Preoperative Respiratory Strength Training is Feasible, Safe, and Improves Pulmonary Physiologic Capacity in Individuals Undergoing Cardiovascular Surgery

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Glossary of Abbreviations:

Cardiac surgical (CS)
Odds ratios (OR)
Respiratory strength training (RST)
Expiratory muscle strength training (EMST)
Inspiratory muscle strength training (IMST)
Maximum expiratory pressure (MEP)
Maximum inspiratory pressure (MIP)
Speech-language pathologist (SLP)
Cough Peak Expiratory Flow (PEF)
London Chest Activity of Daily Living (LCADL)

Central picture legend: Preoperative pulmonary function improved in cardiac surgical patients completing RST.

Central message: Preoperative respiratory muscle strength training is feasible, safe, and improves respiratory physiologic capacity.

Perspective statement: This preliminary research study demonstrates the safety, feasibility, and short-term physiologic impact of a ‘prehabilitation’ respiratory strength training program in cardiac surgical patients. Additional research is needed to determine whether proactive exercise-based training regimens in this patient population may improve postoperative swallowing safety and health outcomes.
Abstract

Objective(s): Determine the safety, feasibility, and physiologic impact of a preoperative respiratory strength training (RST) program in individuals undergoing elective cardiac surgery (CS).

Methods: Twenty-five adults undergoing an elective CS at an academic hospital setting enrolled and completed RST 5 days/week (50 repetitions, 50% training load, ≥3 weeks) at home via telehealth in this open label, prospective, cohort study. RST adherence, telehealth attendance, and adverse events were tracked. Pre- and post-RST outcomes of maximum expiratory pressure (MEP), maximum inspiratory pressure (MIP), voluntary cough spirometry, and patient-reported dyspnea were collected. Descriptives and Wilcoxon signed rank tests were performed.

Results: Two participants (9%) did not complete the prescribed RST program. No significant RST-related adverse events occurred. Treatment adherence for all enrolled participants was 90% and telehealth attendance was 99%. Of the CS patients who completed the prescribed program (n=23, 91%), treatment adherence and telehealth attendance were excellent (98% and 100%, respectively). Significant increases in primary outcomes were observed: MEP mean change: +15.4, 95% CI: +3.4, +27.3, \( p<0.007 \), MIP mean change: +14.9, 95% CI: +9.4, +20.4, \( p<0.0001 \). No statistically significant differences in voluntary cough or perceived dyspnea outcomes were observed, \( p>0.05 \).

Conclusions: These preliminary data demonstrate that a preoperative RST program is safe, feasible and can improve short-term respiratory physiologic capacity (MEP, MIP) in CS patients. Future research is warranted to validate the current findings in a larger cohort of CS patients and to determine if RST improves postoperative extubation outcomes, airway clearance capacity, and aspiration following cardiac surgery.
**Key Words:** dysphagia, swallowing, cardiac surgery, pulmonary function, cough, respiratory strength training

**Ultra-mini abstract:**
This study examined safety, feasibility, and physiologic impact of a ‘prehabilitation’ respiratory strength training (RST) program in adults undergoing elective cardiac surgery (CS). CS patients underwent pulmonary and cough testing before and after a preoperative RST regimen. RST was safe, feasible, and improved expiratory and inspiratory airway clearance physiologic capacity.
Introduction:

Swallowing impairment (dysphagia) is a confirmed postoperative complication of cardiac surgery (CS) that is associated with significant morbidity and mortality.\(^1\)\(^-\)\(^4\) Recent data from our center utilizing fiberoptic endoscopic evaluation of swallowing (FEES) revealed unsafe swallowing in 94% (66% penetration, 29% aspiration) and inefficient swallowing (pharyngeal residue) in 52% of CS patients during the acute postoperative recovery phase.\(^3\) Aspirating CS patients, waited 85 hours longer to resume oral intake, had a 43% longer hospital length of stay (LOS), a $50,000 increased cost of care, and experienced higher rates of pneumonia (odds ratio, OR: 2.6), reintubation (OR: 5.7), and death (OR: 2.8), compared to non-aspirating CS patients.\(^3\)

We also noted that compared to aspirating patients with an ineffective or absent cough response to clear tracheal aspirate, those with an effective cough response to clear tracheal aspirate exhibited reduced rates of pneumonia (0% vs. 23%), reintubation (0% vs. 29%), mortality (0% vs. 9%), readmission (0% vs. 15%), length of hospital stay (15 vs. 21 days), and cost of care ($93,000 vs. $136,000).\(^3\) This latter finding revealed a potential modifiable treatment target, namely airway clearance physiologic capacity to reduce postoperative aspiration, to be targeted in CS patients undergoing planned procedures in the form of a ‘prehabilitation’ \(^5\) respiratory strength exercise program. Although not yet explored in preoperative CS patients, prior research studies in other patient populations with impaired pulmonary function and airway clearance physiologic capacity have demonstrated that a respiratory strength training (RST) program is safe (e.g., minimal adverse events), feasible, and improves respiratory muscle strength, cough effectiveness, and swallowing safety.\(^6\)\(^-\)\(^8\) Furthermore, preliminary studies in CS patients and other postoperative patient populations have found that inspiratory muscle strength training
(IMST) may reduce postoperative adverse health outcomes that may be related to aspiration including pneumonia and hospital length of stay.\textsuperscript{9,10} The current prospective pilot study aimed to test the hypothesis that a preoperative RST program to reduce postoperative aspiration would be safe and feasible and lead to improvements in expiratory and inspiratory pressure generation and airway clearance physiologic capacity in CS patients.

**Materials and Methods:**

**Research Participants:**

Twenty-five individuals attending the University of Florida Cardiovascular clinic, undergoing an elective cardiac surgery, and who lived within a 150-mile radius of the study site were recruited to participate in this study (Figure 1). Inclusion criteria for study participation was: 1) adult between 18-90 years old, 2) undergoing an elective cardiac surgery via sternotomy or extended thoracotomy in three or more weeks, 3) willing to undergo evaluation procedures and to participate in the RST program, and 4) have access to a computer, tablet, or other electronic device and the internet for telehealth sessions. This research study was approved by the University of Florida’s Institutional Review Board on 6/25/2021(IRB202100993) and all enrolled research participants provided written informed consent for publication of study data.

**Study Design:**

This was an open-label prospective, cohort study conducted in 25 CS patients (NCT04887415). Enrolled research participants underwent baseline assessments of pulmonary function (MEP, MIP) and cough function (voluntary PEF, cough spirometry) and completed self-reported dyspnea using the validated London Chest Activity of Daily Living (LCADL) scale. Following baseline testing, participants underwent RST in the home via telehealth with one in-person home
therapy session conducted at each participants’ mid-point to reassess maximum expiratory pressure and inspiratory pressure (MEP, MIP) and to recalibrate respiratory strength trainers. After the prescribed RST program, participants completed a second post-RST, preoperative assessment.

**Respiratory Muscle Strength Training Protocol:**

The RST program consisted of expiratory and inspiratory muscle strength training (EMST, IMST) using the EMST-75 Lite (for 0-75 cm H$_2$O) or the EMST-150 (for 30-150 cm H$_2$O) and the IA-150 devices (Aspire Products, Gainesville, FL) respectively. Trainers were calibrated to a 50% load of individualized MEPs and MIPs. CS patients performed 25 repetitions each (5 sets of 5 repetitions) of the expiratory and inspiratory exercises, 5 days/week leading up to their surgical procedure. Patients were given training logs to track completion of the RST exercises to measure adherence.

**Telehealth Sessions:**

Telehealth sessions were conducted by a research speech-language pathologist (SLP) at least once per week via a secure version of Zoom (Zoom, San Jose, CA). During telehealth sessions, the research SLP ensured that participants performed the prescribed exercises with correct form, completed a safety and adverse event check, answered participant questions, assisted with adherence issues, monitored adverse events, and aided participants in adjusting the resistance of the expiratory and inspiratory training devices based on participant exertion ratings using the Borg Category Ratio 10 Scale. During the adverse event check, the research SLP asked research participants if they were experiencing any pain, fatigue, discomfort, or other adverse events related to the RST protocol. Attendance for telehealth sessions was tracked.

**Home Visits:**
In addition to weekly telehealth sessions, a home visit was conducted by a research SLP at the mid-way RST program timepoint. During the home visit, the research SLP performed check-ins similar to telehealth sessions, retested MEPs and MIPs, and recalibrated the training devices to meet the 50% training load target.

Evaluation Procedures and Outcome Measures:

All pulmonary function measures were performed by a research SLP in accordance with standardized protocols and guidelines from the American Thoracic Society with research participants in an upright seated position with nose clips in place.

Primary Outcome Measures (MEP, MIP):

MEP and MIP measurements were obtained using the MicroRPM handheld device (Micro Direct Inc., Lewiston, ME). For MEP testing, research participants were instructed to take a deep breath in, place their mouth around the mouthpiece, and blow out as forcefully as possible. As needed, the research SLP assisted with lip seal by holding the sides of participants’ cheeks to prevent air leakage. For MIP testing, research participants were instructed to breathe all the air out of their lungs, place their mouth around the mouthpiece, and breathe in as forcefully as possible. Participants performed three MEP and MIP trials. Average MEP and MIP values were used to calibrate expiratory and inspiratory devices, and for subsequent analyses.

Voluntary Cough Peak Expiratory Flow (PEF) and Cough Spirometry:

Voluntary PEF was obtained using a handheld analogue Mini-Wright peak flow meter (Clement Clarke Int., Harlow, United Kingdom) with an ambu disposable face mask (AMBU INC., Columbia, MD) attached to minimize risk of particle aerosolization. For PEF measurements, participants were instructed to cough hard like something was stuck in their throat. Participants performed three PEF trials and the highest value was used for analyses. Voluntary cough
spirometry was performed using an oral pneumotachograph (MLT 1000; ADInstruments, Inc., Colorado Springs, Colorado) connected to an ambu disposable face mask (AMBU INC., Columbia, MD). Cough waveforms were recorded using LabChart Version 7 (Microsoft Corp., Redmond, Washington) on a Mac desktop computer for subsequent analyses. For voluntary cough spirometry, participants were instructed to breathe normally for several breaths before taking a deep breath in and coughing hard like there was something stuck in their throat. Three cough trials were obtained, and the peak values were used for analyses.

London Chest Activity of Daily Living (LCADL) Questionnaire:

Research participants completed the London Chest Activity of Daily Living (LCADL) questionnaire via a REDCap survey on an iPad to measure patient-reported dyspnea during activities of daily living. This questionnaire was selected to more effectively capture how dyspnea impacted individuals during functional day-to-day activities.

Data Analysis:

Voluntary Cough Spirometry Metrics:

Voluntary cough spirometry measurements were performed in a blinded and randomized fashion. One trained rater performed cough spirometry analyses using LabChart Version 7 (Microsoft Corp., Redmond, Washington) per previously established rating protocols.\textsuperscript{16,17} To assess intra-rater reliability, the primary rater randomly selected 20% of the cough spirometry files to re-rate. Re-ratings were performed at least one month after the initial rating. To assess inter-rater reliability, a second trained rater randomly selected 20% of the cough spirometry files to rate. Cough spirometry metrics obtained from analyses included inspiratory phase duration, inspiratory peak flow rate, compression phase duration, expiratory phase duration, peak expiratory flow rate, and cough volume acceleration.\textsuperscript{17}
Statistical Analysis:

Demographic information and pulmonary and cough function data were exported directly from our secure online database, REDCap into JMP version 16.1.0 and Graphpad Prism version 9.4.1 (Graphpad software, San Diego, CA) for statistical analyses. Descriptive statistics were utilized to summarize demographic information and pulmonary and cough function data. Intraclass correlation coefficients (ICC) with 95% confidence intervals (CI) were used to calculate inter and intra-rater reliability for voluntary cough spirometry metrics. Mean differences with 95% CI and Wilcoxon signed rank tests were performed to assess pre-to-post RST changes in pulmonary and cough function.

Results:

Twenty-five adults undergoing an elective cardiac surgery and who met the inclusion criteria were recruited and enrolled in the study. As shown in Figure 1, two individuals (9%) withdrew from the study due to reasons unrelated to the RST program (other medical complications unrelated to RST; no longer wished to participate). No individuals who were approached about participating in this study were unable to participate due to technology barriers for telehealth sessions. Participant demographic data are summarized in Table 1. Adherence for all CS patients enrolled in the study was 90% (35,900/39,900 completed repetitions) and telehealth attendance was 99% (138/140 sessions). Of those who completed the study, Adherence was 98% (35,750/36,650 completed repetitions) and telehealth attendance was 100% (135/135 sessions). Study participants completed the RST program 5-7 days/week (mean: 5.3 days ± 1.5) across a range of 3-10 weeks (mean: 5.9 weeks ± 1.8) leading up to surgery at a 50% MEP/MIP training load. No significant study-related adverse events were observed. Minor adverse events reported
by research participants included: pain (n=2), dizziness (n=7), migraine (n=1), dry throat (n=1),
and bloody nose (n=1).

Primary Outcome Measures (MEP, MIP):

Descriptive outcomes for MEPs and MIPs are provided in Table 2 and Figures 2 and 3.

Significant pre-to-post RST differences were observed for both MEP (+15.4, [95% CI: +3.4, +27.3], \( p = 0.007 \)) and MIP (+14.9, [95% CI: +9.4, +20.4], \( p < 0.0001 \)). A sex sub-analysis revealed that males demonstrated a significantly greater pre-to-post RST improvement in MEPs (+28.8, 95% CI: +15.3, +42.3) compared to females (-2.1, 95% CI: -17.5, +13.3), with an average 30.9 cm H\( \text{2} \)O increase in MEPs for men versus women observed, (95% CI: +10.5, +51.3, \( p = 0.005 \)) (Figure 4).

Secondary Outcomes:

Inter and intra-rater reliability across cough spirometry metrics ranged from good to excellent (average ICCs for inter-rater: 0.95 (95% CI: 0.93, 0.96), average ICCs for intra-rater: 0.90 (95% CI: 0.86, 0.92). Descriptive data for voluntary cough PEF and spirometry outcomes are summarized in Table 2. No significant differences in secondary cough outcomes were noted pre-to-post RST, \( p>0.05 \). LCADL total scores did not significantly differ pre-to-post RST, \( p>0.05 \) (Table 2).

A graphical abstract of the study methods and results is provided in Figure 5.

Discussion:

In this prospective, preliminary research study, we found that a preoperative, moderate load, combined expiratory/inspiratory RST program was safe, feasible, and led to statistically significant improvements in primary outcomes (MEPs and MIPs) but not voluntary cough or LCADL secondary outcomes. These significant improvements in primary outcome measures are
encouraging, and future larger scale clinical trials with adequate power will examine the potential impact of preoperative RST on secondary outcomes.

Retention, adverse events, RST adherence, and telehealth session attendance data support that a preoperative RST program in CS patients is feasible and safe. Weekly telehealth sessions and an in-person home visit from a research SLP at the midway point of the treatment protocol likely contributed to study retention and excellent RST adherence across research participants. The two study drops in this cohort highlight that demographic (e.g., age) and individual-level patient factors (e.g., other significant health conditions, lack of motivation to complete the exercises) may negatively impact RST adherence. Therefore, clinicians working with this patient population may desire to carefully select CS patients who may benefit most from completing this prospective intervention. Additionally, future studies may consider tracking RST adherence in a more sophisticated manner (e.g., a phone application) versus utilizing paper-training logs to allow for more contemporaneous tracking of treatment completion. Notably, given the promising preliminary data from this study, an at-home, ‘prehabilitation’ RST program with remote monitoring may have great potential to gain traction as a preventative exercise program for CS patients awaiting an elective cardiac surgery.

Across research participants, a combined RST regimen led to improvements in expiratory and inspiratory pressure generation (MEPs, MIPs). On average, MEPs and MIPS increased by 17.5% and 22.7%, respectively. Approximately one in every two participants (43%) demonstrated a greater than 15% increase in their expiratory generation pressure, while more than two-thirds (70%) increased their inspiratory pressure generation capacity. These findings are encouraging given that a moderate training load of 50% was utilized. Furthermore, the observed gains in MIPS in this cohort of CS patients were similar to research studies in other patient populations.
that have reported improvements in pressure generation of 25-42% following an RST program, which also led to improvements in cough function and swallowing safety.\textsuperscript{6,8,21} However, although gains in MEPs for the present study were significant, they were reduced compared to other studies that have utilized higher training loads and longer training durations. This finding reveals important areas for future study including dose-response across participants and determining the optimal RST treatment duration and exercise load for CS patients. Future larger-scale clinical research trials are warranted in a larger cohort of CS patients to confirm and expand upon these findings to determine the optimal treatment dosage as well as the long-term impact of completing this ‘prehabilitation’ treatment protocol on post-operative recovery, including reducing the incidence of aspiration and adverse health outcomes. Although not examined in the current study, prior research examining IMST in CS patients and other postoperative patient populations have found that IMST leads to reduced incidence of pulmonary complications and hospital length of stay.\textsuperscript{9,10} Another interesting finding from the current study cohort was that men had significantly higher gains in MEPs post-RST than women, illuminating that sex may play an important role in response to treatment for RST. This finding is aligned with prior research that has shown anatomical and physiological sex-based differences in respiratory function during exercise.\textsuperscript{22} For example, women are known to have smaller lungs compared to men even after accounting for size differences, to have smaller airways than men, and to have a different overall lung and ribcage shape than men.\textsuperscript{22} These anatomical differences likely contribute to physiological differences during exercise for women including increased work of breathing, increased likelihood of exercise-induced arterial hypoxemia, and increased activation of accessory respiratory muscles during inspiration.\textsuperscript{22} Given these anatomical and physiological differences in
respiratory function between men and women, women with cardiopulmonary diseases may have an elevated risk of pulmonary-associated medical complications compared to men. Furthermore, emerging research evidence has found that women have unique cardiovascular risk factors and tend to present with more severe cardiovascular disease at a later age and with more comorbidities. These risk factors are known to negatively impact health outcomes, mortality, and recovery for women following cardiac surgery. As such, it may be particularly important for women undergoing CS to participate in proactive RST regimens preoperatively, yet limited research currently exists regarding the impact of rehabilitation or ‘prehabilitation’ in women.

While post-RST changes in voluntary PEF, cough spirometry metrics, and LCADL scores did not reach statistical significance, promising improvement trends emerged with these secondary outcome measures. On average, voluntary PEF improved from 338 L/min to 353 L/min, and LCADL self-perceived dyspnea scores improved from 25 to 20. These findings are encouraging given that it suggests generalization of the RST training regimen to other relevant respiratory and cough measures, which is in line with prior work examining the impact of EMST in other patient populations with reduced airway clearance physiologic capacity and swallowing safety impairments. Conducting larger scale clinical research trials may provide further insight into whether a combined EMST/IMST training regimen results in short to long-term improvements in other vital respiratory and cough metrics in CS patients.

Limitations:

Although this is the first known research study to prospectively examine the safety, feasibility, and impact of preoperative RST on CS patients, it has several limitations. This was a preliminary, pilot research study, and as such, the sample size was relatively small (n=23) completed the study) and the inclusion criteria for participating in the study were broad, leading
to a more heterogenous sample (e.g., demographics, surgery type, time to surgery, etc.). We also
did not specifically examine potential demographic risk factors that may have contributed to
patient outcomes (e.g., body mass index, other respiratory diagnoses, ejection fraction, etc.) due
to the pilot nature of this work. However, it will be important to investigate how these
demographic and health-related variables may impact risk profiles of CS patients in future larger
scale clinical trials. While this preliminary study resulted in no significant study-related adverse
events and few minor adverse events, it will be important to further examine safety in future
clinical trials because of the small sample size in the current study. In addition to this, it is
possible that the RST adherence rates in this study are biased given that individuals willing to
participate in this study are more likely to be adherent than individuals uninterested in
participating. Furthermore, there was no control group in this study, which limits the ability to
draw firm conclusions regarding the efficacy of RST in CS patients. Given the small sample size,
it was challenging to comprehensively examine how demographic and surgical factors impact
adherence and response to RST. Additionally, given that this was the first study to examine RST
in CS patients, optimal dosage parameters for RST (e.g., intensity, repetitions, duration) were
unknown, emphasizing a need for future research to determine the most favorable exercise
training regimen in this patient population. Given the unknowns regarding optimal treatment
dosage parameters and the real-world challenges of surgery scheduling, a standardized treatment
schedule and duration was not implemented in the present study, however, future studies may
consider utilizing a more standardized approach to further understand RST treatment efficacy
and effectiveness.

Conclusions:
Implementing a preoperative RST program in CS patients is safe and feasible and leads to improvements in expiratory/inspiratory pressure generation. Larger scale trials are needed to statistically power the potential impact of ‘prehabilitation’, exercise-based regimens such as RST on swallowing safety and health outcomes in CS patients.
**Table 1**: Participant demographics of enrolled cardiac surgical patients.

<table>
<thead>
<tr>
<th>Patient characteristics (N=25)</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>67.9±11.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency (%)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sex</strong></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>14 (56%)</td>
</tr>
<tr>
<td>Female</td>
<td>11 (44%)</td>
</tr>
<tr>
<td><strong>Race</strong></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>22 (88%)</td>
</tr>
<tr>
<td>Black</td>
<td>1 (4%)</td>
</tr>
<tr>
<td>Unknown</td>
<td>2 (8%)</td>
</tr>
<tr>
<td><strong>Ethnicity</strong></td>
<td></td>
</tr>
<tr>
<td>Not Hispanic</td>
<td>22 (92%)</td>
</tr>
<tr>
<td>Hispanic</td>
<td>1 (4%)</td>
</tr>
<tr>
<td>Unknown</td>
<td>1 (4%)</td>
</tr>
<tr>
<td><strong>Surgery type</strong></td>
<td></td>
</tr>
<tr>
<td>Mitral Valve</td>
<td>8 (32%)</td>
</tr>
<tr>
<td>Aorta Graft</td>
<td>3 (12%)</td>
</tr>
<tr>
<td>Aortic Arch</td>
<td>3 (12%)</td>
</tr>
<tr>
<td>Maze Procedure</td>
<td>3 (12%)</td>
</tr>
<tr>
<td>Multiple Valve Replacement</td>
<td>2 (8%)</td>
</tr>
<tr>
<td>Aortic Root</td>
<td>1 (4%)</td>
</tr>
<tr>
<td>CABG</td>
<td>1 (4%)</td>
</tr>
<tr>
<td>LVAD</td>
<td>1 (4%)</td>
</tr>
<tr>
<td>Tricuspid Valve</td>
<td>1 (4%)</td>
</tr>
<tr>
<td>Mini Aortic Valve</td>
<td>1 (4%)</td>
</tr>
<tr>
<td>Atrial Appendage Ligation with an Atriclip</td>
<td>1 (4%)</td>
</tr>
</tbody>
</table>

*Note: CABG: Coronary artery bypass grafting, LVAD: Left ventricular assist device*
Table 2: Mean (± SD) values for pulmonary, cough, and swallow function data from 23 cardiac surgical patients pre and post the respiratory strength training (RST) program.

<table>
<thead>
<tr>
<th>Outcome Measures</th>
<th>Mean (SD) Pre-RST</th>
<th>Mean (SD) Post-RST</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pulmonary Function Tests</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum expiratory pressure (cm H20)</td>
<td>105.6 (40.9)</td>
<td>120.9 (49.7)</td>
<td>0.007*</td>
</tr>
<tr>
<td>Maximum inspiratory pressure (cm H20)</td>
<td>73.2 (26.4)</td>
<td>88.1 (30.9)</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td><strong>Voluntary Cough Peak Expiratory Flow and Cough Spirometry Metrics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voluntary cough peak expiratory flow (L/min)</td>
<td>337.7 (128.5)</td>
<td>352.7 (144.3)</td>
<td>0.18</td>
</tr>
<tr>
<td>Inspiratory phase duration (s)</td>
<td>2.02 (1.18)</td>
<td>1.84 (1.04)</td>
<td>0.36</td>
</tr>
<tr>
<td>Inspiratory peak flow rate (L/s)</td>
<td>-2.42 (1.09)</td>
<td>-2.87 (1.75)</td>
<td>0.30</td>
</tr>
<tr>
<td>Compression phase duration (s)</td>
<td>0.33 (0.18)</td>
<td>0.39 (0.28)</td>
<td>0.64</td>
</tr>
<tr>
<td>Expiratory phase duration (s)</td>
<td>0.04 (0.03)</td>
<td>0.04 (0.02)</td>
<td>0.68</td>
</tr>
<tr>
<td>Peak expiratory flow rate (L/s)</td>
<td>8.99 (3.39)</td>
<td>9.21 (3.01)</td>
<td>0.79</td>
</tr>
<tr>
<td>Cough volume acceleration (L/s/s)</td>
<td>302.60 (203.18)</td>
<td>362.13 (275.75)</td>
<td>0.57</td>
</tr>
<tr>
<td><strong>LCADL Dyspnea Scale</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCADL total score</td>
<td>24.95 (11.48)</td>
<td>20.52 (7.99)</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Note: L: liters, s: seconds, min: minutes, DIGEST: Dynamic Imaging Grade of Swallowing Toxicity, PAS: Penetration-Aspiration Scale, LCADL: The London Chest Activity Daily Living
**Figure 1:** Consort flowchart of recruitment and enrollment for clinical trial NCT04887415 from September 2021-September 2022.

**Figure 2:** Mean baseline and post-respiratory strength training group data for primary outcomes of **A)** maximum expiratory pressure (MEP, cm H20) and **B)** maximum inspiratory pressure (MIP, cm H20).

**Figure 3:** Mean baseline and post-respiratory strength training participant level data for primary outcomes of **A)** maximum expiratory pressure (MEP, cm H20) and **B)** maximum inspiratory pressure (MIP, cm H20).

**Figure 4:** Mean (95% CI) change in maximum expiratory pressure (MEP) from pre- to post-respiratory strength training.

**Figure 5:** Preoperative respiratory strength training was safe, feasible, and led to improvements in respiratory physiologic capacity in adults undergoing an elective cardiac surgery.
Bibliography


Enrollment

Assessed for eligibility (n= 25)

Excluded (n= 0)

Allocation

Allocated to intervention (n= 25)
♦ Received allocated intervention (n= 25)

Follow-Up

Lost to follow-up (n=1)
• Participant decided not to have surgery
Discontinued intervention (n=2)
• Other medical complications unrelated to intervention
• No longer wished to participate

Analysis

Analysed (n= 23)
♦ Excluded from analysis (n= 2)
• 2 study drops
Mean difference: +30.9, (95% CI: +10.5, +51.3), p = 0.005
PRESET: Preoperative Respiratory Strength Exercise Training

N=25 cardiac surgical patients
20-86y, 14 male
Respiratory strength training for 3 weeks, 50% load

Cardiac Surgery

Respiratory Strength Training was:
1) Safe
2) Feasible
98% RST adherence
100% telehealth attendance
3) Improved Pulmonary Function

![Graph showing improved pulmonary function](Created in BioRender.com)
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