Left ventricular diastolic function: Effects of high-intensity exercise after acute myocardial infarction

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Objective:
Reduced left ventricular (LV) diastolic function indicates poor prognosis after acute myocardial infarction (AMI). Our aim was to study whether a twelve-week high-intensity interval training program could improve diastolic function in patients with a relatively recent AMI.

Design:
Twenty-eight patients (mean age 56 (SD 8) years) with a recent AMI performed high-intensity interval training twice a week for 12 weeks. Each training session consisted of four 4-minute bouts at 85%-95% of peak heart rate, separated by 4-minute active breaks. A cardiopulmonary exercise test was performed to determine peak oxygen uptake (VO2peak). Echocardiography was performed at rest and during an upright bicycle exercise test.

Results:
There was a significant increase in mitral annulus early diastolic velocity (e') at peak exercise (75 W) from baseline to follow-up (7.9 (1.5) vs. 8.4 (1.7) cm/s, \(P = .012\)), but no change in e' at rest (7.1 (1.9) vs. 7.3 (1.7) cm/s, \(P = .42\)). There was a significant increase in VO2peak (mean (SD), 35.2 (7.3) vs. 38.9 (7.4) ml/kg/min, \(P < .001\)). e' at peak exercise correlated with VO2peak both at baseline and follow-up (\(r = 0.50, P = .007\), and \(r = 0.41, P = .032\)).

Conclusion:
The present study shows that LV diastolic function during exercise is related to VO2peak. We also found an improvement of diastolic function after exercise training, even in a population with a relatively well preserved systolic and diastolic function. The results demonstrate the importance of obtaining measurements during exercise when evaluating the effects of exercise interventions.
1 | INTRODUCTION

Acute myocardial infarction (AMI) can lead to reduced left ventricular (LV) diastolic function, which is an independent prognostic marker in post-infarction patients, even in the absence of reduced LV ejection fraction. There can be multiple mechanisms underlying the reduced function. The replacement of viable myocardium with scar leads to reduced LV compliance. Reduced systolic function reduces recoil, and in the event of unfavorable LV remodeling, the remote myocardium shows impaired calcium-handling leading to impaired early relaxation. In addition, risk factors for coronary artery disease (hypertension, diabetes, physical inactivity) are linked to diastolic dysfunction.

The negative prognostic impact of diastolic dysfunction in post-infarction patients is established, but the management of the condition is still a matter of ongoing research. High-intensity interval training has been shown to improve aerobic capacity in patients with a recent AMI, but a beneficial effect on diastolic function has not been established. Few studies have examined the effect of training on diastolic function in patients with a recent AMI, and the results are conflicting. One study found a small improvement in diastolic function after a 6 week individualized training program, whereas two studies found no change in diastolic function following moderate to high-intensity training programs. However, none of these studies measured diastolic function during exercise, even though they were examining the effect of an exercise intervention. Many patients with diastolic dysfunction have symptoms on exertion, and a diastolic exercise test can be useful in the evaluation of these patients.

A diastolic exercise test can be performed on a bicycle ergometer with increasing load, and may include tissue Doppler measurements to complement mitral inflow measurements. Peak longitudinal early diastolic mitral annular velocity (e') carries important prognostic information, and whereas the early to late filling velocity (E/A) ratio has a nonlinear relationship with diastolic function, e' increases with increasing diastolic function. Thus, tissue Doppler measurements make it easier to interpret changes in diastolic function after interventions. Also, e' and E/e' during an exercise test have been shown to unmask diastolic dysfunction not evident at rest in post-myocardial infarction patients.

Our aim was to study whether a twelve-week high-intensity interval training program could improve diastolic function in patients with a relatively recent myocardial infarction. Also, we wanted to assess the relationship between exercise capacity and diastolic function during exercise in such patients. Our hypotheses were that exercise capacity is related to LV diastolic function measured during exercise, and furthermore that exercise training can improve diastolic function during exercise.

2 | METHODS

2.1 | Study subjects and design

The study subjects were recruited from a larger cardiac rehabilitation study that assessed the feasibility and effect of different modes of high-intensity interval training in patients with coronary artery disease. The subjects in the larger study were randomized to perform treadmill exercise, home-based exercise, or circuit training, but the training intensity, duration and frequency were the same for all subjects. The larger study included 90 patients who had been referred to cardiac rehabilitation at St. Olav’s University Hospital, Trondheim, Norway or Levanger Hospital, Levanger, Norway. Inclusion criteria in the larger study were age above 18 years, diagnosed myocardial infarction, coronary artery bypass graft surgery, or acute coronary syndrome, and ability to perform a maximal treadmill test. Exclusion criteria were heart failure, severe arrhythmias, drug abuse, or a medical condition contraindicating high-intensity interval training. The study was approved by the Regional Committee for Medical and Health Research Ethics and conducted in accordance with the second Helsinki Declaration.

From the larger study, we included patients with a history of myocardial infarction and a complete echocardiogram including exercise measurements at baseline and post-intervention available. Out of 90 patients included in the larger study, 61 patients had a history of myocardial infarction. Two of these were lost to follow-up and four did not complete the training program. In addition, a complete echocardiogram including exercise measurements at baseline and post-intervention was not available in 27 subjects, as this examination had not been routinely performed and saved. The remaining 28 patients were included in the present study. These patients were not significantly different from the other myocardial infarction patients in the larger study with regard to exercise capacity (P = .21), age (P = .52), or gender (P = .71).

As opposed to the larger study, we considered the three training modality groups as one group, as we were interested in the effect of a specific training intensity, rather than comparing the effect of different activity modes. The present study was thus conducted as a single group pre-post interventional study.

2.2 | Exercise intervention

The study subjects performed high-intensity interval training twice a week for 12 weeks. Training was performed as either treadmill exercise, home-based exercise (uphill walking, running, cycling or cross-country skiing), or circuit training with a variety of exercise modalities, including running, cycling, squats and steps. Regardless of activity mode, each training session consisted of four 4-minute bouts at 85%-95% of peak heart rate, separated by 4-minute active breaks at 70% of peak heart rate. The study subjects used a heart rate monitor during all training sessions to obtain the correct heart rate. Subjects who performed at least 70% of the training sessions were considered to have completed the program.

2.3 | Cardiopulmonary exercise test

A cardiopulmonary exercise test was performed at baseline and follow-up to determine peak oxygen uptake (VO_{2peak}) and peak heart
The test was performed according to current guidelines with an individualized ramp treadmill protocol. The starting speed was set as the participants’ fastest preferred walking speed at 5% inclination. The workload was increased by increasing the speed for patients running, and by increasing the inclination for patients walking. Ventilatory gas exchange was analyzed with Metamax II (Cortex Biophysics, Germany). The patients took their usual medication on test days.

2.4 | Echocardiographic examination and analysis

Echocardiography was performed at rest and during an upright bicycle exercise test. The examination was performed by two experienced operators using a Vivid E7 ultrasound scanner (GE Vingmed, Horten, Norway). Resting echocardiography was performed with the patient in the left lateral supine position and included recording of B-mode, color Tissue Doppler and pulsed wave Doppler images in apical 4-chamber and 2-chamber views. Exercise echocardiography was performed with the patient sitting upright on a bicycle ergometer. The workload started at 25 W and increased by 25 W every 2 minutes, up to and including 75 W. Tissue Doppler images of the LV in apical 4-chamber and 2-chamber views and pulsed waved Doppler of mitral inflow were recorded at baseline and during the last minute of each level (Figure 1).

The recordings were stored digitally and analyzed offline with EchoPAC PC (GE Horten) by a single operator. The pre- and post-intervention examinations were renamed and analyzed in random order to avoid bias during the analysis. LV volumes and ejection fraction were measured with the modified biplane Simpson’s method, using the 4-chamber and 2-chamber views. Peak longitudinal mitral annular velocities in systole (s') and early diastole (e') were measured in the septal, lateral, anterior and inferior points of the mitral annulus using color tissue Doppler, and values obtained from the four walls were averaged. Tissue Doppler recordings with fusion of the peak velocity waves of early and late diastole (e' and a') were excluded. Three consecutive cardiac cycles were averaged in all Doppler recordings at rest. In the exercise recordings, only one cardiac cycle was analyzed at each level.

2.5 | Statistical analysis

Values are presented as mean (standard deviation). A paired sample t-test was used to compare VO2peak, hemodynamic and echocardiographic values before and after intervention. A general linear model for repeated measures was used to assess changes during the bicycle test, and a two-way repeated measures ANOVA was used to compare the bicycle test results before and after intervention, including post hoc tests of significant interactions. Correlations were measured by Pearson’s correlation coefficient (r). A P-value of less than .05 was considered statistically significant. Normal distribution of data was assessed by the Shapiro-Wilk test and QQ-plots. In a minority of data sets, the Shapiro-Wilk test indicated non-normal distribution. However, QQ-plots could not definitely confirm non-normality in these cases. Also, removing outliers from these data sets did not change the main findings of this study, and outliers were kept in the final analyses. All statistical analyses were performed with SPSS 21(IBM).

FIGURE 1  Color tissue Doppler imaging of a patient during bicycle exercise testing, from upright rest to 75 W (top left to right bottom). The images shown are recorded in the apical 4-chamber view, with regions of interest placed on the septal (yellow ring) and lateral (blue ring) side of the mitral annulus. Peak e' is highlighted in the figure. The amplitude of the e'-wave increases with increasing workload.
RESULTS

Twenty-eight patients were included in the present study (25 males, three females, mean age = 56 (8), mean time from infarction = 74 (32) days). The average number of training sessions was 23 (2) out of 24 and average time spent in target HR zone during each training session was 11 (4) minutes. Two patients started anti-hypertensive medications and one patient halved his dose of beta-blocker and statin during the intervention period. No ischemic events were registered during testing or training. Baseline characteristics are shown in Table 1.

3.1 | Resting heart rate and blood pressure

There were no changes in resting HR or systolic and diastolic blood pressure from baseline to follow-up. Values are shown in Table 2.

3.2 | VO_{2peak} and peak heart rate

Mean VO_{2peak} increased 3.7 ml/kg/min from baseline to follow-up (P < .001). There was no change in peak HR. Values are shown in Table 2.

3.3 | Resting and exercise echocardiography

There were no changes in echocardiographic variables describing LV diastolic and systolic function at rest. Resting echocardiographic values are presented in Table 3. E, e’ and s’ increased from upright position.

TABLE 1 Baseline characteristics of 28 patients included in the study

| Characteristic                              | Value         |
|--------------------------------------------|---------------|
| Age, mean (SD), years                      | 56 (8)        |
| Time from infarction                       |               |
| Mean (SD), days                            | 74 (32)       |
| Minimum/maximum days                       | 19/139        |
| Female                                     | 3 (11%)       |
| Type of myocardial infarction              |               |
| STEMI                                      | 20 (71%)      |
| NSTEMI                                     | 8 (29%)       |
| Infarction localization                    |               |
| Anterior                                   | 12 (43%)      |
| Inferior                                   | 14 (50%)      |
| Lateral                                    | 2 (7%)        |
| Peak Troponin T (SD), ng/L                 | 3592 (4165)   |
| Revascularized culprit artery              | 26 (93%)      |
| Significant restenosis (in any coronary artery) | 6 (21%) |
| Known diabetes                             | 3 (11%)       |
| Known hypertension                         | 3 (11%)       |
| Receiving beta-blockers                    | 24 (86%)      |
| sReceiving ACE/A-II inhibitors             | 7 (25%)       |

Note: Data are presented as mean (SD).

TABLE 2 Physiological variables at baseline and follow-up

| Variable                          | Baseline | Follow-up | P-value |
|----------------------------------|----------|-----------|---------|
| Heart rate rest, bpm             | 59 (7)   | 58 (8)    | .17     |
| Heart rate peak, bpm             | 168 (14) | 169 (13)  | .26     |
| Systolic BP rest, mmHg           | 136 (18) | 136 (15)  | .93     |
| Diastolic BP rest, mmHg          | 84 (11)  | 84 (9)    | .92     |
| BMI, kg/m^2                      | 28.4 (4.8)| 28.1 (4.7)| .17     |
| VO_{2peak} ml/kg/min             | 35.2 (7.3)|| <.001*  |
| RER, CO_{2}/O_{2} ratio          | 1.12 (0.07)|| 1.09 (0.06)| .046* |

Note: Data are presented as mean (SD).

TABLE 3 Echocardiographic variables at rest at baseline and follow-up

| Variable                          | Baseline | Follow-up | P-value |
|----------------------------------|----------|-----------|---------|
| EF, %                            | 54 (6)   | 54 (5)    | .976    |
| EDV, ml                          | 120 (22) | 123 (24)  | .228    |
| DT, ms                           | 188 (39) | 188 (32)  | .955    |
| IVRT, ms                         | 87 (13)  | 88 (13)   | .737    |
| E, m/s                           | 0.69 (0.17)|| 0.71 (0.15)| .537    |
| A, m/s                           | 0.60 (0.15)|| 0.63 (0.14)| .105    |
| E/A ratio                        | 1.2 (0.3) | 1.1 (0.3) | .454    |
| MAPSE, mm                        | 13 (2)   | 13 (2)    | .317    |
| s’, cm/s                         | 6.0 (1.0) | 5.9 (0.8) | .678    |
| e’, cm/s                         | 7.1 (1.9) | 7.3 (1.7) | .423    |
| E/e’, ratio                      | 10.1 (3.0)|| 10.0 (2.4)| .795    |
| s’ PW, cm/s                      | 7.8 (1.5) | 7.7 (1.2) | .659    |
| e’ PW, cm/s                      | 9.1 (2.5) | 9.1 (2.4) | 1       |

Note: Data are presented as mean (SD).

TABLE 4 Physiological variables at baseline and follow-up

| Variable                          | Baseline | Follow-up | P-value |
|----------------------------------|----------|-----------|---------|
| Heart rate rest, bpm             | 59 (7)   | 58 (8)    | .17     |
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| Systolic BP rest, mmHg           | 136 (18) | 136 (15)  | .93     |
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| BMI, kg/m^2                      | 28.4 (4.8)| 28.1 (4.7)| .17     |
| VO_{2peak} ml/kg/min             | 35.2 (7.3)|| <.001*  |
| RER, CO_{2}/O_{2} ratio          | 1.12 (0.07)|| 1.09 (0.06)| .046* |

Note: Data are presented as mean (SD).

Abbreviations: bpm, beats per minute; BP, blood pressure; BMI, body mass index; VO_{2peak}, maximal oxygen uptake; RER, respiratory exchange ratio at VO_{2peak}. *P < .05.
rest to 75 W, both at baseline and follow-up ($P < .05$). There was no change in mean $E/e'$ from upright rest to 75 W, but a trend toward lower $E/e'$ at 75 W at follow-up ($P = .086$). There was a significant interaction between the 12-week exercise intervention and increasing workloads on $e'$ during exercise ($P = .041$), and $e'$ at 75 W increased 0.5 cm/s from baseline to follow-up ($P = .012$). There were no significant interactions between the exercise intervention and increasing workloads on other echocardiographic variables. Exercise echocardiography values are presented in Table 4 and Figure 2A and B.

### 3.4 Correlation between VO$_{2\text{peak}}$ and echocardiographic variables

There was a significant correlation between VO$_{2\text{peak}}$ and $e'$ at peak exercise (75 W), and the relationship was present both at baseline and follow-up ($r = .50$, $P = .007$, and $r = .41$, $P = .032$). Also, $E/e'$ at supine rest correlated with VO$_{2\text{peak}}$ at follow-up ($r = -.42$, $P = .026$), but not at baseline. There were no significant correlations between VO$_{2\text{peak}}$ and other variables. The results of the correlation analysis including Pearson’s $r$ values are presented in Table 5.

### 4 DISCUSSION

In the present study, we found that LV diastolic function during exercise is related to VO$_{2\text{peak}}$ in post-myocardial infarction patients. We also found a small improvement in diastolic function after exercise training, even in a population with a relatively well-preserved systolic and diastolic function.

#### 4.1 Peak oxygen uptake

The significant increase in VO$_{2\text{peak}}$ found in this study is in accordance with a previous training study including post-infarction patients. These patients had similar baseline characteristics with regards to age, gender, medication, and aerobic capacity and also performed a 12-week high-intensity exercise program.

#### 4.2 Peak oxygen uptake and diastolic function

$e'$ at 75 W was the only variable that correlated with VO$_{2\text{peak}}$ both at baseline and follow-up. VO$_{2\text{peak}}$ has previously been found to correlate with several different tissue Doppler measures of LV function in patients with diastolic dysfunction and patients with coronary artery disease. There are, however, conflicting results on which measure of LV function that is most closely related to VO$_{2\text{peak}}$ in such patients. The answer to this probably depends on the condition studied and the severity of disease. Our findings suggest that among tissue Doppler measures of LV function, $e'$ during exercise correlates best with VO$_{2\text{peak}}$ in post-myocardial infarction patients.
with a relatively well-preserved diastolic function. Including patients with more pronounced diastolic dysfunction could have given a different result. The \( E/e' \) ratio is associated with LV filling pressure and values > 15 indicate elevated filling pressures. \( E/e' \) ratios between 8 and 15 were most frequent in the study population, but are more difficult to interpret.\(^{17}\) Thus, including more patients with pseudo-normal or restrictive filling patterns could have provided a bigger and more representative diversity in \( E/e' \) and perhaps a closer correlation with exercise capacity.

\( \text{VO}_{2\text{peak}} \) is a powerful predictor of mortality in patients with coronary artery disease.\(^{18}\) In light of this and the correlation found in this study, \( e' \) during exercise may add prognostic information in the evaluation of post-myocardial infarction patients, but this needs to be examined in future studies.

### 4.3 Improved diastolic function

\( e' \) at the highest workload increased from baseline to follow-up. The improvement was biologically small, but significant in a population with a relatively well preserved systolic and diastolic function. Of note is that the highest workload for diastolic measurements was 75 W and not the patients’ maximal exercise capacity. It is thus possible that the relative intensity was lower at follow-up, due to increased work capacity after completion of the training program. Performing echocardiography at maximal exercise capacity could potentially have demonstrated bigger improvements in diastolic function, but the use of workloads higher than 75 W was precluded by the merging of \( e' \) and \( a' \) waves at higher heart rates.

Exercise may improve diastolic function by several mechanisms. Both hypertension and increased body mass index (BMI) are associated with diastolic dysfunction\(^{19,20}\) and may be influenced by exercise.\(^{21}\) However, hypertension was rare in the study population, and blood pressure and BMI did not change at follow-up. Increased collagen turnover has also been associated with diastolic dysfunction,\(^{22}\) and an exercise study on patients with diastolic dysfunction found that exercise was associated with reduced plasma levels of pro-collagen type I.\(^{23}\) Thus, reduced collagen turnover may be a mechanism by which exercise improves diastolic function. This relationship could not be confirmed in our study as we did not measure plasma collagen levels.

Our study had no control group. However, the natural course of diastolic function after AMI has been described in several studies. In a study examining the effect of Sildenafil on diastolic function after AMI, there was no change in exercise PCWP from day 2 to week 9, neither in the treatment or in the control group.\(^{24}\) With regards to resting diastolic function, an exercise study found no improvement in the control group from 1 month to 5.5 months following AMI,\(^{7}\) and in a study on Spironolactone there was no change in diastolic function in the control group from 3 days to 6 months after AMI.\(^{25}\) Also,

### TABLE 5 Correlations between echocardiographic indices of left ventricular diastolic function and peak oxygen uptake (\( \text{VO}_{2\text{peak}} \)) in supine position at rest and upright position at exercise

|            | Baseline |            | Baseline |            |
|------------|----------|------------|----------|------------|
|            | \( r \)  | \( P \)-value | \( r \)  | \( P \)-value |
| \( e' \) rest | 0.24 | .23 | 0.33 | .085 |
| \( e' \) 75 W | 0.50 | .007* | 0.41 | .032* |
| \( E/e' \) ratio rest | −0.31 | .11 | −0.42 | .026* |
| \( E/e' \) ratio 75 W | −0.30 | .12 | −0.37 | .051 |
| \( s' \) rest | 0.36 | .06 | 0.19 | .33 |
| \( s' \) 75 W | 0.28 | .15 | 0.12 | .53 |

Note: Data are presented as Pearson correlation coefficients (\( r \)) with corresponding \( P \)-values.

Abbreviations: \( E \), early diastolic transmitral velocity; \( e' \), mitral annulus early diastolic velocity (color TDI); \( s' \), mitral annulus systolic velocity (color TDI).

\(* P < .05.\)
most of the LV systolic recovery appears to take place in the first month after AMI. In the present study, mean time from infarction to inclusion was 74 days, suggesting that most of the post-infarction recovery had already taken place at the time of inclusion.

Most of the patients were taking beta-blockers when participating in the present study. This may have influenced their exercise capacity and diastolic function. In a study including patients with mild to moderate systolic dysfunction after AMI, Metoprolol increased exercise capacity and reduced E/A ratio significantly from day 5-7 to 3 months after infarction compared with placebo. In the present study, patients were included at a mean time of 74 days after infarction. Thus, much of the beneficial effect of beta-blockers may already have taken place before inclusion. Furthermore, in our study, patients using beta-blockers did not have a greater increase in diastolic function during exercise or exercise capacity than patients not using beta-blockers.

Two patients started anti-hypertensive medication and one patient halved his dose of beta-blocker and statin during the intervention period. Removing any or all of these patients from the analyses did not change the main findings of this study.

The patients in the present study had a relatively well preserved diastolic function, and the effect of exercise on patients with more pronounced diastolic dysfunction may be different. In an exercise study including patients with heart failure with preserved systolic function (HFrEF) and a worse diastolic function than our population, a three-month training program significantly increased e' and reduced E/e' at rest. However, this study did not include patients with previous myocardial infarction.

4.4 Diastolic exercise test

In the present study, we found no improvement in diastolic function at rest, but we found an improvement in diastolic function during exercise. Many patients with diastolic dysfunction have symptoms mainly with exertion, and an exercise test is often useful in these patients. E/e' has been found to correlate with invasively measured LV diastolic pressure during exercise, and abnormal E/e' during exercise has been associated with future cardiac events in patients referred for exercise echocardiography. This study adds that exercise echocardiography may be sensitive in detecting changes in diastolic function after training interventions.

In the present study, bicycle exercise did not uncover substantial diastolic dysfunction in the study population as there was a significant increase in e' with increasing workload and only subtle changes in E/e'. These results suggest that our study population had sufficient diastolic function to maintain normal filling pressures during sub-maximal exercise. However, in a recent study including similar post-infarction patients, E/e' did not reflect invasively measured filling pressures during exercise. Pulmonary capillary wedge pressure (PCWP) increased during exercise, while E/e' did not, suggesting that a normal E/e' does not rule out elevated LV filling pressures. However, the exercise test used in this study differed from ours. Most importantly, exercise was performed supine instead of upright, and supine exercise has been shown to give higher E/e' than upright exercise. Whether the upright position is more suitable for measuring E/e' during exercise is not known. Nonetheless, upright bicycle exercise has previously been used to unmask reduced diastolic function in myocardial infarction patients.

We observed a non-significant dip in E/e' at 25 W. The reason for this is uncertain, but previous studies have reported similar results. One can speculate that at the beginning of exercise, an increase in e' driven by increasing heart rate and sympathetic activity, precedes the increase in venous return. The dip may also reflect how the load dependency of e' and E differs at different workloads. The changes are subtle, but suggest that E/e' as a marker of LV filling pressure during exercise must be interpreted with caution.

4.5 Limitations

The present study did not have a control group. This represents an important limitation to the study. However, previous studies have not found spontaneous improvements in diastolic function in patients comparable to our study subjects. Also, assigning patients to a less active control group would have prevented some patients from participating in exercise, which is increasingly being recognized as an important part of the rehabilitation after AMI.

The study population was relatively young, predominantly male and had a relatively well preserved diastolic function. Thus, the findings in this study might not apply to a more heterogeneous population. Future studies should aim to include more female and elderly patients.

Echocardiography during exercise can be challenging due to motion and higher respiratory rates. In our study, the tissue Doppler exercise echocardiography recordings were of acceptable quality in all patients, but only the one cardiac cycle with the best view of the LV at each level was used for tissue Doppler analysis. This may have made the exercise results less robust than the resting recordings, where the average of three consecutive cycles was used.

Previous studies have found that exercise capacity relates more closely to cardiac output than pulmonary capillary wedge pressure during exercise in patients with hypertrophic cardiomyopathy. However, as cardiac output during exercise was not measured in our study, we could not examine its relationship with exercise capacity in infarction patients.

In the present study, assessment of diastolic function was limited to Doppler and tissue Doppler measurements. Strain rate measurements could have been more sensitive in detecting changes in diastolic function. In a study on patients with stable coronary artery disease, high-intensity exercise improved early diastolic strain rate, but not early diastolic mitral annulus velocity. However, strain rate measurement can be technically challenging with respect to motion artifacts and foreshortening in upright bicycle exercise and was not performed in the present study.
The present study shows that LV diastolic function during exercise, but not at rest, is related to VO$_{2\text{peak}}$ in myocardial infarction patients. Interestingly, we found a small improvement of diastolic function assessed by $e'$ after exercise training, even in a population with a relatively well preserved systolic and diastolic function. The results demonstrate the importance of obtaining measurements during exercise when evaluating the effects of an exercise training intervention.

CONFLICT OF INTEREST
The authors have reported no conflicts of interest.

AUTHOR CONTRIBUTIONS
J. Lund: concept/design, data analysis/interpretation, drafting article, critical revision of article, approval of article, statistics. IL.
Amundsen: critical revision of article, approval of article, data collection.
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