Original Article

Descending Aortic Pulsed Wave Doppler can Predict Changes in Cardiac Output during Off-pump Coronary Artery Bypass Surgery

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Retraction and stabilization of the heart can induce rapid and large changes in the hemodynamic state during off-pump coronary artery bypass graft surgery (OPCABG). We aimed to determine if Doppler measurement of flow in the descending artery with transesophageal echocardiography (TEE) can provide a beat-to-beat assessment of changes in cardiac output (CO) in 26 OPCABG patients. Simultaneous measurements were performed of CO using thermodilution, and descending aortic flow ($Flow_{DA}$) with TEE, prior to grafting, and during grafting to the left anterior descending artery (LAD), circumflex (Cx) and right coronary artery (RCA) territories. CO decreased from baseline (SD) values of 6.2 (1.7), to 5.4 (1.8) L/min during grafting to the LAD, 4.4 (1.5) L/min to the Cx territory, and 4.4 (1.4) L/min to the RCA territory ($P<0.001$). There was poor correlation between CO and $Flow_{DA}$ between individuals. In a subgroup of 16 patients who had grafts to all territories, the changes in $Flow_{DA}$, occurred in the same direction and magnitude as changes in CO ($P=0.062$, RM-ANOVA for factor*time interaction). Doppler assessment of flow in the descending aorta is able to track changes in CO during OPCABG. (Ann Thorac Cardiovasc Surg 2003; 9: 314–8)

Key words: cardiac output, echocardiography, Doppler, off-pump coronary artery bypass graft surgery

Introduction

Off-pump coronary artery bypass graft surgery (OPCABG) is becoming an increasingly popular method of myocardial revascularisation for both routine and high risk patients.[1) During positioning the heart for grafting, however, there is potential for sudden and profound hemodynamic deterioration, especially for posteriorly placed grafts.[2)]

Ideally, assessment of cardiac output (CO) should be "beat-to-beat" so that reductions in CO during positioning of the heart or during grafting can be rapidly identified. Conventional assessment of CO using thermodilution, either with bolus injection or continuous CO catheter, requires several minutes to detect changes in output. Transesophageal echocardiography (TEE) can measure CO,[3)] by using Doppler measurements of blood flow velocity through the left ventricular outflow tract, aortic valve, pulmonary artery or right ventricular outflow tract. These calculations may take several minutes to perform, and are unsuitable for continuous monitoring of CO. Also, during displacement of the heart, these TEE windows are distorted because the heart is retracted away from the esophagus. CO estimation with TEE, may therefore, be unreliable at the time when hemodynamic instability is most likely to occur.

Pulsed wave Doppler assessment of blood flow velocity in the descending aorta ($Flow_{DA}$), however, is easily obtained. This TEE window, is not subject to alteration during displacement of the heart, and can be used as a continuous monitor during positioning and grafting. Esophageal Doppler devices are available which estimate continuous CO. These measure aortic diameter with M-

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mode echocardiography, and assess blood flow velocity in the descending aorta with Doppler.[4] The same concept can be applied to a standard TEE probe, where the cross-sectional area of the descending aorta can be measured, and pulsed wave Doppler velocities obtained from the descending aortic long axis view. In order to estimate CO from descending aortic flow, the "stand-alone" Doppler devices must assume that a fixed proportion of total blood flow is distributed to the arteries proximal to the descending aorta, and that the Doppler incident angle is constant, across a range of patients. These assumptions have not been well validated in a range of patients, nor under altered hemodynamic states. Studies comparing esophageal Doppler with thermodilution show mixed results with some studies showing good correlation,[5,6] others showing poor correlation or wide variability.[7,8] Leather et al.[9] showed increased bias and variability after sympathectomy with lumbar epidural.

The aims of this study were to identify whether a consistent relationship between total CO and $Flow_{DA}$ exists across a range of patients; to assess whether changes in $Flow_{DA}$ are parallel to changes in CO; and to report the degree of hemodynamic compromise during multivessel OPCABG.

Methods

The Royal Melbourne Hospital Ethics Committee approved the study and written informed consent was obtained from the patients. Twenty-six patients underwent elective OPCABG using "Octopus III" stabilizer (Medtronic, Inc., Minneapolis, MN, USA) by a single surgeon. All patients received pedicled arterial Y-graft CABG.[10] These techniques represent the standard approach to CABG for our surgical team, and these patients were not purposefully selected for the study. Patient monitoring included thermodilution pulmonary artery catheter (834HF75, Baxter Healthcare Corporation, Irvine, CA, USA) and TEE using a multiplane transducer (OmniPlane II transducer and SONOS 2500 or 5500 machine, Philips Medical Systems, Andover, MA, USA). Independent observers performed simultaneous measurements with thermodilution and with TEE prior to grafting, and during grafting to the left anterior descending artery (LAD), the circumflex (Cx) and the right coronary artery (RCA) territories.

Three thermodilution CO measurements were averaged, using 10 ml of 5% dextrose solution at room temperature. If there was a greater than 10% difference in the curves, further measurements were performed and the high and low values were excluded.[3]

The descending aortic short axis view was obtained 2-3 cm beyond the origin of the left subclavian artery. The cross sectional area (CSA) was measured by planimetry during systole. The descending aortic long axis view was then obtained and the volume sampling point of the pulsed wave Doppler was placed in the far lateral center of the aorta so as to minimise the angle of insonation (Fig. 1). The velocity time integral (VTI) of the spectral display was measured.

$Flow_{DA}$ was calculated by:

$$Flow_{DA} = VTI \times CSA \times \text{heart rate}.$$

All echocardiography measurements were performed off-line for two beats by two independent operators, and averaged.

The sequence of grafting was to perform LAD territory grafts first, followed by sequential anastomoses to Cx and then RCA territories. We employ a deep pericardial suture to retract the pericardium, and position the patient in various degrees of Trendelenburg position, and lateral rotation to help with heart displacement. The baseline measurement was performed just prior to the displacement of the heart for the first graft. The heart was not returned to baseline position between measurements. To return to true baseline condition would have added considerable time delay to the operation. Measurements were performed once the coronary artery was opened and grafting commenced. No patient required inotropic support during grafting, and minor hemodynamic aberrations were treated with volume loading, vasopressor support using metaraminol or ephedrine. As we do not commence grafting until the hemodynamic conditions are stable, the measurement periods are performed during a period of hemodynamic stability.

Statistical methods

Because CO and $Flow_{DA}$ are measurements of flow at different points in the circulation, they are not directly comparable. To identify whether a consistent relationship (ratio of flows) existed between CO and $Flow_{DA}$, ordinary least products regression was performed to identify the closeness of correlation and to see if there was fixed or proportional bias,[11] for the regression model: $CO=a+b(Flow_{DA})$. In brief, if the 95% confidence interval (CI) for the intercept a includes the value 0, then there is no fixed bias, and for the slope b includes the value 1, then there is no proportional bias. To identify if the changes in CO were matched by parallel changes in $Flow_{DA}$, repeated measures ANOVA with Greenhouse-Geisser adjustment, was performed on a subgroup of 16

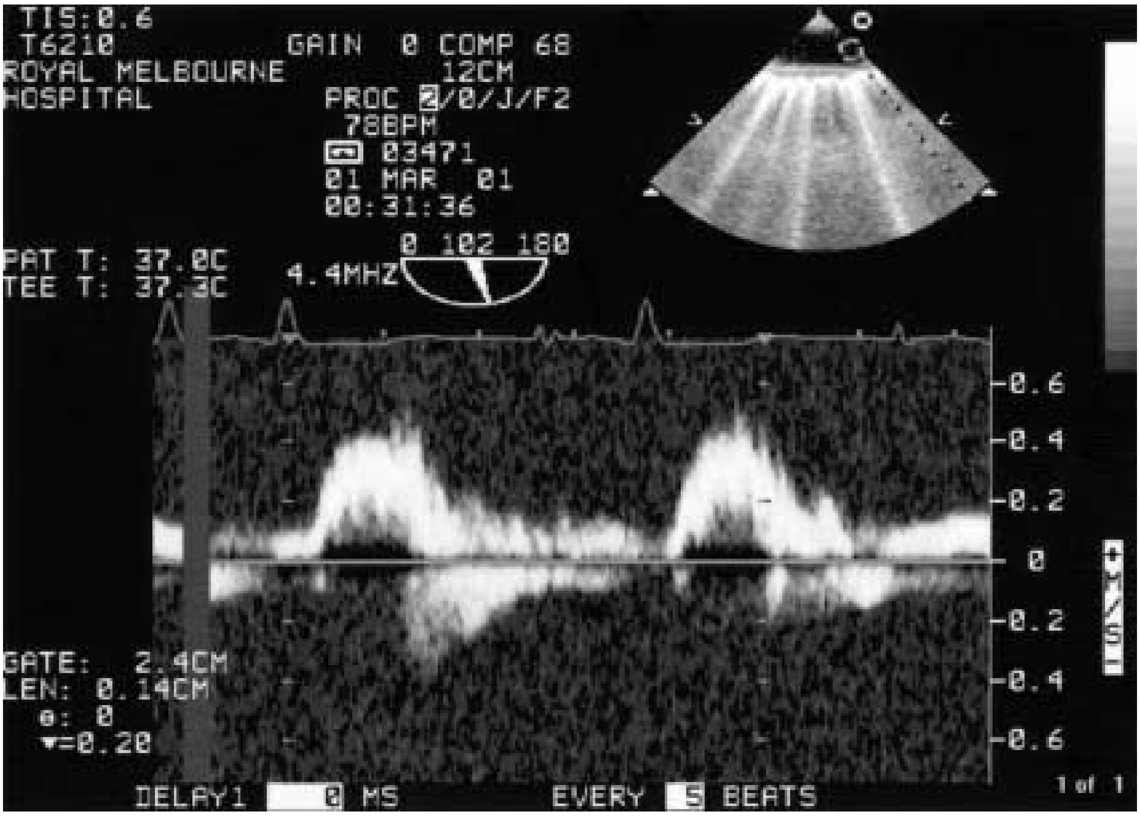

Fig. 1. Echocardiographic image of pulsed wave Doppler spectral display of flow in the descending aorta. The VTI is manually traced around each systolic beat. The position of the cursor is seen in the top right hand image of the descending aorta in the long axis, and is placed in the far lateral sector of the screen.

patients who had grafts performed to all territories. All analyses were done using SYSTAT v. 9 (SPSS Inc., Chicago, IL, USA). Values are summarized as mean ± standard deviation (SD).

Results

CO decreased from baseline values of 6.2±1.7 L/min to 5.4±1.8 L/min during grafting to the LAD, 4.4±1.5 L/min to the Cx territory, and 4.4±1.4 L/min to the RCA territory (P<0.001).

As expected, $Flow_{DA}$ was consistently less than CO at all time periods (P=0.003). The relationship for all measurement is shown in Fig. 2, and shows wide scatter of data. The values for the ordinary least products regression analyses are shown for each grafting position in Table 1. Fixed and proportional bias was only present for RCA measurements. Correlation was poor for all measurement periods.

Changes in CO and $Flow_{DA}$ occurred in parallel. This is illustrated in Fig. 3, where the ratio (measurement/baseline value %) is overlayed for each method and time period. There was no significant difference with repeated measures ANOVA (P=0.062) for the interaction of method and grafting position, indicating that the direction and magnitude of changes for CO and $Flow_{DA}$ were not different. Although not significantly different, the direction and magnitude of change between methods was least concordant for the RCA territory measurements.

The differences between observers[1,2] for aortic area measurements were 0.12 cm^2; 95% CI, –0.13 to 0.36 cm^2; P=0.321; and for VTI measurements were –0.28 cm; 95% CI, –0.45 to –0.12 cm; P=0.001.

Discussion

We found that clinically important changes in CO occur during grafting to the Cx and RCA territories. The magnitude of change is similar to that reported by Nierich et al.[2] for multivessel OPCABG.

We found poor correlation between total CO and flow in the descending aorta. The relationship between CO and $Flow_{DA}$ varies considerably between patients, which limits this technique as a method of indirectly measuring total CO. For a consistent relationship between CO and $Flow_{DA}$

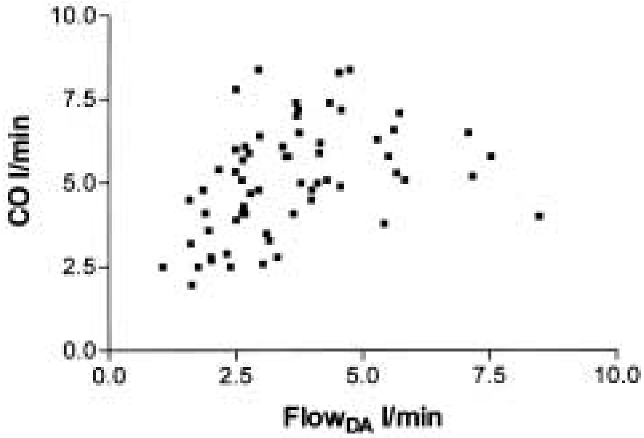

Fig. 2. Ralationship between CO and FlowDA for all measurement.

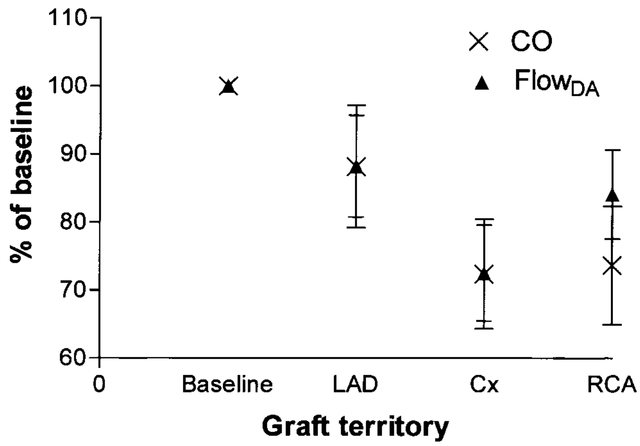

Fig. 3. All values are value/baseline value expressed as percent. Baseline values are 100%. Error bars are 95% CI of the mean (p=0.062).

Table 1. Ordinary least products regression equation data for the relationship between CO and FlowDA

Time	*n*	*r*	P	*a*	95% CI	*b*	95% CI
Baseline	26	0.390	0.049	1.79	–0.388, 3.38	1.02	0.54, 1.49
LAD	24	0.343	0.101	1.04	–1.30, 3.38	1.27	0.63, 1.91
Cx	20	0.046	0.076	1.40	–0.50, 3.29	1.08	0.50, 1.67
RCA	19	0.260	0.282	2.58	1.21, 3.94*	0.58	0.22, 0.94#

n, number of pairs; *r*, Pearson product-moment correlation coefficient; P, for null hypothesis r=0; *a*, *b*, coefficients in regression model CO=a+b(FlowDA).
* indicates fixed bias and # indicates proportional bias.
LAD, left anterior descending artery; Cx, circumflex; RCA, right coronary artery.

to occur, there needs to be a constant proportion of CO distributed to vessels proximal to the descending aorta, a constant incident angle for the Doppler beam, and for these factors to remain constant during a range of hemodynamic states. It is perhaps unrealistic to expect an absence of inter-patient variability. Within our patient sample, for example, the relationship of the descending aorta to the esophagus can alter the lie of the aorta (in the long axis) within the echocardiography sector, resulting in a Doppler incident angle from 10-20 degrees in some cases to 45-50 degrees in others. Because the Doppler cursor is manually placed in the far lateral sector, the incident angle is always less than 90 degrees and often less than 45 degrees. Our data has implications for the application of "stand-alone" esophageal Doppler devices for CO estimation. Although second generation devices now incorporate M-mode echocardiography to determine aortic cross-sectional dimension,[6] they still rely on the same assumptions of a constant proportion of blood flow (usually around 70%) and a constant Doppler incident angle. Bernardin et al.[5] found good correlation with thermodilution (r=0.92), but found a significant variation in the relationship after a fluid replacement intervention. DiCorte et al.[7] found poorer correlation (r=0.55) with aortic electromagnetic flowmeter measurement of CO. Leather and Wouters[9] tested whether changes in lower limb vascular resistance could alter the reliability of esophageal Doppler by performing measurements before and after administration of epidural anesthesia in patients undergoing radical prostatectomy. They found an initial bias of –0.89 L/min and limits of agreement of –2.67 to 0.88 L/min which increased to 0.55 L/min and –3.21 to 4.3 L/min after epidural anesthesia, indicating that blood flow redistribution may limit the value of indirect assessment of CO with esophageal Doppler.

For intraoperative management of acute hemodynamic changes, however, the trend is perhaps more valuable than the absolute value of CO. The trend is made more valuable if it is displayed on a "beat-to-beat" basis rather than occurring over several minutes. This is of particular importance during OPCABG, where profound changes in CO can occur within a period of seconds. Our study showed that the changes seen with $Flow_{DA}$ occurred in parallel with changes in total CO. Because aortic dimension does not alter with time, the changes in Doppler spectral display indicate similar changes in CO. In practice, we measure the Doppler VTI and CO prior to commencement of grafting to establish the "size" of the Doppler spectral display that is consistent with "acceptable CO". During hemodynamic manipulations, a decrease in the amplitude of Doppler display signifies a reduction in CO and vice versa. In OPCABG, with the patient positioned in the steep Trendelenburg position, the presence of flow in the distal aorta, is reassuring that blood flow to the gut and renal organs is adequate.

It is possible to calculate the $Flow_{DA}$, and in our experience this takes about 60 seconds. It is comparable to thermodilution and perhaps faster than a continuous CO catheter device. The real value, however, is not in the absolute value obtained by calculation, but in the observation of the beat-to-beat trend, which is instantaneous. It does, however, require that the anesthesiologist is continually observing the trend, in addition to observing the other hemodynamic parameters. The $Flow_{DA}$ allows the anesthesiologist to add "flow" information to "pressure" information in determining the cause of hypotension.

Our study has several important limitations. Firstly, we did not manually correct for the Doppler incident angle. It is possible that the correlation between CO and $Flow_{DA}$ may have been better if we had corrected for the angle of insonation. Secondly, we did not return to a true baseline position between measurements as this would increase the number and magnitude of positional changes between each grafting territory. All measurements and comparisons, however, were performed on simultaneously acquired samples. Practical application of this method in real-time, requires visual estimation of changes in the size of the Doppler spectral display, rather than actual measurement. This reduces the accuracy of this technique to a "qualitative" rather than "quantitative" assessment. It would be an advantage if automatic measurement of VTI by the machine in real-time were possible. We assumed that the CO measurements with thermodilution were correct and not influenced by retraction of the heart. It is possible that retraction of the heart could lead to compression of the right ventricular outflow tract, leading to under filling of the pulmonary artery. It is unknown whether this can produce error in thermodilution measurements. There was a statistically significant difference between observers for VTI measurements, but the magnitude of the difference is small (5-10% of values) and clinically insignificant.

Measurement of descending aortic flow with TEE allows "beat-to-beat" assessment of changes in CO in OPCABG.

Acknowledgments

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