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A case report of cardiopulmonary exercise testing and incentive spirometry-guided breathing pattern alteration for a severely tachypnoeic kyphoscoliotic patient undergoing major thoracic surgery for suspected lung malignancy

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Abstract

A case report of a severely dyspnoeic kyphoscoliotic patient intended for an elective major thoracic surgery for suspected lung malignancy. With baseline near maximal breathing frequency and shallow breaths and poor lung mechanics, the first encountered anaesthetist considered this patient too high risk for lobectomy. This case illustrated the application of cardiopulmonary exercise testing to provide an objective assessment of the patient's functional capacity, ventilatory efficiency and delineation of modifiable respiratory components that guide the formulation of individualized prehabilitation programme. It also depicted the perioperative role of an off-label use of incentive spirometry in providing visual feedbacks and led to subsequent assessment breathing pattern alternation. Patient underwent the lung resection uneventfully and returned to normal lifestyle on postoperative day 4.

Keywords

Respiratory medicine, surgery, anaesthesia/pain, cardiopulmonary exercise testing, prehabilitation, tachypnea, breathing abnormalities, ankylosing spondylitis, kyphoscoliosis

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Introduction

In the past, patients with significant tachypnoea having restrictive lung disease diagnosed with spirometry will be turned down for surgery. It is difficult to differentiate if it is due to the limitation by the restrictive lung or due to their breathing habit to minimize work of breathing (WOB).[1] Compared to resting physiologic tests, exercise tests provide more objective assessment and differentiate physiological causes or specific physiologic contributors of unexplained or disproportionate dyspnoea.[2,3] Cardiopulmonary exercise (CPEX) provided perioperative clinicians with objective assessment of patient's functional capacity and parenchymal function. This helped to differentiate the cause of tachypnoea and provide more objective risk stratification.[4]

Ankylosing spondylitis (AS) has multiple cardiac manifestations for example, aortic valve diseases, conduction disturbances, cardiomyopathy and ischaemic heart disease and pulmonary manifestations such as upper lobes fibrosis, interstitial lung disease, chest wall restriction, sleep apnoea, and spontaneous pneumothorax.[5] Objective assessment including ECG, echocardiography, lung function test, 6-min walking test, CPEX and arterial blood gases were suggested to patients with long-standing AS and spine and rib cage deformities presenting for major surgery.[6] Respiratory exercise of incentive spirometry[7] and inspiratory muscle training (IMT) are shown to improve cardiopulmonary functions in AS patients. Other breathing exercises such as pursed-lip breathing, abdominal breathing, thoracic breathing exercises

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could also be considered as they were shown beneficial in patients before lung resection to reduce postoperative pulmonary complications.[8]

WOB is the amount of energy or O_2 consumption needed by the respiratory muscles to produce enough ventilation and respiration to meet the metabolic demands of the body. With restrictive lung diseases, elastic work (approximately 65% of the overall WOB) is increased because of impaired chest wall recoil/lung parenchymal disease. Increasing the respiration rate decreases the elastic WOB and total WOB.[9] Therefore, patients with restrictive lung disease were commonly educated to adopt rapid shallow breathing to reduce WOB, and VE/VCO_2 in the CPEX was adopted as a surrogate to the assessment of ventilatory efficiency.

In this patient, CPEX was applied to provide an objective assessment and differentiate modifiable breathing pattern abnormality from a truly severe restrictive lung disease. With subsequent success in physical pre-habilitation with incentive spirometry and IMT, the authors found it worth writing up to inform other perioperative clinicians as future reference.

Case

This was a 67-year-old lady with history of ankylosing spondylitis for more than 20 years (HLA-B27 positive). She has a very kyphotic thoracic spine (see Figure A1 and A2 in Appendix). Her lumbosacral spine X-ray showed fused lumbar spine and suspected fused sacroiliac joint on pelvis X-ray. She had occasional on and off back pain without any regular analgesic; otherwise, she does not have hip pain and lower-limb weakness. Other extra articular manifestations included lung fibrotic changes and uveitis. She has not been prescribed any DMARD or biologics for over the past 20 years. Her follow-up by rheumatology team was stopped since 2012. She has not received any rheumatological assessment and treatment for over 10 years. She was independent for self-care and could walk unaided on level ground for 1 h. The patient has history of paroxysmal supraventricular tachycardia with electrophysiological study confirmed typical atrioventricular nodal re-entry tachycardia and was treated with radiofrequency ablation a few months before preoperative assessment. Since then, she is asymptomatic so far. She also has hyperlipidemia on atorvastatin. The pre-operative liver and renal function was grossly normal. She was diagnosed with left upper lobe lung carcinoma on routine checkup and was referred for preoperative anaesthetic assessment for an elective video-assisted thoracoscopic surgery (VATS) for left upper lobe resection.

Preoperative assessment

On the first preoperative assessment, she presented with tachypnea of respiratory rate 40–50/min at rest with significant use of accessory muscles. Her first spirometry test suggested a restrictive lung pattern (FVC 0.79L; FEV_1 0.56L and FEV1/FVC ratio 70.9%; ppo FEV_1 33.6%; ppo DLCO 61%). Echocardiogram was done with satisfactory systolic function and unremarkable structures or valves, and there was no sign of pulmonary hypertension. Six-minute walk test was 350 m.

The first assessing anaesthetist classified patient as ASA class III and regarded patient having severe tachypnea with poor lung mechanics as too high risk to proceed with lung resection, due to the limited respiratory reserves and high risks of perioperative desaturation and requirement of postoperative ventilatory support. And therefore, he has liaised with thoracic surgeons for shared decision-making, and meanwhile, referred patient for CPEX for objective risk stratification as per the recommendations of American College of Chest Physicians.

First, CPEX revealed a baseline respiratory rate of 40/min which subsequently increased to 50/min. There was no desaturation throughout the test. The peak oxygen consumption (VO_2 peak) was 20 ml/kg/min suggestive of a normal functional capacity, whereas the ventilatory equivalent for CO_2 at anaerobic threshold was 20 which suggested a normal ventilatory efficiency. An increase in tidal volume from 200 ml to 450 ml was observed as per workload increased during the test. Her baseline arterial blood gas result was grossly normal (pH 7.39 and pO_2 level of 12.8 kPa, pCO_2 was 6.03 kPa), except the pCO_2 was a bit high. This served as another circumferential evidence to support our postulation that this patient has adopted a habitual rapid but shallow breathing pattern with a normal minute ventilation to minimize the WOB, as compared to slow and deep breathing, and therefore, we regarded the near maximal breathing frequency as modifiable with prehabilitation.

Therapeutic interventions

(1) ***Using incentive spirometry as visual feedbacks:*** Incentive spirometry was used off-label as an aid to provide visual feedbacks during her breathing pattern alternation training. The patient was trained to utilize the incentive spirometry to not only promote deep inspiration but also to monitor and adjust their breathing pattern. By observing the piston indicator, the patient could visually gauge the depth and duration of inspiration, providing immediate feedback on her respiratory effort. This visual aid was instrumental in helping the patient learn to adopt a new breathing pattern with a larger tidal volume and a slower respiratory rate, and it also provided an objective tool for perioperative nurse to assess her training progress at home via video-conferencing.

(2) ***Home inspiratory muscle training:*** IMT was prescribed to patient with the resistance set to 30% of her maximal inspiratory pressure (MIP). Patient was required to follow the instructions of the physiotherapist to perform 15-min IMT at a 5-breath

Table 1. Patient's major investigation results before and after training.

Test parameters	Before training	4 weeks after training	8 weeks after training, 2-week after COVID infection
FVC	0.79 L	0.96 L	1.1 L
FEV_1	0.56 L	0.93 L	1.02 L
$ppoFEV_1$	33.7%	58.6%	65.5%
DLCO	9.9 ml/min/mmHg	(not repeated)	(not repeated)
ppoDLCO	61%	(not repeated)	(not repeated)
MIP	29 cmH_2O	48 cmH_2O	45 cmH_2O
VE/VCO_2 at AT	29.7 L/min	33.2 L/min	30.5 L/min
pH	7.39	7.41	(not repeated)
pCO_2	6.03 kPa	6.13 kPa	(not repeated)
pO_2	12.82 kPa	12.04 kPa	(not repeated)

MIP: maximal inspiratory pressure.

cycle every day and night. A target to train her up to average MIP for female population (48 cmH_2O) was aimed.

Follow-up and outcomes

Her training progress was followed up via tele-clinics (video-conferencing) once a week during the initial 4 weeks of training programme and 2 weeks after COVID infection by our perioperative nurses and anaesthetists. During the video conferencing, patient was asked to demonstrate her technique of using incentive spirometry and IMT, and the breathing patterns and the tidal volume were assessed as displayed by patient breathing through the incentive spirometry with her eyes closed (i.e. with the visual feedbacks taken off).

Lung function test and CPEX were repeated to assess the training efficacy at 4-week intervals. This patient adopted a new breathing pattern with larger tidal volume (450–500 ml) and slower respiratory rate (15–20/min) after 8 weeks. MIP was improved from 29 to 45 cmH_2O. FEV1 improved from 0.56 L to 1.02 L with the predicted postoperative FEV_1 ($ppoFEV_1$) improved significantly from 33% to 65% (see Table 1).

While awaiting surgery, patient got COVID-19 infection causing postponement of the operation, and she had symptoms of fever, productive cough with generalized malaise, but did not require hospitalization or oxygen supplement for COVID-19 infection, and the infection was regarded as mild-to-moderate in severity. She received symptomatic relief and was taught coughing exercise by the physiotherapist. She continued training and demonstrated good lung function after recovery.

Patient's lung pathology was assessed by thoracic surgeons as ground glass opacity with feature compatible with slow growing tumour prior to the decision of prehabiliation. Based on the poor lung mechanics in pre-operative assessment and the near-maximal breathing frequency, shared decision-making on non-operative management with radiotherapy was also discussed with the patient and her family. Therefore, during the process of prehabilitation, our team had maintained a closed-loop communication with the surgical team before we offered an extended course of prehabilitation. Patient and the family were also well informed the possibility of tumour progression in case of malignancy, and decision to abort the prehabilitation and go for radiotherapy was also consented in case of no observable progress of prehabilitation. The first CT report suggested a mass (1.6 × 3.4 × 3.1 cm) which was not seen on CXR. CT scan was not repeated before operation. Interval CXR and bronchoscopy with bronchial aspirate for culture and cytology was repeated during the prehabilitation and no abnormality was detected. The patient was classified as pT1cN0 stage 1 (see Figure A3 in Appendix for CT images).

She eventually received VATS and left upper lobe lobectomy at 3 months from prehabilitation. From the pathological report, the tumour bulk of the adenocarcinoma is around 28 mm in size. The breathing issues were well communicated among surgeons and intensivists facilitating early stepping down from ICU to general ward on post-operative day 2 and discharge home on day 4. Recovery was smooth.

Discussion

This patient first presented with near-maximal breathing frequency and poor lung mechanics and was turned down by the assessing anaesthetist for lung resection. Subsequent risk stratification with CPEX and review of arterial blood gas suggested this patient's tachypnoea was attributable to modifiable habitual breathing abnormality rather than fixed irreversible restrictive lung disease. Therefore, an individualized physical prehabilitation programme was initiated, aiming for breathing pattern alternation and strengthening of inspiratory muscle.

It is known that immediately after the surgical procedure, respiratory rate would be higher and tidal volume would be smaller than those observed immediately before the surgical procedure.[10] Therefore, pre-existing rapid shallow breathing would be expected to be worsen after surgery.

Breathing alteration of patient breathing at near-maximal respiratory rate pre-operatively provide her with more post-operative respiratory reserve after lung resection. As her lung volume was expected to decrease after lung resection and be adversely affected by other factors such as atelectasis or pain. Postoperative respiratory compensation was commonly achieved by increasing the breathing rate. A slower baseline respiratory breathing could provide her with more compensatory reserve after surgery.

Techniques described to treat breathing pattern disorder involved enhancing patient's awareness of own breathing pattern and changing the pattern with breathing exercise.[11] To allow this patient to visualize and improve her awareness of breathing alteration, incentive spirometry, which was typically used to help patients improve their lung function after surgery,[12] was adopted to provide visual aid to monitor patient's own depth of breathing and prehabilitation progress.

For patients undergoing VATS resection of lung cancer, incentive spirometry patient group has demonstrated significantly lower risk of pneumonia and reduced hospitalization costs.[13] Current evidence on incentive spirometry with AS patient suggested it may improve lung mechanics and arterial blood gases compared to conventional exercise alone.[14] But its use for breathing alteration especially in perioperative period would require more study to follow. It could potentially be adopted for a wider range of patients with restrictive lung diseases, paving the way for a more structured and effective offsite prehabilitation training approach.

Patient's initial VE/VCO_2 was lower than that after breathing alteration, suggesting that her WOB was lower with a rapid shallow breathing pattern.[15] But her VE/VCO_2 after training was still within normal range.[16] Taking into account in the perioperative setting, we suggest to alter her breathing pattern into a deep and slower breathing pattern. Theoretically, the alveolar ventilation would also be increased with a lower respiratory rate for the same minute ventilation due to dead space, and there would be less diagnostic confusion for post-operative respiratory complications because tachypnea is often a sign of respiratory distress.

Patient's ppoFEV1 and MIP also improves after training. The ppoFEV1 is commonly applied for risk stratification for patients undergoing thoracic operation, while MIP is a surrogate for inspiratory muscle strength, and was considered as a predictor for ventilator weaning after mechanical ventilation in surgical patients. Currently, there is insufficient evidence or study discussing perioperative breathing alteration on improving breathing mechanics in this patient group. The improvement in this patient may be contributed by incentive spirometry and IMT on top of breathing pattern alteration. Therefore, it is worth further quality study to look into the benefits on this patient group.

Conclusion

This case demonstrated the success in the application of CPEX and incentive spirometer to provide objective guidance in differentiating fixed irreversible ventilatory limitations from trainable lung conditions, which is worth reporting to inform other healthcare perioperative professionals the possibility of prehabilitation in this group of previously apparently unfit patients.

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Ethics approval

Our institution does not require ethical approval for reporting individual cases or case series.

Informed consent

Oral informed consent with written documentation in patient's record was obtained from the patient(s) for their anonymized information to be published in this article.

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Appendix

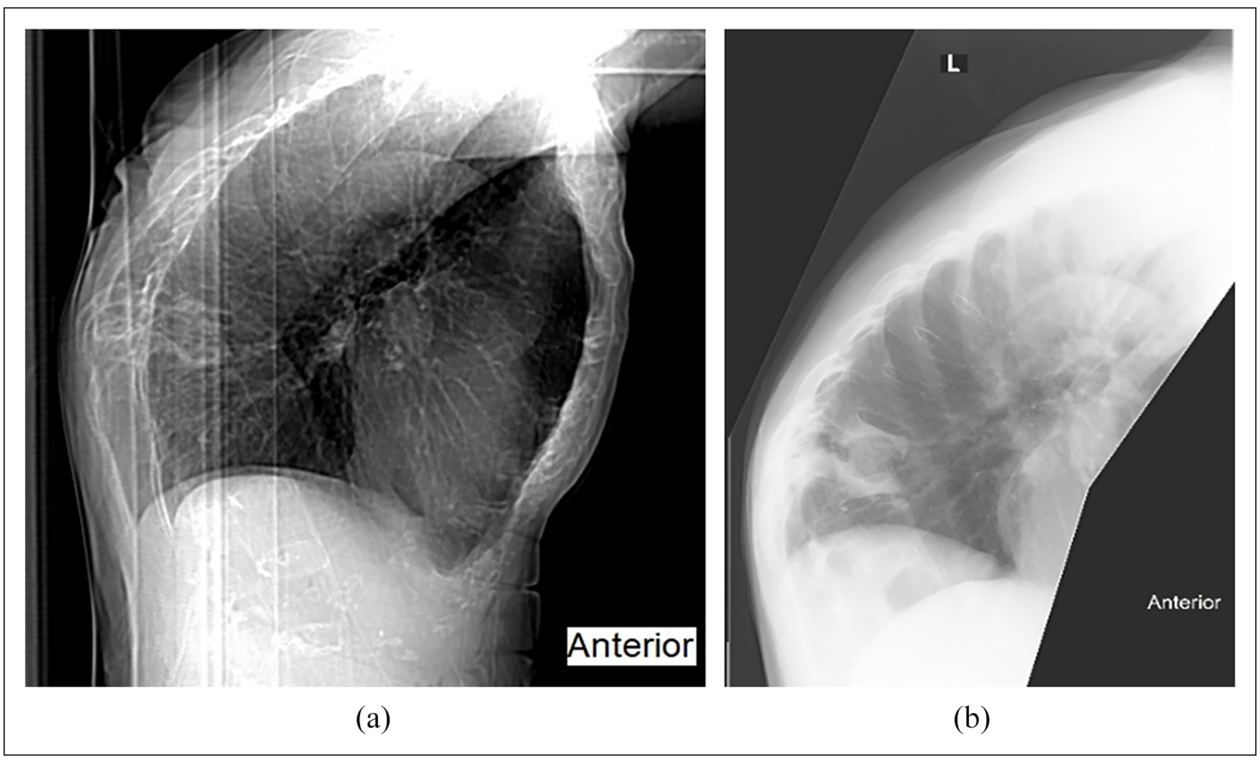

Figure A1. Lateral view of this patient in (a) CT thorax and (b) XR thoracic spine.

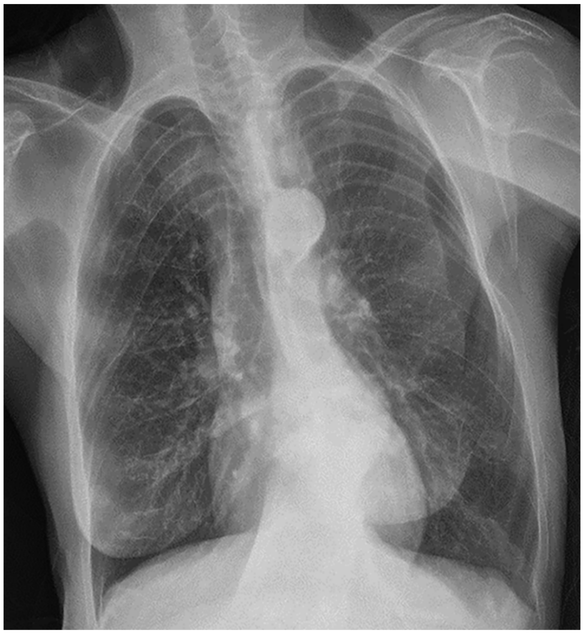

Figure A2. AP view of CXR.

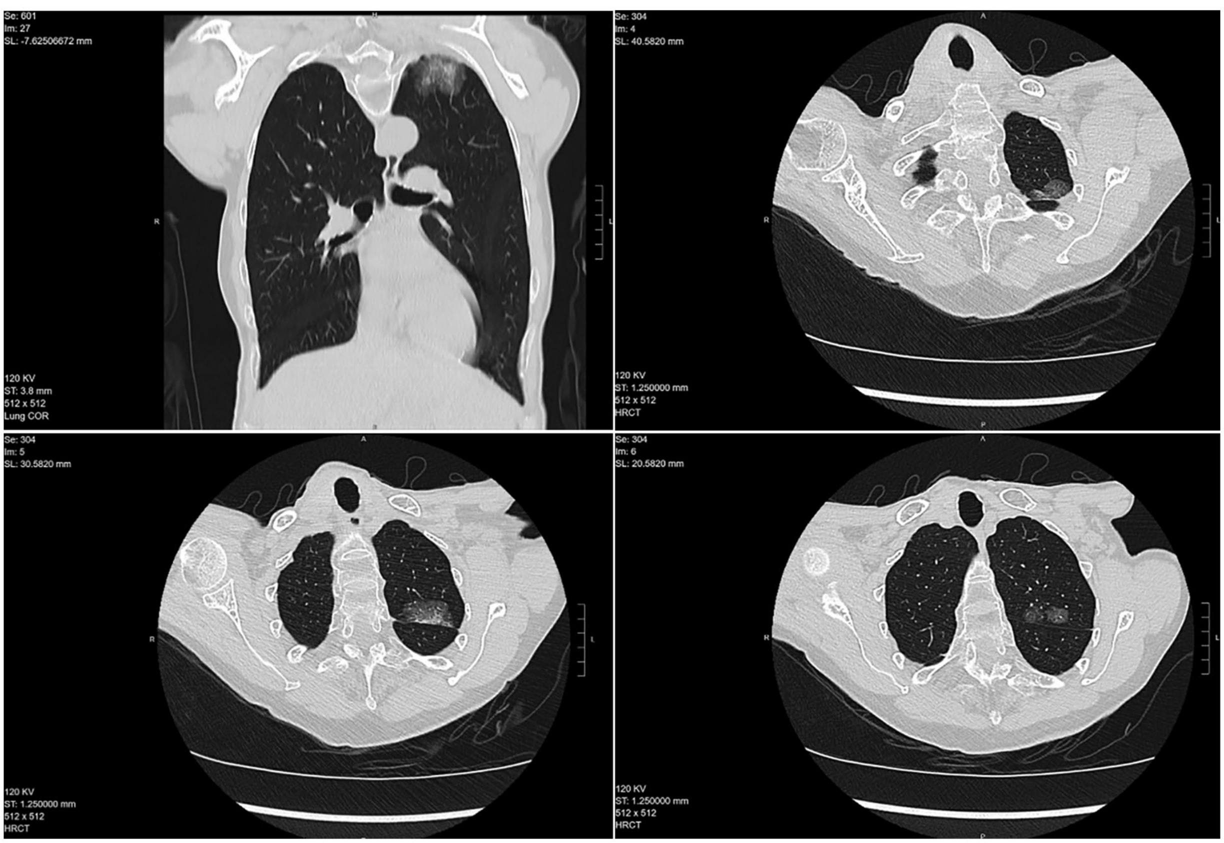

Figure A3. Preoperative CT images.