Assessment of Prosthetic Heart Valve Function by Doppler Echocardiography
A Decade of Experience

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Almost 30 years have passed since the first successful use of an artificial heart valve for the treatment of severe valvular heart disease. Replacement of dysfunctional native heart valves with either mechanical or bioprosthetic materials has become the standard therapy for hemodynamically significant lesions with over 110,000 such procedures performed worldwide in 1988. Despite the general success of such valves in the treatment of advanced valvular heart disease, the ideal prosthesis has yet to be developed. All prosthetic valves are mildly stenotic as well as insufficient. Likewise, all are subject to the development of complications including thrombosis, infection, degeneration, dehiscence, fibrous ingrowth, and embolization, and all may manifest hemodynamically significant insufficiency or obstruction secondary to these complications. Throughout the years, a variety of noninvasive techniques including auscultation, fluoroscopy, phonocardiography, and M-mode and two-dimensional echocardiography have been used with limited success in the evaluation of patients with suspected prosthetic valve dysfunction. However, none of these techniques has been sufficiently sensitive or specific to achieve widespread clinical applicability, and cardiac catheterization has remained the reference standard in the evaluation of such patients. The signs and symptoms of prosthetic valvular dysfunction are often subtle or nonspecific and are not of sufficient magnitude to justify exposing the patient to a costly invasive procedure. Furthermore, cardiac catheterization does not lend itself well to repeated or longitudinal studies. During the past decade, very persuasive evidence has accumulated suggesting that through the use of Doppler echocardiography the clinician now has available a noninvasive, accurate and reproducible means by which to evaluate prosthetic valve function.

The study by Burstow and coworkers1 in this issue of Circulation shows that if Doppler and catheterization techniques are used appropriately and meticulously, nearly identical information will be derived regarding prosthetic valve function. In this study, Burstow et al examined 42 prosthetic valves (20 aortic, 20 mitral, one tricuspid, and one pulmonic) in 36 patients with simultaneous Doppler and catheter techniques. An excellent correlation was shown between the two techniques for both peak instantaneous \( r=0.94 \) and mean pressure gradients \( r=0.96 \). The investigators did not compare valve areas derived from Doppler with valve areas derived from direct hemodynamic measurements. Although not the primary purpose of their study, the investigators did summarize the clinical outcome in their study group. Sixteen prosthetic valves were diagnosed as being dysfunctional (seven stenotic and nine insufficient). At operation, 13 of the 16 valves were subsequently confirmed as being dysfunctional and were replaced, and the remaining three patients were treated medically.

Holen and colleagues2 first described the use of Doppler echocardiography in the evaluation of prosthetic heart valves in 1979. Since that time, many studies have reported on the Doppler echocardiographic characteristics of normal and dysfunctional prostheses.3–8 The vast majority of these studies have used the clinical assessment of patient status to establish normal values for a variety of prosthetic heart valves and have used subsequent catheterization and surgical findings for confirmation of abnormal findings. More recently, Wilkins et al9 reported on simultaneous catheter-derived hemodynamics and Doppler recordings in a group of patients with mitral and tricuspid prosthetic valves, and Burstow et al in this issue of Circulation similarly compared direct hemodynamic measurements in aortic and mitral prostheses with measurements obtained by Doppler echocardiography.

Prosthetic Valve Stenosis
Doppler echocardiography seems ideally suited for evaluation of patients with suspected prosthetic

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valve stenosis. The technique has become the procedure of choice for evaluation of patients with suspected native mitral and aortic valve stenosis. Because all prosthetic valves are inherently stenotic, Doppler echocardiography can be successfully used to measure transvalvular pressure gradients. If the interrogating Doppler beam is carefully aligned parallel to flow, peak and mean transvalvular pressure gradients can be accurately measured by applying the modified Bernoulli equation: \( \text{gradient} = 4v_{\text{max}}^2 \), where \( v_{\text{max}} \) is the maximal transvalvular velocity. As previously reported by Schoenfeld et al., the study by Burstow et al reemphasizes the inferior correlation between pulmonary wedge and left ventricular-derived gradients to left atrial and left ventricular-derived gradients in comparison to Doppler-derived transvalvular gradients. Also, particularly in the case of aortic prostheses, the valve should be examined from multiple views to minimize the angle of incidence between the Doppler beam and flow so that accurate Doppler gradients can be generated. The addition of color flow imaging may be helpful in that respect. The clinician also needs to be aware of the difference between the artificially derived "peak to peak" pressure gradient traditionally reported at cardiac catheterization and the "peak instantaneous" pressure gradient measured by continuous wave Doppler.

Although not addressed by Burstow et al, transvalvular pressure gradients are often insufficient to fully assess a patient with suspected prosthetic valve stenosis. Patients with severe left ventricular dysfunction, for instance, may have only a mildly elevated transvalvular aortic pressure gradient in the presence of significant stenosis because of low cardiac output. To circumvent these problems, many cardiac ultrasound laboratories routinely calculate aortic valve area by using the continuity equation and mitral valve area by using pressure halftime methodology. Although valve areas measured by Doppler techniques do not appear to correlate as well with valve areas determined by the Gorlin equation at cardiac catheterization as do valve areas derived from pressure gradient data, there is sufficient correlation to allow clinical decisions to be made with reasonable certainty.

Caution must be exercised in the direct application of these noninvasive hemodynamic data in the individual patient. Numerous studies have emphasized that individual variability exists from patient to patient even for specific valve types and sizes. Normal values, for instance, for peak transvalvular aortic gradient in a normally functioning 21-mm St. Jude's aortic prosthesis range from 4–40 mm Hg. Fortunately, in clinically stable patients, these measurements are quite reproducible on serial studies, indicating that a baseline study in clinically stable patients after valve replacement might help subsequent assessment when the patient becomes symptomatic.

**Prosthetic Valve Insufficiency**

Most normally functioning prosthetic heart valves are mildly insufficient. Because Doppler echocardiography is such a sensitive technique for detecting valvular regurgitation, it is not surprising that this "physiologic insufficiency" is detected in a high percentage of patients with prosthetic heart valves. The characteristics of this type of insufficiency in normally functioning prosthetic valves include a weak Doppler signal and relatively small jet areas and width, usually confined to within a centimeter of the valve plane. The introduction of color flow Doppler has been very helpful in distinguishing pathologic from physiologic regurgitation. Paravalvular leaks are much more readily identified using color flow mapping techniques than conventional Doppler. Some familiarity with the mechanics of the various prosthetic heart valves is also helpful in the interpretation of regurgitant signals. Minimal regurgitation in a normally functioning single tilting disc Medtronic's valve, for instance, is often centrally located along the guiding strut, whereas two small regurgitant jets are often seen after closure of a normally functioning bileaflet St. Jude's medical prosthesis. Demonstration of moderate-to-severe insufficiency by Doppler criteria has a high predictive value for prosthetic valve dysfunction. Several studies have shown the high sensitivity and specificity of the Doppler echocardiographic diagnosis of significant prosthetic valve insufficiency, particularly with aortic prostheses. Demonstration of mitral prosthetic insufficiency has been slightly more limited probably because of technical factors including increased distance of the left atrium from the transducer and masking of the regurgitant signal by the prosthetic valve. Transesophageal echocardiography has been shown to be quite helpful in this regard, increasing the yield of evaluation of prosthetic mitral valve insufficiency.

**Summary**

Since the first report of the application of Doppler echocardiography in the evaluation of prosthetic heart valves 10 years ago, dozens of studies have reaffirmed the usefulness of this technique in the noninvasive assessment of transvalvular hemodynamics. Most of these studies have established "normal values" for Doppler-determined pressure gradients and valve areas of prosthetic mitral and aortic valves. Although these studies have established the "normal range," they have all emphasized the individual variability in clinically normal functioning valves. Most of these studies have confirmed the extraordinary sensitivity and specificity of Doppler in detecting prosthetic valve dysfunction. The study by Burstow et al further emphasizes the excellent correlation obtained with simultaneous Doppler and catheter transvalvular pressure gradient measurements. The addition of both color flow Doppler techniques and transesophageal echocardiography...
can only serve to enhance the clinical diagnostic accuracy of this technique. At the present time, Doppler echocardiography is clearly the procedure of choice for the evaluation of the patient with suspected prosthetic heart valve dysfunction.

References


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