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Preoperative Intensive Inspiratory Muscle Training to Prevent Postoperative Pulmonary Complications in High-Risk Patients Undergoing CABG Surgery

A Randomized Clinical Trial

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OVER THE LAST DECADES, coronary artery bypass graft (CABG) surgery and perioperative care have improved considerably,¹⁻³ resulting in a lower overall complication rate. However, the rate of postoperative pulmonary complications (PPCs) has remained stable,^{4,5} possibly because CABG surgery is now performed in more fragile (high-risk) patients at greater risk of PPCs as a consequence of their comorbid conditions.^{1,6} Postoperative pulmonary complications therefore continue to influence patient morbidity and mortality, length of hospital stay, and overall resource utilization, despite advances in preoperative, intraoperative, and postoperative care.^{6,7} Respiratory physiotherapy has a limited effect on the occurrence of PPCs, but studies performed to date were often flawed methodologically and tended to include relatively healthy patients who underwent CABG surgery rather than patients with comorbidity and high-risk profiles.⁸ Moreover, chest physical therapy was usually administered after the operation, whereas the preferred strategy is to identify, on the basis of known risk factors, and treat

Context Postoperative pulmonary complications (PPCs) after coronary artery bypass graft (CABG) surgery are a major source of morbidity and mortality, and increase length of hospital stay and resource utilization. The prehospitalization period before CABG surgery may be used to improve a patient's pulmonary condition. The efficacy of preoperative inspiratory muscle training (IMT) in reducing the incidence of PPCs in high-risk patients undergoing CABG surgery has not yet been determined.

Objective To evaluate the prophylactic efficacy of preoperative IMT on the incidence of PPCs in high-risk patients scheduled for elective CABG surgery.

Design, Setting, and Patients A single-blind, randomized clinical trial conducted at the University Medical Center Utrecht, Utrecht, the Netherlands, with enrollment between July 2002 and August 2005. Of 655 patients referred for elective CABG surgery, 299 (45.6%) met criteria for high risk of developing PPCs, of whom 279 were enrolled and followed up until discharge from hospital.

Intervention Patients were randomly assigned to receive either preoperative IMT (n=140) or usual care (n=139). Both groups received the same postoperative physical therapy.

Main Outcome Measures Incidence of PPCs, especially pneumonia, and duration of postoperative hospitalization.

Results Both groups were comparable at baseline. After CABG surgery, PPCs were present in 25 (18.0%) of 139 patients in the IMT group and 48 (35.0%) of 137 patients in the usual care group (odds ratio [OR], 0.52; 95% confidence interval [CI], 0.30-0.92). Pneumonia occurred in 9 (6.5%) of 139 patients in the IMT group and in 22 (16.1%) of 137 patients in the usual care group (OR, 0.40; 95% CI, 0.19-0.84). Median duration of postoperative hospitalization was 7 days (range, 5-41 days) in the IMT group vs 8 days (range, 6-70 days) in the usual care group by Mann-Whitney *U* statistic ($z = -2.42$; $P = .02$).

Conclusion Preoperative IMT reduced the incidence of PPCs and duration of postoperative hospitalization in patients at high risk of developing a pulmonary complication undergoing CABG surgery.

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Box 1. Pulmonary Risk Score***Score 1 Point for Each Parameter**

Age >70 years

Cough and expectoration

Diabetes mellitus

Smoker

Chronic obstructive pulmonary disease: FEV₁ <75%_{predicted} or pulmonary medication used

Body mass index >27.0†

Score 2 PointsSpirometry: FEV₁ <80%_{predicted} and FEV₁/FVC <70%_{predicted}

*FEV₁ indicates forced expiratory volume in the first second of expiration; FVC, forced vital capacity. A score of 1 or 2 is given for each parameter; therefore, if a patient is older than 70 years and has a cough and expectoration, he or she is assigned 2 points, 1 point for each. Low risk is defined as 0 or 1 point and high risk as 2 or more points.

†Calculated as weight in kilograms divided by height in meters squared.

patients who might benefit the most before surgery.⁹⁻¹³ We designed a single-blind, randomized clinical trial to study the prophylactic efficacy of preoperative physical therapy, including inspiratory muscle training (IMT), on the incidence of PPCs, especially pneumonia, in patients at high risk of developing PPCs who underwent CABG surgery.

METHODS**Participants**

The trial was performed at the Department of Cardiac Surgery, University Medical Center Utrecht, Utrecht, the Netherlands. The protocol (02/035-E) was approved on July 4, 2002, by the institutional review board and ethics committee. Patients scheduled for primary elective CABG surgery who had the ability to understand informed consent were eligible. Exclusion criteria were surgery performed within 2 weeks of initial contact, a history of cerebrovascular accident, use of immunosuppressive medication for 30 days before surgery, and presence of a neuromuscular disorder, cardiovascular instability, or an an-

eurysm. Written informed consent was obtained from all participants.

Preoperative Assessment and Risk Stratification

Demographics and preoperative risk factors were prospectively recorded by means of a standardized interview. Preoperative age, sex, weight, height, body mass index (calculated as weight in kilograms divided by height in meters squared), type of surgical procedure, current diagnoses, pulmonary status, history of smoking, history of myocardial infarction, diabetes mellitus, spirometry, and respiratory muscle testing were recorded. Data obtained from medical records included duration of surgery, duration of mechanical ventilation, and perioperative complications. Included patients were closely monitored during their entire hospital stay until discharged.

On the basis of the definitions of risk factors of the Society of Thoracic Surgeons,¹⁴ a review by Brooks-Brunn,¹⁵ and the investigators' experience,¹⁶ the following parameters were scored to determine a patient's risk of developing PPCs: age, productive cough, diabetes mellitus, history of tobacco smoking, chronic obstructive pulmonary disease, body mass index, and pulmonary function tests. An external investigator stratified the patients (1-10 weeks before surgery) into 2 risk groups on the basis of their scores (low risk defined as 0 or 1 point and high risk as 2 or more points) (BOX 1).

Randomization and Intervention

Patients at high risk of developing PPCs were randomly assigned, 1 to 10 weeks before surgery, to undergo preoperative IMT or usual care. A computer-generated randomization table was used, and individual allocations were placed in sealed envelopes. An external investigator blinded to the allocation sequence picked consecutive allocation envelopes for consecutive participants.

The intervention group received preoperatively individualized, tailored

exercises, namely, IMT; incentive spirometry; education in active cycle of breathing techniques; and forced expiration techniques.¹⁷⁻¹⁹ The intervention group trained daily, 7 times a week, for at least 2 weeks before the actual date of surgery. Each session consisted of 20 minutes of IMT, which was performed 6 times a week without supervision and once a week with supervision by a physical therapist (E.H.J.H.), who measured the strength and endurance of the inspiratory muscles after each week of training. The patients were instructed to record daily IMT progression, complaints, and adverse events in a diary and were trained to breathe with an inspiratory threshold-loading device (threshold IMT). The inspiratory load of the IMT is calibrated in cm H₂O and can be increased by removing the mouthpiece and tightening the spring. The patients started breathing at a resistance equal to 30% of their maximal inspiratory mouth pressure (P_{i-max}), measured at baseline, for 20 minutes.²⁰ The resistance was increased incrementally, based on the rate of perceived exertion scored on the Borg scale.²¹ If the rate of perceived exertion was less than 5, the resistance of the inspiratory threshold trainer was then increased incrementally by 5%. The supportive-educative component consisted of detailed preoperative instruction in active cycle of breathing techniques with an incentive spirometer (Coach 2, DHD Healthcare, Wampsville, NY) and forced expiration technique.^{19,22} Participant's satisfaction and motivation were determined after the intervention period by means of an anonymously completed questionnaire. At baseline, all patients received information about the surgery and a schedule of hospitalization events.

The usual care group received care as usual the day before surgery (ie, instruction on deep breathing maneuvers, coughing, and early mobilization).

Both groups received similar incentive spirometry, chest physical therapy, and mobilization scheme after operation.

Outcome Measures and Sample Size

The success of IMT was evaluated on basis of maximal inspiratory muscle strength (P_{i-max}) and endurance (P_{m-peak}/P_{i-max}), where P_{m-peak} indicates maximal peak pressure. The primary outcome, the incidence of PPCs, was scored by a blinded independent investigator on an ordinal scale of 1 to 4, using the operational definition of Kroenke et al (BOX 2).²³ We defined a clinically significant PPC as 2 or more items in the grade 2 complications or 1 item in the grade 3 or 4 complications. When only abnormal radiological findings were found, without clinical symptoms or changes in auscultation, the complications were considered subclinical (eg, grade 1 PPC).²⁴ A microbiologist, who was independent and blinded to patients' allocation, collected data from the medical chart and clinical records, assessed bacteriology samples, and evaluated other data indicative for bronchitis, pneumonia, or both, according to the criteria of the Centers for Disease Control and Prevention.²⁵

The secondary outcome was duration of postoperative hospitalization. Admission and discharge dates were retrieved by the microbiologist from the patients' records and used to calculate duration of postoperative hospitalization.

To calculate sample size, we used available data from the University Medical Center Utrecht on PPC incidence. At the start of the study, the incidence of PPC grade of at least 2 was 30%.²⁶ A 10% reduction in PPC incidence due to IMT was considered clinically relevant, requiring approximately 584 patients (292 in each group), with a power of 80% at the $P=.05$ level of statistical significance. Interim analyses were performed after half the required participants had been enrolled ($n=292$), as stipulated by the medical ethics committee. The O'Brien-Fleming boundary was used for the level of significance ($P\leq .025$).²⁷ The study was stopped at the request of the University Hospital Institutional Review Board based on the results of the interim

Box 2. Operational Definitions of Postoperative Pulmonary Complications*

Grade 1

Cough, dry

Microatelectasis: abnormal lung findings and temperature $>37.5^{\circ}\text{C}$ without other documented cause; results of chest radiograph either normal or unavailable

Dyspnea, not due to other documented cause

Grade 2

Cough, productive, not due to other documented cause

Bronchospasm: new wheezing or preexistent wheezing resulting in change therapy

Hypoxemia: alveolar-arterial gradient >29 and symptoms of dyspnea or wheezing

Atelectasis: radiological confirmation plus either temperature $>37.5^{\circ}\text{C}$ or abnormal lung findings

Hypercarbia, transient, requiring treatment, such as naloxone or increased manual or mechanical ventilation

Adverse reaction to pulmonary medication

Grade 3

Pleural effusion, resulting in thoracentesis

Pneumonia, suspected: radiological evidence without bacteriological confirmation

Pneumonia, proved: radiological evidence and documentation of pathological organism by Gram stain or culture

Pneumothorax

Reintubation postoperative or intubation, period of ventilator dependence does not exceed 48 hours

Grade 4

Ventilatory failure: postoperative ventilator dependence exceeding 48 hours, or reintubation with subsequent period of ventilator dependence exceeding 48 hours

*Source: Kroenke et al.²³

analysis with pneumonia as the end point. The institutional review board thought it was no longer ethical to withhold IMT from the patients in the usual care group.^{28,29}

Statistical Analysis

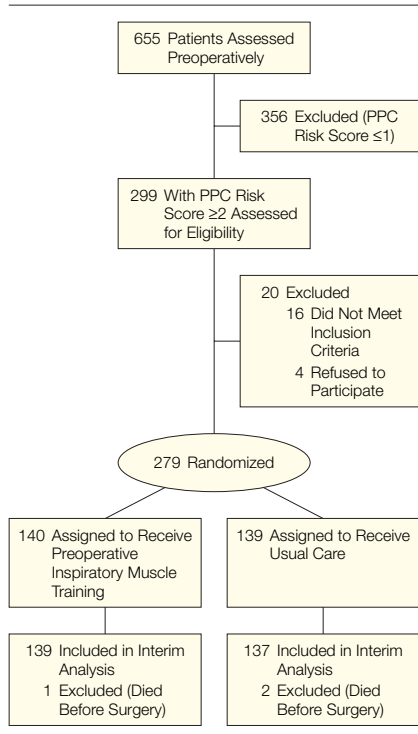
All collected data were stored in SPSS version 12.0 (SPSS Inc, Chicago, Ill) and checked for completeness, and tested with the Kolmogorov-Smirnov for normality. In the case of a missing value, the last observation was carried forward. Analysis was undertaken on an intention-to-treat basis. Summary descriptive statistics were computed for the preoperative and perioperative variables, including frequencies, means, and SDs. Postoperative pulmonary complications were compared between the

IMT and usual care group with the odds ratio (OR). Differences in nominal variables between the IMT group and the usual care group were tested with the Pearson χ^2 test. Duration of postoperative hospitalization and mechanical ventilation was compared between the 2 groups with the Mann-Whitney U test. An effect of the IMT was estimated within groups with the paired sample t test and between groups with the 1-way analysis of variance. Statistical tests were 2-sided and $P\leq .05$ was considered statistically significant.

RESULTS

Procedural Outcomes and Baseline Characteristics

Six hundred fifty-five patients awaiting elective, primary CABG surgery were

Figure. Flow Diagram of the Study Participants

PPC indicates postoperative pulmonary complication.

recruited at the University Medical Center Utrecht between July 2002 and August 2005 (FIGURE). Of these, 299 (45.6%) were considered at high risk of developing PPCs and eligible for inclusion. Twenty patients were excluded (14 underwent valve repair, 2 had no surgery but percutaneous transluminal coronary angioplasty, and 4 refused to participate without giving a reason), resulting in 279 high-risk patients being included in the study. These patients were randomly assigned to the 2 study groups (140 were allocated to IMT group and 139 to usual care group). Because 3 patients died (1 patient in the IMT group before starting the IMT and 2 patients in the usual care group) before surgery, data for 139 patients in the IMT group and 137 in the usual care group were available for the interim analysis.

Baseline characteristics are shown in TABLE 1. Both groups had a similar preoperative cardiac and pulmonary his-

tory. The mean (SD) number of weeks awaiting surgery was 8.2 (5.9) weeks for the IMT group and 7.0 (5.4) weeks for the usual care group ($P=.11$). The wide range reflects the lengthy waiting period for some of the participants. The duration of surgery, number of coronary vessels affected by disease, and cardiopulmonary bypass time were not significantly different in the 2 groups. The median duration of mechanical ventilation was significantly longer in the usual care group (5 hours; range, 1-79 hours) than in the IMT group (4 hours; range, 1-1287 hours) by Mann-Whitney U statistic ($z=-3.842$; $P=.001$).

Success of IMT

All participants in the intervention group recorded their daily inspiratory muscle workout in the diaries and the rating of perceived exertion on the Borg scale. No participants dropped out and all participants in the IMT group returned the questionnaire (mean [SD] scores for satisfaction and motivation on a 10-point scale were 8.1 [0.6] and 8.4 [0.9], respectively). Patients in the IMT group exercised for a mean of 29.7 days (range, 14-90 days) without experiencing adverse events during and after training sessions. The mean (SD) inspiratory muscle strength, assessed by measuring the P_{i-max} at residual volume, increased significantly from 81.1 (29.5) cm H₂O at baseline to 95.6 (31.6) cm H₂O ($P<.001$) at the end of the preoperative training period in the IMT group, but not in the usual care group (80.3 [31.4] vs 79.5 [31.3] cm H₂O, respectively; $P=.28$). Respiratory muscle endurance, expressed by the relationship between P_{m-peak} and P_{i-max} , also increased significantly after training in the IMT group (48.8% [15.7%] vs 56.0% [15.1%], respectively; $P<.001$), but not in the usual care group (50.7% [14.4%] vs 51.8% [16.4%], respectively; $P=.24$). One day before surgery, there were statistically significant differences in both the inspiratory muscle strength and endurance between the 2 groups

($F=32.84$, $P<.001$; and $F=6.61$, $P=.01$; respectively). Both P_{i-max} and P_{m-peak}/P_{i-max} increased statistically significantly during the first 4 weeks of IMT; thereafter, this increase leveled off.

Primary Outcome Measure

In-hospital data were available for all participants. A total of 25 (18.0%) of the 139 patients in the IMT group and 48 (35.0%) of 137 patients in the usual care group developed a PPC grade of at least 2 (TABLE 2). This difference was statistically significant (OR, 0.52; 95% confidence interval [CI], 0.30-0.92). The incidence of pneumonia was 6.5% (9/139 patients) in the IMT group and 16.1% (22/137 patients) in the usual care group (OR, 0.40; 95% CI, 0.19-0.84). The bacteriological spectrum was similar in both groups. Three (13.6%) of 22 patients in the usual care group developed respiratory failure as a consequence of pneumonia and died after surgery; none of the patients in the IMT group died. Another patient in the usual care group died after surgery as a result of cardiac failure (OR, 0.54; 95% CI, 0.48-0.60).

To account for differences in the baseline characteristics between groups of patients evident after randomization undergoing IMT and usual care, we performed 2 post hoc analyses. In the first analysis, we performed a stratified analysis among smokers and nonsmokers, and found that the study effect persisted only in the smokers group ($\chi^2=4.62$; $P=.03$) and not in the nonsmokers group ($\chi^2=2.77$; $P=.10$). We also performed a logistic regression analysis looking at the relationship of potentially confounding variables (eg, smoking, New York Heart Association classification, diabetes mellitus, duration of surgery, duration of mechanical ventilation) and the primary outcome, and found that none of these potential confounders were significantly associated.

Secondary Outcome Measure

The median duration of postoperative hospitalization was 7 days (range, 5-41 days) in the IMT group and 8 days

(range, 6-70 days) in the usual care group (Table 2), which was significantly different by Mann-Whitney U statistic ($z = -2.42$; $P = .02$).

COMMENT

To our knowledge, this is the first randomized clinical trial of a preoperative prophylactic tailored physical therapy intervention in patients scheduled for primary elective CABG surgery, based on artery occlusion, who are at high risk of developing PPCs. As hypothesized, preoperative physical therapy with IMT in high-risk patients significantly improved inspiratory muscle function. Moreover, in patients receiving preoperative physical therapy, the incidence of PPCs was reduced by 50% compared with patients receiving usual care. Consequently, the duration of postoperative hospitalization was significantly lower in the IMT group.

Our strategy of selecting patients at high risk of developing PPCs on the basis of risk factors was successful. Only 6 (1.4%) of 356 patients who were identified as being low risk of developing a PPC developed postoperative pneumonia vs 31 (11.2%) of 276 patients who were identified as being high risk of developing such complications. This shows that it is possible to identify preoperatively those patients at high risk of developing a PPC. The overall risk profile of both groups was similar to that of patients undergoing CABG surgery in the United States captured in the Society of Thoracic Surgeons National Adult Cardiac Surgery Database experience.³⁰

In patients at high risk of developing PPCs, IMT resulted in significant improvement (18% increase) in mean (SD) inspiratory muscle strength and respiratory muscle endurance (from 81.1 [29.5] cm H₂O at baseline to 95.6 [31.6] cm H₂O, respectively) and 15% increase at the end of the training period without causing adverse effects (from 48.8% [15.7%] to 56.0% [15.1%], respectively). These results are in line with the study results by Weiner et al,^{11,31} which involved patients undergoing CABG surgery with a low risk of developing PPCs; Nomori et al,³² which in-

involved patients undergoing thoracic surgery; and McConnell et al,³³ which involved healthy patients. Our data suggest that preoperative IMT make the patients more resistant to the detrimental consequences of surgery, decreasing the

Table 1. Baseline Characteristics of Patients in the IMT and Usual Care Group

Characteristics	No. of Patients (%)		P Value*
	IMT Group (n = 139)	Usual Care Group (n = 137)	
Age, mean (SD), y	66.5 (9.0)	67.3 (9.2)	.28
Sex			
Male	108 (77.7)	107 (78.1)	.61
Female	31 (22.3)	30 (21.9)	
BMI, mean (SD)	28.3 (5.5)	28.1 (3.2)	.75
History of cigarette smoking†	45 (32.4)	52 (38.0)	.48
Productive coughing	43 (30.9)	37 (27.0)	.97
Lung function tests (% _{predicted})			
FEV ₁	83.3 (20.4)	83.2 (18.6)	.74
FVC	89.8 (17.1)	90.4 (16.7)	.92
FEV ₁ /FVC	96.0 (14.6)	95.5 (12.6)	.45
IVC	89.9 (16.4)	88.1 (16.0)	.54
FEV ₁ /IVC	71.3 (13.1)	71.8 (11.9)	.96
Respiratory muscle tests			
P _{T-max} , cm H ₂ O	81.1 (30.3)	80.3 (31.4)	.21
P _{T-peak} /P _{T-max} , %	48.8 (15.7)	50.7 (14.4)	.80
P _{E-max} , cm H ₂ O	112.8 (31.2)	118.6 (25.7)	.19
Left ventricle function			
Ejection fraction ≥50%	84 (60.5)	89 (65.0)	.41
Ejection fraction 30%-49%	33 (23.7)	42 (30.7)	
Ejection fraction <30%	22 (15.8)	6 (4.3)	
History of myocardial infarction	37 (32.5)	48 (35.0)	.67
Hypertension	65 (57.0)	61 (44.5)	.06
Hypercholesterolemia	36 (25.9)	36 (26.3)	.32
New York Heart Association class‡			
I	27 (19.4)	5 (3.6)	.12
II	21 (15.1)	24 (17.5)	
III	88 (63.3)	105 (76.5)	
IV	3 (2.3)	3 (2.2)	
Presence of comorbid conditions while taking medication			
History of COPD	27 (19.4)	30 (21.9)	.50
Diabetes mellitus	50 (43.9)	45 (32.8)	.08
Duration of surgery, mean (SD), min	257.4 (70.4)	273.4 (109.1)	.06
Cardiopulmonary bypass time, mean (SD), min	87.9 (55.9)	96.2 (57.8)	.16
Duration mechanical ventilation, median (range), h	4 (1-1287)	5 (1-79)	.01
No. of affected vessels			
1	30 (21.6)	26 (19.0)	.44
2	40 (28.8)	30 (21.9)	
3	69 (49.6)	81 (59.1)	
Type of surgery			
On-pump CABG	112 (80.6)	114 (83.2)	.48
Off-pump CABG	27 (19.4)	23 (16.8)	

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); CABG, coronary artery bypass graft; COPD, chronic obstructive pulmonary disease; FEV₁, forced expiratory volume in the first second of expiration; FVC, forced vital capacity; IMT, inspiratory muscle training; IVC, inspiratory vital capacity; P_{E-max}, maximal expiratory mouth pressure; P_{T-max}, maximal inspiratory mouth pressure; P_{T-peak}, maximal peak pressure.

*Two-tailed.

†Defined as smoking within the past 8 weeks.

‡Defined as a functional and therapeutic classification for prescription of physical activity for cardiac patients. Class I indicates patients with no limitation of activities (experience no symptoms from ordinary activities); class II, patients with slight, mild limitation of activity (comfortable with rest or mild exertion); class III, patients with marked limitation of activity (comfortable only at rest); and class IV, patients who should be at complete rest, confined to bed or chair (any physical activity brings on discomfort and symptoms occur at rest).

Table 2. Duration of Postoperative Hospitalization and Level of PPCs Between the IMT and Usual Care Groups*

Outcome	IMT Group (n = 139)	Usual Care Group (n = 137)	Odds Ratio (95% CI)	P Value
Duration of postoperative hospitalization, median (range), d	7 (5-41)	8 (6-70)		.02
Level of PPC				
Grade 1	114 (82.0)	89 (65.0)	1.90 (1.09-3.38)	.02
Grade 2	14 (10.1)	18 (13.1)	0.63 (0.41-0.95)	.02
Grade 3	10 (7.2)	24 (17.5)	0.44 (0.23-0.84)	.01
Grade 4	1 (0.7)	6 (4.4)	0.20 (0.02-1.64)	.09
PPC grade \geq 2	25 (18.0)	48 (35.0)	0.52 (0.30-0.92)	.02
Pneumonia	9 (6.5)	22 (16.1)	0.40 (0.19-0.84)	.01

Abbreviations: CI, confidence interval; IMT, inspiratory muscle training; PPC, postoperative pulmonary complication. *Data are presented as number (percentage) unless otherwise specified.

median duration of mechanical ventilation, which was significantly longer in the usual care group (5 hours) than in the IMT group (4 hours) (Table 1). Inspiratory muscle training also promoted postoperative recovery, because the median duration of hospitalization was shorter in the 9 patients in the IMT group who developed pneumonia than it was in the 22 patients in the usual care group who developed pneumonia (11.5 vs 13.0 days, respectively).

The 9 patients in the IMT group who developed pneumonia had trained for longer than the participants who did not develop pneumonia (mean [SD], 40.71 [19.2] vs 28.95 [17.3] days, respectively; $P=.13$). However, in the 9 participants from the IMT group who developed pneumonia, the mean (SD) inspiratory muscle strength was not significantly increased between baseline and 1 day before surgery (78.63 [27.5] vs 80.85 [31.3] cm H₂O, respectively; $P=.35$). The inspiratory muscle endurance also did not significantly increase between baseline and 1 day before surgery (51.11% [14.5%] vs 51.89% [15.8%], respectively; $P=.72$). In contrast, the mean (SD) inspiratory muscle strength and inspiratory muscle endurance increased significantly between baseline and 1 day before surgery in the 130 participants who did not develop pneumonia (P_{i-max} , 82.64 [31.2] vs 90.00 [32.5] cm H₂O, respectively; $P<.001$; and P_{m-peak}/P_{i-max} , 50.34% [14.1%] vs 54.58% [16.3%], respectively; $P<.001$).

These outcomes are comparable with the results of the study by Nomori et

al,³² which showed that IMT before thoracic surgery may prevent PPCs. In a small, nonrandomized study, Rajendran et al¹³ investigated the role of preoperative short-term pulmonary rehabilitation in patients with chronic obstructive pulmonary disease who underwent CABG surgery. The authors showed that preoperative short-term pulmonary rehabilitation in these patients improved pulmonary function; decreased the incidence of atelectasis, consolidation, and pneumothorax as confirmed by chest roentgenogram; and decreased health care expenditure as evidenced by shorter ventilation time and hospital stay. Castillo and Haas¹² concluded that the use of preoperative and postoperative chest physical therapy strongly reduced the number of patients who developed atelectasis, but did not significantly affect the number of patients who developed respiratory complications due to infection.

Preoperative physical therapy before abdominal as well as open-heart surgery has been found to diminish postoperative radiological alterations, auscultation, blood gases, and length of hospital stay, and to improve quality of life.^{24,34-36} No single physical therapy intervention is better than other interventions in preventing PPCs.³⁷ It is well known that dysfunction of the respiratory muscles due to surgery may lead to a reduction in vital capacity, tidal volume, and total lung capacity.³⁸ This may cause atelectasis in the basal lung segments and a decreased functional residual capacity, which affects the gas exchange

properties of the lung by increasing the ventilation/perfusion mismatch. In addition, atelectasis may be a risk factor for pulmonary infections, which have significant morbidity and mortality in this patient population.³⁸ In severe cases, these consequences of impaired respiratory muscle function may lead to respiratory failure and death.³⁹ Also, pneumonia is associated with the duration of mechanical ventilation.⁴⁰ In our study, the duration of mechanical ventilation was significantly longer in the usual care group than in the preoperative physical therapy group. Because none of the other baseline and perioperative characteristics differed between the 2 groups, the difference in the duration of ventilatory support may be attributable to preoperative physical therapy with IMT.

The generalizability of our findings may be restricted because our study had a few limitations. In everyday clinical practice, different physical therapists train patients potentially eligible for IMT; whereas in our RCT, all the patients were trained by the same physical therapist. Thus, it is important to investigate the effects of IMT in a so-called naturalistic/pragmatic trial or in clinical practice.⁴¹ Also, during implementation Hawthorne effects will not be so prominent. Lastly, although the randomization appeared effective, there were some variables (cigarette smoking) that distinguished the 2 groups. It is possible that these along with other measures that were not significantly different after randomization may be confounding variables. Sensitivity analyses that evaluated both their collective effect and then the isolated effect of cigarette smoking on outcome failed to reveal anything but a conservative bias.

Postoperative pulmonary dysfunction after CABG surgery is associated with a longer duration of mechanical ventilation, difficulty weaning the patient, and prolonged hospitalization, and may be associated with higher mortality.^{6,38,42} We found that preventive physical therapy with IMT administered to patients at high risk of PPCs before CABG surgery was associated with an increase in inspiratory force and

a decrease in the incidence of PPCs and length of hospitalization. We consider this to be an important presurgical intervention that appears to be effective at reducing morbidity.

Author Contributions: Mr Hulzebos had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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Acquisition of data: Hulzebos, Favié, Van Meeteren. **Analysis and interpretation of data:** Hulzebos, Helders, De Bie, Van Meeteren.

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