Effect of Acute Changes in Heart Rate on Doppler Pulmonary Artery Acceleration Time in a Porcine Model*

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Doppler measurements of pulmonary artery (PA) acceleration time (AT) have been used clinically to estimate PA pressure. However, these studies have been performed primarily in patients without tachycardia. To determine the effect of acute changes in heart rate on PA AT, atrial pacing studies were performed in seven closed-chest pigs. Pulsed Doppler PA flow velocity recordings were obtained from a parasternal position at pacing rates from 100 to 140 beats/min. PA pressure remained constant (mean ± SD = 14 ± 5 mm Hg) over the entire range of paced rates. When PA Doppler measurements were compared at heart rates of 100 and 140 beats/min, there were decreases at the higher heart rate in both acceleration time (110 ± 12 vs 83 ± 11 ms, p < 0.01) and ejection time (ET) (315 ± 23 vs 237 ± 21 ms, p < 0.01). In contrast, there was no change in either PA peak flow velocity (69 ± 15 vs 62 ± 18 cm/s) or the ratio of AT/ET (0.35 ± 0.02 vs. 0.36 ± 0.03). Consequently, when estimating PA pressure in states of tachycardia, the PA AT/ET ratio may be a more useful measurement than PA acceleration time. (Chest 1988; 94:994-97)

**Table**

| PA = pulmonary artery | AT = acceleration time | ET = ejection time | PFV = peak flow velocity |

**Material and Methods**

**Protocol**

Seven pigs weighing 45 to 79 kg were anesthetized with halothane after endotracheal intubation. An intra-arterial catheter was inserted to monitor systemic arterial pressure and a triple-lumen thermodilution catheter was used to measure right atrial and PA pressures and cardiac output. A pacing wire was inserted transvenously into the right atrium to pace the heart at rates from 100 to 140 beats/min. Each pacing interval was maintained for at least five minutes to allow for stabilization of hemodynamic parameters. The following invasive hemodynamic measurements were made at baseline and at each pacing increment: systemic and pulmonary arterial pressures, stroke volume, and cardiac output.

**Doppler Measurements**

Doppler echocardiographic studies were performed using a commercially available ultrasound instrument that combined a mechanical sector scanner for two-dimensional imaging with a spectrum analyzer-based pulsed Doppler velocimeter (Biosound Corp). Two-dimensional images recorded from a parasternal approach were used to locate the pulmonary artery in a short-axis view. The Doppler sample volume, a cylinder 10 mm long and approximately 4 mm in diameter, was positioned in the pulmonary artery to obtain pulsed Doppler recordings featuring the maximum PA flow velocity and the least spectral dispersion. The transducer was angulated until PA flow velocity recordings demonstrating these characteristics were obtained. A minimum of four beats was averaged to obtain the measurement for each heart rate. As previously described, peak flow velocity (PFV) was measured at the midpoint of the darkest portion of the spectrum at the time of the peak velocity (ie, peak modal velocity) (Fig 1). Acceleration time

**Figure 1** Method of making measurements from pulsed Doppler flow velocity recordings in the pulmonary artery. Peak flow velocity (PFV) was measured in cm/s at midpoint of darkest portion of the spectrum at time of peak velocity, ie, peak modal velocity. Acceleration time (AT) was measured in ms from onset of flow to attainment of peak velocity Ejection time (ET) was measured in ms from onset to end of systolic flow.

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was measured from the onset of flow to the time of peak velocity. Ejection time (ET) was measured from the onset to the end of systolic flow. In addition, the ratio of acceleration time divided by ejection time (AT/ET ratio) was calculated.

RESULTS

Table 1 summarizes the data for Doppler PA peak flow velocity, acceleration time, ejection time, AT/ET ratio, and PA pressure in seven pigs at atrially paced heart rates of 100 and 140 beats per minute. Mean PA pressure (14 ± 5 mm Hg) remained constant over the entire range of paced heart rates. As shown in Table 1 and Figure 2, both PA acceleration time and PA ejection time were decreased at the higher heart rate (p<0.01). The PA acceleration time decreased from a mean (± SD) of 110 ± 12 to 83 ± 11 ms in going from a paced heart rate of 100 to 140 beats/min. The PA ejection time decreased from 315 ± 23 to 237 ± 21 ms over this range of heart rates. In contrast, the PA peak flow velocity and the AT/ET ratio did not change significantly over this range of heart rates. The AT/ET ratio was .35 ± .02 at a heart rate of 100 and 0.36 ± .03 at a heart rate of 140 beats/min. Figure 2 displays PA flow velocity recordings from an experimental pig obtained at heart rates of 100 (upper panel) and 140 (lower panel) beats/min. PA pressure remained the same at both heart rates in this and the other pigs. Although both PA acceleration time and PA ejection time were less at the higher heart rate, the AT/ET ratio remained unchanged.

DISCUSSION

Several Doppler methods have been outlined for evaluating pulmonary artery pressure. The modified Bernoulli equation has been used to estimate PA systolic pressure from the peak velocity of the tricuspid regurgitation jet.10-13 This equation has also been used to estimate PA diastolic pressure from the peak flow velocity in the pulmonic regurgitation jet.14 The isovolumic relaxation time has been used in conjunction with a heart rate nomogram published by Burstin to estimate PA systolic pressure.15,16 Each of these methods has strengths and limitations. For example, the tricuspid regurgitation and pulmonic regurgitation jets cannot always be recorded in the clinical situation. Further, the isovolumic relaxation time is affected by factors other than heart rate and PA pressure—for example, the right atrial pressure—and may give erroneous estimates of PA pressure with high right atrial pressures.

Doppler measurement of acceleration time in the pulmonary artery or right ventricular outflow tract has been noted to be useful in estimating the PA pressure by several authors.17 We have noted that in patients with PA acceleration time <120 ms, mean PA pressure (in mm Hg) is inversely related to the pulmonary artery acceleration time (r = -0.87) by the following equation:

PA mean pressure = 90 - 0.62 × PA AT

However, this and other studies relating PA acceleration time to PA pressure have been performed primarily in patients not exhibiting tachycardia. Since it might be expected that increased heart rate would shorten time-based measurements such as accelera-
tion time and ejection time, we evaluated the use of
the PA AT/ET ratio as a technique for correcting for
increased heart rate. A similar approach would involve
correcting for heart rate directly by dividing PA AT by
the square root of R-R interval.
Although using the AT/ET ratio is helpful in solving
one of the problems associated with PA acceleration
time measurements, many other problems must be
considered. First, various investigators have noted
that the position of the Doppler sample volume in the
pulmonary artery may affect the PA acceleration time
measurement. Specifically, recording from near the
PA wall or distally in the pulmonary artery toward its
bifurcation may lead to erroneously decreased meas-
urements of acceleration time. In the current study,
we recorded from the parasternal view near the
pulmonic valve, centrally in the vessel, and angulated
the transducer to obtain the PA velocity tracings having
the least spectral dispersion and highest peak flow
velocity. This technique minimized the possibility of
recording erroneously short measurements of PA ac-
celeration time. However, it has recently been pointed
out in human subjects that the highest flow velocity in
the pulmonary artery may frequently be recorded from
a subcostal approach. Nonetheless, since we
recorded from the same parasternal position at all
paced rates, our conclusions regarding changes in the
flow velocity measurements should remain valid. In
addition, we sought to overcome the effects of respi-
ration on PA flow velocity measurements by measuring
the complexes that demonstrated the highest peak
flow velocities.
Finally, it should be noted that although PA ac-
celeration time is useful for the evaluation of pulmonary
hypertension, this Doppler measurement is affected
not only by PA pressure, but also by pulmonary blood
flow and pathologic changes in the pulmonary vascular
bed. For example, patients with an atrial septal
defect who exhibit high PA pressure associated with
high pulmonary blood flow may have a PA acceleration
time in the normal range (>120 ms). Clearly, pulmo-
nary artery resistance is an important factor influenc-
ing the PA acceleration time. It has also been noted
that in patients with severe pulmonary hypertension,
the PA ejection time may shorten greatly, tending to
normalize the PA AT/ET ratio. In these cases, it may
be helpful to examine the ratio of right ventricular
ejection period to ejection time, which becomes
significantly increased.

When estimating PA pressures in tachycardic states
using Doppler PA flow velocity measurements, the PA
AT/ET ratio may be a more useful measurement than
PA acceleration time. In the presence of tachycardia,
the diagnosis of pulmonary hypertension should be
strongly considered when the ratio of PA AT/ET falls
2 SD below the mean noted for normal PA pressure in
our study—ie, below 0.30.
Studies are currently in progress in a porcine model
to document the relative effects of tachycardia and
acute pulmonary hypertension in producing shorten-
ing of the Doppler PA acceleration time. It might
also be useful to assess whether there is significant
variation in PA acceleration time over heart rates
ranging from 60 to 100 beats/min in cases of both
normal and elevated PA pressure. Finally, it should
be emphasized that in this study, the effects of acute
changes in heart rate on PA acceleration time were
evaluated in an animal model. Acute Doppler meas-
urements of acceleration time and ejection time may
differ from those detected in patients with chronic
pulmonary hypertension. Nonetheless, this study em-
phasizes the importance of correcting the PA accele-
ration time for another time-based measurement such
as ejection time.

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