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Differences in Pulmonary Artery Wedge Pressures Obtained by Balloon Inflation *versus* Impaction Techniques

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Pulmonary artery wedge pressures (PAWPs) first were obtained by advancing non-balloon-tipped catheters under fluoroscopic guidance into an "impacted wedge" (IW) position and more recently by advancing flow-directed, balloon-tipped catheters into a balloon wedge (BW) position. Deflated balloon-tipped catheters may migrate into an IW position, which promptly should be recognized and the catheter repositioned until a pulmonary artery tracing is seen and a BW pressure once again can be obtained. We noticed in two patients, one with catheter migration and the other after cardiac catheterization, a difference between IW and BW pressures and wave forms. These observations prompted a prospective clinical study to characterize more clearly these differences.

REPORT OF CASES

Patient 1: A 65-year-old man with fever, bilateral pulmonary infiltrates, cardiac murmur, and suspected infective endocarditis of the mitral valve was admitted to the ICU. A 7 French balloon-tipped flow-directed pulmonary artery catheter was passed into a BW position, documenting a mean pressure of 12 mmHg and A and V wave amplitudes above the diastolic baseline of 2 and 4 mmHg, respectively. Because respiratory insufficiency progressed, his trachea was intubated, and he was ventilated with intermittent mandatory ventilation and positive end expiratory pressure. The pulmonary artery catheter was removed, since hemodynamic compromise had not been documented. The patient improved rapidly, but attempts to wean him from the ventilator resulted in severe hypoxemia. A pulmonary artery catheter again was inserted, and similar BW pressures were obtained.

Because the patient appeared to have clinically significant mitral regurgitation, cardiac catheterization was performed. The right heart chambers were catheterized with a No. 7 Lehman (non-balloon-tipped) catheter and pressures were recorded. A mean IW pressure of 24 mmHg, a post-A-wave pressure of 13 mmHg, and a peak V-wave amplitude of 44 mmHg were demonstrated. A left ventriculogram confirmed significant mitral regurgitation. After the patient had been returned to the ICU, a BW pressure tracing still did not demonstrate a large V-wave, so an IW pressure measurement was obtained; the tracing was identical to that obtained with the Lehman catheter.

Patient 2: A 56-year-old man had a 7 French pulmonary artery catheter inserted for monitoring during an episode of acute respiratory failure. The bedside nursing personnel requested evaluation of the position of the catheter because they suspected that the catheter had migrated to an IW position. Blood obtained from the distal lumen of the catheter had a *p*H of 7.61, a P_{CO_2} of 19 mmHg, and a P_{O_2} of 233 mmHg, while systemic arterial blood had a *p*H of 7.48, a P_{CO_2} of 25 mmHg, and a P_{O_2} of 151 mmHg. A post A-wave pressure was 15 mmHg, and A and V wave amplitudes were 5 mmHg and 15 mmHg, respectively.

The catheter was withdrawn until a pulmonary artery tracing was obtained. Blood obtained from the distal lumen at that time demonstrated a *p*H of 7.44, a P_{CO_2} of 31 mmHg, and a P_{O_2} of 28 mmHg. A BW pressure obtained with the catheter in that position demonstrated a post A-wave pressure of 17 mmHg, and A and V wave amplitudes that both were only 3.5 mmHg.

METHODS

Sixty patients in the ICU who had pulmonary artery catheters inserted through a commercially available sterile shield qualified for our clinical study, which was approved by the Hospital Research Practices Committee. All manipulations of the catheter were performed by members of the ICU physician staff. Systemic artery pressure and pulmonary artery pressure tracings or an electrocardiogram (ECG) and pulmonary artery pressure tracings were recorded. The balloon was inflated and a BW wave form recorded. Then the balloon was deflated, and the catheter advanced into an IW position identified by the loss of the phasic pulmonary artery wave form and the presence of obvious A and V waves typical of a wedged wave form. Simultaneous arterial pressure or ECG and IW pressures again were recorded. The catheter then was withdrawn to the point in the pulmonary artery where inflation of the balloon with 1 to 1.5 ml air was necessary to obtain a BW pressure.

All PAWPs were measured at end-expiration and recorded. The catheter transducer system was not flushed once the comparison sequence was begun. The wedge position was documented by a shift of the peak pressure event in the wave form as compared with the peak event in the pulmonary artery wave form. The post A wave, peak V wave, and mean PAWPs were recorded electronically, and differences between the BW and IW pressures were analyzed by a paired Student's *t* test for significance of $P < 0.05$.

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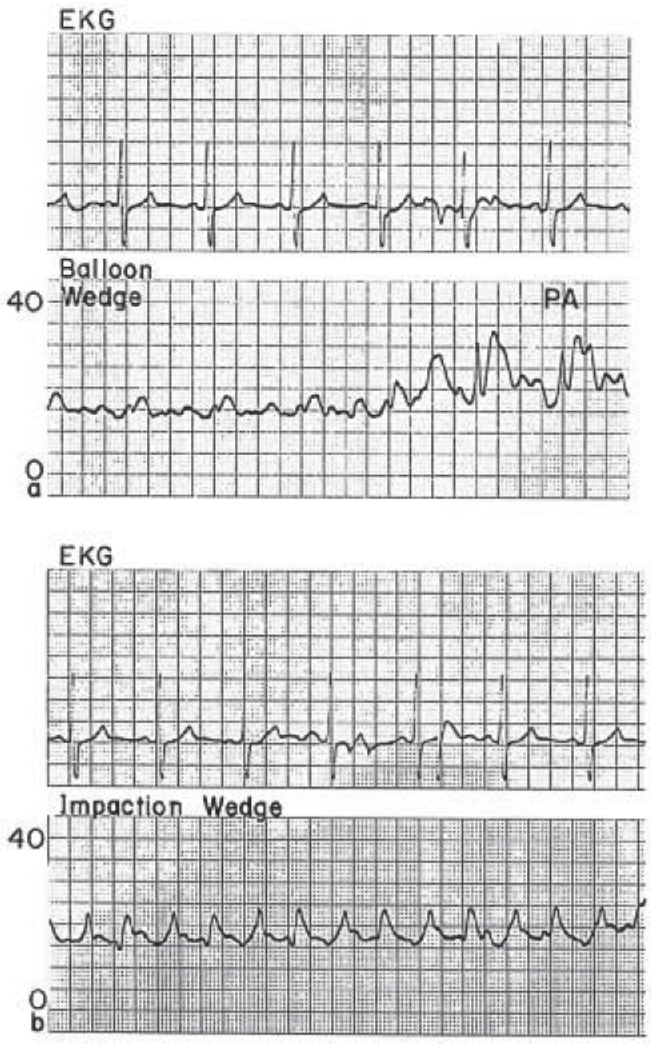

FIG. 1. Comparison of wedge pressure and correlation with electrocardiogram. *A*. Wedge pressure by balloon inflation (BW). *B*. Wedge pressure by catheter impaction (IW). Pressures obtained a few minutes apart.

RESULTS

In many patients, an IW pressure was not obtainable due to the limitation of catheter length available within the sterile shield. In addition, several patients had very damped BW and IW wave forms, which made comparisons impossible. Twelve of the 60 patients demonstrated obvious differences in wave form between the two PAWPs. The IW tracings demonstrated greater phasic changes in A and V wave amplitudes (fig. 1) and generally had higher pressures then the BW tracings (table 1). Among these 12 patients, eight had an IW V-wave amplitude at least 5 mmHg greater than the BW V-wave amplitude (fig. 2). The differences in V-wave amplitude and post-A wave pressure obtained in the two catheter positions were significant ($P < 0.05$). The comparison of mean PAWPs yielded no statistically significant difference, which partially may be explained by the larger mean BW pressure (7 mmHg) in patient 1.

DISCUSSION

PAWP is an indirect measurement of left ventricular filling or left ventricular end-diastolic pressure. The absolute value and the wave form of the wedge pressure may be affected by a variety of factors, including the location of the catheter tip,[1] the intravascular volume, the natural resonant frequency and damping of the catheter–transducer system,[2] and the compliance of the left ventricle, the left atrium, and the pulmonary artery.[3]

Differences in wedge pressure wave forms obtained by balloon inflation and impaction techniques are relatively common but usually are clinically unimportant. However, the additional information obtained by using both techniques in certain critically ill patients may aid in diagnosis and treatment. Although there are recognized limitations to basing a definitive diagnosis of mitral regurgitation on the presence of V waves on a BW tracing,[3] failure to demonstrate large V waves with bedside pulmonary artery catheterization in the patient 1 contributed to the delay in diagnosis of mitral regurgitation. Such a delay in the diagnosis of an acute hemodynamically compromising event may contribute to a fatal outcome.[4] Additionally, Moser and Spragg[5] have suggested routine impaction wedging during catheter insertion, and Braunwald and Gorlin[6] have shown this to be a safe procedure in a large series of patients.

TABLE 1. Impaction *versus* Balloon Wedge Pressure Measurements

Patient	1	2	3	4	5	6	7	8	9	10	11	12
V-Wave Amplitude												
IW	31	17	9	25	37	29	23	12	11	22	21	26
BW	32	11	8	20	32	23	22	7	6	21	16	21
Mean PAWP												
IW	24	14	9	22	28	21	21	11	7	19	16	18
BW	31	9	8	20	25	17	18	6	5	19	14	19
Post A-Wave Amplitude												
IW	28	14	8	21	27	19	18	9	5	17	19	14
BW	29	7	7	19	24	16	17	6	4	17	13	18

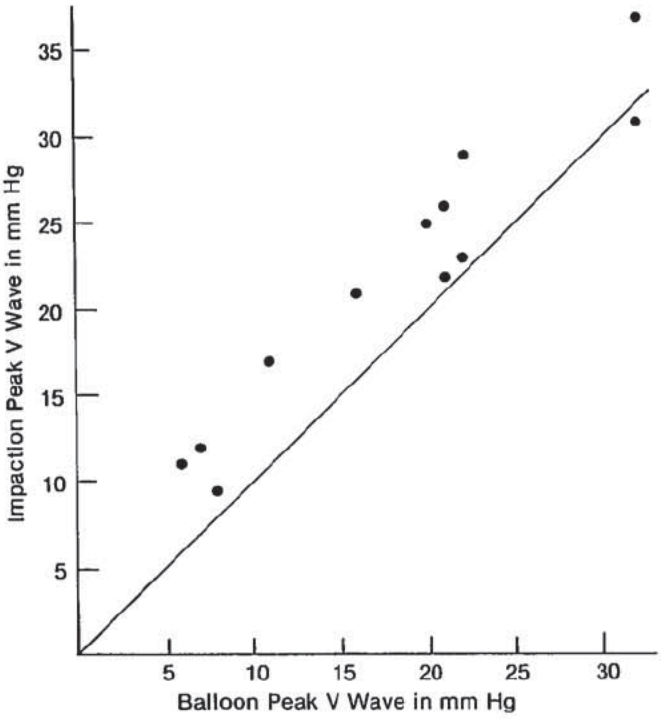

FIG. 2. Comparison of impaction peak V waves with balloon peak V waves. Straight line equals line of identity, which shows that the impaction peak V waves were higher than balloon peak V waves.

Perhaps the difference in wedge pressure wave forms can be explained in part by variations in the diameter of the pulmonary artery system at the sites where BW and IW pressure are obtained. Bell *et al.*[1] performed wedge pulmonary arteriograms to document the anatomy at the site of wedging and showed that the manner of catheter impaction in different areas (such as at a bifurcation), in dilated vessels, or in tortuous vessels may determine whether a phasic tracing or an unsatisfactory tracing is obtained. An additional factor may be some damping characteristic of the inflated or overinflated balloon. The inflating pattern of the balloon in human cadavers, as demonstrated radiographically with contrast media inflation, varied with whether the balloon was in the mid or distal portion of the pulmonary artery.[7] The larger cross-sectional area of the pulmonary vasculature distal to an inflated balloon may create a more compliant system than the smaller cross-sectional area of vessels distal to a catheter advanced to an impacted position. The latter, less compliant system might produce A and V waves of greater amplitude.

In summary, there appear to be differences (20% of our patients) in BW and IW pressures that have not been described previously. Impacting the catheter with an uninflated balloon may result in a better tracing of A and V wave forms, thus giving additional information about left-sided cardiac events.

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