For many years cardiologists were not much interested in studying right ventricular function and the role of the right ventricle in heart failure and in other disease states has therefore been largely underestimated. More recently a consensus has grown on the critical role of right ventricular function in patients with advanced congestive heart failure. The estimation of right ventricular function is nowadays warranted in the standard evaluation of patients with heart failure either due to ischemic heart disease or to primary dilated cardiomyopathy, since it is helpful in the clinical assessment and in the prognostic stratification of such patients. Most information may be obtained non-invasively using sound but simple and reproducible echocardiographic indicators of right ventricular function.

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For many years cardiologists were not much interested in studying right ventricular function and the role of the right ventricle in heart failure and in other disease states has therefore been largely underestimated.

In recent years, there has been a growing consensus among cardiologists on the critical role of right ventricular function in patients with advanced congestive heart failure. A more widespread use of a simplified echocardiographic approach to the evaluation of the right ventricle has greatly contributed to the higher awareness of the importance of this chamber. In fact, although echocardiography does not allow calculation of right ventricular volumes and ejection fraction, it is now accepted that clinically useful indicators of right ventricular function can be obtained by M-mode and two-dimensional echocardiography (Figs. 1 and 2).

Over the last 5 years we have therefore been able to reach a better understanding of why right ventricular dysfunction occurs in patients with advanced heart failure and what is its clinical and prognostic significance in such patients.

Why does right ventricular dysfunction occur in advanced heart failure patients?

Due to its peculiar anatomic characteristics, it is easier for the right ventricle to tolerate volume overload than pressure overload; as a matter of fact, an inverse relation between pulmonary artery pressure and right ventricular ejection fraction has uniformly been shown in previous studies. However, in patients with advanced heart failure right ventricular dysfunction not only may be a consequence of pulmonary hypertension but it may be related either to primary myocardial disease or to ischemia/infarction. A small case-controlled study (10 patients with ischemic heart disease and 10 patients with idiopathic dilated cardiomyopathy) suggested that, for similar levels of left ventricular dysfunction, right ventricular systolic function is more altered in idiopathic dilated cardiomyopathy. The issue of the coupling between pulmonary artery pressure and right ventricular ejection fraction has also been addressed in a study enrolling 379 patients with advanced heart failure due to either dilated cardiomyopathy or ischemic heart disease. The study confirmed, as expected, the inverse relationship between right ventricular ejection fraction measured with rapid response thermodilution and pulmonary artery pressure but it also showed that the slope of this relationship does not differ according to the etiology of heart failure. From a clinical point of view this observation is not irrelevant since a previous hypothesis was that the knowledge of right ventricular function could be helpful to identify the etiology of disease in patients with heart failure. In addition, the inverse re-
The relationship between afterload and function is not a mathematical rule and exceptions are not infrequent in clinical practice\textsuperscript{10}. First, right ventricular ejection fraction can be preserved in a substantial number of patients despite the presence of pulmonary hypertension; the reason for this is not clear, but it is tempting to hypothesize a more recent onset of pulmonary hypertension in such patients. Second, right ventricular dysfunction may be observed in patients with normal pulmonary artery pressure; possible explanations are a primary reduction in right ventricular contractility or excessive reduction in right ventricular preload due to overtreatment with diuretic drugs or atrial fibrillation. Importantly, these observations may be relevant from a prognostic point of view.

Molecular biology strongly supports the hypothesis that pulmonary hypertension is the primary cause for myocardial contractile failure of the right ventricle: a recent study demonstrated that the integrity of the amino (N)-terminus of dystrophin (a protein which plays a key role in the transduction of physical forces in the striated muscle) is disrupted both in the left and in the right ventricle of end-stage heart failure patients and that unloading the left ventricle via a left ventricular assist device ameliorates cardiac structure not only in the left but in the right ventricle as well\textsuperscript{12}.

**What is the clinical and prognostic significance of right ventricular dysfunction in advanced heart failure patients?**

**Right ventricular dysfunction and reduced exercise tolerance.** It is well known that the symptoms of chronic heart failure are poorly related to the degree of left ventricular dysfunction and much more dependent on the alterations of skeletal muscle characteristics\textsuperscript{13}. However, the pulmonary circulation and right ventricular function are important determinants of exercise performance in heart failure patients. Although an inverse relationship has been demonstrated between peak oxygen consumption and resting pulmonary artery pressure and vascular resistance, as a matter of fact, the impact of pulmonary hypertension on the cardiac output response to exercise seems to be modulated by right ventricular function: a substantial proportion of pulmonary hypertension patients showed a decrease in capillary wedge pressure and an increase in right atrial pressure during exercise, a hemodynamic profile indicating right ventricular failure\textsuperscript{14,15}. In fact, peak oxygen consumption correlated significantly with resting or peak exercise right ventricular ejection fraction\textsuperscript{16,17}.

**Right ventricular dysfunction and prognosis.** Right ventricular function estimated at echocardiography or
at radionuclide ventriculography is an important prognostic indicator in patients with heart failure due to ischemic heart disease or primary dilated cardiomyopathy. Interestingly, the systolic excursion of the tricuspid annular plane turned out to be a significant and independent predictor of mortality after having included in the multivariate model the NYHA class and the well consolidated echocardiographic predictors such as left ventricular ejection fraction and the deceleration time of the E wave. The finding that right ventricular dysfunction correlates significantly with other prognostic indicators in heart failure, such as heart rate variability or plasma brain natriuretic levels, further reinforces the importance of the right ventricle as determinant of prognosis in such patients. Two studies emphasized the importance of combining information on right heart hemodynamics with a functional evaluation of the right ventricle when trying to define the risk of patients with advanced heart failure. The first one demonstrated that right ventricular ejection fraction (obtained using rapid-response thermodilution) and mean pulmonary artery pressure have independent and additive prognostic value: the association of pulmonary hypertension with right ventricular dysfunction yielded a very poor prognosis whereas in the presence of pulmonary hypertension and normal right ventricular ejection fraction the prognosis was similar to that of the patients with normal pulmonary pressure. The second study, performed in the subgroup of patients who underwent a test of reversibility of pulmonary hypertension, showed that, although the acute reduction in pulmonary vascular resistance did not predict the outcome, a better prognosis was observed in those patients in whom the afterload reduction elicited a substantial improvement in right ventricular ejection fraction, indicating the presence of right ventricular functional reserve. The concept that right ventricular contractile reserve can be of help to stratify the prognosis was previously suggested in a small population of NYHA class IV patients: a 100% increase in right ventricular end-systolic elastance predicted a better short-term outcome. Unlike the calculation of load-independent contractility indices, the evaluation of changes in right ventricular ejection fraction after an acute afterload reduction is a simpler method to disclose the presence of a functional reserve of the right ventricle.

Conclusions

The estimation of right ventricular function is warranted in the standard evaluation of patients with heart failure due to ischemic heart disease or primary dilated cardiomyopathy. It is helpful for clinical assessment and for prognostic stratification of such patients, and it is therefore an important tool to plan the follow-up. To this aim, the possibility of using sound but simple and reproducible echocardiographic indicators of right ventricular function allows to obtain the feasibility which is necessary in serial clinical testing.

References