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Comparison of maximal elastance and systolic wall thickening using arterial tonometry and gated myocardial SPECT in patients undergoing coronary artery bypass grafting

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ABSTRACT

Myocardial SPECT using ^{99m}Tc-sestamibi, ^{99m}Tc-tetrofosmin, ^{201}Thallium is widely used in nuclear cardiology. Left ventricular systolic wall thickening (SWT) by SPECT and regional maximal elastance (rE_{max}) using arterial tonometry were compared.

rE_{max} was calculated from time–pressure and time–volume curves. In normal heart, improvement of SWT was 4.1±11%, while 6.0±16% in dilated heart. Improvement of rE_{max} was 0.67±1.0 mmHg/mL in normal heart and 0.32±0.7 mmHg/mL in dilated heart ($p<0.05$). rE_{max} can be an alternative variable as an index of regional contractility.

1. Introduction

Left ventricular systolic wall thickening (SWT) measured by gated myocardial SPECT is used to evaluate regional left ventricular wall contractility (Germano et al., 1997; Sharir et al., 2001). Automatic quantification of SWT was commonly used, and its reproducibility is superior to echocardiography (Paeng et al., 2001).

However, SWT depends on left ventricular volume, because SWT is measured by percentage increase of myocardial thickness from end-diastole to end-systole. Dilated left ventricle usually has thin diastolic wall thickness, and minor improvement of wall thickness on systolic phase makes thickening score greater. Criteria of abnormal SWT according to end-diastolic wall thickness have not been clarified.

Maximal elastance (E_{max}) is known to be another marker of myocardial contractility. E_{max} is a volume-independent marker, and is not influenced by preload or afterload (Suga, 2003a, b; Suga and Paul, 1994). Recently, the method to calculate regional maximal elastance (rE_{max}) using volume data from gated SPECT and pressure profile obtained from arterial tonometry was developed (Senzaki et al., 1996; Lee et al., 1999; Kim et al., 2001).

In this study, we compared rE_{max} with systolic thickening in patients with ischemic heart disease, and investigated the changes of rE_{max} and systolic thickening after coronary artery bypass grafting (CABG).

2. Materials and methods

2.1. Subjects

Nineteen patients who have ischemic heart disease and underwent CABG were included. There were 15 males and 4 females, ranging in age from 55 to 77 y (60±5 y). Fourteen patients had triple-vessel disease, 4 patients had two-vessel disease, and one had left anterior descending (LAD) artery disease.

2.2. Myocardial SPECT

Rest ^{201}Tl-dipyridamole stress ^{99m}Tc-sestamibi gated SPECT was performed before CABG. Patients refrained from consuming caffeine-containing beverages for 24 h and fasted for 4 h before the study. At 10 min after an injection of 111 MBq of ^{201}Tl, the rest SPECT image was acquired. Then, dipyridamole of 0.56 mg/kg was continuously injected over 4 min for the stress study. After 3 min of the completion of dipyridamole infusion, 925 MBq of ^{99m}Tc-sestamibi were injected. Gated SPECT with ^{99m}Tc-sestamibi was performed 90 min after the stress study.

SPECT was performed with a dual-head gamma camera equipped with a low-energy high-resolution collimator (Vertex

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EPIC; ADAC Laboratories). Thirty-two step-and-shoot images were acquired at intervals of 3° for 25 s per step. For gating, 16 frames per cardiac cycle with prefixed R–R intervals and 40% windows were used. Images were reconstructed with a Butterworth filter at a cutoff frequency of 0.35 and order 10 for ^{201}Tl and at a cutoff frequency of 0.45 and order 10 for ^{99m}Tc-sestamibi. Rest ^{201}Tl-dipyridamole stress ^{99m}Tc-sestamibi gated SPECT was repeated 3 months after CABG with the same protocol as that used for the preoperative study.

The reconstructed images were analyzed by use of an automatic quantifying software package (AutoQUANT; ADAC Laboratories) without manual intervention. For the regional analysis, a 20-segment model was adopted. Stress and rest segmental perfusion were quantified and expressed as percentages of maximal uptake. Segmental wall thickening was expressed as a percentage of the end-diastolic wall thickness. The left ventricular ejection fraction (LVEF), end-systolic volume (ESV) and end-diastolic volume (EDV) were also measured by quantitative gated SPECT.

2.3. Regional maximal elastance

Radial arterial pressure was measured during gated SPECT with tonometry (SphygmoCor, PWV Medical, Australia). Regional time-elastance curves were obtained using pressure data from radial artery tonometry and volume data from gated SPECT.

A time–pressure curve of the radial artery was acquired and transformed into central time–pressure curve. Assuming the iso-pressure in left ventricular cavity, time–pressure curve obtained from tonometry was used for every region. The regional elastance curve $E(t)$ was calculated using pressure curve $P(t)$ and volume curve $V(t)$. We developed Cardiac SPECT Analyzer (CSA) software for automatic calculation of regional E_{max}.

2.4. Statistics

Differences between groups were evaluated using χ^2 test for categorical variables and unpaired t-test for continuous variables. Paired t-test was used to compare pre and post CABG changes of parameters. To assess correlation between variables, correlation coefficient was acquired.

3. Results

EDV and ESV decreased from 123.4±42.6 to 93.6±33.2 ml ($p<0.01$) and from 66.3±40.2 to 48.1±25.9 ml ($p<0.01$) after CABG, respectively. Ejection fraction (EF) improved from 50.3±14.2 to 55.4±15.2% ($p<0.01$). Global E_{max} improved from 2.2±1.2 to 2.5±1.2 ($p<0.01$) (Fig. 1).

Global E_{max} showed good correlation with EF in preoperative measurement ($r=0.8333$, $p<0.0001$). After CABG, correlation between global E_{max} and EF decreased but there was still statistical significance ($r=0.6442$, $p=0.0029$) (Fig. 2). Global E_{max} showed negative correlation with EDV both in preoperative and postoperative measurement ($r=-0.8606$, $p<0.0001$ in preoperative, $r=-0.7740$, $p=0.0001$ in postoperative) (Fig. 3).

rE_{max} and SWT showed good correlation between pre CABG and post CABG measurements (Fig. 4, $r=0.8487$ $p<0.0001$ in rE_{max}, $r=0.7300$, $p<0.0001$ in SWT). However, rE_{max} showed weak correlation with SWT both in pre CABG and post CABG

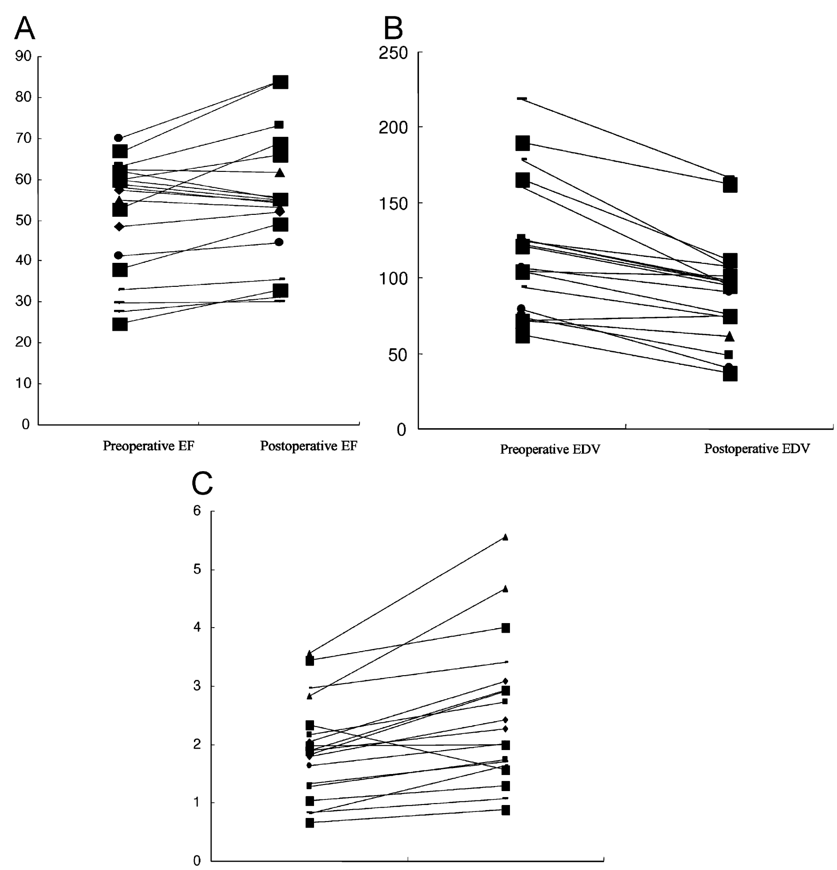

Fig. 1. Postoperative changes of EF(A), EDV(B) and global E_{max}(C).

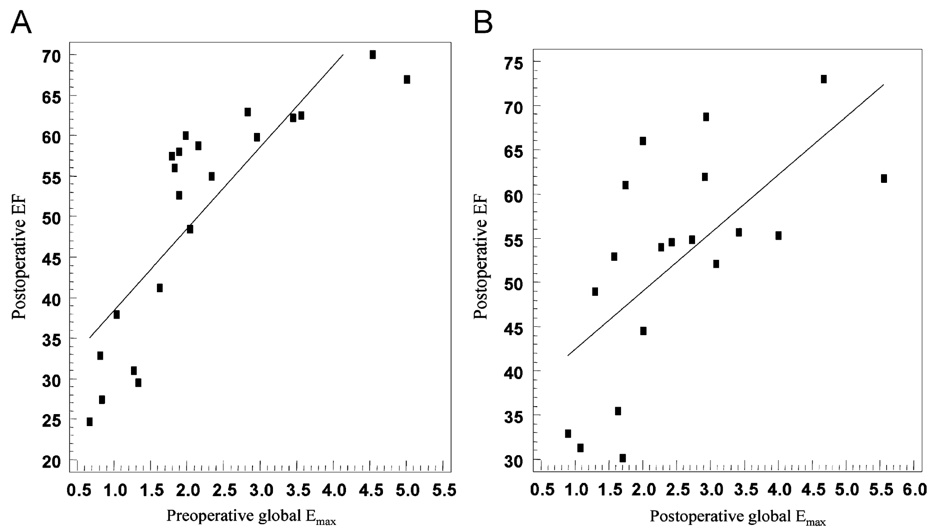

Fig. 2. Comparison of global E_{max} with EF in preoperative ($r = 0.8333$, $p<0.0001$) and in postoperative state ($r = 0.6442$, $p<0.0029$).

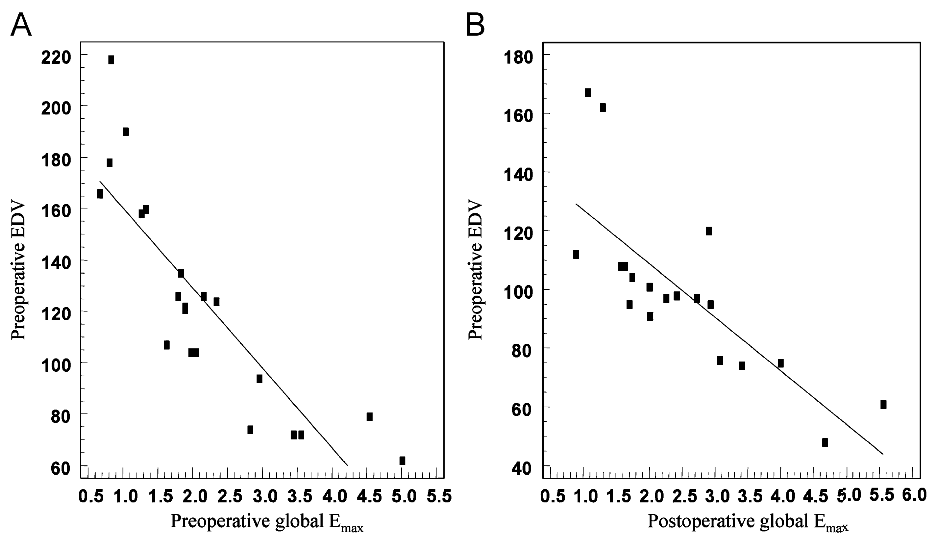

Fig. 3. Comparison of global E_{max} with EDV in preoperative ($r = -0.8606$, $p<0.0001$) and in postoperative state ($r = -0.7740$, $p<0.0001$).

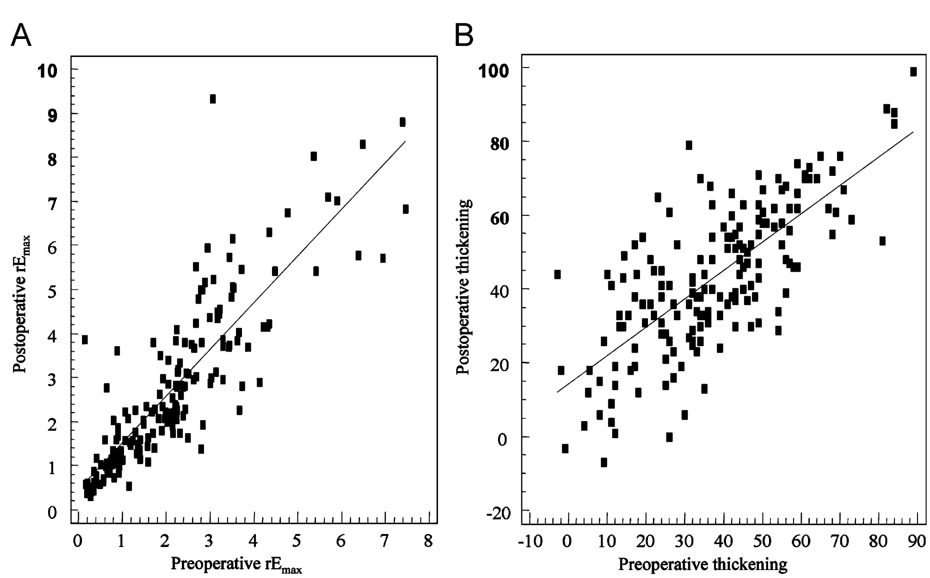

Fig. 4. Correlation of pre- and postoperative rE_{max} (A, $r = 0.8487$, $p<0.0001$) and correlation of pre- and postoperative systolic thickening (B, $r = 0.7300$, $p<0.0001$).

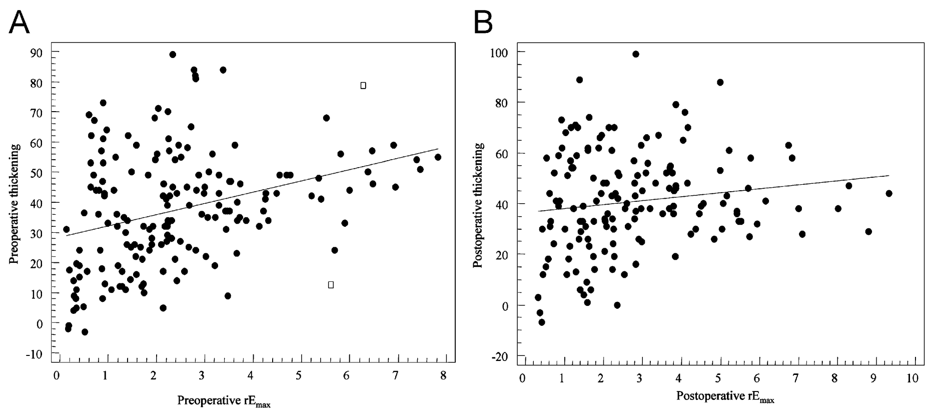

Fig. 5. Correlation of rE_{max} and thickening in preoperative (A, $r = 0.3335$, $p < 0.0001$) and in postoperative state (B, $r = 0.1503$, $P = 0.0646$).

Table 1
Characteristics of patient groups.

	Group I (normal sized heart, $n = 14$)	Group II (dilated heart, $n = 5$)	*p*-Value
Age	60±5	62±8	$p > 0.05$
Sex (M:F)	11:3	5:0	$p > 0.05$
Hypertension	64%	40%	$p > 0.05$
Diabetes	36%	20%	$p > 0.05$
3-vessel:2-vessel:1-vessel	9:4:1	5:0:0	$p > 0.05$
EF	58.3±7.4	30.5±5.1	$p < 0.0001$
Maximal elastance (E_{max})	2.7±1.1	0.94±0.25	$p = 0.0028$
End-diastolic volume (EDV)	99±23.3	182±23	$p < 0.0001$

measurements (Fig. 5, $r = 0.3335$, $P < 0.001$ in pre CABG, $r = 0.1503$, $P = 0.0646$ in post CABG).

According to preoperative EDV, subjects were categorized into normal sized left ventricle group (group I, EDV<150 ml, 14 patients) and dilated left ventricle group (group II, EDV⩾150 ml, 5 patients). The cut-off value of EDV was set arbitrarily considering reported normal limits of EDV (Nakajima et al., 2007). There were significant differences between group I and group II in EF, rE_{max} as well as EDV (Table 1).

Thickening improvements after CABG were 4.0±11.7% in group I and 6.0±16.8% in group II ($p > 0.05$). However, rE_{max} improvements after CABG were 0.67±1.03 mmHg/ml in group I and 0.32±0.71 mmHg/ml in group II ($p < 0.05$). Although thickening change tended to be higher in group II than group I, rE_{max} improvement in group II was significantly lower than group I ($p < 0.05$).

4. Discussion

This study demonstrated that E_{max} could be used as a marker of ventricular contractility. Global E_{max} showed good correlation with EF, while rE_{max} had weak correlation with SWT.

We suggest that SWT has limitation in dilated heart, because SWT depends on end-diastolic wall thickness. End-diastolic wall is thin in dilated heart, and small improvement of systolic wall thickness yields high thickening score. Therefore, we should consider end-diastolic wall thickness when we evaluate regional function using systolic thickening. Same thickening score would have different clinical meaning according to end-diastolic thickness.

Although E_{max} is known to be a volume-independent marker of myocardial contractility, clinical use was limited due to invasiveness of measurement. We reported that non-invasive measurement of E_{max} was possible using arterial tonometry and volume data from gated SPECT. In addition, software to calculate rE_{max} automatically was developed (Lee et al., 2002; 2003a, b). Arterial tonometry was performed in radial artery during gated SPECT images, which was simple and convenient. Clinical usage of rE_{max} is expected due to feasibility of measuring method.

Global E_{max} showed good correlation with EF in this study. EF obtained by gated SPECT is well-known global marker of left ventricular function, and is reported to be reproducible in repetitive study (Germano et al., 1995). We showed that global functional status assessed by EF and global E_{max} had good correlation, despite of different measuring parameters.

However, rE_{max} had week correlation with SWT. We demonstrated that the difference between rE_{max} and SWT was more marked after categorization according to EDV. SWT improvement after CABG in dilated heart was unexpectedly higher, compared with that of rE_{max}. We did not perform further study to assess regional wall function, so we could not conclude which test was more accurate. But considering that rE_{max} is volume-independent and thickening is volume-dependent, we suggest that SWT should be corrected according to end-diastolic wall thickness or EDV.

Assumption that regional pressure of LV cavity was equal was made in this study to calculate E_{max}, which could be limitation. However, we thought that feasibility of non-invasively acquiring data could overcome this limitation. Lack of gold standard to evaluate parameter of left ventricular contractility is another limitation of this study. Further studies using MRI or other imaging method to assess myocardial function will be needed.

5. Conclusion

This study suggests that that E_{max} is an independent marker of myocardial contractility. In patients with dilated LV cavity, improvement of systolic wall thickening was greater despite poor improvement of E_{max}. We concluded that E_{max} should be considered as another marker of myocardial contractility, especially in patients with dilated LV cavity.

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