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DOPPLER ECHOCARDIOGRAPHY: VALIDITY OF A QUANTITATIVE ANALYSIS OF VELOCITY CURVES

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The clinical evaluation of the Doppler diagnosis was performed at the level of inferior vena cava for quantification of tricuspid insufficiency (TI) and in the aortic arch for evaluation of aortic insufficiency (AI). The ratios were calculated between systolic and diastolic components: 1. for AI, between peak systolic and end diastolic components, 2. for TI between peak systolic and peak diastolic components. The results showed that: 1. the compliance of the vessels may prevent the propagation of moderate modifications of velocity curves; 2. associated valvular stenosis may disturb curves even far downstream; 3. systolodiastolic variations of vessel diameter may modify the relationship between angiographic grades and ratios: 0.890 for TI (61 patients) and 0.86 for pure AI (65 patients); for both lesions, the differences between the groups, defined according to the angiographic grade, were significant.

1. Introduction

Doppler velocimeters display spectral distributions or velocity curves which depend on both the accuracy of the signal processing, the signal-to-noise ratio, the occurrence of turbulences and the angle between the ultrasonic beam and the axis of displacement of blood cells [2]. This angle has to be assessed in three dimensions and, mainly at the level of cardiac chambers, the orientation of stream lines with respect to walls is not well defined; thus the angle cannot be measured in many instances. These problems, usually, prevent a quantitative measurement of velocity. The purpose of this paper is to study the theoretical and clinical value of a method for overcoming this limitation.

2. Principle

The principle of this method is to analyse velocity with a high signal-to-noise ratio, in a region where the shape of velocity profile does not vary along the cardiac cycle and where there is no turbulence. Provided those conditions, the different components of a velocity curve along the cardiac cycle are considered as corresponding to stream lines analysed with the same angle with respect to the ultrasonic beam. Therefore, the calculation of a ratio between two components of a curve cancells out the angle factor, since it is the same for numerator and denominator. In order to achieve these conditions, it is necessary to perform the measurements within straight vessels, at some distance from the lesions, instead of within the heart, at the level of the valves.

3. Evaluation of the apparatus

3.1. Apparatus

Commercially available spectrum analysers provide a visual presentation of the distribution of Doppler frequencies; some systems allow calculation of mean velocity which have an accuracy limited in many instances. Moreover, a comparison of the zero-crossing counter output with the data obtained using a spectrum analyser has demonstrated that the zero-crossing counter is accurate in all the cases where the spectral presentation demonstrates the presence of a rather narrow velocity distribution within the sample volume. For this reason, we decided to use the output of a zero-crossing counter and a small sample volume [5]. Some potential sources of limitation were studied: signal-to-noise ratio, low frequencies due to wall motion, high-pass filters, occurrence of aliasing.

3.2. Signal-to-noise ratio

In order to test the influence of the signal-to-noise ratio, the bandwidth of the apparatus was screened using single frequencies mixed with electronically generated noise. The input frequency was compared with the output of the velocimeter for different levels of noise. The results show that the relationship between the two latter parameters is a straight line over a range which increases with the signal-to-noise ratio. For the values encountered in practice, the upper limit of this range corresponds approximatively to one third of the pulse repetition rate [4].

3.3. Wall motion

The artifacts related to wall motion were studied by adding a low frequency with increasing amplitude to a Doppler signal. The results show that low frequency introduces errors in the assessment of the direction of velocity. It emphasizes the importance of high-pass filters, in spite of the limitations that they introduce in the vicinity of the zero velocity: low frequencies are ignored and measurements are no longer accurate over a range that depends on the cut-off frequency of the filter.

3.4. Aliasing

Aliasing may occur in pathological or, even, in physiological conditions. It can be detected and avoided by increasing the pulse repetition rate and/or the angle between the ultrasonic beam and the axis of the flow.

4. Clinical evaluation

The clinical value of the method was evaluated with the purpose of a quantitative evaluation of aortic and tricuspid insufficiency.

4.1. Aortic insufficiency

4.1.1. Method

The modifications of flow due to aortic incompetence were studied at the level of the aortic arch, at the beginning of its descending part: this position was selected in order to avoid asymetries of velocity profile occurring in the ascending and the horizontal part of the aortic arch [6]. The recording was performed using a transducer positioned in the suprasternal notch and orientating the ultrasonic beam posteriorly and to the left; the descending part of the aorta is recognized by its echo landmark and its flow running away from the transducer during systole. It can be analyzed using a *2D* echo transducer but, in order to set a high signal-to-noise ratio, it is often necessary to use a single crystal probe.

4.1.2. Velocity curves

If the aortic valve is normal, the velocity has a negative U shaped component during systole, a brief and small reversal component during the beginning of diastole and is equal to zero during the end diastolic phase. In case of significant aortic insufficiency there appears a positive reversal velocity throughout diastole. The ratio was calculated between the peak systolic and the end diastolic amplitude of the velocity curve.

4.1.3. Results

The calculated ratio was compared to a four-stage semi-quantification obtaine using selective supravalvular aortography on a series of 93 patients [3]. The correlation coefficient was 0.81; it increased up to 0.86 when considering only patients without associated aortic stenosis (pressure drop of less than 10 mm Hg at the level of the aortic orifice). All the differences between the groups were highly significant.

4.1.4. Comments

Some sources of limitation appeared clearly, some moderate regurgitation did not produce any end diastolic flow reversal at the level of the descending aorta; it may be due to the high-pass filters and/or to the compliance of the upstream part of the aortic arch.

Usually, for clinical needs, an evaluation of regurgitant flow is considered as more useful than the measurement of velocity; therefore the systolo-diastolic variations of diameter may be misleading; fortunately, the more severe the insufficiency is, the more variations are important.

4.2. Tricuspid insufficiency

4.2.1. Method

Tricuspid insufficiency was studied using velocity curves recorded within the inferior vena cava: the transducer was located in the epigastric area on the patient lying in a supine position, in order to display the inferior vena cava behind the liver; it is recognized according to its echo landmarks and its flow pattern regulated both by the heart and respiration. Recordings were made during the expiratory apnea in order to prevent any Valsalva manoeuver.

4.2.2. Velocity curves

The normal flow pattern was studied on 10 healthy subjects: there is a predominent negative systolic component, the diastolic negative component has a smaller amplitude and it ends at the onset of the atrial contraction that may produce a brief reversal flow. In the case of atrial fibrillation, the amplitude of the systolic component is smaller and the end diastolic flow reversal disappears.

In case of mild regurgitation, the amplitude of the systolic component decreases; if the regurgitation is moderate or severe, a positive systolic flow reversal appears.

The Doppler index of tricuspid regurgitation was calculated between the systolic velocity amplitude (measured at the top of the T wave of the ECG) and the peak diastolic anterograde velocity.

4.2.3. Results

The Doppler index was compared with a 5 grade semiquantification obtained using selective right ventricular angiography [1]. On a series of 62 patients, the correlation between angio and Doppler parameters is highly significant ($r = 0.89$), all the differences between the groups are significant; and using a variance analysis, we found an F value of 47.84.

4.2.4. Comments

At the level of the vena cava, variations of vessel diameter appeared to be small. The limitations due to high-pass filters were not important because a low cut-off frequency was used, according to limited wall motion. Otherwise, in some instances the index could not be calculated owing to atrial arrhythmias such as atrial flutter.

5. Conclusions

In order to obtain accurate relative velocity measurements using Doppler echocardiography, it is necessary:

— to have an appropriate setting of the pulse repetition rate and of the highpass filters,

– to have a good position of the sample volume with respect to velocity profiles,

– to have a high signal-to-noise ratio.

Provided those conditions, it is worthwhile to calculate the ratios between the parameters of the velocity curves, namely at the level of the great vessel. This procedure allows an accurate evaluation of tricuspid or aortic insufficiencies.

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