Background. Using echocardiography, perioperative assessment of systolic function by fractional area change (FAC) is questionable in patients suffering from mitral regurgitation (MR). Tei index, an index expressing global cardiac function, has been reported to be unchanged after mitral valve surgery. We tested the hypothesis where the Tei index could be useful in assessing the perioperative cardiac function in patients undergoing mitral valve repair (MVR).

Methods. Twenty-five patients were enrolled. Transoesophageal echocardiography was performed perioperatively before and after the correction of MR. We compared the impact of the MVR on the left ventricular FAC and the Tei index. FAC was calculated from the transgastric short-axis view and Tei index was determined from the four chambers and deep transgastric views.

Results. Two patients were excluded because of poor acoustic windows. FAC significantly decreased after MVR from 53 (9)% to 42 (10)% (P<0.001), while Tei index was unaffected (0.46 (0.16) vs 0.47 (0.17), NS). A significant relationship was found between the preoperative Tei index and the postoperative FAC (R=−0.64, P<0.001). Moreover, a significant and clinically relevant relationship was determined between the predicted (using preoperative Tei index) and the measured postoperative FAC (R=0.64, P<0.001).

Conclusions. FAC but not the Tei index is influenced by MVR. The preoperative determination of the Tei index allows predicting postoperative FAC and offers the opportunity to identify patients in whom a severe unsuspected systolic dysfunction could render difficult the weaning from cardiopulmonary bypass.

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preload, Lutz and colleagues\textsuperscript{6} found that this index can be influenced by an increase in preload in mechanically ventilated patients. Moreover, Moller and colleagues\textsuperscript{7} reported that the Tei index is only affected by changes in load conditions in healthy volunteers. Conversely, several experimental studies have shown that Tei index is affected by acute and large changes in loading conditions.\textsuperscript{8–10} Finally, a recent clinical study reported that Tei index is unchanged before and after MR.\textsuperscript{11} We tested the hypothesis that Tei index could be less affected in the perioperative period than fractional area change (FAC) in patients undergoing mitral valve repair (MVR). Therefore, we simultaneously measured FAC and Tei index in anaesthetized patients before and after MVR. This surgical procedure was favoured because it preserves the mitral apparatus, which is involved in the maintenance of LV architecture by avoiding LV dilation and preserving LV function by actively participating in its contraction.\textsuperscript{12–14} Indeed, previous clinical studies have clearly demonstrated that mitral valvuloplasty provides superior postoperative LV systolic performance than conventional mitral valve replacement.\textsuperscript{15}

**Methods**

This prospective study was approved by our Ethical Committee (Comité de Protection des Personnes, CPP Pitié-Salpêtrière, Paris, France). Authorization was granted to waive the informed consent for the study as care for patients conformed to the standard procedures currently used in our surgical unit. Twenty-five consecutive patients scheduled for MVR were prospectively enrolled. Non-inclusion criteria were as follows: the presence of a supraventricular arrhythmia or coronary artery disease, coexisting valvular disease with the exception of tricuspid regurgitation and any contradiction for transoesophageal echocardiography (TOE).

After the induction of anaesthesia, a TOE probe (Ultrasound Transducer, Philips, Bothell, WA, USA) was carefully introduced. TOE examinations (SONOS 5500, Hewlett-Packard, Andover, MA, USA) were performed by experienced operators after sternotomy and was repeated after weaning from CPB but before any inotropic support. Any interventions that might affect the echocardiographic variables (vasopressors infusion, fluid loading, or changes during deep anaesthesia) were not performed during the measurements. All the echocardiographic images were recorded during a period of brief apnoea and under haemodynamic monitoring on an optical disk for offline measurements later. For each echocardiographic parameter, a mean of three retrospective offline measurements were obtained from consecutive beats. Furthermore, all the echocardiographic views were acquired in a similar order. First, the mid-oesophageal four-chamber view enabled recording of the pulse-wave Doppler of mitral inflow. The Doppler cursor was positioned at the tip of the mitral leaflets during diastole allowing the calculation of the interval between cessation and onset of mitral inflow. This interval corresponds to the sum of isovolumetric contraction time, ejection time, and isovolumetric relaxation time. Secondly, the deep transgastric long-axis view permitted recording of the pulsed-wave Doppler of the LV outflow signal and measurement of the ejection time. The Tei index is defined as the sum of isovolumetric contraction and relaxation times divided by the ejection time (Fig. 1). Thirdly, LV end-diastolic and end-systolic areas were obtained through the transgastric mid short-axis view to calculate FAC, defined as the difference between the end-diastolic and end-systolic areas of the LV, divided by the LV end-

\[
\text{Tei index} = \frac{\text{IVCT} + \text{IVRT}}{\text{ET}} = \frac{(a-b)}{b}
\]

**Fig 1** Measurement of Tei index. (a) The interval (a) represents the interval between the cessation and onset of mitral inflow (mid-oesophageal four-chamber view). This time corresponds to the sum of isovolumetric contraction, ejection time, and isovolumetric relaxation. (b) Ejection time (b) is measured from the pulsed-wave Doppler recordings of the left ventricular outflow signal (deep transgastric view). The Tei index is defined as the sum of the times of isovolumetric contraction and relaxation times (a–b) divided by the ejection time (b).
diastolic area expressed as a percentage. The recording of these three consecutive views never exceeded 6 min. Data were analysed independently by two observers each of whom reviewed the data twice. Inter- and intra-observer reproducibilities were assessed by the analysis of 10 randomly selected recordings for each measured echocardiographic parameter. Reproducibility was expressed as a percentage of the error (SD) and calculated as the absolute difference between two sets of measurements divided by the mean value of the measurements.

The variables are expressed as mean (sd). Comparison of two means was performed using a paired Student’s t-test. Correlation between two variables was performed using the least-square method. We used the Tei index to predict the postoperative FAC. Then, we compared the predicted and observed FAC using the Bland-Altman method and by calculating the bias, precision, and proportion of outliers, a priori defined as a difference between predicted and observed FAC greater than 10%. P<0.05 was required to rule out the null hypothesis. Statistical analysis was performed with NCSS (Statistical Solutions Ltd, Cork, Ireland).

Results

Twenty-five patients who underwent MVR were prospectively included in our study; two patients lacked suitable acoustic windows and were excluded. The perioperative characteristics of the patients are summarized in Table 1. A tricuspid regurgitation was diagnosed in eight patients before operation. Three patients (13%) required inotropic support for CPB weaning and this was introduced only after the postoperative TOE measurements were completed. Minor residual MR was found in six patients. No systolic anterior movement of the anterior mitral valve was observed. The inter- and intra-observer reproducibilities of the TOE measurements are shown in Table 2. During echocardiographic measurements, haemodynamic profile of the patients was stable (Table 3).

Changes in haemodynamic and echocardiographic variables before and after the surgical procedure are summarized in Table 4. After surgical correction of MR, FAC significantly decreased while the Tei index was not significantly altered (Table 4, Fig. 2).

As the Tei index was not found to be influenced by the correction of MR, we studied whether the preoperative

Table 1 Baseline, intraoperative, and postoperative patient characteristics (n=23). Data are expressed as mean (sd) or %: ACE-I, angiotensin-converting enzyme-inhibitors

<table>
<thead>
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<th>Variable</th>
<th>Beginning</th>
<th>Middle</th>
<th>End</th>
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<tbody>
<tr>
<td>Age (yr)</td>
<td>59 (13)</td>
<td>59 (13)</td>
<td>59 (13)</td>
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<tr>
<td>Male/female</td>
<td>15/8</td>
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<td>Aetiology of mitral insufficiency</td>
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<td>Infarct endocarditis (%)</td>
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<tr>
<td>Myxomatous (%)</td>
<td>39</td>
<td>39</td>
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<td>Fibroelastic (%)</td>
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<td>39</td>
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<tr>
<td>Unknown (%)</td>
<td>9</td>
<td>9</td>
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<td>Type of mitral surgical repair</td>
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<td>Prosthetic annuloplasty (%)</td>
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<td>Posterior leaflet quadrangular resection (%)</td>
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<td>22</td>
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<td>Posterior leaflet cleft closure (%)</td>
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<td>Transposition of leaflet chordae (%)</td>
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<tr>
<td>Autologous pericardial patch (%)</td>
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<td>Anterior leaflet chordae shortening (%)</td>
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<tr>
<td>Preoperative medications</td>
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<tr>
<td>ACE-I (%)</td>
<td>35</td>
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<tr>
<td>Beta-blockers (%)</td>
<td>17</td>
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<td>Amiodarone (%)</td>
<td>26</td>
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<td>26</td>
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<tr>
<td>Intraoperative variables</td>
<td>Duration of cardiopulmonary bypass (min)</td>
<td>75 (18)</td>
<td>75 (18)</td>
</tr>
<tr>
<td>Ejection time (ms)</td>
<td>292 (43)</td>
<td>292 (43)</td>
<td>292 (43)</td>
</tr>
<tr>
<td>LV end-diastrastic area (cm²)</td>
<td>28.4 (7.1)</td>
<td>28.4 (7.1)</td>
<td>28.4 (7.1)</td>
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<tr>
<td>LV end-systolic area (cm²)</td>
<td>13.3 (4.3)</td>
<td>13.3 (4.3)</td>
<td>13.3 (4.3)</td>
</tr>
<tr>
<td>Fractional area change (%)</td>
<td>53 (9)</td>
<td>53 (9)</td>
<td>53 (9)</td>
</tr>
<tr>
<td>Tei index</td>
<td>0.46 (0.16)</td>
<td>0.46 (0.16)</td>
<td>0.46 (0.16)</td>
</tr>
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</table>
determination of Tei index could be used to predict post-operative FAC. As shown in Figure 3, a significant relationship between these two parameters was found (\( R^2 = 0.64, P < 0.001 \)). According to this mathematical model, the relation between preoperative Tei index and postoperative predicted FAC is: \( \text{FAC}_p \% = 61 - 41 \times \text{Tei} \) (Fig. 3). When comparing the predicted and observed postoperative FAC (Fig. 4), we observed that the bias was 0.1 (7.7) % (NS), precision was 6.3 (4.2) %, and the proportion of outliers was 20%. As shown in Figure 4, a significant relationship was also found between these two parameters (\( R = 0.64, P < 0.001 \)). Finally, despite this trend, we could not observe any significant difference in the mean value of the Tei index of patients requiring inotropic support from those who did not require any drugs [0.58 (0.11) vs 0.44 (0.16), \( P = 0.17 \)].

Discussion

The major findings of the present study are that: (i) the LV FAC decreased after MVR, whereas the Tei index remained unaffected by the surgical procedure; (ii) the preoperative value of the Tei index allowed estimation of the postoperative value of FAC after the correction of MR.

In the presence of MR, LV loading conditions are modified with a trend to increased preload and decreased afterload. Under these haemodynamic conditions, the assessment of myocardial contractility by ejection phase measurements is inappropriate, as these are well-known to be influenced by acute changes in loading conditions. It has been demonstrated that ejection fraction decreases after surgical correction of MR. During mitral valve replacement, this reduction in ejection fraction may in part be explained by myocardial depression related to the removal of the mitral apparatus in addition to the changes in loading conditions. For this reason, only patients undergoing MVR have been included in our study. Conversely, the decline in ejection fraction observed during the correction of MR using valvuloplasty can certainly be attributed to changes in LV loading conditions. We hypothesized that this surgical procedure preserves the systolic performance of the LV, thus illustrating the preoperative overestimation and unreliability of ejection fraction or FACs as measures of ejection phase.

We assumed that the Tei index would be a useful tool in the assessment of systolic function in the presence of MR. The LV load independence of this myocardial global index remains to be a subject of controversy in the literature. Some authors clearly reported that Tei index is weakly influenced by changes in loading conditions and heart rate in clinical settings. Lutz and colleagues found that Tei index is only affected by the increase in preload in mechanically ventilated patients. Similarly, Moller and colleagues reported that Tei index is only affected by changes in load conditions in healthy volunteers. Under experimental conditions, in which a large magnitude of loading changes may be induced, other authors have clearly demonstrated the load-dependence of the Tei index. We have compared the ability of FAC and the Tei index to assess the systolic function in patients with
MR, by analysing the influence of MVR. As previously reported, a significant reduction in the ejection phase measurement after MVR was observed in the present study. This finding may be explained by numerous factors. First, a decrease in preload was induced by the absence of regurgitating volume after MVR. Secondly, an increase in LV afterload occurs after hermetic closure of the mitral leaflets induced by surgical repair. This significantly enhances LV systolic wall tension and provokes a decrease in FAC. Thirdly, the myocardial dysfunction after CPB could be involved in the decrease in FAC. However, this mechanism is unlikely because of the brief duration of aortic clamping, and the fact that in MR valvular–ventricular interaction preserves LV contractility. Conversely, we could observe a significant increase in heart rate and a lower systolic arterial blood pressure after surgical procedure, both factors which should tend to increase FAC. In the present study, the Tei index remains unchanged after MVR. This finding is consistent with the results of other authors demonstrating that the Tei index is not influenced by valve dysfunction. Among the ejection indexes, Simpson ejection fraction is the current gold standard. However, the relation between FAC and ejection fraction is usually quite good. Fifth, myocardial failure in our series, we cannot exclude that the patients included did not suffer from diastolic dysfunction. Thirdly, a negative inotropic effect of anaesthetic drugs cannot be ruled out. Many attempts have been made to predict systolic function after the correction of MR.

In the present study, we found a significant relationship between the preoperative Tei index and the postoperative FAC: postoperative FAC = 61 - 41 × preoperative Tei index. Interestingly, a similar correlation was previously established by Lax and colleagues between ejection fraction and Tei index in 55 patients with previous myocardial infarction, ejection fraction = 60 - 34 × Tei index. The prediction of the postoperative FAC presents several advantages. First, to date, FAC remains an easy parameter to assess and is widely used in the perioperative period. Secondly, the prediction of postoperative FAC allows us to anticipate a probably difficult weaning from CPB. Currently, it may not be feasible to replace FAC by the preoperative Tei index as this parameter is still not widely used in clinical practice despite the abundant literature available.

The following points must be considered in the assessment of the clinical relevance of our study. First, the current literature has for the most part focused on late postoperative LV function after valve surgery, whereas, we have studied the early postoperative period to provide data at this critical stage. Secondly, TOE measurements were performed under general anaesthesia with opened chest and do not enable generalization of our results to conscious, spontaneously breathing patients with MR. Thirdly, the Tei index was calculated from pulse wave Doppler. However, further investigation should consider the measurement of Tei index from tissue Doppler imaging, which is apparently less variable as recently reported. Fourth, in our study, FAC has been evaluated. Among the ejection indexes, Simpson ejection fraction is the current gold standard. However, the relation between FAC and ejection fraction is usually quite good.

To evaluate the agreement between FAC and FACp, the Bland-Altman method was used to calculate the mean difference and the 95% limits of agreement between the two methods. The latter parameter is of especial interest in clinical practice, as it indicates the maximum deviation of the observed FAC from the predicted FAC. As shown in Fig 4A, the mean difference between FAC and FACp was 0.41 (± 2 standard deviations: -60.34) preoperative Tei index. The Bland-Altman method revealed that the accuracy of the Tei index in 23 patients included in the study, FACp was calculated using the following formula: FACp = FACo - FAC /

\[ \text{preoperative Tei index} \times 0.41 (R = -0.64, P < 0.001). \] (B) Bias and variation of the measured FAC after mitral valve repair and the predicted FAC by using the Tei index. The dotted lines represent ± 2 standard deviations (precisions of the bias, according to the Bland-Altman method).
one can argue that the choice of the MVR model may have induced a selection bias, as this surgery is often proposed to patients with MR at an early stage of the disease, when their systolic function is still preserved. However, the range of FAC in our patients was large enough to reflect a realistic sampling of the population, and to establish an accurate correlation between Tei index and the postoperative FAC. Finally, although the preoperative determination of Tei index allowed us to predict postoperative FAC, we were unable to predict patients requiring inotropic for weaning from CPB. Consequently, it remains necessary to investigate the impact of preoperative Tei index in predicting the weaning management from CPB in future studies.

To conclude, in contrast to FAC, the Tei index remains unchanged after MVR, suggesting that this parameter is less sensible to changes in LV loading conditions. In addition, its unchanged after MVR, suggesting that this parameter is less preload dependent and can be measured by transoesophageal echocardiography during mechanical ventilation. Eur J Anaesthesiol 2003; 20: 872–7


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