

High Concordance of Invasive and Echocardiographic Mean Pressure Gradients in Patients with a Mechanical Aortic Valve Prosthesis

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Background and aim of the study: Conflicting data exist regarding the accuracy of echocardiographic Doppler gradients compared to invasive pressure gradients in the hemodynamic assessment of patients with prosthetic aortic valves. The study aim was to determine the correlation between these measurements for mechanical single- and double-leaflet aortic valve prostheses in vivo.

Methods: Forty-four patients with an aortic valve prosthesis were included in this prospective study. Transthoracic echocardiography was performed immediately before the invasive measurements. Left ventricular pressure measurements were achieved by either atrial transseptal puncture and antegrade, transmitral left ventricular catheterization or - in the case of mitral valve replacement - direct left ventricular puncture.

Results: Comparison of echocardiographic and inva-

sive mean pressure gradients of all examined aortic prosthetic valves revealed a Pearson correlation $r = 0.59$ ($p < 0.001$). The mean pressure gradient was overestimated by 7.4 mmHg with echocardiography. Classifying patients into clinically relevant categories (mild, moderate, severely increased pressure gradient) resulted in a kappa value of 0.72 and an agreement of 86.4%. There was no relevant difference between single- and double-leaflet valves.

Conclusion: A high concordance was found between echocardiographic and invasive mean pressure gradients in vivo. Invasive measurements of the prosthetic valve gradients therefore seem to be indicated only in patients with contradictory echocardiographic and clinical findings.

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The first mechanical orthotopic heart valve replacement was performed in 1960. Since then, the number of valve replacements has increased steadily and today, more than 250,000 patients have received a prosthetic heart valve, about half of which are mechanical valves (1). Consequently, there is an increasing demand for the evaluation of prosthetic valves during follow up. The assessment of hemodynamic performance of prosthetic valves is complex, and echocardiographic follow up is - together with clinical examination - the most important diagnostic tool to determine valve function and prognosis. The quality of echocardiographic diagnostics has improved over the past few decades. Today, maximal velocity, maximal instantaneous and mean pressure gradient, regurgitation, effective orifice area (EOA) and morphological changes and aortic valve opening area can be determined non-invasively

by using echocardiography (2,3).

Mechanical heart valves, even if they function normally, differ from healthy valves in pressure and velocity characteristics because they are to some degree obstructive to the blood flow. In most prosthetic aortic valves, an increased pressure gradient compared to normal healthy subjects is seen. Normal values for echocardiographic assessment of valve prostheses have been updated and recently reviewed (4).

For most patients, echocardiography with Doppler provides reliable data, but in everyday clinical practice discrepancies between clinical status and echocardiographic results are not uncommon. A persistently elevated pressure gradient can lead to reoperation if the patient deteriorates clinically. In these cases, invasive measurements are undertaken prior to a second valve replacement in order to quantify pressure gradients and to exclude coronary artery disease prior to thoracotomy. In patients with clinically suspected valve dysfunction, a radiographic assessment of the valve opening movements is performed during invasive measurements.

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Conflicting data exist regarding the accuracy of echocardiographic Doppler gradients in patients with prosthetic aortic valves (5,6). The normal values of pressure gradients for prosthetic valves have often been obtained from in-vitro studies. In-vivo data are often analyzed in only small numbers of patients, and large inter-individual variation is common. Previous studies have either determined native stenotic aortic valves (7,8) or have applied in-vitro methods to compare Doppler and invasive pressure gradients in prosthetic valves (6,9,10).

An in-vivo comparison of instantaneous echocardiographic and invasive pressure gradients of prosthetic valves requires left ventricular pressure measurements to be made because retrograde cannulation of a mechanical aortic valve can lead to catheter entrapment, thrombus formation or even disruption of the valve. Left ventricular pressure measurement is achieved either by atrial transseptal puncture and transmitral antegrade left ventricular cannulation or - in the case of mitral valve replacement - direct left ventricular puncture.

The study aim was to determine the correlation of invasively and echocardiographically measured mean pressure gradients of mechanical aortic valve prostheses in vivo, and to determine whether the correlation holds true for single- and double-leaflet valve prostheses.

Clinical material and methods

Patients

A total of 44 consecutive patients (11 women, 33 men; mean age 56.0 ± 13.9 years; range: 23 to 74 years) who received an aortic valve prosthesis between January 1995 and February 2002 was included in this prospective diagnostic study. The patients were referred from outpatient clinics because of non-invasive prosthetic valve function that was discrepant from clinical status. Among these patients, 25 received a sin-

gle-leaflet valve and 19 a bileaflet valve (Table I). Three patients received both aortic and mitral prosthetic valves. The mitral valve prostheses implanted were one Björk-Shiley (23 mm), one CarboMedics (31 mm) and one Sorin Carbon (29 mm).

Valve implantation

The prosthetic aortic valves were implanted with the major area of flow towards the greater curvature of the ascending aorta. In tilting-disc valves, the major orifice faced towards the non-coronary leaflet, whilst in bileaflet valves one leaflet faced the right cusp. The region of major flow during systole was at the non-coronary leaflet, as described previously (11-13).

Investigations

The invasive and echocardiographic investigations were indicated clinically, and all patients provided their informed consent. The mean interval following valve replacement was 8.7 years (median 9 years; range: 1 to 24 years). The patients were normotensive (blood pressure $<130/80$ mmHg) and had a resting heart rate of less than 90 beats/min on the day of examination. Among patients in sinus rhythm ($n = 32$), three heart cycles for both invasive and non-invasive measurements were analyzed to determine pressure gradients. Among patients in atrial fibrillation ($n = 12$), the mean value of ten beats was calculated.

Echocardiography

Echocardiography was performed immediately prior to the invasive measurements. In only one patient were the measurements performed exactly at the same time to ensure that the pressure gradients were recorded at the same cardiac output. Echocardiography was performed using a Toshiba System SSH 160 equipped with a 3.75-MHz transducer and a 1.9-MHz pencil transducer (Toshiba Corp., Tokyo, Japan), and a Vivid Five System (GE, Vingmed, Horton, Norway) with a 2.5 MHz transducer.

Table I: Prosthetic aortic valve types examined in this study.

Valve type	Manufacturer	Size (mm)	No. implanted (%)
Single-leaflet (n = 25)	Björk-Shiley	21-29	12 (27.2)
	Medtronic Hall	19-25	12 (27.2)
	Lillehei-Kaster	19	1 (2.3)
Double-leaflet (n = 19)	St. Jude Medical	19-27	15 (34.1)
	CarboMedics	23-25	3 (6.8)
	Duromedics	23	1 (2.3)
Total			44 (100)

Values in parentheses are percentages.

Transthoracic Doppler measurements were performed from apical and suprasternal windows. The left ventricular ejection fraction (LVEF) was assessed by planimetry from apical four- and two-chamber views (Simpson's rule). The aortic root diameter was measured as the largest diameter in the parasternal long-axis view, using the leading edge method. Quantification of the aortic valve pressure gradient was obtained by continuous-wave Doppler (maximum and mean pressure gradient) according to the simplified Bernoulli equation.

Invasive hemodynamic measurements

The invasive hemodynamic measurements (right atrial pressure, right ventricular pressure, pulmonary artery pressure, pulmonary capillary wedge pressure, left atrial pressure, left ventricular pressure, aortic pressure) and transseptal left ventricular cannulation (using Mullins' technique) were performed prior to angiographic examinations in order to avoid changes to the hemodynamics by contrast media. No sedation was administered to avoid any hemodynamic effects that might influence the invasive measurements. The mean pressure gradient of the prosthetic valve was measured from simultaneous pressure recordings using an F6R-catheter (Cordis Corp., Miami, USA) in the ascending aorta (30-50 mm distal to the prosthetic valve) and in the left ventricle using a Mullins catheter (FastCath 7F; St. Jude Medical, Minnetonka, USA). In three patients who underwent mitral and aortic valve replacement the left ventricular pressure was obtained by direct left ventricular puncture (CIBA needle 18G; W. Cook Europe, Bjaeverskov, Denmark).

Statistical analysis

Results were expressed as mean \pm SD. Mean values

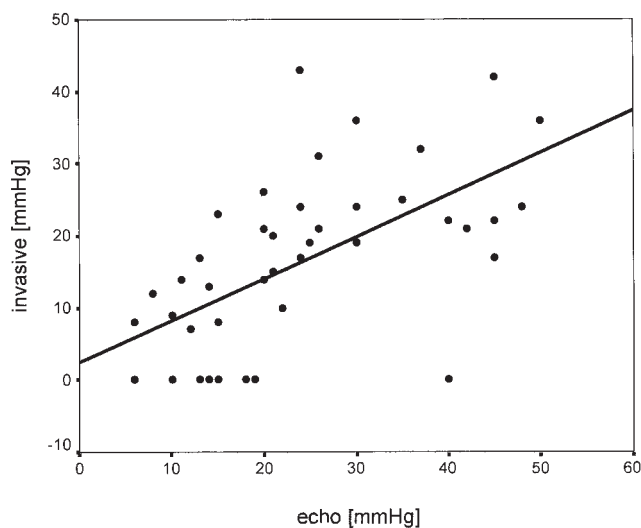


Figure 1: Correlation between echocardiographic and invasive mean pressure gradients.

were compared using a paired *t*-test, and a *p*-value <0.05 was considered to be statistically significant. The method of Bland-Altman (14) was used to assess methodological agreement between invasive and non-invasive measurement of mean pressure gradients. The correlation was calculated as Pearson's *r* coefficient. Diagnostic accuracy of the invasive and non-invasive pressure gradients was assessed using 2x2 tables with kappa (κ) statistics. SPSS 10.0 (Chicago, USA) and S-plus 2000 (MathSoft Inc., USA) software was used for these calculations.

Results

The mean LVEF measured echocardiographically at the time of examination was $48 \pm 16\%$. The LVEF had no effect on the changes in echocardiographic and invasive pressure gradients (LVEF $>40\%$ ($n = 31$), mean difference (Δ) = 7.06 mmHg versus LVEF $<40\%$ ($n = 13$), mean $\Delta = 8.23$ mmHg; $p = 0.82$).

The mean aortic root diameter, as assessed echocardiographically in the parasternal long-axis view, was 28.0 ± 8.0 mm. Three patients had an aortic root diameter >35 mm.

The mean pressure gradients recorded by Doppler echocardiography ranged from 6 to 50 mmHg (mean 23.6 ± 12.2 mmHg; median 20.5 mmHg), and the invasively recorded gradients ranged from 0 to 42 mmHg (mean 16.2 ± 12.0 mmHg, median 17.0 mmHg).

Comparison of echocardiographic and invasive mean pressure gradients of all examined aortic prosthetic valves (single- and double-leaflet) revealed $r = 0.59$ ($p < 0.001$) and an intra-class correlation coefficient (ICC) of 0.50. The 95% confidence interval (CI) was 8.7-19.0 mmHg (Fig. 1).

A comparison of echocardiographic and invasive

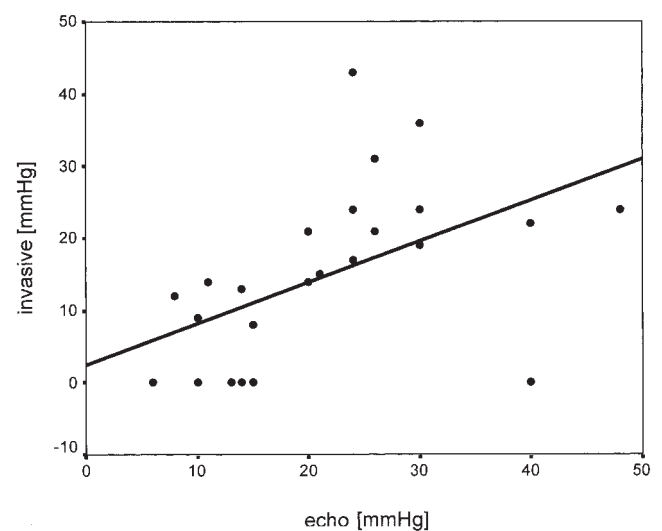


Figure 2: Single-leaflet aortic valves: Correlation between echocardiographic and invasive mean pressure gradients.

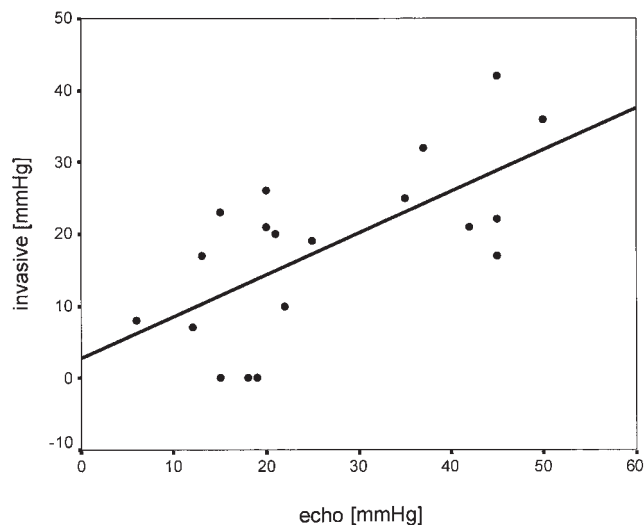


Figure 3: Double-leaflet aortic valves: Correlation between echocardiographic and invasive mean pressure gradients.

pressure gradients of single-leaflet valves revealed $r = 0.51$ ($p = 0.01$) and $ICC = 0.43$. The 95% CI was 8.5-21.0 mmHg (Fig. 2).

Comparison of echocardiographic and invasive pressure gradients of double-leaflet valves showed $r = 0.67$ ($p = 0.002$) and $ICC = 0.54$. The 95% CI was 3.1-22.0 mmHg (Fig. 3).

A mean overestimation of the mean pressure gradient by 7.4 mmHg with echocardiography was documented (Fig. 4). There was no relevant difference in the overestimation of echocardiographic pressure gradients between single- and double-leaflet valves.

In order to apply the pressure gradients to the patient's clinical situation, the patients were grouped into three categories according to the classification of native aortic valve stenosis (15): (i) Normal, mean pressure gradient <20 mmHg; (ii) mild stenosis, mean pressure gradient of 21-50 mmHg; and (iii) severe stenosis, mean pressure gradient >51 mmHg (2). The invasive and non-invasive pressure gradients classified 38 of all 44 patients within the same category, resulting in a κ value of 0.72 and an agreement of 86.4%. For single-leaflet valves, $\kappa = 0.75$ and agreement 88.0%, while for bileaflet valves, $\kappa = 0.68$ and agreement 84.2%. The difference between single- and double-leaflet valves was not statistically significant.

Discussion

The results of the present study indicated a high concordance of invasive and echocardiographic mean pressure gradients in patients with newer prosthetic aortic valves, as well as in patients who underwent mitral and aortic valve replacement. To the present authors' knowledge, this report has included the

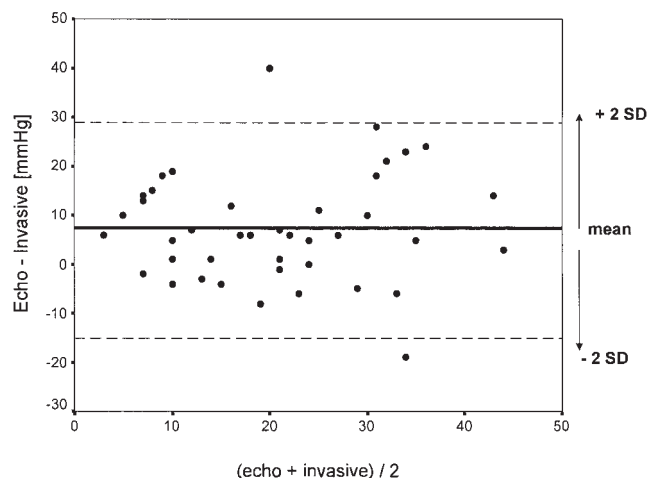


Figure 4: Bland-Altman plot of differences between echocardiographic and invasive mean pressure gradients (mean \pm 2 SD).

largest number of patients receiving these modern aortic valve prostheses.

In the past, studies have compared invasive and echocardiographic pressure gradients of prosthetic aortic valves in vitro, and have produced conflicting results. In an in-vitro study of prosthetic aortic valves, Bech-Hanssen et al. (10) studied bileaflet St. Jude Medical valves and found there to be a misleading correlation of echocardiographic and catheter pressure.

An overestimation of Doppler pressure gradients in Starr-Edwards, St. Jude Medical and Hancock prostheses in the aortic position has been demonstrated (6,9), and although this was confirmed in the present study the overestimation was clinically not relevant.

The systematic overestimation of Doppler gradients has been attributed to the phenomenon of 'pressure recovery'. Flow energy is the sum of pressure and kinetic energy. In stenotic valves, pressure energy decreases and velocity increases, but distal to the stenosis a part of the kinetic energy is reconverted to pressure energy (= pressure recovery). Pressure recovery is seen in stenotic native and prosthetic valves (16,17), and is dependent upon the valve orifice area, valve design and the diameter of the ascending aorta. A higher grade stenosis and a narrow diameter of the ascending aorta favor pressure recovery (18). Such recovery is greater in bileaflet than in tilting-disc valves, and greater in larger than in smaller prostheses (19). As the catheter pressure is usually recorded more distally than the echocardiographic Doppler measurement in the proximal jet, there is a systematic divergence between these measurements. To account for differences in pressure gradients due to pressure recovery, Vandervoort et al. (20) proposed that a 'pressure loss constant' be applied to Doppler measure-

ments. However, as the present results have shown a good concordance between echocardiography and catheter gradients, this constant appears to complicate everyday routine and provide no diagnostic benefit.

Invasive and non-invasive measurements were compared in 20 patients with prosthetic aortic valves in only one previous in-vivo study with a similar design (21). However, the types of valve used by these authors (42.8% Starr-Edwards, 19.0% biological) differed from those used in the present patient population. Taking into account the lower number of patients and the different spectrum of valve types, the present study results confirmed the high concordance of the two modes to obtain pressure gradients, although the degree of correlation was lower than in other investigations.

In eight patients, an invasive pressure gradient of 0 mmHg was found, and in seven of these the echocardiographic pressure gradient was not clinically relevant (<20 mmHg). In one patient, however, the discrepancy (0 versus 40 mmHg) remained unclear, but might have been due the echocardiographic measurement of a high velocity within turbulent flow.

In two patients with single-leaflet valves there was a low concordance of the pressure gradients. In one patient, Doppler overestimated the invasive pressure gradient by 40 mmHg, whilst in another the pressure gradient was underestimated by 20 mmHg. The hemodynamic data of these patients did not reveal any abnormalities, this being reflected by the intra-class coefficient, but Pearson's correlation coefficient failed to reflect this (22).

In the present clinical setting, the simplified Bernoulli equation was used rather than the full Bernoulli equation, which includes proximal velocity, and this may have led to an overestimation occurring. Normally, in prosthetic aortic valves the proximal velocity is <1 m/s (23), but none of the present patients had left ventricular outflow obstruction.

Study limitations

The initial limitations were that only mechanical valves were monitored, and that only mean pressure gradients were compared rather than peak pressure gradients or EOAs. Mean pressure gradients were selected because they have been studied previously, and their analysis has shown a higher correlation of invasive and non-invasive mean pressure gradients in aortic stenosis than invasive peak-to-peak pressure gradients and maximal instantaneous Doppler pressure gradients (24). The calculation of EOA is problematic in prosthetic aortic valves, and shows wide variation if measured in vivo (25). A further limitation was the non-simultaneous measurement of pressure gradients with potentially different hemodynamic sit-

uations. Both normotensive and stable patients were examined at rest, without sedation, without fasting situations, and in a recumbent position; thus, variations due to extrinsic factors seemed unlikely.

In conclusion, the present results showed a high concordance of echocardiographic and invasive mean pressure gradients in patients with prosthetic aortic valves. According to these results, no invasive examination is necessary in clinically stable patients with a constantly elevated mean pressure gradient at echocardiography. Also, in the case of an increasing echocardiographic gradient over time and clinical signs of valve dysfunction (e.g. dyspnea), no invasive examination of the valve is indicated. Only in rare cases with contradictory findings in echocardiography or clinical assessment, should invasive measurements be performed.

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