Early effect of surgical revascularisation on left ventricular twist function

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Abstract

Aim
The direct effect of coronary artery bypass graft (CABG) surgery on early recovery of myocardial function, particularly twist and rotation is not well studied. The aim is to assess the early response of the 3 myocardial components, circumferential, longitudinal and oblique to CABG in a group of patients with isolated coronary disease.

Methods: We studied 14 patients, age 64±10 years, before CABG and before hospital discharge using various Doppler echocardiographic techniques including speckle tracking imaging, and compared them with 28 age and gender matched controls.

Results
Before surgery: Compared to controls, patients had significantly reduced left ventricular ejection fraction (LVEF) (p=0.01) but maintained stroke volume (SV) (p=0.5). Diastolic left ventricular (LV) function indices were statistically abnormal (p=0.01). LV lateral wall long axis amplitude of motion and myocardial systolic velocities were both reduced (p=0.01) as was septal amplitude of motion (p=0.05). LV peak global longitudinal strain (GLS) was reduced as were systolic (GLSRs) and early diastolic (GLSRe) global longitudinal strain rates (p=0.01 for all). LV peak basal and apical rotations, twist and torsion were not different. Q-peak basal rotation was shorter than controls (p=0.01).

After surgery: None of these measurements changed except peak GLS which further reduced (p=0.01). Pre-operatively, SV correlated with global LV function; twist (r=−0.65, p=0.01), and LV torsion (r=−0.66, p=0.01) but LVEF did not correlate with either. Post-operatively, SV correlated with E/A ratio (r=0.66, p=0.01), and the time interval Q- peak basal rotation rate (r=0.8, p=0.002). LVEF correlated with the time interval Q- peak LV twist (r=0.6, p=0.04).

Conclusion
CABG does not result in significant early detectable segmental LV functional improvement along any of its three myocardial components, but stroke volume becomes dependent on early basal rotation and filling pressures.

Key words: coronary artery disease; coronary artery bypass surgery; LV function; twist and longitudinal strain.

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Introduction

It is well established that coronary artery disease (CAD) impairs myocardial function, even in patients with no prior acute insult. Even in the presence of preserved systolic circumferential ventricular function, diastolic function has been shown, by various invasive and non-invasive techniques, to be significantly disturbed. Measurements of subendocardial function i.e. long axis function, in particular, are frequently abnormal, in systole and diastole, in coronary artery disease, even at rest and in the absence of symptoms. LV myocardial fibre architecture delineates clearly a third component of fibres i.e. the oblique layer and studies by magnetic resonance tagging and echocardiography speckle tracking have demonstrated the important role these fibres have in contributing to the overall pump function as well as clinical outcome, in various cardiac syndromes. Myocardial revascularisation procedures, PCI has been shown to improve ventricular function, within 48 hours of establishing optimum perfusion. However, similar effect on ventricular rotation and twist function, which reflect the oblique myocardial fibres, has not been thoroughly investigated.

We aimed in this study to assess the early effect of surgical revascularisation on myocardial deformation measurements and LV rotation and twist function, using recently developed speckle tracking echocardiography (STE) and, as well as other functional parameters, in a group of patients who underwent CABG.

Methods

We studied 14 patients, all males, age (64±10 years) who underwent CABG at Heart Centre of Umeå University Hospital, using Doppler echocardiography performed one day before surgery and 4-6 days post-operatively, on either a clinical ward or in the thoracic intensive care unit. No patient had cardiac decompensation before surgery or any clinical or echocardiographic evidence for significant valve disease. Clinical details are summarised in (Table 1). Twenty eight age-matched healthy individuals, age (60±10 years, 13 males) randomly selected from the Umeå population list of the Swedish Tax Bureau were also studied using the same echocardiographic protocol who served as controls. No control had evidence for structural or functional heart disease, risk factors for CAD, or was taking medications. Patients and
controls had given informed consent to participate in the study, which was approved by the Regional Ethics Committee of Umeå in accordance with the ethical guidelines of the 1975 Declaration of Helsinki as reflected in a priori approval by the institution’s human research committee.

Patients and controls were studied while in the left lateral decubitus position or in the optimum position for obtaining the best echocardiographic window. The echocardiographic examination was performed using the commercially available Vivid 7 echocardiograph (GE Medical Systems, Horten, Norway) equipped with an adult 1.5-4.3 MHz phased array transducer. Standard 2-dimensional images, Doppler and tissue-Doppler data were acquired from the parasternal and apical views (4-, 2- and 3-chamber) and digitally stored in cine-loop format. Image analysis was subsequently done offline using commercially available software system (General Electric, EchoPAC version 8.0.1, Waukesha, Wisconsin, US). LV end-diastolic volume (EDV) and LV end-systolic volume (ESV) were measured using the Simpson’s biplane method and LVEF was calculated. LV outflow tract velocity (LVOT) and velocity time integral (VTI) were obtained from the apical five-chamber view using pulsed wave Doppler. Stroke Volume (SV) was measured as the product of LVOT cross sectional area multiplied by the VTI.

\[ SV = \pi \times \left( \frac{LVOT \, diameter}{2} \right)^2 \times LVOT \, VTI. \]

LV filling velocity was acquired using the pulsed wave Doppler recording of the transmitral early (E) and late (A) diastolic velocities, from which E/A ratio was calculated. Myocardial systolic and diastolic velocities were recorded using pulsed wave Tissue Doppler Imaging (TDI) technique from the apical 4-chamber view. The sample volume was positioned at the basal segments of the septal and LV free wall, from which peak systolic velocity (s'), and peak early (e') and atrial (a') diastolic velocities were obtained. E/e' ratio then was calculated.

**Table 1: Patients characteristics and clinical details**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Patients undergoing CABG (n=14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>64±10</td>
</tr>
<tr>
<td>Male gender</td>
<td>14</td>
</tr>
<tr>
<td>Smoking and ex-smoker</td>
<td>8 (57%)</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>5 (36%)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>13 (93%)</td>
</tr>
<tr>
<td>Hypercholesterlaemia</td>
<td>14 (100%)</td>
</tr>
<tr>
<td>History of MI</td>
<td>7 (50%)</td>
</tr>
<tr>
<td>Three vessel CAD</td>
<td>8 (57%)</td>
</tr>
<tr>
<td>Systolic blood pressure (mmHg)</td>
<td>136±16</td>
</tr>
<tr>
<td>Diastolic blood pressure (mmHg)</td>
<td>79±8</td>
</tr>
</tbody>
</table>

CAD, coronary artery disease; MI, myocardial infarction

LV torsion function

Speckle-tracking analysis was used to study LV basal and apical rotation, cavity twist, and torsion. Parasternal short-axis images of the LV were acquired at 2 different levels: (1) basal level, identified by the mitral valve, and (2) apical level, as the smallest cavity achievable distal to the papillary muscles. Circumferential rotation was calculated using an automatic frame-to-frame tracking system of grey scale features at a similar frame rate to previous for each short-axis level and were stored in cine-loop format for offline analysis. The software identified acoustic markers (speckles) in the grey-scale image within the region of interest (ROI) and tracked these speckles frame by frame, enabling angle-independent calculations of different parameters i.e. velocity, strain and rotation. The ROI of the LV was set on the endocardial to epicardial margins of the cavity, thus delineating the whole circumference. The software calculated LV rotation from the apical and basal short-axis images as the average angular displacement of the 6 standard segments with respect to the ventricular centroid. Counter-clockwise rotations were marked as positive values and clockwise rotations, as negative values when viewed from the LV apex. We used Q-Q analysis of the superimposed ECG of the cardiac cycle. The time interval between Q wave and aortic valve closure (AVC) was measured from the pulsed-wave Doppler and was configured to other heart cycles with similar heart rate. LV twist was defined as the net difference (in degrees) between apical and basal rotations. LV torsion was then calculated as the ratio between LV twist (in degrees) and the LV diastolic longitudinal length (cm) between the LV apex and the mitral plane. Time-to-peak LV basal and apical rotations were taken as the time interval between the Q wave and peak relevant rotation.

**Statistical Analysis**

All data were analysed using statistical SPSS software package version 19.0 for windows (SPSS, Inc. Chicago, IL). Continuous variables were expressed as mean ±SD. The comparison in continuous variables between normal controls and patients were assessed using 2-tailed unpaired student t- test or Mann-Whitney U test, as appropriate. Difference between patient data before and after surgery was assessed by paired Student t- test. Correlations were tested with Pearson’s coefficients. A p value < 0.05 was considered statistically significant.

**Reproducibility**

Torsion measurements in the present study were performed by a single observer. To assess reproducibility, these measurements were repeated by the same observer on the same echocardiographic images in 6 patients, 6-8 weeks apart. The reproducibility of cardiac rotation measurements of our laboratory has been previously reported, being 5-19%.
Results

Controls vs patients before surgery (Table 2)

Reliable speckle-tracking curves for rotation analysis data was obtained in all 14 patients. There was no age or gender difference between patients and controls. Compared to controls, patients had significantly reduced LVEF (p=0.01) but maintained stroke volume (SV) (84±23 ml vs 79±14 ml, p=0.5). Diastolic LV function indices were statistically abnormal showing prolonged E wave deceleration time (p=0.01) and lower E/A ratio (p=0.01). LV lateral wall long axis amplitude of motion and systolic velocities were both significantly reduced (p=0.01) as was septal amplitude of motion (p=0.05). Septal systolic velocities were not different from controls (p=0.1). LV peak global longitudinal strain (GLS), systolic (GLSRs) and early diastolic (GLSRe) global longitudinal strain rates were all reduced (p=0.01 for all). LV peak basal and apical rotations and twist were not different from controls, as was peak LV torsion. Despite a slower heart rate in patients compared to controls (56±6 vs 65±8 bpm, p=0.01) at the time of the echocardiographic examination, the time interval Q-peak basal rotation was significantly shorter in patients (p=0.01).

After surgery vs before surgery

Similar measurements were obtained post-operatively in all patients. None of the indices of global, segmental or regional rotation measurements differed after CABG with respect to pre-operative measurements, except peak longitudinal GLS which reduced further compared with pre-operative values (p=0.01).

Determinants of LV ejection function (Table 3)

Pre-operatively, SV correlated with global LV function in the form of twist (r= -0.65, p=0.01), and LV torsion (r= -0.66, p=0.01) but LVEF did not correlate with either. Post-operatively SV correlated with E/A ratio (r=0.66, p=0.01), and the time interval Q- peak basal rotation rate (r=0.8, p=0.002). LVEF correlated with the time interval Q- peak LV twist (r=0.6, p=0.04).

Discussion

The findings of this study show that in a group of multivessel coronary artery disease patients, recruited for surgical revascularisation, segmental and global preoperative LV function were impaired but there was no detectable functional improvement early after CABG, on any of the three components of myocardial fibre function, circumferential, longitudinal or oblique. However, CABG resulted in significant change of functional determinants of stroke volume, instead of being twist and torsion before surgery they became diastolic filling indices and time relations of basal LV rotation and twist after surgery.

Data interpretation

Our findings are contrary to what we have previously shown after percutaneous coronary intervention (PCI) when myocardial revascularisation resulted in early recovery of LV subendocardial function within 48 hours of procedure, with significant regression of long axis incoordination and improvement of segmental time relations. The different results between the two treatments was not a complete surprise since CABG is a complex procedure which involves cardiac arrest, cardioplegia, bypass circulation and electric DC cardioversion, along with a cocktail of medications, known to have direct effect on inotropic and synchronous myocardial function. In view of that, it is a challenge to identify the exact reason behind the lag in myocardial response to the CABG procedure, despite the fact that all our patients underwent complete revascularisation compared with the one vessel PCI we previously reported. Our results however, are in line with what Koh T et al previously showed in the form of early normalisation of time relations, well before amplitude and velocity changes after CABG. PCI on the other hand is a direct vascular procedure which does not involve the myocardium apart from seconds of acute ischaemia during balloon inflation; hence any alteration in myocardial function (Table 3)
Table 3: Correlation between global LV systolic function variables pre and post operatively

<table>
<thead>
<tr>
<th></th>
<th>Correlation (r)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-operative</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroke Volume (ml)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Twist</td>
<td>-0.65*</td>
<td>0.011</td>
</tr>
<tr>
<td>Torsion</td>
<td>-0.66*</td>
<td>0.015</td>
</tr>
<tr>
<td>S' (left)</td>
<td>0.41</td>
<td>0.14</td>
</tr>
<tr>
<td>S' (Septal)</td>
<td>0.31</td>
<td>0.28</td>
</tr>
<tr>
<td><strong>LV Ejection Fraction (%)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Twist</td>
<td>-0.18</td>
<td>0.54</td>
</tr>
<tr>
<td>Torsion</td>
<td>0.20</td>
<td>0.52</td>
</tr>
<tr>
<td>S' (left)</td>
<td>0.38</td>
<td>0.18</td>
</tr>
<tr>
<td>S' (Septal)</td>
<td>0.29</td>
<td>0.32</td>
</tr>
<tr>
<td><strong>Post-operative</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroke Volume (ml)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E/A ratio</td>
<td>0.66*</td>
<td>0.013</td>
</tr>
<tr>
<td>Q- peak basal rotation rate</td>
<td>0.80**</td>
<td>0.002</td>
</tr>
<tr>
<td>Q-peak LV twist</td>
<td>0.03</td>
<td>0.92</td>
</tr>
<tr>
<td><strong>LV Ejection Fraction (%)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E/A ratio</td>
<td>-0.17</td>
<td>0.58</td>
</tr>
<tr>
<td>Q-peak basal rotation rate</td>
<td>-0.39</td>
<td>0.90</td>
</tr>
<tr>
<td>Q- peak LV twist</td>
<td>0.60*</td>
<td>0.04</td>
</tr>
</tbody>
</table>

*: p<0.05, **: p<0.01

S’, peak systolic myocardial velocity

function after procedure is likely to be directly related to the revascularisation. However, our findings do not necessarily reflect inevitable failure of LV function to improve following CABG, in view of the short follow up period after procedure. Studies have already shown that segmental and overall LV functions improve weeks after CABG, but, with increase in EF and regression of ventricular dyssynchrony. It must also be acknowledged that coronary artery disease influences regional function in a heterogeneous way, depending on the extent of stenoses in different vessels, the development of collateral supply, and dynamic factors that control myocardial oxygen supply and demand, hence the difference of early myocardial response to CABG and PCI.

In this study we also aimed to emphasise the response of oblique myocardial fibre function to surgical revascularisation, but have found that it does not differ from the rest of the components of the myocardial muscle bulk, again confirming the importance of post-operative follow up time required for functional recovery. We still believe that it is very likely that the subendocardium is the first to recover after CABG since it is the most vulnerable to ischaemia, perhaps followed by the oblique layer function then the circumferential muscle layer. This remains to be confirmed.

Clinical implications: Our findings support the current practice and recognition of pre-operative segmental and global LV function in assessment of surgical risk, since we have already demonstrated no early mechanical response after CABG where stroke volume becomes depending on filling pressures and time relations of the basal region of the LV myocardium. Patients with worse, basal myocardial function, are then likely to have the stroke volume entirely depending on filling pressures and hence the need for critical early post-operative management.

Limitations: The main limitation of this study is the small sample volume, however it seems that the findings are consistent, and the predictors of stroke volume, in particular, are statistically strong. We are unable to identify the exact mechanism behind the lagged response of myocardial function to CABG and to correlate findings with detailed post-operative course including medications. We do not have longer term follow up of the same group of patients, because the study was based on the currently used clinical protocols.

Conclusion: In patients with maintained overall LV systolic function coronary artery bypass surgery does not result in detectable early change in myocardial components function, including twist and torsion, opposite to conventional PCI. The post-operative dependence of stroke volume on filling pressures rather than the pre-operative basal myocardial function highlights the important role of individual patient assessment before surgery.

Statement of ethical publishing

The authors state that they abide by the statement of ethical publishing of the International Cardiovascular Forum Journal.

Conflict of interest:

The authors have no conflict of interest to disclose.

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