Heart failure with preserved ejection fraction: recent concepts in diagnosis, mechanisms and management

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ABSTRACT

It is estimated that half of all patients with heart failure (HF) have HF with preserved ejection fraction (HFrEF). Yet this form of HF remains a diagnostic and therapeutic challenge. Differentiating HFrEF from other causes of dyspnoea may require advanced diagnostic methods, such as exercise echocardiography, invasive haemodynamics and investigations for ‘HFpEF mimickers’. While the classification of HF has relied heavily on cut-points in left ventricular ejection fraction (LVEF), recent evidence points towards a gradual shift in underlying mechanisms, phenotypes and response to therapies as LVEF increases. For example, among patients with HF, the proportion of hospitalisations and deaths due to cardiac causes decreases as LVEF increases. Medication classes that are efficacious in HF with reduced ejection fraction (HFrEF) have been less so at higher LVEF ranges, decreasing the risk of HF hospitalisation but not cardiovascular or all-cause death in HFrEF. These observations reflect the burden of non-cardiac comorbidities as LVEF increases and highlight the complex pathophysiological mechanisms, both cardiac and non-cardiac, underpinning HFrEF. Treatment with sodium-glucose cotransporter 2 inhibitors reduces the risk of composite cardiovascular events, driven by a reduction in HF hospitalisations; renin-angiotensin-aldosterone blockers and angiotensin-neprilysin inhibitors result in smaller reductions in HF hospitalisations among patients with HFrEF. Comprehensive management of HFrEF includes exercise as well as treatment of risk factors and comorbidities. Classification based on phenotypes may facilitate a more targeted approach to treatment than LVEF categorisation, which sets arbitrary cut-points when LVEF is a continuum. This narrative review summarises the pathophysiology, diagnosis, classification and management of patients with HFrEF.

RECENT CONCEPTS IN DIAGNOSIS OF HFpEF

The evolving definition of HFrEF

Almost two decades ago, it was demonstrated that patients with heart failure (HF) and mild or no reduction in left ventricular ejection fraction (LVEF) had better outcomes than patients with severe systolic dysfunction.1 Mechanistic studies revealed that some of these patients even had normal filling pressures at rest and that a complex interplay existed between pathological cardiac and non-cardiac processes.2 Heart failure with preserved ejection fraction (HFrEF) was first defined as HF in patients with an LVEF >40%.3 4 Major cardiovascular societies then introduced HF with mid-range and subsequently, mildly reduced ejection fraction (HFmrEF), to describe HF with LVEF 40%–50%.3 4 HFpEF is now defined as HF with LVEF >50%, in absence of prior reduced LVEF.3 However, these classifications of HF according to arbitrary cut-points in LVEF do not appear consistent with recent evidence, which points to a gradual shift and considerable overlap in underlying mechanisms, phenotypes and response to therapy as LVEF increases (figure 1).3–5 HF therapies have generally not been effective at reducing cardiovascular (CV) death beyond LVEF 40%–50% or HF hospitalisation beyond 55%–60%, reflecting the contribution of non-cardiac comorbidities as LVEF increases.7 8 Meta-analyses and mechanistic studies demonstrated the overlapping pathophysiology and response to therapies between HF with reduced ejection fraction (HFrEF) and HFmrEF.7 8 Thus, the definition of HFpEF will continue to evolve as new information regarding phenotypes emerges.

Current diagnostic approach and its limitations

HFpEF can be defined as HF with normal LVEF and elevated left ventricular (LV) filling pressure at rest or during exercise.9 It is not feasible to subject all patients with HFpEF to an invasive exercise haemodynamic study. Most guidelines define HFpEF clinically as (1) the presence of symptoms and signs of HF; (2) an LVEF ≥50%; (3) careful exclusion of ‘HFpEF mimickers’; and (4) evidence of elevated LV filling pressure or non-invasive correlates (elevated E/e’ ratio, increased left atrial volume, elevated natriuretic peptides (NP)).4 9

The diagnostic criteria for HFpEF are not without limitations. First, the optimal LVEF threshold to define HFpEF is still debated. Several ‘HFpEF’ randomised clinical trials (RCTs) have used lower LVEF cut-offs (40%–45%) to maximise event rates and thus attain statistical power to demonstrate treatment effect. Patients with HFmrEF appear to have similar pathophysiology and treatment response as those with HFrEF, so their inclusion in trials of HFpEF favours treatments effective in HFrEF.7 8 Second, NP levels may not always guide diagnosis as they tend to be lower in HFrEF than HFrEF, likely due to lower diastolic wall stress and higher prevalence of obesity.3 Third, while these criteria rely on measurements at rest, left-sided filling pressures increase only with exercise in many patients with HFpEF; patients who do not experience dyspnoea or demonstrate signs of elevated LV filling pressure at rest require advanced testing such as exercise echocardiography or invasive

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Review

exercise haemodynamics to unmask abnormal diastolic reserve (figure 2). E:e’ during exercise has been shown to correlate reasonably well with invasively measured pulmonary capillary wedge pressure (PCWP) (figure 2). However, imaging studies during exercise are subject to limitations posed by body habitus and operator experience. Invasive haemodynamics provide a direct measurement of PCWP during exercise, although the diagnostic threshold is still debated (exercise PCWP ≥25 mmHg or ΔPCWP/Δcardiac output slope >2.0 mmHg/L/min).

Two HFpEF diagnostic algorithms—the H2FPEF score and the European Society of Cardiology HFA-PEFF algorithm—combine clinical characteristics and diagnostic parameters to distinguish HFpEF from non-cardiac dyspnoea (tables 1–2). Implementation of these scores in different populations has demonstrated little overlap between patients with high H2FPEF and HFA-PEFF scores; however, both scores identify patients at high risk of HF events. Validation of these scores against invasive haemodynamics demonstrated reasonable performance: the area under the receiver operating characteristic curve was 0.73–0.74. Still, up to 23% of patients were misclassified in both scores, typically occurring in patients with low scores who met invasive HFpEF criteria. Thus, low scores may not exclude HFpEF. Furthermore, a substantial proportion of patients have an intermediate probability for HFpEF using this classification system and require further testing.

HFpEF mimickers and specific cardiac aetiologies of HFpEF

While most cases of HFpEF are associated with known risk factors and comorbidities, ‘HFpEF mimickers’ such as lung disease, pulmonary embolism, right-sided HF secondary to pulmonary hypertension and renal failure can present with similar symptoms and signs. Also, several specific cardiac disorders can present with HFpEF. These can be classified into diseases that affect the myocardium and those that alter cardiac loading conditions (table 3). Cardiac amyloidosis, for example, is present in up to 13% of patients with HFpEF on routine...
Recent insights in HFpEF pathophysiology

HFpEF results from a complex interplay between risk factors, comorbidities and cardiac pathology that impact LV structure, haemodynamics and systemic organ function (figure 3). In a normal LV, volume increases during diastole are accompanied by minimal pressure increases due to enhanced diastolic suction; LV end-diastolic pressure (LVEDP) remains normal with exercise. In HFpEF, due to increased chamber stiffness, the diastolic pressure-volume relationship is shifted upwards and left compared with a normal LV (figure 2). Volume changes thus lead to larger increases in LVEDP. Additionally, in most patients with HFpEF, the exercise-induced increase in cardiac output is blunted due to poor contractile reserve and chronotropic incompetence. In overt HFpEF, the elevated LVEDP persists at rest, resulting in poor exercise tolerance (figure 2).

Cardiac and non-cardiac mechanisms

The importance of non-cardiac mechanisms in HFpEF is highlighted by the decreasing proportion of HF hospitalisations and CV deaths as LVEF increases. Non-cardiac abnormalities in HFpEF can be grouped by organ systems. Chronic obstructive pulmonary disease, sleep disordered breathing and lung biopsy, even when not clinically suspected. Targeted therapies exist for most of these conditions, and it is important that they are excluded when a clinical diagnosis of HFpEF is made.

HFpEF phenotypes

The identification of phenotypes—subgroups with similar clinical and pathophysiological characteristics that are distinct from other subgroups—may allow for the identification of specific HFpEF subgroups more amenable to therapy. As LVEF increases, patients with HF are more commonly women, more commonly have hypertension and atrial fibrillation, less commonly have ischaemic heart disease, and have lower NP levels. Machine learning algorithms have separated patients into phenogroups based on the presence of clinical characteristics, biomarker and imaging profiles. Although external validation is pending for most studies, the importance of this approach is demonstrated by robust stratification of clinical outcomes according to HF phenotypes. Different HFpEF phenotypes may reflect different underlying pathophysiology. For example, cardiomyocyte calcium homeostasis was markedly abnormal in diabetic and hypertensive HFpEF but not in ischaemic HFpEF. Obese patients with HFpEF have markedly different clinical, haemodynamic and molecular changes compared with non-obese patients with HFpEF. However, current phenogroups are not mutually exclusive and a given patient can fit into different phenogroups, limiting the uptake of this approach. Future research should focus on external validation and on integrating phenotype-based classification schemes in clinical practice and in RCT recruitment.

RECENT DEVELOPMENTS IN HFPEF MANAGEMENT

Lifestyle-based therapy

Up to 80% of patients with HFpEF are overweight, and weight loss has beneficial effects on cardiac relaxation and metabolic profile in older patients without HF. In a small RCT in obese patients with HFpEF, a calorie-restricted diet alone or in combination with exercise training (ET) was associated with significant weight loss and an increase in absolute peak oxygen consumption (VO2peak). Together, diet and exercise had additive effects. A low-sodium diet has been associated with favourable haemodynamic changes in HFpEF. ET has beneficial effects in HFpEF and associated comorbidities such as atrial fibrillation and coronary artery disease. A meta-analysis of 8 RCTs with 463 patients with HFpEF found

Table 1 H,FPEF score

<table>
<thead>
<tr>
<th>Clinical variable</th>
<th>Values</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy</td>
<td>Body mass index &gt;30 kg/m²</td>
<td>2</td>
</tr>
<tr>
<td>Hypertensive</td>
<td>2 or more hypertensive medicines</td>
<td>1</td>
</tr>
<tr>
<td>Atrial Fibrillation</td>
<td>Paroxysmal or persistent</td>
<td>3</td>
</tr>
<tr>
<td>Pulmonary hypertension</td>
<td>Doppler echocardiographic estimated PASP &gt;35 mm Hg</td>
<td>1</td>
</tr>
<tr>
<td>Elder</td>
<td>Age &gt;60 years</td>
<td>1</td>
</tr>
<tr>
<td>Filling pressure</td>
<td>Doppler echocardiographic E/e’ &gt;9</td>
<td>1</td>
</tr>
</tbody>
</table>

1–2: low likelihood; 3–4: intermediate likelihood; ≥5: high likelihood of HFpEF.

Table 2 Heart Failure Association PEFF algorithm: stepwise approach in diagnosing heart failure with preserved ejection fraction (P–F)

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Additional tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>Initial work-up (step 1 (P): Pretest assessment)</td>
<td>Symptoms and/or signs of HF, Comorbidities/risk factors, ECG, Standard echocardiography, Natriuretic peptides, Ergometry/6MWT or PET</td>
</tr>
<tr>
<td>E</td>
<td>Diagnostic work-up (step 2 (E): Echocardiographic and natriuretic peptide score)</td>
<td>Comprehensive echocardiography, Natriuretic peptides, if not measured in step 1</td>
</tr>
<tr>
<td>F1</td>
<td>Advanced work-up (step 3 (F1): Functional testing in case of uncertainty)</td>
<td>Diastolic stress test: exercise stress echocardiography, Invasive haemodynamic measurements</td>
</tr>
<tr>
<td>F2</td>
<td>Aetiological work-up (step 4 (F2): Final aetiology)</td>
<td>Cardiovascular MRI, Cardiac or non-cardiac biopsies, Scintigraphy/CT/PET, Genetic testing, Specific laboratory tests</td>
</tr>
</tbody>
</table>

CPET, cardiopulmonary exercise testing; HF, heart failure; 6MWT, 6 min walk test; PET, positron emission tomography.
### Table 3: Specific cardiac aetiologies underlying HFpEF: overview of specific aetiological diagnoses presenting with signs and symptoms of HFpEF

<table>
<thead>
<tr>
<th>Conditions affecting the myocardium</th>
<th>Clinical clues</th>
<th>Diagnostic approach</th>
<th>Important considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epicardial</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Microvascular</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infiltrative cardiomyopathies and storage disorders</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amyloidosis</td>
<td></td>
<td></td>
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<tr>
<td>Sarcoïdosis</td>
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<tr>
<td>Storage disorders including haemochromatosis</td>
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<tr>
<td>Hypertrophic cardiomyopathies</td>
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<td></td>
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<tr>
<td>Immune, inflammatory, metabolic and toxic cardiomyopathies</td>
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<td></td>
</tr>
<tr>
<td>Conditions that alter cardiac loading conditions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypertensive urgency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acquired or congenital valvular heart disease, particularly left-sided valvular regurgitation or stenosis</td>
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<td></td>
<td></td>
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<tr>
<td>Pericardial diseases such as constrictive pericarditis</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Arrhythmias, ventricular and supraventricular</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High output state: anaemia, sepsis, pregnancy, liver disease, thyroid disease, myeloproliferative disorders, arteriovenous fistula, beriberi disease and obesity</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Conditions affecting the myocardium**

- **Epicardial**
  - Chest pain
  - ECG changes
  - Abnormal stress testing
  - Abnormal LV GLS

- **Microvascular**
  - ECG evidence of ischaemia in the absence of focal wall motion abnormalities or perfusion defects on stress testing
  - Can cause abnormal LV GLS

**Infiltrative cardiomyopathies and storage disorders**

- **Amyloidosis**
  - Bilateral carpal tunnel syndrome
  - Biceps tendon rupture
  - Lumbar spinal stenosis
  - Autonomic dysfunction
  - Severely reduced tissue Doppler s’, e’ and a’
  - Relative apical sparing on LV GLS
  - LV, RV and atrial septal hypertrophy
  - Pericardial effusion

- **Sarcoïdosis**
  - Extracardiac manifestations of sarcoïd
  - Conduction system disorders
  - Ventricular arrhythmias in preserved LVEF
  - Basal septal thinning

- **Storage disorders including haemochromatosis**
  - Family history, young age of onset
  - Skin, hair, muscle, neurological abnormalities
  - Elevated serum creatine kinase, liver enzymes
  - Diabetes

- **Hypertrophic cardiomyopathies**
  - Family history, young age of onset
  - LV hypertrophy in the absence of hypertension
  - Biventricular hypertrophy
  - LV GLS abnormal in the anteroseptum or apex

- **Immune, inflammatory, metabolic and toxic cardiomyopathies**
  - History of specific exposure to immune, inflammatory, metabolic or toxic agent

**Conditions that alter cardiac loading conditions**

- **Hypertensive urgency**
  - LV GLS abnormal in the basal septum
  - Significant LV hypertrophy

- **Acquired or congenital valvular heart disease, particularly left-sided valvular regurgitation or stenosis**
  - Murmur
  - Echocardiography is generally diagnostic

- **Pericardial diseases such as constrictive pericarditis**
  - Respiratory variation in mitral inflow
  - Diastolic septal bounce
  - Hepatic vein diastolic flow reversal during expiration
  - Septal e’ velocity > lateral e’ velocity

- **Arrhythmias, ventricular and supraventricular**
  - HF symptoms in conjunction with palpitations
  - Paroxysmal HF symptoms

- **High output state: anaemia, sepsis, pregnancy, liver disease, thyroid disease, myeloproliferative disorders, arteriovenous fistula, beriberi disease and obesity**
  - Tachycardia
  - Wide pulse pressure and warm extremities
  - High cardiac output calculated by echocardiography
  - Symptoms and signs specific to the underlying disorder

**Diagnostic approach**

- Coronary CT angiography
- Invasive angiography
- Invasive angiography with pharmacological provocation
- Stress perfusion CMR
- Stress cardiac PET
- Cardiac PET
- Non-cardiac biopsy
- CMR
- Endomyocardial biopsy
- Tc-DPD or Tc-PYP scintigraphy
- Serum/urine immunofixation, free light chains
- Genetic testing
- Echocardiography
- CMR
- Genetic testing
- Holter monitor
- Exercise test
- Laboratory tests
- Echocardiography

**Important considerations**

- CAD → increased risk of HFpEF
- Complete revascularisation of epicardial stenosis → improved overall outcomes
- Effect of therapies targeted towards microvascular dysfunction → under investigation
- Storage diseases more common in younger patients; amyloidosis, sarcoidosis and haemochromatosis in older adults
- Often manifesting as restrictive cardiomyopathy
- Elevated 5-year mortality in adults
- Endomyocardial biopsies may be limited by sampling bias, especially in cases of suspected cardiac sarcoidosis
- Targeted therapies exist or are under investigation
- May progress to restrictive or dilated cardiomyopathy
- Expression of myocardial hypertrophy is age-dependent
- Hypertension is an important risk factor for HFpEF
- Volume overload (mitral or aortic regurgitation)
- Increased afterload (aortic or mitral stenosis)
- Treatment specific for valvular pathology
- Patients with constrictive pericarditis usually meet clinical and echocardiographic criteria for HFpEF
- Risk factors: history of pericarditis, cardiac surgery, radiation to the chest wall and tuberculosis
- Can cause haemodynamic compromise and symptoms mimicking HFpEF
- High-output heart failure should always be considered in patients presenting with normal LVEF; shortness of breath and congestion
- The comorbidities listed here should be actively excluded before a diagnosis of HFpEF is made
that ET improved VO_{peak}, 6 min walk distance and quality of life scores. A recent RCT compared standard moderate continuous training with high-intensity interval training. A significant improvement in the primary outcome of VO_{peak} after 3 months of in person ET was shown, regardless of training modality. However, the benefit in VO_{peak} was not sustained during a 9-month home-based supervised extension of training, highlighting the importance of supervised ET. Supervised cardiac rehabilitation remains underused in HF overall and is not reimbursed for patients with HFpEF in many countries.

Atrial fibrillation is commonly associated with HFpEF and may account for some of the symptoms. A 6-month exercise programme combining supervised and home-based aerobic exercise resulted in a significant decrease in the recurrence of atrial fibrillation and a reduction in symptom severity at 12 months. Other studies have shown benefit of risk factor management, including weight loss and ET, on atrial fibrillation symptoms and severity. Future studies should focus on how to successfully implement and sustain ET in these patients.

### Medical therapy

Given the pathophysiological complexity of HFpEF and the interplay with commonly associated comorbidities, the treatment of HFpEF should begin with evidence-informed management of risk factors and comorbidities. To date, no medical therapy has demonstrated a reduction in all-cause or CV death in trials of HFpEF. Despite a lack of robust evidence, diuretics have been the mainstay of HFpEF management and are recommended for relief of symptoms due to volume overload. Beta-blockers are often prescribed in HFpEF to treat comorbidities such as coronary artery disease and atrial fibrillation. A meta-analysis of three medium-sized RCTs demonstrated a reduction in all-cause mortality, but a vast majority had LVEF <50%. RCTs of beta-blockers in HFpEF are a major unmet need. It is likely that some patients with HFpEF benefit from beta-blockers, while in others beta-blockers can worsen chronotropic incompetence. Additionally, beta-blocker type (vasodilating, such as carvedilol, vs primary rate-controlling, such as metoprolol) may have differential effects across HFpEF phenotypes.

### Table 3

Continued

<table>
<thead>
<tr>
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<th>Clinical clues</th>
<th>Diagnostic approach</th>
<th>Important considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid dysregulation in chronic renal disease</td>
<td>Patient with end-stage renal disease</td>
<td>Laboratory tests</td>
<td>Complex interactions between end-stage renal disease and HFpEF</td>
</tr>
<tr>
<td>Pulmonary hypertension</td>
<td>Patient with sleep apnoea or lung disease including chronic obstructive pulmonary disease</td>
<td>Echocardiography</td>
<td>Altered right heart loading conditions due to pulmonary hypertension also cause LV diastolic dysfunction</td>
</tr>
</tbody>
</table>

**CAO**, coronary artery disease; CMR, cardiac MRI; GLS, global longitudinal strain; HF, heart failure; HFpEF, heart failure with preserved ejection fraction; LV, left ventricular; LVEF, left ventricular ejection fraction; PET, positron emission tomography; RV, right ventricular; Tc-DOP, technetium-99m 3,3-diphosphono-1,2-propanodicarboxylic acid; Tc-PYP, technetium-99m pyrophosphate.

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**Figure 3** Features of HFpEF. Phenotype is influenced by different risk factors, comorbidities, pathology, LV structure, haemodynamics and organ dysfunction in each patient. HFpEF, heart failure with preserved ejection fraction; LA, left atrium; LV, left ventricle; PA, pulmonary artery; RV, right ventricle.
Renin-angiotensin-aldosterone system (RAAS) inhibitors and mineralocorticoid receptor antagonists (MRAs) have an established role in HFpEF, but have been less effective in HFpEF, likely because the RAAS plays a less prominent pathophysiological role as LVEF increases. Trials of ACE inhibitors and angiotensin II receptor blockers (ARBs) have failed to show a significant reduction in all-cause or CV death in HFpEF (table 4), but have decreased the risk of HF hospitalisation.

The TOPCAT (Treatment of Preserved Cardiac Function Heart Failure With an Aldosterone Antagonist) trial of the MRA spironolactone in HFpEF failed to show an overall benefit in the primary composite outcome of CV death or HF hospitalisation. However, in an exploratory analysis including only patients from the Americas, a small benefit on the primary outcome was noticed. In both TOPCAT and the TOPCAT-Americas subgroup, spironolactone was associated with a reduced risk of HF hospitalisation. Machine learning analysis of the TOPCAT trial identified a phenotype characterised by obesity, diabetes, renal disease and inflammation that exhibited higher risk of CV events and a better response to spironolactone treatment. However, these results have not been validated externally, and only an RCT enriched for certain phenotypes will provide evidence for phenotype-based treatment (figure 4).

The angiotensin receptor neprilysin inhibitor (ARNI) sacubitril-valsartan did not reduce the composite of CV death or total HF hospitalisations in patients with HF and LVEF ≥45% relative to valsartan in the PARAGON-HF (Prospective Comparison of ARNI With ARB on Global Outcomes in HFpEF) trial, but significantly reduced HF hospitalisations. Of note, patients with elevated troponin or recent HF hospitalisation were at higher risk of CV events and were more likely to benefit from ARNI. In addition, benefits were higher in patients previously using MRA. We can speculate that these HFpEF phenotypes—more likely to be associated with structural heart disease and volume overload—may be more responsive to ARNI treatment.

In the EMPEROR-PRESERVED trial, sodium-glucose cotransporter 2 inhibitor (SGLT2i) empagliflozin reduced the risk of composite CV death or total HF hospitalisation in HF with LVEF >40%. The benefit was driven by a reduction in HF hospitalisations. There was no statistically significant treatment-LVEF interaction, but benefits did not extend beyond LVEF of 60% in a subgroup analysis. Furthermore, in the SOLOIST-WHF (Effect of Sotagliflozin on Cardiovascular Events in Patients with Type 2 Diabetes Post Worsening Heart Failure) trial, the dual SGLT2 and SGLT1 inhibitor sotagliflozin reduced the primary outcome of CV death and HF hospitalisations in patients with diabetes and worsening HF (both HFrEF and HFpEF), driven by reduced HF hospitalisations. It is likely that future updates of HF treatment guidelines will include a recommendation to use SGLT2i in HFpEF.

**Sex and race or ethnicity differences**

Epidemiological studies and randomised trials demonstrate a female predominance in HFpEF (50%–84%) due to differences in age and risk factors; after adjusting for these differences, men and women are at equal risk of developing HFpEF. In the TOPCAT-Americas trial, a post-hoc analysis showed no sex differences in the primary composite outcome, but women had a greater reduction in all-cause mortality with spironolactone compared to men (interaction p=0.02). In a prespecified subanalysis of the PARAGON-HF trial, the benefits of sacubitril-valsartan on the primary composite outcome (total HF hospitalisations and CV death) were sustained up to a higher LVEF in women (up to 60%) than in men (up to 45%). A meta-analysis of trials of RAAS inhibitors was consistent with this finding; the benefits of candesartan, spironolactone and sacubitril-valsartan were sustained to a higher LVEF in women than in men. This may be partially explained by differences in LV remodelling due to ageing, with more concentric remodelling in women, leading to a comparatively higher LVEF in women for any given LV volume.

Analyses of race or ethnicity differences in HFpEF have been limited by underenrolment of Black, Indigenous and people of colour in clinical trials relative to disease prevalence and inadequate reporting of treatment effect by racial or ethnic subgroups. In the USA, Black patients have a lower healthcare utilisation and risk of in-hospital mortality from HF, including HFpEF, but may be faced with higher rate of readmissions due to disparities in access to subspecialty and ambulatory care. There is no evidence from TOPCAT or EMPEROR-PRESERVED that there are racial differences in treatment effect of MRAs and SGLT2is, respectively.

**Integration of remote monitoring and multidisciplinary technology deployment**

With recent expansion of telemedicine encounters, clinician-patient interactions are increasingly supported by digital and device innovations. Virtual visits have been associated with
better adherence to clinic follow-up. Implantable remote pulmonary artery (PA) pressure-guided monitoring for patients with HfPef, New York Heart Association (NYHA) class III symptoms and a prior hospitalisation was associated with a 46% reduction in HF hospitalisations compared with routine care.41

The GUIDE-HF (Haemodynamic-Guided Management of HF) trial, testing whether this benefit extended to patients with NYHA class II–IV symptoms and without a history of hospitalisation, found that PA pressure-guided management did not reduce the composite endpoint of all-cause mortality and total HF events.42 More RCTs are warranted in this field, including novel approaches such as patient-activated therapy and multisensory device algorithms.

**Multidisciplinary care integration and health services in HfPef**

HfPef remains a diagnostic challenge and is often poorly managed, but clinical pathways and multidisciplinary teams can facilitate better care.43 Dedicated HfPef clinical programmes, nurse visiting programmes or ‘dyspnea clinics’ have been proposed to streamline diagnosis, management and follow-up.

### Table 4: Primary results and sex differences in major phase III randomised cardiovascular outcome clinical trials that included patients with HfPef

<table>
<thead>
<tr>
<th>Study (publication year)</th>
<th>Drug</th>
<th>Patients (n)</th>
<th>% women</th>
<th>LVEF (%)</th>
<th>Outcome</th>
<th>Overall treatment effect, HR (95% CI)</th>
<th>Sex-specific treatment effect</th>
<th>P value for treatment–sex interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACEI/ARB</td>
<td></td>
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</tr>
<tr>
<td>CHARM-Preserved (2003)†</td>
<td>Candesartan vs placebo</td>
<td>3023 40</td>
<td>&gt;40</td>
<td></td>
<td>Primary: composite of CV death or HF hospitalisation</td>
<td>0.89 (0.77 to 1.03)</td>
<td>No difference in primary outcome or all-cause death</td>
<td>Not reported</td>
</tr>
<tr>
<td>PEP-CHF (2006)††</td>
<td>Perindopril vs placebo</td>
<td>850 55</td>
<td>≥40</td>
<td></td>
<td>Primary: composite of all-cause death or unplanned HF hospitalisation</td>
<td>0.92 (0.70 to 1.21)</td>
<td>Not reported</td>
<td>Not reported</td>
</tr>
<tr>
<td>I-PRESERVE (2008)††</td>
<td>Irbesartan vs placebo</td>
<td>4128 61</td>
<td>≥45</td>
<td></td>
<td>Primary: composite of all-cause death or first CV hospitalisation</td>
<td>0.95 (0.86 to 1.05)</td>
<td>Not reported, but lower rate of primary endpoint in women regardless of treatment</td>
<td>Not reported</td>
</tr>
<tr>
<td><strong>Digitalis</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>DIG-PEF (2006)†</td>
<td>Digoxin vs placebo</td>
<td>988 41</td>
<td>&gt;45</td>
<td></td>
<td>Primary: composite of HF death or HF hospitalisation</td>
<td>0.82 (0.63 to 1.07)</td>
<td>Not reported</td>
<td>Not reported</td>
</tr>
<tr>
<td><strong>Beta-blocker</strong></td>
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<tr>
<td>SENIORS subanalysis (2009)§</td>
<td>Nebivolol vs placebo</td>
<td>752 50</td>
<td>&gt;35</td>
<td></td>
<td>Primary: all-cause mortality or HF hospitalisation</td>
<td>0.81 (0.63 to 1.04)</td>
<td>Not reported</td>
<td>Not reported</td>
</tr>
<tr>
<td>J–DHF (2013)††</td>
<td>Carvedilol vs placebo</td>
<td>245 42</td>
<td>&gt;40</td>
<td></td>
<td>Primary: composite of CV death or HF hospitalisation</td>
<td>0.90 (0.54 to 1.49)</td>
<td>0.68</td>
<td></td>
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<tr>
<td><strong>MRA</strong></td>
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<tr>
<td>TOPCAT (2014)†</td>
<td>Spironolactone vs placebo</td>
<td>3445 52</td>
<td>≥45</td>
<td></td>
<td>Primary: composite of CV death or HF hospitalisation</td>
<td>0.89 (0.77 to 1.04)</td>
<td>Women: 0.89 (0.71–1.12) M: 0.89 (0.73–1.09)</td>
<td>0.99</td>
</tr>
<tr>
<td>TOPCAT-Americas (2014)†</td>
<td>Spironolactone vs placebo</td>
<td>1767 50</td>
<td>≥45</td>
<td></td>
<td>Primary: composite of CV death or HF hospitalisation</td>
<td>0.82 (0.69 to 0.98)</td>
<td>Women: 0.81 (0.63–1.05) M: 0.85 (0.67–1.08)</td>
<td>0.84</td>
</tr>
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<td><strong>ARNI</strong></td>
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<tr>
<td>PARAGON (2019)†</td>
<td>Sacubitril–valsartan vs valsartan</td>
<td>4882 52</td>
<td>≥45</td>
<td></td>
<td>Primary: composite of CV death and total HF hospitalisations</td>
<td>0.87 (0.75 to 1.01)</td>
<td>Women: 0.73 (0.59–0.90) M: 1.03 (0.84–1.25)</td>
<td>0.017</td>
</tr>
<tr>
<td>SGLT2i</td>
<td></td>
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<td></td>
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<tr>
<td>EMPEROR-PRESERVED (2021)§</td>
<td>Empagliflozin vs placebo</td>
<td>5988 45</td>
<td>&gt;40</td>
<td></td>
<td>Primary: composite of CV death and first HF hospitalisation</td>
<td>0.79 (0.69 to 0.90)</td>
<td>Women: 0.75 (0.61–0.92) M: 0.81 (0.69–0.96)</td>
<td>0.54</td>
</tr>
<tr>
<td>SOLOIST-WHF (2021)§</td>
<td>Sotagliflozin vs placebo</td>
<td>1222 34</td>
<td>All</td>
<td></td>
<td>Primary: composite of CV death, HF hospitalisations and urgent HF visits</td>
<td>0.67 (0.52 to 0.85)</td>
<td>Women: 0.80 (0.51–1.25) M: 0.62 (0.47–0.82)</td>
<td>Not reported</td>
</tr>
</tbody>
</table>

Sex-specific treatment effects were not reported for HfPef only; data refer to patients with HfPef and HfRf combined.

ACEI, ACE inhibitor; ARB, angiotensin II receptor blocker; ARNI, angiotensin receptor neprilysin inhibitor; CV, cardiovascular; DIG-Pef, Digitalis Investigator Group - Preserved Ejection Fraction; EMPEROR-Preserved, Empagliflozin Outcome Trial in Patients with Chronic Heart Failure with Preserved Ejection Fraction; HF, heart failure; HfPEF, heart failure with preserved ejection fraction; HfRf, heart failure with reduced ejection fraction; I–PRESERVE, Irbesartan in patients with Heart Failure and Preserved Ejection Fraction; J–DHF, Japanese Diastolic Heart Failure study; LVEF, left ventricular ejection fraction; MRA, mineralocorticoid receptor antagonist; PARAGON, Prospective Comparison of ARNI With ARB on Global Outcomes in HfPef; PEP-CHF, Perindopril in Elderly People with Chronic Heart Failure; SENIORS, Study of the Effects of Nebivolol Intervention on Outcomes and Rehospitalisation in Seniors With Heart Failure; SGLT2, sodium-glucose cotransporter 2 inhibitor; SOLOIST-WHF, Effect of Sotagliflozin on Cardiovascular Events in Patients with Type 2 Diabetes Post Worsening Heart Failure; TOPCAT, Treatment of Preserved Cardiac Function HF With an Aldosterone Antagonist.
of patients, but most admissions in patients with HFpEF are secondary to non-cardiac causes.1 A multidisciplinary approach to treatment targeted at common cardiac and non-cardiac comorbidities may help improve outcomes.17 Additionally, transitional care services after hospital discharge improve patient-reported outcomes and may decrease emergency department visits, particularly in women.44-46

CONCLUSIONS
Invasive exercise haemodynamics remain the gold standard to diagnose HFpEF, but are not feasible for all patients. Clinical scores as well as exercise echocardiography aid the clinician in discerning HFpEF from its mimickers and from non-cardiac causes of dyspnoea. The three-category classification of HF by LVEF must be reconsidered in light of emerging evidence showing considerable overlap between HFrEF and HFmrEF in pathophysiology and response to treatment. LVEF is a continuous variable, and response to HF therapies appears to be graded; HF pharmacotherapies, including beta-blockers, RAAS inhibitors, ARNI and SGLT2i, that reduce both CV death and HF hospitalisation at lower LVEFs are less effective at reducing death but continue to reduce HF hospitalisation at higher LVEFs. This points to the non-cardiac mechanisms that underpin or accompany HF and differences in underlying pathophysiology as LVEF increases. Care of HF at the higher range of LVEF should entail investigations to exclude mimickers and strategies to address cardiac and non-cardiac comorbidities. Novel insights into HFpEF pathophysiology, including an understanding of sex-based differences and phenotypes, may help narrow down subgroups of patients who may respond to further personalised treatment.

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Acknowledgements Parts of figure 1 were provided by Servier Medical Art (http://smart.servier.com) used under CC-BY-3.0 licence.

Contributors HGCV was invited by the journal to provide this review and assumes responsibility for project supervision. ABG, RK and HGCV contributed to the conception or design of the work. ABG, RK, AS and HGCV drafted the manuscript. FZ, KD, KS and SJS critically revised the manuscript. All authors gave final approval and are accountable for the integrity and accuracy of the work.

Funding The study was funded by the Canadian Institutes of Health Research to HGCV, and the Heart and Stroke Foundation of Canada to HGCV.

Competing interests FZ has received fees for serving on the board of Boston Scientific; consulting fees from Novartis, Takeda, AstraZeneca, Boehringer Ingelheim, GE Healthcare, Relypsia, Servier, Boston Scientific, Bayer, Johnson & Johnson, and Resmed; and speaking fees from Pfizer and AstraZeneca. KD received consultancy fees from Abbott and an investigator-initiated study grant from Boehringer Ingelheim; and is supported by the Netherlands Heart Institute (ICIN) and an ESC Heart Failure Association Research Grant. KS is an advisory board member and consultant for Bayer, Boehringer Ingelheim, Bristol Myers Squibb, Cytokinetics, Janssen, Novartis and Novo Nordisk, and receives honoraria. SJS has received research grants from Actelion, AstraZeneca, Corvia, Novartis and Pfizer, and has received consulting fees from Abbott, Actelion, AstraZeneca, Amgen, Aria CV, Axon Therapies, Bayer, Boehringer Ingelheim, Boston Scientific, Bristol Myers Squibb, Cardiora, CVRx, Cytokinetics, Edwards Lifesciences, Eisai, Eisai, Impulse Dynamics, Intellia, Ionis, Ironwood, Lilly, Merck, MyoKardia, Novartis, Nordo Nordisk, Pfizer, Prothena, Regeneron, Rixus, Sanofi, Shifamed, Tenax, Tenaya and United Therapeutics. The other authors report no conflicts of interest with regard to this manuscript.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not required.

Ethics approval This study does not involve human participants.

Provenance and peer review Commissioned; externally peer reviewed.

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