Non-invasive technique for diagnosing atrial septal defect and assessing shunt volume using directional Doppler ultrasound

Correlations with phasic flow velocity patterns of the shunt

Daniel Kalmanson, Colette Veyrat, Claude Derai, Charles-Henri Savier, Max Berkman, and Paul Chiche

From the Departments of Cardiology, Fondation Opthalmologique A. de Rothschild and Hôpital Tenon, Paris, France

In 30 patients in sinus rhythm with atrial septal defect, confirmed by cardiac catheterization, the jugular flow velocity curve was recorded transcutaneously with a directional ultrasonic Doppler velocimeter. In all cases characteristic anomalies of the trace were noted. A physiopathological interpretation of these anomalies is proposed, supported by the instantaneous phasic flow velocity patterns of the shunt itself. This could be recorded in 10 cases at the site of the defect by means of an ultrasonic catheter velocimeter. Furthermore, a statistically significant correlation was displayed between the jugular venous flow velocity curve anomalies and the volume of the shunt as determined by classical dye dilution technique. It is concluded that the transcutaneous Doppler technique provides a new, non-invasive method of assessing both diagnosis and approximate volume of the shunt in patients with atrial septal defect who are in sinus rhythm.

It is generally accepted that the diagnosis of atrial septal defect is in most instances a matter of clinical acumen. Cardiac catheterization for pressure measurements and dye dilution technique, however, are often required in clinically dubious presentations or whenever surgical management may be recommended, in order to provide further information about pulmonary artery pressure and above all, the volume of the shunt. For many years the need has been felt for a non-traumatic approach to gain this information and, in particular, the recording of the jugular venous pulse tracing has been proposed, though with little agreement on its usefulness (Luisada, 1948; Reinhold, 1955; Wood, 1950; Haroutunian, Neill, and Otis, 1958; Tavel *et al.*, 1968).

The recent successful use of the jugular venous flow velocity curve recorded transcutaneously with a directional ultrasonic Doppler flowmeter (Kalmanson, Veyrat, and Chiche, 1968), for exploring the haemodynamics of the right heart has raised the

possibility of solving these problems in a more reliable way. Indeed, the jugular venous flow velocity curve (Fig. 1) has been shown to reflect faithfully the mechanical events of right heart contraction and to be affected whenever right heart disease is present. It, therefore, appeared enticing to verify whether this technique could provide a new aid for the diagnosis of atrial septal defect, a disease that undoubtedly involves the right heart haemodynamics, and, if so, to check whether a significant relation could be found between the specific anomalies of the jugular venous flow velocity curve and the volume of the shunt as measured by classical dye dilution methods.

Subjects and methods

Thirty patients in sinus rhythm with an atrial septal defect, 20 women and 10 men, ranging in age from 8 to 53 years, were studied. In all cases the diagnosis was confirmed by cardiac catheterization, using the Telco¹ manometer. Twenty-three patients had a pure, isolated atrial septal

¹ TELCO, Gentilly, France.

FIG. 1 Normal pattern of jugular venous flow curve, physiological interpretation and time relation. From top to bottom: electrocardiogram, phonocardiogram showing heart sounds, jugular venous pulse, and jugular venous flow velocity tracings. The negative a wave of the jugular venous flow velocity curve is due to atrial contraction (backflow wave); the positive s wave to both atrial relaxation and downward movement of the tricuspid floor induced by ventricular contraction; the d wave to the rapid filling phase of the right ventricle; ic: Isometric contraction notch.

defect. Four cases were associated with a cleft mitral valve, 1 with a mitral stenosis (Lutembacher's syndrome), 2 with partial anomalous pulmonary venous return; 26 were considered as ostium secundum, 4 as ostium primum type. In no case did the pulmonary artery pressure exceed 30 mmHg.

In addition, 2 control groups of patients were studied for comparison:

- 1) Twenty-five normal subjects with normal clinical examination, x-rays, and electrocardiogram, or with an innocent systolic murmur at the left sternal border, in whom an atrial septal defect was eventually ruled out by cardiac catheterization.
- 2) Fifty patients with involvement of the right heart (ventricular septal defect, Ebstein's disease, tricuspid insufficiency and stenosis, pulmonary stenosis, constrictive pericarditis) all in sinus rhythm.
- i) We used the directional transcutaneous ultrasonic Doppler velocimeter (Sophia¹ VUS 180 and 135), the details and performances of which have been reported elsewhere (Chiche *et al.*, 1968; Kalmanson *et al.*, 1969b). This device

¹ SOPHIA Co. Ltd. 78-Mantes-la-ville, France.

FIG. 2 Jugular venous flow velocity tracing in normal subject. Note that the summit of the s wave occurs at the time of the end of the T wave of the electrocardiogram. The O point remains consistently and conspicuously above the zero line. Distance between 2 successive spikes (upper row) equals 1 sec.

makes it possible to record and measure externally the mean instantaneous blood flow velocity with a reasonable approximation and to discern its direction. The transducer is placed, according to a previously described technique (Kalmanson *et al.*, 1968), behind the internal extremity of the right clavicle, the patient lying on his back, the head being slightly raised on a pillow. The traces were taken with quiet respiration and held expiration, and inscribed using a Mingograf 81,

FIG. 3 Jugular venous flow velocity in atrial septal defect. The summit of the s wave clearly occurs earlier than normally. Note the precipitous fall of the descending limb of the s wave, the appearance of a deep negative O wave encompassing late systole and early diastole, and the small amplitude of the d wave. The a wave is no longer negative. Massive shunt: $p = 1.54$, shunt volume = 200 per cent of systemic cardiac output.

seven-channel direct inkwriting recorder, simultaneously with electrocardiogram lead II and frequency selecting phonocardiogram at the 2nd left intercostal space or at the apex. Chart speed is either 25 or 50 mm/sec. Distance between two successive spikes (upper row) equals 1 sec. Square notches are irrelevant as far as this text is concerned.

ii) In 10 cases during routine cardiac catheterization, a directional ultrasonic Doppler probe mounted at the tip of a No. 7 French catheter was inserted into the axillary or the saphenous vein and placed under x-ray and pressure control at the site of the atrial septal defect. This was done during a pull-back manoeuvre from the left atrium. The technique has been described elsewhere (Kalmanson *et al.*, 1969b; Kalmanson *et al.*, 1972). The velocity catheter measures the instantaneous blood flow velocity approximately 5 mm ahead of its tip, and discerns forward and reverse (but not lateral) flow. The traces were recorded during quiet respiration in unanaesthetized patients and inscribed on a four-channel Mingograf 34, direct inkwriting recorder. Respiration was recorded using a mercury strain gauge fixed on the chest wall.

iii) The volume of the shunt was measured in 26 patients (excluding the 4 cases with a cleft mitral valve) by means of dye (indocyanine green) dilution curves, using a Kipp² apparatus with an ² Kipp Co. Ltd. Delft, Holland.

FIG. 5 Jugular venous flow velocity versus jugular venous pulse trace in atrial septal defect. Upper row: jugular venous flow velocity tracing. The curve discloses the typical pattern, which is diagnostic of atrial septal defect. ($\rho=1$, volume of the shunt 50 per cent of cardiac output). Lower row: jugular venous pulse tracing. The a wave is conspicuously and consistently taller than the V wave. There is no evidence from the jugular venous pulse curve for the diagnosis of atrial septal defect.

FIG. 4 Jugular venous flow velocity trace in atrial septal defect. The pattern is similar to that of Fig. 3. The Z point occurs between the two components of the second heart sound. $\rho=1.13$, volume of the shunt: 70 per cent of the cardiac output. The variations of the depth of the O wave are related to respiration.

FIG. 6 Jugular venous flow velocity trace in atrial septal defect. Anomalies of the trace are more discreet than in the preceding Figures. However, a small O wave can be elicited with a Z point occurring after the pulmonary second heart sound, but timing of the summit of the s wave and depth of the a wave are normal. $\rho=0.89$, volume of the shunt 30 per cent of cardiac output.

arterial cell. The injected dose never exceeded 5 mg, and at least 4 traces were studied for each patient. Injections were made either in a peripheral vein or in the superior vena cava, in order to rule out the possibility of a preferential circulation in a branch of the pulmonary artery. The results, calculated according to a previously described procedure (Savier, Kin, and Facquet, 1963), were expressed as a percentage of the systematic cardiac output.

Results: (1) Jugular venous flow velocity traces

The recorded curves represent the velocity of the jugular venous flow or that of blood flow shunting through the atrial septal defect, calibrated in cm/sec.

Normal subjects The normal curve (Fig. 2) displays a positive systolic *s* wave, triangular in shape, the summit of which occurs at or after the summit of the electrical T wave; a positive diastolic *d* wave and, finally, a partly negative *a* wave. The junction point *O* between the *s* and *d* waves remains consistently above the zero line, except in 5 hyperkinetic cases.

Patients with atrial septal defect in sinus rhythm Fig. 3, 4, and 5 display the main pattern found in these cases. The basic anomaly starts at end-systole. In typical cases, the curve, after a normal, or even higher than normal, ascent during early and midsystole suddenly shows a premature, more or less precipitous, descent, i.e. occurring before its normal timing, before the summit of the electrocardiogram T wave. The trace then falls down, crosses the zero line before, at the time of, or closely after the pulmonary component of the second heart sound. Thereafter the curve displays an entirely negative wave, more or less deep, triangular in shape, with an *O* point clearly below the zero line. It is followed by a positive *d* wave, usually decreased in amplitude (in the typical pattern). The end-diastolic *a* wave is also in typical cases clearly diminished in amplitude and can even become positive. The amplitude of the *O* and *a* waves may be equal, and even the *O* point may appear below the level of trough of the *a* wave.

This pattern may be subject to some variations (Fig. 6 and 7). The summit of the *s* wave may be of normal timing or the *d* wave may have a normal height or the *a* wave may not be decreased. But in all cases, the basic anomaly remains consisting of the amputation of the *s* wave in late systole, the crossing of the zero line in the neighbourhood of the second heart sound (pulmonary component), and the occurrence of

FIG. 7 Jugular venous flow velocity trace in atrial septal defect. The *d* wave is unusually tall, but a premature summit of the *s* wave and the occurrence of a negative *O* wave are present. ($p = 1.17$, volume of the shunt: 85% of cardiac output).

a clear-cut negative, triangular wave of late systolic and/or early diastolic timing.

Variations with respiration (Fig. 8) In all patients, inspiration increased the *s* and *d* waves, raising the *O* point. In some instances, the *O* point may even cross the zero line, so that the trace then becomes (during inspiration) of normal pattern. But in all cases, at end expiration, the typical anomalous pattern can be elicited.

FIG. 8 Jugular venous flow velocity trace in atrial septal defect. Variations with respiratory movements. During expiration, the tracing discloses the typical pattern diagnostic for atrial septal defect. During inspiration, however, the *O* point is raised above the zero line, and the pattern is almost normal, save for the occurrence of the summit of the *s* wave trace.

Jugular venous flow velocity with continuous flow In rare instances, the whole jugular venous flow velocity curve is situated well above the zero line, due to the superimposition of continuous flow to the pulsatile flow. Nevertheless, the same general pattern of the trace is present, and will appear more clearly if the zero line is replaced by a horizontal line passing at the level of the *ic* notch corresponding to the isometric contraction.

Patients with right heart diseases and without atrial septal defect. Most exceptionally the above-mentioned pattern could be elicited. Even in cases of tricuspid insufficiency, where the *s* wave may be biphasic, the overall pattern is different, in particular the amputation of the *s* wave starts in early systole, the *s* wave is decreased, and the *d* wave is considerably increased.

Subjects with hyperkinetic states (Fig. 9) In some young adults with hyperkinetic state, the jugular venous flow velocity curve may be similar at first sight to the atrial septal defect pattern. In particular, the descending limb of the *s* wave may occasionally override the zero line. However, a careful examination of the trace will show that apart from the increased heart rate, the velocities at maxima of all the waves are proportionally increased, and this is not the case in atrial septal defect.

Correlations with volume of shunt In order to characterize quantitatively the anomaly of the jugular venous flow velocity curve described above, we chose to measure the

FIG. 9 Jugular venous flow velocity in hyperkinetic state. During expiration the pattern resembles that of an atrial septal defect. It will be noticed that all velocities are proportionately raised. In particular the trough of the *a* wave remains well below that of the *O* wave.

ratio: $\rho = \frac{RP_2}{RZ}$, *Z* being the zero crossing point of the descending limb of the *s* wave and *P*₂ being defined as the maximum vibration of the second heart sound recorded in the medium-high and high frequency band (Fig. 10). On account of the respiratory variations of the timing of the *Z* point, the shortest *RZ* interval was selected from several sequences of the trace. This shortest *RZ* interval always corresponded to end-expiration. Table 1 gives the values of the ratio ρ and of the corresponding volume of the shunt measured by dye dilution in 26 cases (thus excluding the 4 cases associated with a cleft mitral valve). The plotting of these corresponding values (Fig. 11) shows a significant relation. Statistical analysis of the results is as follows: $r=0.95$, $P<0.001$, regression equation: $y = -191.65 + 239.46(x - 0.7)$.

Results: (2) Intracardiac flow velocity patterns of shunt

Though a more complete and detailed publication is in preparation, we present in Fig. 12 to 14 the main patterns encountered during Doppler catheterization. As a convention, positive deflection represents a flow velocity of a left-to-right shunt, and negative deflection

FIG. 10 Determination and measure of the parameter ρ . The ratio $\rho = \frac{RP_2}{RZ}$ was selected as highly representative of the degree of prematurity of the *Z* point, a characteristic anomaly of the curve.

TABLE I Correspondence between the value of the parameter ρ and the volume of the shunt as determined by Cardiogreen dye dilution technique

Patient No.	Value of ρ	Per cent of systemic cardiac output
1	0.83	10
2	1.16	90
3	0.83	30
4	1.54	200
5	0.91	38
6	1	50
7	1.09	60
8	1.05	60
9	0.89	30
10	1.18	90
11	1.09	50
12	1.21	90
13	1.22	95
14	0.85	20
15	1	50
16	1.09	60
17	1	50
18	1.11	70
19	1.17	85
20	1.10	63
21	1.16	80
22	1.13	100
23	1	50
24	1	50
25	0.89	30
26	1.13	70

that of a right-to-left one. Fig. 12 shows a minute negative wave in early systole, followed by three successive positive waves: one late systolic and early diastolic, triangular in shape, the summit of which occurs very close to the second heart sound; one mid-diastolic positive wave, triangular in shape; and a third positive wave during the PR interval. The patterns, and in particular the respective amplitude of the three positive waves, vary with respiration. The same pattern is shown in Fig. 13, but the small negative wave of early systole is inconstant and disappears during expiration. In Fig. 14, the systolic and diastolic waves are fused. Inspiration decreases and expiration increases the magnitude of the positive shunt velocities, and have the opposite effects on the negative ones.

Comments and discussion

For many years attempts have been made to prove the diagnosis of atrial septal defect by non-traumatic techniques, especially the recording of the jugular venous pulse. The occurrence of a tall, peaked V wave, clearly over-topping the summit of the A wave (V/A ratio superior to 1) has been shown to be highly consistent with the diagnosis of atrial septal defect with normal pulmonary arterial

FIG. II Relationship between the parameter ρ and the volume of the shunt. On the abscissa are plotted the values of ρ , on the ordinate the values of the volume of the shunt expressed as a percentage of the systemic cardiac output. Numbers in brackets refer to the number of cases. This diagram reveals a small scatter, confirmed by a high correlation coefficient. In dotted line, the regression line.

FIG. 12 Flow velocity trace of an atrial septal defect shunt. From top to bottom: electrocardiogram lead II, phonocardiogram at the second left interspace. Shunt velocity trace, calibrated in cm/sec. Above the zero line, positive, the curve represents left-to-right shunting, below the zero line, negative, the inverse shunting from right to left. Note the minute negative wave, like a 'W' in early systole. The left-to-right shunt has three major components: S, late systolic and early diastolic, D, mid-diastolic, and A, end-diastolic.

pressure (Luisada, 1948; Reinhold, 1955; Wood, 1950; Altman, 1956; Nadas, 1957; Hartman, 1960; Bory, 1966; Colman, 1966; Haroutunian *et al.*, 1958; Tavel *et al.*, 1968). Though the reliability of such an abnormal pattern is usually considered as very high, the frequency of its occurrence remains controversial. Reinhold (1955) seems to be the only author to give a 100 per cent figure of frequency, but this figure may be related to the selection of his series of 25 cases in most of whom the shunt was very large. Bory (1966) and Tavel *et al.* (1968) from their series claimed a frequency less than or equal to 50 per cent, whereas Wood (1950) did not find a tall V wave in more than 8 per cent of his cases. Furthermore, no significant correlation could be substantiated between this pattern and the magnitude of the shunt. These conflicting and rather deceiving figures, as well as theoretical considerations of the manifold advantages of flow velocity versus pressure information (Kalmanson, 1971) led us to look for a new, non-invasive, velocimetric approach to the diagnosis of atrial septal defect, based on the recording of the jugular venous flow velocity curve anomalies.

Recent progress in ultrasonic instrumentation has now put into current use, with an increasing frequency, the transcutaneous recording of blood flow by means of a directional Doppler probe. In particular, the curve recorded at the site of the internal jugular vein has been shown to represent the mean instantaneous flow velocity with a reasonable approximation for clinical use, and also to reflect faithfully the successive mechanical events of right heart contraction (Kalmanson *et al.*, 1968). It should be incidentally pointed out that the *qualitative*, not the *quantitative*, aspect of the curves has been considered throughout the present study. The physiological interpretation of the normal pattern is reproduced in Fig. 1. Moreover, a recent study has brought additional data supporting the view that systolic acceleration of blood flow into the right atrium (represented by the *s* wave) originated from *both* atrial relaxation and downward displacement of the closed tricuspid floor (Kalmanson, Veyrat, and Chiche, 1971). It was only logical to anticipate that atrial septal defect – a disease that obviously interferes with the filling of the right atrium – would be likely to disturb venous return and therefore affect the pattern of the jugular venous flow velocity trace. This assumption has been consistently substantiated by our findings in all our 30 cases.

Analysis of the jugular venous flow

FIG. 13 Flow velocity trace of an atrial septal defect shunt. Same general appearance as in Fig. 12, but the amplitude of the *S* wave is conspicuously greater than that of the *D* wave. The minute negative wave at early systole is almost absent. Note the variations of amplitude of the *D* and *A* waves.

velocity anomalies In typical cases, a clear-cut, premature, and often precipitous fall of the systolic wave could be elicited on the tracings: a fact that means that the systolic inflow is being slowed down in late systole, before the occurrence of the normal descent of the *s* wave. The finding that in all cases, with the exception of two associated with continuous flow in the caval veins, the curve crosses the zero line in late systole and remains under that line during early diastole, implies that reversal of flow takes place in the caval system, originating from the right atrium. The usually low amplitude of the *d* wave in many instances also suggests that inflow into the right atrium is impeded during diastole as well. Summing up, the basic disturbance of

FIG. 14 Flow velocity tracing of an atrial septal defect shunt, recorded by Doppler catheterization. Here the *S* and *D* wave are fused. The negative early systolic wave is present only during inspiration (two last complexes) which decreases the positive velocities, and increases the negative ones.

the jugular venous flow velocity curve consists of a general decrease of the end-systolic, mid-diastolic, and sometimes presystolic parts of the traces, and, most important, of an end-systolic and/or early diastolic negative wave. Interpreted in terms of haemodynamics, these findings suggest a slowing down of the inflow into the right atrium at three different periods of the cycle: late systolic, mid-diastolic, end-diastolic, and, most important, a reversal of flow at end-systole and/or early diastole (Fig. 15).

It seemed reasonable to assume that these effects of slowing down and reversal of blood flow were intimately related to, and most probably provoked by, the eruption of blood into the right atrium from the left atrium, through the septal defect, competing with, and thus impeding, the normal filling procedure of the right atrium from the caval system. In order to verify such an assumption, the phasic velocity pattern of the shunt itself was recorded at the site of the defect by means of a directional Doppler catheter-tip velocimeter and compared with the jugular venous flow velocity traces.

Analysis of velocimetric pattern of shunt

Though a more detailed study is in preparation, the main results can be briefly summarized as follows.

Apart from a minute right-to-left shunt in early systole, the shunt occurs from left to right throughout late systole and diastole, but displays in the typical pattern 3 distinct waves of acceleration: a late systolic (S) wave prolonged into early diastole, a mid-diastolic (D) wave, and a late diastolic (A) wave during atrial contraction (Fig. 12–14). The respective amplitude of these 3 waves varies appreciably depending on respiration, heart rate, and other factors which are now being investigated. The S and D waves may be fused, giving rise to a large shunting wave encompassing late systole, early, and mid-diastole. It is noteworthy that our findings are in general agreement with those of Gamble *et al.* (1965), and of Levin *et al.* (1968), though these are at some variance with each other. Gamble and co-workers, using fiberoptics, found a three-wave pattern, whereas Levin and collaborators, studying the interatrial pressure gradient as well as biplane cineangiocardiology, reported a double wave pattern. The discrepancy between the findings of these authors can be explained by the possibility of both patterns occurring, which our recordings appear to confirm. The variability of the shunt velocity pattern could also explain some of the variations encountered at the level of the jugular

FIG. 15 Schematized relation between jugular venous flow velocity and shunt velocity curves in atrial septal defect in sinus rhythm. From top to bottom: electrocardiogram, phonocardiogram shunt velocity, and jugular venous flow velocity traces. In dotted line, the normal pattern; in bold line, the atrial septal defect pattern. Hatched area stresses the difference of velocity waveform of jugular venous flow velocity between normal and atrial septal defect cases. The atrial septal defect shunting pattern chosen here is a three wave pattern. The premature summit of the S wave lines up with the beginning of the S curve of the shunt. The jugular venous flow velocity curve of a patient with atrial septal defect appears roughly to be derived from the normal pattern by subtracting the amplitude of the atrial septal defect shunting velocity curve, except for the end-diastolic part. The S and D waves correlate well with the anomalies of the jugular venous flow velocity curve.

venous flow velocity trace. The schema in Fig. 15 shows the satisfactory relation between the jugular venous flow and the atrial septal defect shunt velocity traces: the jugular venous flow velocity curve appears to be drawn from the normal pattern after 'subtraction' of the atrial septal defect shunt velocity curve, except for the a wave. In other words, save

for the atrial contraction interval, the timing and pattern relation of both curves seem to support the assumption of a direct haemodynamic influence of the shunt flow upon the venous return, and in particular as seen from the jugular venous flow. We have no direct evidence to account for the discrepancy of the *a* and *A* waves. One could indeed anticipate that the shunt wave during atrial contraction would enhance the normally occurring back-flow into the cavae, which is not the case, since the *a* wave is usually decreased in depth. Only a hypothesis can be proposed. It has been suggested (Kalmanson *et al.*, 1969a) that during atrial contraction the right atrium may be divided into two parts separated geographically by a 'watershed'. Above this line, blood flows back into the caval system, and below it, it flows down towards the right ventricle. It could be assumed that the pathological alterations of the right atrium may induce a shift of the line of 'watershed' towards the orifices of the cavae. This hypothesis needs further investigation.

Diagnostic value of the jugular venous flow velocity curve The fact that in all our cases the diagnosis could be confirmed by the jugular venous flow velocity anomalies, even in cases where the shunt was small, supports the statement that this type of recording is highly sensitive. However, it is most likely that minute shunts, as in patent foramen ovale for instance, may not be discernible, since their haemodynamic effects on venous return are not significant. Fig. 5 illustrates a typical case where the jugular venous pulse curve is normal ($V/A < 1$), whereas the jugular venous flow velocity trace conspicuously displays the atrial septal defect pattern. Such a striking difference in fidelity between both types of recording may be surprising at first sight. However, it should be borne in mind that the jugular venous pulse curve reflects the *absolute value of the pressure* within the internal jugular vein (and in the right atrium), which may not be affected by the interatrial shunt, especially if the latter is not very large. The reason for this is that the magnitude of the shunt is not related to the pressure in the right atrium, but to the interatrial pressure gradient. On the other hand, the jugular venous flow velocity curve reveals the alterations of the *instantaneous velocity of blood flow*, a much more sensitive parameter to haemodynamic disturbances because it is precisely determined by pressure gradient (McDonald, 1960; Kalmanson, 1971). It is noteworthy that Reinhold's series of recordings from patients with atrial septal defect where the jugular venous pulse

pattern was consistently conclusive, was one in which there was a great number of patients with large defects.

Apart from the sensitivity, the reliability of the described pattern seems satisfactory, though some states or diseases may simulate it at first sight. This is mainly the case in hyperkinetic states, in which the descending limb of the *s* wave may override the zero line, but also in tricuspid insufficiency where the *s* wave may be partly negative. But in most of these confusing cases summarized in Table 2 the remainder of the curve departs from the atrial septal defect pattern, due to specific anomalies produced by the hyperkinetic state or the right heart disease. In other words, after careful screening of the curve, it is unlikely that a disease other than atrial septal defect would reproduce on the jugular venous flow velocity trace the *combined* typical anomalies and *their enhancement during expiration*.

Postoperative changes In a very few (2) cases, the defects were surgically closed but the anomalies did not disappear completely but only partially regressed, in spite of complete closure. The persistence of a high *V* wave postoperatively on the jugular venous pulse curve has already been reported. This embarrassing finding has been attributed to the fact that after the surgical closure of the atrial septal defect, the right atrium, keeping its anomalous compliance (Tavel *et al.*, 1968) or altered by surgery (Bory, 1966), does not return to a normal anatomical and haemodynamic state. This 'seditious fact', however, should leave a suspicion that there might be additional factors involved in the determination of the venous return disturbances, and requires further investigation.

Quantitative appraisal of shunt volume: Correlation of jugular venous flow velocity anomalies and shunt volume

(a) *Appraisal of shunt volume* Dye dilution techniques are now currently used for the

TABLE 2 Diseases that can simulate an atrial septal defect pattern on the jugular venous flow velocity curve

Disease	Patient No.	Zero crossing	Small d wave	Small a wave
Tricuspid insufficiency	9	all (but different patterns)	3 with TS	No
Pulmonary artery hypertension	20	2	No	No
Ventricular septal defect	15	2	1	No
Constrictive pericarditis	10	2	1	2
Hyperkinetic states	5	5	1	1

determination of left-to-right shunts, and their results have been shown to correlate well with those obtained by the Fick method (Carter *et al.*, 1960; Laurencet, Mehmél, and Rutishauser, 1970). There are reasons to believe that the dilution technique, based on a better mixing of blood, may reflect more faithfully the quantitative importance of the shunt; furthermore, the use of the intracaval dye injection may help rule out preferential circulation in a branch pulmonary artery. On the other hand, it cannot make the distinction between left-to-right shunts and insufficiency of the AV valves. Therefore, the 4 cases associated with a cleft mitral valve were excluded from this study.

(b) *Determination of the parameter ρ* Among the different parameters of the jugular venous flow velocity curve that could characterize the importance of the shunt, ρ which is related to how soon and abruptly the basic pattern anomaly appears, seemed particularly relevant. It is worth mentioning that RZ as well as RP2 are well defined, P2 being defined as the maximum vibration of the second heart sound and very clearly pointed out in the medium high or high frequency channels. The fact that its value constantly varies throughout the respiratory cycle made it necessary to select its highest value at end expiration, i.e. at a time when simultaneously instantaneous venous return is at its lowest and instantaneous atrial septal defect shunt velocity is at its highest.

Furthermore, ρ is the ratio of two time intervals ranging about 400 msec each. The time constants of the electrocardiogram and phonocardiogram channels of the Elema recorder are of an order of magnitude of 1 msec, and practically invariable. The time constant of the VUS Sophia velocimeter is about 20 msec, and may vary for the considered amplitudes and frequencies of only a few milliseconds. The resulting errors on ρ are not likely to exceed 1 per cent. This is in keeping with the results concerning the linearity of ρ .

The results of the statistical analysis clearly appear in Fig. 12 and show a significant relation between ρ and the volume of the shunt.

Conclusions

It may be concluded from this study that the recording of the jugular venous flow velocity curve turns out to be a reliable method of assessing in an easy, quick, and non-injurious way both the diagnosis of atrial septal defect and a first approximation of the magnitude of the shunt. Furthermore, the data provided by

the velocity curves recorded at the site of the septal defect with an ultrasonic Doppler catheter-tip flowmeter substantiate to a certain extent the physiopathological explanations of the basic anomalies of the jugular venous flow tracings.

The authors are indebted to Professor J. P. Benhamou (Paris) who performed the statistical analysis and Dr. D. Tunstall-Pedoe (Oxford) for his correction of the English translation.

References

- Altman, R. (1956). *Der Venenpuls*. Urban and Schwarzenberg, Berlin.
- Bory, M. (1966). (Editor) *Le Jugulogramme - Son Intérêt en Cardiologie*. Meiffren, Marseille.
- Carter, S. A., Bajec, D. F., Yannicelli, E., and Wood, E. H. (1960). Estimation of left-to-right shunt from arterial dilution curves. *Journal of Laboratory and Clinical Medicine*, 55, 77.
- Chiche, P., Kalmanson, D., Veyrat, C., and Toutain, G. (1968). Enregistrement transcutané du flux artériel par fluxmètre directionnel à effet Doppler. Description d'un appareillage et premiers résultats. *Bulletin et Mémoires de la Société Médicale des Hôpitaux de Paris*, 119, 87.
- Colman, A. L. (1966). *Clinical Examination of the Jugular Venous Pulse*. Charles C. Thomas, Springfield, Illinois.
- Gamble, W. J., Hugenoltz, P. G., Monroe, R. G., Polanyl, M., and Nadas, A. S. (1965). Use of fiber-optics in clinical cardiac catheterization. *Circulation*, 31, 328.
- Haroutunian, L. M., Neill, C. A., and Otis, A. B. (1958). The contour of the right atrial wave in twenty-seven cases of atrial septal defect and in other cardiac conditions. *Bulletin of the Johns Hopkins Hospital*, 102, 176.
- Hartman, H. (1960). The jugular venous tracing. *American Heart Journal*, 59, 698.
- Kalmanson, D. (1971). Pour une nouvelle approche de l'hémodynamique cardiovasculaire. *Presse Médicale*, 79, 275.
- Kalmanson, D., Novikoff, N., Chiche, P., and Derai, C. (1969a). Study and physiological interpretation of blood velocity curves recorded within the right heart with a directional Doppler flowmeter catheter tip. *Comptes-Rendus Hebdomadaires des Séances de l'Académie des Sciences*, 269, 1097.
- Kalmanson, D., Toutain, G., Novikoff, N., and Derai, C. (1972). Retrograde catheterisation of left heart cavities in dogs by means of an orientable directional Doppler catheter-tip flowmeter: a preliminary report. *Cardiovascular Research*, 6, 309.
- Kalmanson, D., Toutain, G., Novikoff, N., Derai, C., Chiche, P., and Cabrol, C. (1969b). Le cathétérisme vélocimétrique du cœur et des gros vaisseaux par sonde ultrasonique directionnelle à effet Doppler. Rapport préliminaire. *Annales de Médecine Interne*, 120, 685.
- Kalmanson, D., Veyrat, C., and Chiche, P. (1968). Le retour veineux droit enregistré par voie transcutanée au niveau de la veine jugulaire interne chez le sujet normal. Interprétation physiologique des courbes. *Bulletin et Mémoires de la Société Médicale des Hôpitaux de Paris*, 119, 873.
- Kalmanson, D., Veyrat, C., and Chiche, P. (1971). Atrial versus ventricular contribution in determining systolic venous return. A new approach to an old riddle. *Cardiovascular Research*, 5, 293.

- Laurencet, F. L., Mehmehl, H., and Rutishauser, W. (1970). Evaluation quantitative des shunts gauche-droite par les courbes de dilution périphériques. *Archives des Maladies du Coeur et des Vaisseaux*, **63**, 424.
- Levin, A. R., Spach, M. S., Boineau, J. P., Canent, R. V., Jr., Capp, M. P., and Jewett, P. H. (1968). Atrial pressure - flow dynamics in atrial septal defects (secundum type). *Circulation*, **37**, 476.
- Luisada, A. A. (1948). *Heart. A Physiologic and Clinical Study of Cardiovascular Diseases*, p. 258. Williams and Wilkins, Baltimore.
- McDonald, D. A. (1960). *Bloodflow in Arteries*. Edward Arnold, London.
- Nadas, A. S. (1957). *Pediatric Cardiology*. W. B. Saunders, Philadelphia and London.
- Reinhold, J. (1955). Venous pulse in atrial septal defect. A clinical sign. *British Medical Journal*, **1**, 695.
- Savier, C. H., Kin, G., and Facquet, J. (1963). Sur une nouvelle méthode d'évaluation des insuffisances valvulaires à partir des courbes de dilution. *Archives des Maladies du Coeur et des Vaisseaux*, **56**, 992.
- Tavel, M. E., Bard, R. A., Franks, L. C., Feigenbaum, H., and Fisch, C. (1968). The jugular venous pulse in atrial septal defect. *Archives of Internal Medicine*, **121**, 524.
- Wood, P. (1950). *Diseases of the Heart and Circulation*, p. 216. Eyre and Spottiswoode, London.

Requests for reprints to Dr. D. Kalmanson, Fondation Ophtalmologique A. de Rothschild, 29, rue Manin, 75-Paris (19e), France.