

## Editorial

# Effect of age on pressure-flow dynamics in secundum atrial septal defect

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The first descriptions of the haemodynamic events in isolated atrial septal defect date back to the 1940s,<sup>1-9</sup> yet a complete understanding of the precise flow patterns across the defect remains elusive. This is partly because of the complex and varying pressure and volume characteristics of the atria themselves, even with an intact septum, and partly because attempts to time and quantify the components of the interatrial shunt with available techniques of investigation have produced conflicting results.

Two papers in this issue draw attention once more to the vagaries of this subject.<sup>10 11</sup> Both indicate inter alia that haemodynamic patterns change with age or duration of left to right shunting, and appreciation of this fact may help explain the disparate interpretations of the variable interatrial pressure-flow dynamics in atrial septal defect. Galve *et al* confirm that a right to left shunt occurs in an appreciable number of patients (15%),<sup>10</sup> an observation first described as "cyanose tardive" by Bard and Curtillet in 1889,<sup>12</sup> and subsequently demonstrated by peripheral<sup>13</sup> or central<sup>4 6 7 9 14-16</sup> oximetry, angiocardiology,<sup>17 18</sup> or by dye dilution,<sup>15 17</sup> fiberoptic catheter,<sup>19</sup> or echocardiographic<sup>20</sup> and intracardiac Doppler<sup>21</sup> techniques. The reported incidence of right to left shunting varies from 14%<sup>22</sup> to 100%.<sup>17</sup> Galve *et al* show that this phenomenon is not associated with increased right atrial, right ventricular, or pulmonary artery pressures.<sup>10</sup> Although a right to left shunt has been found in cases of atrial septal defect in infancy<sup>9</sup> and childhood,<sup>9 23</sup> Gault *et al*<sup>24</sup> and Dexter,<sup>16</sup> in the 1955 St Cyres lecture, also emphasise that this event occurs predominantly in older patients.

Parikh *et al*<sup>11</sup> have approached the haemodynamic conundrum from the viewpoint of atrial pressure wave morphology and show that the alteration of the normal right atrial wave form ("a" > "v" wave) to a pattern of a dominant "v" wave ("v" > "a"), so called

"left atrialisation" of the right atrial wave form, previously described as a feature of large atrial septal defects, becomes less frequent with increasing age. Furthermore, "right atrialisation" ("a" > "v") of the normal left atrial wave form ("v" > "a")—which is less important clinically since it is not evident in the jugular venous pulse but is unexpected and intriguing haemodynamically—occurs more frequently in older patients. Do these alterations of the phasic wave form and the occurrence of right to left shunting, both of which are age dependent and apparently unrelated to raised right atrial and right ventricular end diastolic pressures, give a clue to the circumstances promoting the right to left shunt? To evaluate this possibility knowledge of the precise timing of the right to left shunt is crucial, but previous reports have been contradictory.

Levin *et al*, in a seminal paper on the atrial pressure-flow dynamics in secundum atrial septal defects,<sup>17</sup> showed that the major left to right shunt and pressure gradient occur during late ventricular systole and early diastole, coincident with the atrial "v" waves and while the atrioventricular valves are closed, with augmentation during the "a" wave of atrial contraction. Minute right to left shunts and pressure gradients were noted in all cases during very brief periods at the onset of ventricular contraction and occasionally during early ventricular diastole (at the trough of the "y" descent). In none of these patients, however, was the right to left shunt detected in the systemic circulation by the indicator dilution method suggesting that the transatrial shunt was small, occurred at a phase when the mitral valve was closing, and was simply washed back into the right atrium with the ensuing "v" wave. It is noteworthy that all patients in this series were young (under 14 years). Using a directional ultrasonic Doppler probe mounted at the tip of a catheter and placed at the site of the atrial septal defect, Kalmanson *et al* measured the instantaneous forward and reverse blood flow velocity and confirmed the timing of bidirectional shunts as above.<sup>21</sup> (The ages were not identified in this group of 10 patients.) On the other hand, Lind and

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Wegelius, using cineangiography after an injection of a contrast medium into the inferior vena cava of children, showed that small transient right to left shunts occur during atrial diastole but that the coexistence of severe pulmonary stenosis results in a dominant right to left flow during atrial systole.<sup>18</sup> Shaffer *et al* also show that reversal of the interatrial gradient synchronous with a right to left flow occurs during atrial systole in patients with pulmonary stenosis.<sup>14</sup> Even after relief of pulmonary valve stenosis residual impairment of right ventricular distensibility may lead to a right to left shunt in association with elevated right atrial "a" waves.<sup>25</sup> Rasmussen *et al* quantified the net right to left shunt by polarographic determination of systemic arterial oxygen tension during pure oxygen breathing and found that a right to left shunt occurred in 55% of their patients with isolated atrial septal defects and that the magnitude correlated best with the height of the right atrial "a" wave.<sup>13</sup> All patients in this study were over 15 years old. Since right atrial systole starts about 20 ms before that of the left,<sup>2 13 26</sup> the right atrial systolic force may be unopposed at this time, thus encouraging flow from right to left.

It seems likely, therefore, that different methods of detection will give widely varying frequencies of a right to left shunt; "transient" shunting into the left atrium (detected by cineangiography or Doppler techniques) occurs in most, if not all, patients of any age with large atrial septal defects whereas "sustained" shunting into the systemic circulation (demonstrated by dye dilution and oxygen tension or saturation studies) occurs less frequently, with a tendency to evolve with age, and takes place at a different phase of the cardiac cycle in association with a prominent right atrial "a" wave.

Many theories have been advanced to explain the right to left shunt apart from those instances when a vena cava connects directly with the left atrium<sup>27 28</sup> or the right ventricle is hypoplastic.<sup>29</sup> Early reports ascribed this phenomenon to congestive heart failure<sup>1 3 16</sup> or increased pulmonary vascular resistance,<sup>6 16 23 30</sup> but Galve *et al* refer to several reports of isolated cases in which neither heart failure nor pulmonary hypertension was present.<sup>10</sup> It is of interest that even in patients with severe pulmonary vascular disease, in whom right to left shunting is more common, mean right atrial and right ventricular end diastolic pressures are not raised.<sup>16</sup> Some authors propose that normal anatomical features favour flow from the inferior vena cava to the left atrium,<sup>15 18 27</sup> but why this should happen in only some cases is not clear. The size of the defect is rarely so large<sup>9</sup> as to permit common mixing,<sup>16</sup> as in a common atrium. While decreased compliance of the right heart chambers is often incriminated as the cause of right to left

shunting,<sup>10 11 15 16 27 31</sup> it has been difficult to reconcile this with the finding of normal mean right atrial and right ventricular end diastolic pressures,<sup>14 7 9 16 20 22 23 31</sup> or with the equal mean pressures in the two atria in the case of large defects.<sup>5 7 16</sup> Several authors claim that the direction of interatrial flow, in the face of equal filling pressures, depends on the relative distensibilities of the two ventricles,<sup>4 7 11 16 25 31</sup> but this does not explain why a right to left shunt is often associated with a large left to right shunt.<sup>16</sup>

With few exceptions,<sup>17 11 14 17</sup> however, most authors appear to overlook two important factors. One is the role of phasic interatrial pressure gradients on flow direction; Shaffer *et al* showed that a presystolic right to left shunt and "a" wave gradient can coexist with a left to right shunt and mean and "v" wave gradients.<sup>14</sup> The other factor that acts as a major determinant of these cyclical events is the relative compliance or distensibility of the atria as well as the ventricles during different phases of the cardiac cycle, as described lucidly and in detail by Hull as long ago as 1949.<sup>7</sup>

In normal individuals, the decreased deformability of the left atrium, considered to be due to the thicker left than right atrial wall and the smaller venous reservoir on the left,<sup>1-3 7 11</sup> results in higher pressures in the left atrium during maximal venous inflow ("v" wave), whereas the longer, narrower, and more muscular left than right ventricle<sup>8</sup> results in somewhat higher left atrial pressures during atrial outflow (ascending "y" and "a" waves). Suga showed experimentally that the effective source pressure for ventricular filling was not the continuous mean atrial pressure but the mean pressure during ventricular diastole only,<sup>32</sup> and this pressure becomes raised with decreased atrial compliance. In the presence of a small atrial septal defect the higher left atrial pressures during all phases of the cardiac cycle result in almost continuous left to right flow, accentuated during the "v" and "a" peaks.<sup>17</sup> When the interatrial communication is large and unrestrictive with equalisation of the mean pressures, however, the relative ventricular resistances have a major influence on the "a" wave gradient at end diastole but little effect on the "v" wave gradient since the atrioventricular valves are closed during maximal filling of the atria,<sup>7 14 17</sup> and left to right flow at this stage is facilitated by the greater distensibility of the right atrium. Since this is essentially a passive phenomenon with free run-off through a large septal defect, the relatively non-distensible left atrium remains small, as noted clinically and at necropsy,<sup>7</sup> while the right atrium dilates to accommodate the increased volume. Thus in the face of equal filling (or mean atrial) pressures the direction of flow will be determined by relative ventricular distensibilities dur-

ing atrial systole ("a" wave) and by relative atrial compliance during atrial diastole ("v" wave).

A comprehensive explanation for the seemingly paradoxical findings at different ages is now possible. In the newborn and the infant, the persisting fetal hypertrophy of the right atrium and ventricle will tend to resist the left to right shunt during both the "a" and "v" waves and probably accounts for the rare presentation at this age.<sup>33,34</sup> Later, in the young patient, the increased pulmonary blood flow and pulmonary venous return augments the left atrial pressures, especially during the maximal filling phase—that is synchronous with the "v" wave—and left to right shunting is encouraged. The mean right atrial pressure increases to match that of the left, though the left atrial "v" wave remains dominant and the left to right shunt large, and small "transient" right to left shunts may occur at the onset of ventricular systole.<sup>17,19,21</sup> After a variable period of time, depending on the size of the defect and volume of the left to right shunt, the dilated right atrial wall eventually becomes less compliant and the incremental flow into this chamber results in accentuation of its "v" wave relative to its "a" wave—that is, "left atrialisation" of the right atrial wave form. After many years, active contraction of the hypertrophied right atrium against the chronically overloaded, hypertrophied, and decreasingly compliant right ventricle results in a dominant "a" wave once more—that is, "normalisation" of the right atrial wave form—and a "sustained" presystolic right to left shunt is promoted while the left to right shunt may decrease.<sup>10</sup> Since the left atrium remains relatively non-compliant, acting mainly as a conduit during venous filling, the right atrial "a" wave kick is reflected in the left atrium—that is, "right atrialisation" of the left atrial wave form.

This explanation remains speculative, and other factors may well be implicated in the complex (and controversial) pressure-flow dynamics in atrial septal defect. The interesting studies reported in this issue emphasise the effects of age<sup>10,11</sup> and the importance of phasic events<sup>11</sup> and point to areas which require further investigation. Firstly, the presence of a right to left "a" wave gradient coincident with a right to left shunt in older patients needs to be proved. While these authors compare the height of the right atrial "a", "v", and mean pressures in groups with or without a right to left shunt,<sup>10</sup> or with "left" or "right atrialisation" of the right or left atrial wave form respectively,<sup>11</sup> it is the phasic "a" or "v" wave gradient in each patient which dictates flow direction. (A study is now in progress in which flow direction at the atrial septal defect is observed by the recently developed external pulsed Doppler probe combined with cross sectional echocardiography and correlated with simultaneous left and right atrial pressures.)

Secondly, and more difficult to achieve, will be the demonstration of decreased compliance in the hypertrophied right ventricle before the development of appreciably raised end diastolic pressures and pulmonary hypertension. As yet there appears to be no satisfactory method for directly assessing chamber wall compliance other than that derived indirectly from pressure measurements.

In practical terms, the recognition of a "sustained" right to left shunt and "a" wave gradient in the setting of normal or slightly raised pulmonary artery pressures, rather than a prominent right atrial "v" wave as suggested by Parikh *et al*,<sup>11</sup> should encourage early surgery even if the left to right shunt is not large,<sup>27,31</sup> since this situation implies increasing stiffness of the right atrium and ventricle and may be the harbinger of atrial arrhythmias or myocardial decompensation and tricuspid valve reflux.

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