009 were included in a prospective registry. Echocardiography was performed prior to CRT to assess apical rocking, defined as motion of the LV apical myocardium perpendicular to the LV long axis.[38] After multi-variable analyses, apical rocking was associated with less major adverse cardiac events (defined as combined end point of cardiac death and/or HF hospitalization and/or appropriate therapy) [hazard ratio (HR) 0.44, 95% confidence interval (CI) 0.25–0.77]. The septal deformation patterns were studied in 284 CRT candidates (*Figure 2*). The pattern of septal deformation is providing important prognostic information in CRT candidates in addition to ordinary clinical, electrocardiographic, and echocardiographic predictors of outcome in HF patients. The Septal wasted work, the apical rocking, the identification of the pattern of septal deformation are three important strain methods that seem to be able to provide optimism that, 1 day, imaging, echo-techniques might finally help in identifying best the candidates to CRT and will help in decreasing the rate of non-response that is still close to 30%.[38–41]

Morris *et al.*[42] studied 238 healthy subjects and a cohort of 642 patients characterized by asymptomatic patients ($n = 216$) and patients with HFpEF ($n = 218$), and HF with reduced EF ($n = 208$) from 10 centres in a prospective multi-centre trial. The normal range of RV systolic strain analysing the healthy subjects was: RV global strain -24.5 + 3.8% and RV free wall strain -28.5 + 4.8%. RV global and free wall systolic strain were significantly linked to the symptomatic status of the patients. RV myocardial parameters were able to detect subtle RV systolic abnormalities in patients with HF better than usual indices previously proposed.

The ratio of trans-mitral early filling velocity (*E*) to early diastolic tissue velocity (e') is a key diastolic function parameter. The early diastolic strain rate (e'sr) has been proposed as a substitute for e' in the *E*/e' ratio for better estimation of LV-filling pressure. A study assessed the predictive value of combined *E*/e'sr-ratio and GLS for prognosis in systolic HF. Three hundred and thirty patients were analysed. After multi-variate adjustment, GLS (HR: 1.48, $P = 0.025$) and the

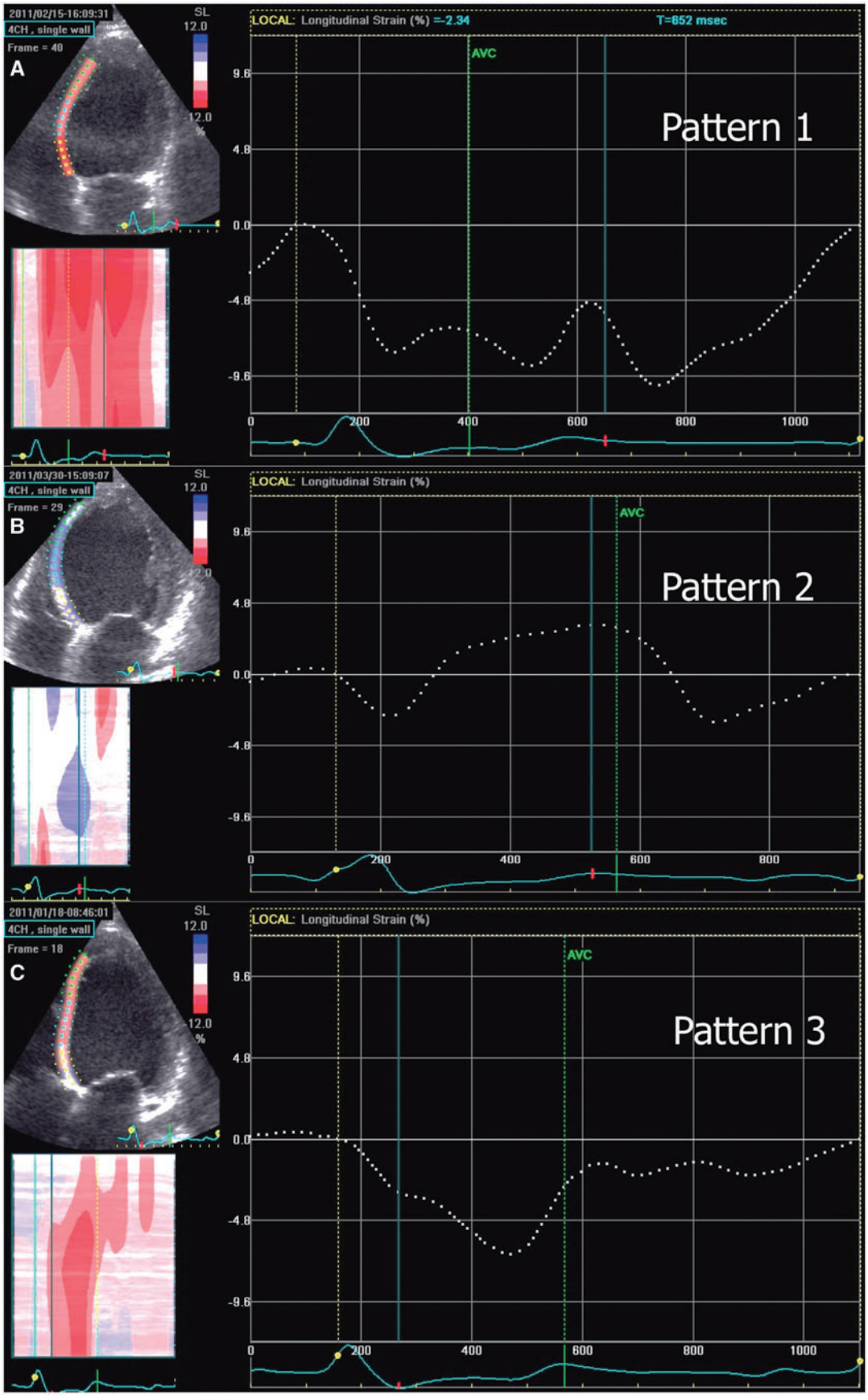

Figure 2 The two patterns of septal longitudinal strains that are associated with a favourable response to cardiac resynchronization therapy. Modified from Menet *et al.*[40]

E/e'sr ratio (HR: 1.41, $P = 0.002$) were both independent predictors. Patients with impaired GLS (absolute value 7.5%) and elevated *E*/e'sr ratios (*E*/e'sr ≥ 195 cm) showed poor outcomes.[43]

The Intervention in Myocarditis and Acute Cardiomyopathy-2 study was a prospective, multi-centre trial investigating myocardial recovery in subjects with symptoms onset of 6 months and LVEF ≤ 40% of non-ischaemic dilated cardiomyopathy related to idiopathic cardiomyopathy or myocarditis. LVEF and DF were measured at presentation and at 6-month follow-up. In patients with recent onset non-ischaemic cardiomyopathy, DF recovery was associated with favourable outcomes independent of LVEF improvement, adding incremental prognostic value to these patients.[44]

Specifically, in HFpEF, a study analysed 733 (69% male) non-diabetic patients with sinus rhythm, preserved systolic function, and estimated glomerular filtration rate higher than 60 mL/min/1.73 m^2. In all patients, echocardiograms were performed and LA expansion index was calculated. Renal function was evaluated annually. The LA expansion index is a useful early indicator of renal function decline and may enable the possibility of early intervention to prevent renal function from worsening.[45] Two other studies looked at the LA size and function in HFpEF.[46,47] Another study sought to determine if markers of diastolic dysfunction are associated with AF development among patients with HFpEF.[47] The risk of AF decreased with increasing peak A wave velocities (per 10 cm/s increase: HR = 0.83, 95% CI = 0.72–0.96). Diastolic parameters of LA function possibly are more important markers of AF risk than LA dilation in HFpEF.

The study by Tournoux *et al.*[48] examined the role of electrocardiogram-gated single-photon emission CT myocardial perfusion imaging equilibrium radionuclide angiography (ERNA) (known also as radionuclide ventriculography) to predict CRT response in patients with ischaemic and non-ischaemic cardiomyopathy in 146 patients with HF. Intra-ventricular dyssynchrony was calculated as the delay between the earliest and most delayed 20% of the LV phases. Comparing survival between CRT and non-CRT patients according to dyssynchrony status, no difference was found in survival in patients with no ERNA dyssynchrony while a significant difference was observed in ERNA patients with high level of mechanical dyssynchrony. The observations of this study can be of great clinical interest, as the results suggest a difference of CRT effect depending on the presence of mechanical dyssynchrony, and that nuclear imaging might have a promising role in prognostication and pre-implantation CRT response prediction among patients with HF.

Heart valve diseases

The new percutaneous treatments and the best analysis of valves thanks to 3D capabilities lead to many publications. In aortic valve stenosis (AS), the trans-aortic valve implantation remains associated with periprocedural complications like the need for a pacemaker implantation. The pre-existing Right Bundle Branch Block (RBBB) and elevated left coronary cusp calcification were identified as independent predictors for permanent pacemaker implantation.[49] Asymptomatic AS patients remain to be followed and not operated before symptoms. Valuable results have been published demonstrating the value of heart valve clinics (HVC). A structured HVC programme results in the detection of symptoms at an earlier and less severe stage and thus in an optimized timing of surgery. The dissemination of such centres of excellence should therefore be promoted.[50]

Also, in asymptomatic AS, it has been demonstrated that patients with LV asymmetry had more than three times the risk of aortic valve replacement (AVR) (HR: 3.16; 95% CI: 1.77–5.66; $P < 0.001$) compared with patients with no LV asymmetry.[51] Carstensen *et al.*[52] published also a nice paper demonstrating the value of strain echocardiography for predicting the risk of need to aortic valve replacement in asymptomatic AS patients. Reduced basal longitudinal strain was a significant predictor of future AVR in asymptomatic patients with AS, independently of clinical characteristics, conventional echocardiographic measures, and coronary pathology. Many studies have been demonstrating the value of echocardiography pre- but also per-trans catheter aortic valve replacement. One study in 31 patients by García-Martín *et al.*[53] concluded that a new automatic 3D-transoesophageal echocardiographic software allows modelling and quantifying the aortic root with high reproducibility. There was good correlation between the automated measurements and other 3D-validated techniques including cardiac-CT. Bartel *et al.*[54] published a nice review paper about transoesophageal and intracardiac echocardiography for guiding the implantation of transcatheter aortic valve implantation (TAVI). Nevertheless, a nice paper about 165 patients and written by Abdelghani *et al.*[55] underscored the current limit of echocardiography for quantifying the paravalvular regurgitation if the traditional VARC-II criteria are considered. A multi-modality approach for solving this difficult issue is probably required.

Advanced 4D flow is a novel method that allows assessing blood flow velocity in 3D in relation to aortic size and geometry. Garcia *et al.*[56] studies 165 subjects divided in 50 with bicuspid aortic valve (BAV), 50 with tricuspid aortic valve (TAV), and 65 controls, and their main findings were that a single acquisition of 4D flow characterized local morphological and haemodynamic differences between groups along the various aortic segments; BAV showed higher PV and flow displacement than TAV patients, in spite of having similar mid-ascending aorta diameter size.

An elegant CMR study showed that BAV relatives expressed had an altered aortic shape and increased vortex flow despite the absence of valvular disease or aortic dilatation. These data suggest a heritable component of BAV-related aortopathy affecting aortic shape and determining aberrant blood flow, independent of valve morphology.[57]

In regard to mitral valve regurgitation (MR) and anatomy, CT, CMR and also 3D echocardiography have been used for improving the description of the disease and for best planning interventions. For instance, it has been demonstrated that the mitral annulus is enlarged and stiff in secondary MR patients, whereas in fibroelastic deficiency and Barlow disease, it is characterized by excessive dynamicity during systole. Enhanced annular dynamics leads to significant changes in grade of MR measured by 3D TEE particularly in those with late onset MR.[58] Also Mihaila *et al.*[59] demonstrated that using a new 3D echocardiographic software allowing a quantification of mitral annulus size and dynamic, mitral annulus reduced function correlates with the MR severity and the LA size and function, but not with the LV function in patients with primary mitral regurgitation. That might be a valuable information for best understanding the pathophysiology of the disease and that new 3D echocardiographic capabilities allow very precise and sophisticated measurements.

The tricuspid valve (TV) has also been explored by several studies. In pulmonary arterial hypertension (PAH), tricuspid regurgitation

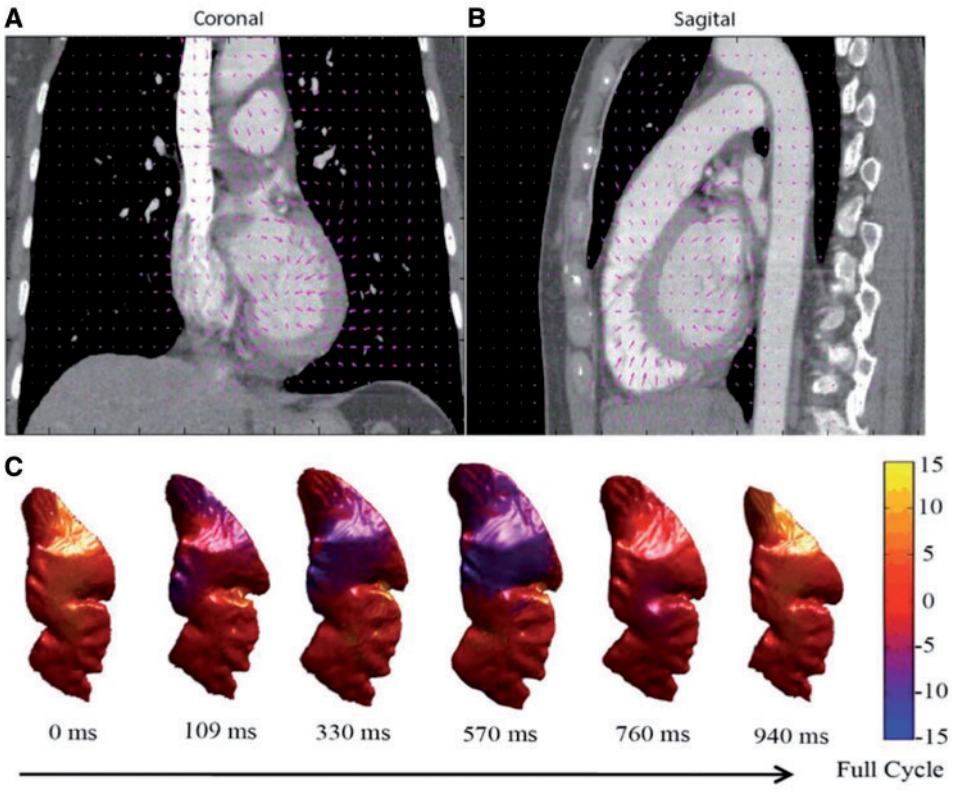

Figure 3 Motion vector field derived from the image based motion-estimation algorithm is shown in coronal (*A*), sagittal (*B*) views. Each vector (pink arrow) is shown on every 16 voxels. (*C*) 3D reconstruction of the CT image to indicate left atrial appendage surface deformation over a cardiac cycle (colour-coded by area change ratio: blue, contraction; yellow, stretch). (Modified after Al-Issa *et al.*[71]).

(TR) progression was associated with worsening pulmonary hypertension and adverse RV and TV apparatus remodelling. TR progression is associated with poor outcome in PAH.[60] In addition to tethering and short length of the leaflets, TV morphological abnormality predicted residual TR after TV annuloplasty.[61] 3D printing of the TV from 3D TTE data has been demonstrated to be feasible with highly conserved fidelity and may improve the understanding of leaflets, annulus, and right heart cavities. This technique has the potential for rapid integration into clinical practice to assist with decision-making, surgical planning, and teaching.[62]

Cardiac MR is also becoming an even more important tool to study patients with valve disease. In particular, it excels in the ability to accurately measure left and RV volumes and mass over time and thus to study the progression of left and RV remodelling in such valve disease. In the Ramipril in AS (RIAS) trial, a randomized double-blind placebo controlled trial of 100 patients with moderate or severe AS, Bull *et al.*[63] used CMR to study LV mass over time and demonstrated that this drug may modestly decrease LV mass and slow AS progression over time. In 20 patients with mitral regurgitation undergoing interventional edge-to-edge repair (Mitraclip), Lurz *et al.*[64] used CMR to evaluate the reverse remodelling and demonstrated significant improvement of mitral regurgitation fraction and LV end-diastolic volume, however without significant improvement in LVEF or RV function and cardiac output or biventricular forward flow. CMR also plays an important role in patients with AS undergoing TAVI. In 69 of such patients, Ruile *et al.*[65] compared the reliability of pre-procedural aortic annulus assessment by non-contrast 3D magnetic resonance angiography to contrast enhanced cardiac CT angiography and found that this technique allowed similar good assessment of aortic annulus dimensions and calcifications as CT. It might thus be useful to avoid contrast exposure in patients at increased risk for contrast-induced nephropathy. Also after TAVI, phase-contrast CMR is useful for quantification of paravalvular aortic regurgitation (PAR). Indeed, PAR quantification is often difficult by 2D transthoracic echocardiography. This was shown by a paper of Salaun *et al.*[66] in 30 patients demonstrating high reproducibility of PAR measurements by CMR and the ability to correct TTE underestimation of PAR severity. Finally, similar to cardiomyopathies, there is currently intense interest in tissue characterization by T1 mapping and ECV fraction in valve diseases. Singh *et al.*[67] evaluated the test–retest reproducibility in 10 patients with CMR and found that reproducibility was excellent, demonstrating the usefulness of this approach for longitudinal studies of patients with valve disease.

Finally, two other studies evaluated the usefulness of aortic stiffness measurement, an important maker of cardiovascular risk in the MESA study. First Noda *et al.*[68] demonstrated that CMR had good test–retest, intra- and inter-reader reliability of ascending and descending aortic arch pulse wave velocity and strain in 25 participants

undergoing 2 CMR tests over 13 days. Then Ohyama *et al.*[69] evaluated in 1160 MESA participants the progression of aortic stiffness over 10 years' time and correlated them to baseline values, demographic variables, baseline risk factors and change in risk factors, and chronic risk exposure. They demonstrated that greater mean blood pressure, and a history of smoking history were associated with increased aortic stiffening over 10 years.

Structural heart disease imaging has become a mainstream application of cardiac CT. van Rosendael *et al.*[70] studied the geometrical changes of the TV and RV in patients with functional tricuspid regurgitation (TR) using a 320-detector row CT. The authors demonstrated that significant TR is associated with remodelling of the tricuspid annulus, tethering of the anterior and septal leaflets, and RV remodelling. In a retrospective study, Al-Issa *et al.*[71] utilized a novel image-based motion-estimation (iME) CT to quantify LA appendage (LAA) regional function. The study enrolled patients referred for AF ablation who underwent pre-ablation cardiac CT with retrospective ECG gating. To assess myocardial deformation, area change ratio, and area change rate were calculated over the endocardial surface of the LAA (*Figure* 3). Both metrics were significantly lower in the stroke/TIA group versus the control group and LAA regional dysfunction is independently associated with a history of stroke/TIA. In summary, cardiac CT is multi-faceted image modality capable of providing useful information not only on CAD characteristics, but also on valve morphology and cardiac structure.

Congenital heart disease

CMR is a valuable technique for assessment of patients with congenital heart disease. Pushparajah *et al.*[72] used Hybrid X-ray and CMR catheterization to assess haemodynamic response to low dose dobutamine in 13 patients with hypoplastic left heart syndrome (HLHS) post-Fontan. They combined the haemodynamic information from invasive catheterization with ventricular volumes, stroke volume and ejection fraction to compute pulmonary artery and systemic vascular resistance, fenestration flow, aorto-pulmonary collateral flow and TR. They demonstrated that PVR and ventricular function were not the rate-limiting steps in the reduced ability of HLH Fontan patients increasing their CI during stress, but rather a lack of recruitable preload due to the Fontan circuit and the lack of the driving force of a subpulmonary ventricle.

An important expert consensus document by ASE and EACVI provides a review and advices of the optimal application of 3D echocardiography in congenital heart disease including technical considerations, image orientation, application to different lesions, procedural guidance, and functional assessment.[73] The expert consensus paper of the Imaging Working Group of the Association for European Paediatric and Congenital Cardiology (AEPC) and the Cardiovascular Magnetic Resonance Section of the EACVI describes indications for CMR in children with congenital and acquired heart disease.[14]

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References

1. Edvardsen T, Bucciarelli-Ducci C, Saraste A, Pierard LA, Knuuti J, Maurer G *et al.* The year 2014 in the *European Heart Journal—Cardiovascular Imaging*. Part I. *Eur Heart J Cardiovasc Imaging* 2015;**16**:712–8.
2. Edvardsen T, Plein S, Saraste A, Pierard LA, Knuuti J, Maurer G *et al.* The year 2014 in the *European Heart Journal–Cardiovascular Imaging*: part II. *Eur Heart J Cardiovasc Imaging* 2014;**15**:1180–4.
3. Cardim N, Galderisi M, Edvardsen T, Plein S, Popescu BA, Andrea AD *et al.* Role of multimodality cardiac imaging in the management of patients with hypertrophic cardiomyopathy: an expert consensus of the European Association of Cardiovascular Imaging Endorsed by the Saudi Heart Association. *Eur Heart J Cardiovasc Imaging* 2015;**16**:280.
4. Galderisi M, Cardim N, Andrea AD, Bruder O, Cosyns B, Davin L *et al.* The multi-modality cardiac imaging approach to the Athlete's heart: an expert consensus of the European Association of Cardiovascular Imaging. *Eur Heart J Cardiovasc Imaging* 2015;**16**:353.
5. Badano LP, Miglioranza MH, Edvardsen T, Colafranceschi AS, Muraru D, Bacal F *et al.* European Association of Cardiovascular Imaging/Cardiovascular Imaging Department of the Brazilian Society of Cardiology recommendations for the use of cardiac imaging to assess and follow patients after heart transplantation. *Eur Heart J Cardiovasc Imaging* 2015;**16**:919–48.
6. Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L *et al.* Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *Eur Heart J Cardiovasc Imaging* 2015;**16**:233–70.
7. Nagueh SF, Smiseth OA, Appleton CP, Byrd BF, Dokainish H, Edvardsen T *et al.* Recommendations for the evaluation of left ventricular diastolic function by echocardiography: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *Eur Heart J Cardiovasc Imaging* 2016;**17**:1321–60.
8. Lancellotti P, Price S, Edvardsen T, Cosyns B, Neskovic AN, Dulgheru R *et al.* The use of echocardiography in acute cardiovascular care: recommendations of the European Association of Cardiovascular Imaging and the Acute Cardiovascular Care Association. *Eur Heart J Cardiovasc Imaging* 2015;**4**:119–46.
9. Donal E, Lip GYH, Galderisi M, Goette A, Shah D, Marwan M *et al.* EACVI/EHRA Expert Consensus Document on the role of multi-modality imaging for the evaluation of patients with atrial fibrillation. *Eur Heart J Cardiovasc Imaging* 2016;**17**:355–83.
10. Marwick TH, Gillebert TC, Aurigemma G, Chirinos J, Derumeaux G, Galderisi M *et al.* Recommendations on the use of echocardiography in adult hypertension: a report from the European Association of Cardiovascular Imaging (EACVI) and the American Society of Echocardiography (ASE). *Eur Heart J Cardiovasc Imaging* 2015;**16**:577–605.
11. Acampa W, Gaemperli O, Gimelli A, Knaapen P, Schindler TH, Verberne HJ *et al.* Role of risk stratification by SPECT, PET, and hybrid imaging in guiding management of stable patients with ischaemic heart disease: expert panel of the EANM cardiovascular committee and EACVI. *Eur Heart J Cardiovasc Imaging* 2015;**16**:1289–98.
12. Gimelli A, Neglia D, Schindler TH, Cosyns B, Lancellotti P, Kitsiou A. Nuclear cardiology core syllabus of the European Association of Cardiovascular Imaging (EACVI). *Eur Heart J Cardiovasc Imaging* 2015;**16**:349–50.
13. Nieman K, Achenbach S, Pugliese F, Cosyns B, Lancellotti P, Kitsiou A. Cardiac computed tomography core syllabus of the European Association of Cardiovascular Imaging (EACVI). *Eur Heart J Cardiovasc Imaging* 2015;**16**:351–2.
14. Valsangiacomo Buechel ER, Grosse-Wortmann L, Fratz S, Eichhorn J, Sarikouch S, Greil GF *et al.* Indications for cardiovascular magnetic resonance in children with congenital and acquired heart disease: an expert consensus paper of the Imaging Working Group of the AEPC and the Cardiovascular Magnetic Resonance Section of the EACVI. *Eur Heart J Cardiovasc Imaging* 2015;**16**:281–97.
15. Haugaa KH, Basso C, Badano LP, Bucciarelli-Ducci C, Cardim N, Gaemperli O *et al.* Comprehensive multi-modality imaging approach in arrhythmogenic cardiomyopathy-an expert consensus document of the European Association of Cardiovascular Imaging. *Eur Heart J Cardiovasc Imaging* 2017;**18**:237–53.
16. Edvardsen T, Donal E, Bucciarelli-Ducci C, Maurovich-Horvat P, Maurer G, Popescu BA. The years 2015–2016 in the *European Heart Journal—Cardiovascular Imaging*. Part I. *Eur Heart J Cardiovasc Imaging* 2017;**18**:1092–8.
17. Saberniak J, Leren IS, Haland TF, Beitnes JO, Hopp E, Borgquist R *et al.* Comparison of patients with early-phase arrhythmogenic right ventricular cardiomyopathy and right ventricular outflow tract ventricular tachycardia. *Eur Heart J Cardiovasc Imaging* 2017;**18**:62–9.
18. Haland TF, Almaas VM, Hasselberg NE, Saberniak J, Leren IS, Hopp E *et al.* Strain echocardiography is related to fibrosis and ventricular arrhythmias in hypertrophic cardiomyopathy. *Eur Heart J Cardiovasc Imaging* 2016;**17**:613–21.
19. Ong KC, Geske JB, Hebl VB, Nishimura RA, Schaff HV, Ackerman MJ *et al.* Pulmonary hypertension is associated with worse survival in hypertrophic cardiomyopathy. *Eur Heart J Cardiovasc Imaging* 2016;**17**:604–10.
20. Peteiro J, Fernandez X, Bouzas-Mosquera A, Monserrat L, Méndez C, Rodriguez-Garcia E *et al.* Exercise echocardiography and cardiac magnetic resonance

imaging to predict outcome in patients with hypertrophic cardiomyopathy. *Eur Heart J Cardiovasc Imaging* 2015;**16**:423–32.
21. Kim EK, Lee S-C, Hwang JW, Chang S-A, Park S-J, On YK *et al*. Differences in apical and non-apical types of hypertrophic cardiomyopathy: a prospective analysis of clinical, echocardiographic, and cardiac magnetic resonance findings and outcome from 350 patients. *Eur Heart J Cardiovasc Imaging* 2016;**17**:678–86.
22. Bravo PE, Luo H-C, Pozios I, Zimmerman SL, Corona-Villalobos CP, Sorensen L *et al*. Late gadolinium enhancement confined to the right ventricular insertion points in hypertrophic cardiomyopathy: an intermediate stage phenotype? *Eur Heart J Cardiovasc Imaging* 2016;**17**:293–300.
23. Rodrigues JCL, Amadu AM, Dastidar AG, Hassan N, Lyen SM, Lawton CB *et al*. Prevalence and predictors of asymmetric hypertensive heart disease: insights from cardiac and aortic function with cardiovascular magnetic resonance. *Eur Heart J Cardiovasc Imaging* 2016;**17**:1405–13.
24. Minamisawa M, Koyama J, Sekijima Y, Ikeda S, Kozuka A, Ebisawa S *et al*. Comparison of the standard and speckle tracking echocardiographic features of wild-type and mutated transthyretin cardiac amyloidoses. *Eur Heart J Cardiovasc Imaging* 2016;**17**:402–10.
25. Bhatti S, Watts E, Syed F, Vallurupalli S, Pandey T, Jambekar K *et al*. Clinical and prognostic utility of cardiovascular magnetic resonance imaging in myeloma patients with suspected cardiac amyloidosis. *Eur Heart J Cardiovasc Imaging* 2016;**17**:970–7.
26. Mohty D, Boulogne C, Magne J, Varroud-Vial N, Martin S, Ettaif H *et al*. Prognostic value of left atrial function in systemic light-chain amyloidosis: a cardiac magnetic resonance study. *Eur Heart J Cardiovasc Imaging* 2016;**17**:961–9.
27. Iles LM, Ellims AH, Llewellyn H, Hare JL, Kaye DM, McLean CA *et al*. Histological validation of cardiac magnetic resonance analysis of regional and diffuse interstitial myocardial fibrosis. *Eur Heart J Cardiovasc Imaging* 2015;**16**:14–22.
28. aus dem Siepen F, Buss SJ, Messroghli D, Andre F, Lossnitzer D, Seitz S *et al*. T1 mapping in dilated cardiomyopathy with cardiac magnetic resonance: quantification of diffuse myocardial fibrosis and comparison with endomyocardial biopsy. *Eur Heart J Cardiovasc Imaging* 2015;**16**:210–6.
29. Putko BN, Yogasundaram H, Chow K, Pagano J, Khan A, Paterson DI *et al*. Normal left-atrial structure and function despite concentric left-ventricular remodelling in a cohort of patients with Anderson-Fabry disease. *Eur Heart J Cardiovasc Imaging* 2015;**16**:1129–36.
30. Nadel J, Lancefield T, Voskoboinik A, Taylor AJ. Late gadolinium enhancement identified with cardiac magnetic resonance imaging in sarcoidosis patients is associated with long-term ventricular arrhythmia and sudden cardiac death. *Eur Heart J Cardiovasc Imaging* 2015;**16**:634–41.
31. Raimondi F, Iserin F, Raisky O, Laux D, Bajolle F, Boudjemline Y *et al*. Myocardial inflammation on cardiovascular magnetic resonance predicts left ventricular function recovery in children with recent dilated cardiomyopathy. *Eur Heart J Cardiovasc Imaging* 2015;**16**:756–62.
32. Buss SJ, Breuninger K, Lehrke S, Voss A, Galuschky C, Lossnitzer D *et al*. Assessment of myocardial deformation with cardiac magnetic resonance strain imaging improves risk stratification in patients with dilated cardiomyopathy. *Eur Heart J Cardiovasc Imaging* 2015;**16**:307–15.
33. Meloni A, Positano V, Ruffo GB, Spasiano A, Ascola DGD, Peluso A *et al*. Improvement of heart iron with preserved patterns of iron store by CMR-guided chelation therapy. *Eur Heart J Cardiovasc Imaging* 2015;**16**:325–34.
34. Mordi I, Carrick D, Bezerra H, Tzemos N. T1 and T2 mapping for early diagnosis of dilated non-ischaemic cardiomyopathy in middle-aged patients and differentiation from normal physiological adaptation. *Eur Heart J Cardiovasc Imaging* 2016;**17**:797–803.
35. Florian A, Rösch S, Bietenbeck M, Engelen M, Stypmann J, Waltenberger J *et al*. Cardiac involvement in female Duchenne and Becker muscular dystrophy carriers in comparison to their first-degree male relatives: a comparative cardiovascular magnetic resonance study. *Eur Heart J Cardiovasc Imaging* 2016;**17**:326–33.
36. Ponikowski P, Voors AA, Anker SD, Bueno H, Cleland JGF, Coats AJS *et al*. 2016 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure: the task force for the diagnosis and treatment of acute and chronic heart failure of the European Society of Cardiology (ESC)Developed with the special contribution of the Heart Failure Association (HFA) of the ESC. *Eur Heart J* 2016;**37**:2129–200.
37. Hasselberg NE, Haugaa KH, Bernard A, Ribe MP, Kongsgaard E, Donal E *et al*. Left ventricular markers of mortality and ventricular arrhythmias in heart failure patients with cardiac resynchronization therapy. *Eur Heart J Cardiovasc Imaging* 2016;**17**:343–50.
38. Ghani A, Delnoy PP, Ottervanger JP, Ramdat Misier AR, Smit JJ, Adiyaman A *et al*. Association of apical rocking with long-term major adverse cardiac events in patients undergoing cardiac resynchronization therapy. *Eur Heart J Cardiovasc Imaging* 2016;**17**:146–53.
39. Boe E, Russell K, Eek C, Eriksen M, Remme EW, Smiseth OA *et al*. Non-invasive myocardial work index identifies acute coronary occlusion in patients with non-ST-segment elevation-acute coronary syndrome. *Eur Heart J Cardiovasc Imaging* 2015;**16**:1247–55.
40. Menet A, Bernard A, Tribouilloy C, Leclercq C, Gevaert C, Guyomar Y *et al*. Clinical significance of septal deformation patterns in heart failure patients receiving cardiac resynchronization therapy. *Eur Heart J Cardiovasc Imaging* 2017;**18**:1388–97.
41. Stankovic I, Prinz C, Ciarka A, Daraban AM, Kotrc M, Aarones M *et al*. Relationship of visually assessed apical rocking and septal flash to response and long-term survival following cardiac resynchronization therapy (PREDICT-CRT). *Eur Heart J Cardiovasc Imaging* 2016;**17**:262–9.
42. Morris DA, Krisper M, Nakatani S, Köhncke C, Otsuji Y, Belyavskiy E *et al*. Normal range and usefulness of right ventricular systolic strain to detect subtle right ventricular systolic abnormalities in patients with heart failure: a multicentre study. *Eur Heart J Cardiovasc Imaging* 2017;**18**:212–23.
43. Chan Y-H, Lee H-F, Wu L-S, Wang C-L, Wu C-T, Yeh Y-H *et al*. Ratio of transmitral early filling velocity to early diastolic strain rate predicts outcomes in patients with systolic heart failure. *Eur Heart J Cardiovasc Imaging* 2017;**18**:79–85.
44. Cavalcante JL, Marek J, Sheppard R, Starling RC, Mather PJ, Alexis JD *et al*. Diastolic function improvement is associated with favourable outcomes in patients with acute non-ischaemic cardiomyopathy: insights from the multicentre IMAC-2 trial. *Eur Heart J Cardiovasc Imaging* 2016;**17**:1027–35.
45. Hsiao S-H, Chiou K-R. Renal function decline predicted by left atrial expansion index in non-diabetic cohort with preserved systolic heart function. *Eur Heart J Cardiovasc Imaging* 2017;**18**:521–8.
46. Donal E, Lund LH, Oger E, Bosseau C, Reynaud A, Hage C *et al*. Importance of combined left atrial size and estimated pulmonary pressure for clinical outcome in patients presenting with heart failure with preserved ejection fraction. *Eur Heart J Cardiovasc Imaging* 2017;**18**:629–35.
47. O'Neal WT, Sandesara P, Patel N, Venkatesh S, Samman-Tahhan A, Hammadah M *et al*. Echocardiographic predictors of atrial fibrillation in patients with heart failure with preserved ejection fraction. *Eur Heart J Cardiovasc Imaging* 2017;**18**:725–9.
48. Tournoux F, Chequer R, Sroussi M, Hyafil F, Algalarrondo V, Cohen-Solal A *et al*. Value of mechanical dyssynchrony as assessed by radionuclide ventriculography to predict the cardiac resynchronization therapy response. *Eur Heart J Cardiovasc Imaging* 2016;**17**:1250–8.
49. Fujita B, Kütting M, Seiffert M, Scholtz S, Egron S, Prashovikj E *et al*. Calcium distribution patterns of the aortic valve as a risk factor for the need of permanent pacemaker implantation after transcatheter aortic valve implantation. *Eur Heart J Cardiovasc Imaging* 2016;**17**:1385–93.
50. Zilberszac R, Lancellotti P, Gilon D, Gabriel H, Schemper M, Maurer G *et al*. Role of a heart valve clinic programme in the management of patients with aortic stenosis. *Eur Heart J Cardiovasc Imaging* 2017;**18**:138–44.
51. Sigvardsen PE, Larsen LH, Carstensen HG, Sørgaard M, Hindsø L, Hassager C *et al*. Prognostic implications of left ventricular asymmetry in patients with asymptomatic aortic valve stenosis. *Eur Heart J Cardiovasc Imaging* 2017; doi: 10.1093/ehjci/jew339.
52. Carstensen HG, Larsen LH, Hassager C, Kofoed KF, Jensen JS, Mogelvang R. Basal longitudinal strain predicts future aortic valve replacement in asymptomatic patients with aortic stenosis. *Eur Heart J Cardiovasc Imaging* 2016;**17**:283–92.
53. García-Martín A, Lázaro-Rivera C, Fernández-Golfín C, Salido-Tahoces L, Moya-Mur J-L, Jiménez-Nacher J-J *et al*. Accuracy and reproducibility of novel echocardiographic three-dimensional automated software for the assessment of the aortic root in candidates for thanscatheter aortic valve replacement. *Eur Heart J Cardiovasc Imaging* 2016;**17**:772–8.
54. Bartel T, Edris A, Velik-Salchner C, Müller S. Intracardiac echocardiography for guidance of transcatheter aortic valve implantation under monitored sedation: a solution to a dilemma? *Eur Heart J Cardiovasc Imaging* 2016;**17**:1–8.
55. Abdelghani M, Tateishi H, Spitzer E, Tijssen JG, de Winter RJ, Soliman OII *et al*. Echocardiographic and angiographic assessment of paravalvular regurgitation after TAVI: optimizing inter-technique reproducibility. *Eur Heart J Cardiovasc Imaging* 2016;**17**:852–60.
56. Garcia J, Barker AJ, Murphy I, Jarvis K, Schnell S, Collins JD *et al*. Four-dimensional flow magnetic resonance imaging-based characterization of aortic morphometry and haemodynamics: impact of age, aortic diameter, and valve morphology. *Eur Heart J Cardiovasc Imaging* 2016;**17**:877–84.
57. Schnell S, Smith DA, Barker AJ, Entezari P, Honarmand AR, Carr ML *et al*. Altered aortic shape in bicuspid aortic valve relatives influences blood flow patterns. *Eur Heart J Cardiovasc Imaging* 2016;**17**:1239–47.
58. van Wijngaarden SE, Kamperidis V, Regeer MV, Palmen M, Schalij MJ, Klautz RJ *et al*. Three-dimensional assessment of mitral valve annulus dynamics and impact on quantification of mitral regurgitation. *Eur Heart J Cardiovasc Imaging* 2017; doi: 10.1093/ehjci/jex001.
59. Mihaila S, Muraru D, Miglioranza MH, Piasentini E, Aruta P, Cucchini U *et al*. Relationship between mitral annulus function and mitral regurgitation severity and left atrial remodelling in patients with primary mitral regurgitation. *Eur Heart J Cardiovasc Imaging* 2016;**17**:918–29.

60. Medvedofsky D, Aronson D, Gomberg-Maitland M, Thomeas V, Rich S, Spencer K *et al*. Tricuspid regurgitation progression and regression in pulmonary arterial hypertension: implications for right ventricular and tricuspid valve apparatus geometry and patients outcome. *Eur Heart J Cardiovasc Imaging* 2017;**18**:86–94.
61. Utsunomiya H, Itabashi Y, Mihara H, Kobayashi S, De Robertis MA, Trento A *et al*. Usefulness of 3D echocardiographic parameters of tricuspid valve morphology to predict residual tricuspid regurgitation after tricuspid annuloplasty. *Eur Heart J Cardiovasc Imaging* 2017;**18**:809–17.
62. Muraru D, Veronesi F, Maddalozzo A, Dequal D, Frajhof L, Rabischoffsky A *et al*. 3D printing of normal and pathologic tricuspid valves from transthoracic 3D echocardiography data sets. *Eur Heart J Cardiovasc Imaging* 2017;**18**:802–8.
63. Bull S, Loudon M, Francis JM, Joseph J, Gerry S, Karamitsos TD *et al*. A prospective, double-blind, randomized controlled trial of the angiotensin-converting enzyme inhibitor Ramipril In Aortic Stenosis (RIAS trial). *Eur Heart J Cardiovasc Imaging* 2015;**16**:834–41.
64. Lurz P, Serpytis R, Blazek S, Seeburger J, Mangner N, Noack T *et al*. Assessment of acute changes in ventricular volumes, function, and strain after interventional edge-to-edge repair of mitral regurgitation using cardiac magnetic resonance imaging. *Eur Heart J Cardiovasc Imaging* 2015;**16**:1399–404.
65. Ruile P, Blanke P, Krauss T, Dorfs S, Jung B, Jander N *et al*. Pre-procedural assessment of aortic annulus dimensions for transcatheter aortic valve replacement: comparison of a non-contrast 3D MRA protocol with contrast-enhanced cardiac dual-source CT angiography. *Eur Heart J Cardiovasc Imaging* 2016;**17**:458–66.
66. Salaun E, Jacquier A, Theron A, Giorgi R, Lambert M, Jaussaud N *et al*. Value of CMR in quantification of paravalvular aortic regurgitation after TAVI. *Eur Heart J Cardiovasc Imaging* 2016;**17**:41–50.
67. Singh A, Horsfield MA, Bekele S, Khan JN, Greiser A, McCann GP. Myocardial T1 and extracellular volume fraction measurement in asymptomatic patients with aortic stenosis: reproducibility and comparison with age-matched controls. *Eur Heart J Cardiovasc Imaging* 2015;**16**:763–70.
68. Noda C, Ambale Venkatesh B, Ohyama Y, Liu C-Y, Chamera E, Redheuil A *et al*. Reproducibility of functional aortic analysis using magnetic resonance imaging: the MESA. *Eur Heart J Cardiovasc Imaging* 2016;**17**:909–17.
69. Ohyama Y, Teixido-Tura G, Ambale-Venkatesh B, Noda C, Chugh AR, Liu C-Y *et al*. Ten-year longitudinal change in aortic stiffness assessed by cardiac MRI in the second half of the human lifespan: the multi-ethnic study of atherosclerosis. *Eur Heart J Cardiovasc Imaging* 2016;**17**:1044–53.
70. van Rosendael PJ, Joyce E, Katsanos S, Debonnaire P, Kamperidis V, van der Kley F *et al*. Tricuspid valve remodelling in functional tricuspid regurgitation: multidetector row computed tomography insights. *Eur Heart J Cardiovasc Imaging* 2016;**17**:96–105.
71. Al-Issa A, Inoue Y, Cammin J, Tang Q, Nazarian S, Calkins H *et al*. Regional function analysis of left atrial appendage using motion estimation CT and risk of stroke in patients with atrial fibrillation. *Eur Heart J Cardiovasc Imaging* 2016;**17**:788–96.
72. Pushparajah K, Wong JK, Bellsham-Revell HR, Hussain T, Valverde I, Bell A *et al*. Magnetic resonance imaging catheter stress haemodynamics post-Fontan in hypoplastic left heart syndrome. *Eur Heart J Cardiovasc Imaging* 2016;**17**:644–51.
73. Simpson J, Lopez L, Acar P, Friedberg M, Khoo N, Ko H *et al*. Three-dimensional echocardiography in congenital heart disease: an expert consensus document from the European Association of Cardiovascular Imaging and the American Society of Echocardiography. *Eur Heart J Cardiovasc Imaging* 2016;**17**:1071–97.