Evaluation of the utility of vibration response imaging device and Operation Planning Software in the assessment of patients before lung resection surgery

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Abstract

Background and objectives: A variety of methods have been used to evaluate patients with lung cancer to define a patient cohort at high risk for postoperative mortality and respiratory complications associated with lung resection surgery. Our aim was to evaluate the utility of vibration response imaging (VRI) Operation Planning Software (O-Plan) in assessing suitability for surgical resection and for the prediction of postoperative forced expiratory volume in 1 s (ppoFEV1). Methods: A total of 58 subjects with lung cancer underwent evaluation prior to lung resection surgery and postoperative lung function after surgery. Results: Preoperative pulmonary function tests and quantitative breath sound measurements by VRI were performed in all patients to estimate postoperative lung function. In addition, 20 patients underwent perfusion scan prior to surgery. VRI O-Plan predictions (12 pneumonectomies and 46 lobectomies) showed good correlation and concordance (Lin’s coefficient) with postoperative FEV1 (l) (r = 0.865, Lin’s coefficient 0.858) and FEV1 (%) (r = 0.877, Lin’s coefficient 0.861) 4—6 weeks after surgery. Predicted and postoperative measured FEV1 showed no significant differences (p > 0.05). Average lung function predicted postoperative values were similar for perfusion and VRI O-Plan calculations with a correlation of 0.74 and concordance of 0.700. Conclusions: VRI O-Plan has shown high accuracy in predicting postoperative FEV1 after lung resection surgery. Given its simplicity of operation and the non-invasive nature of VRI and O-Plan, it could be a good alternative to perfusion scan in pre-surgery assessment.

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1. Introduction

Various pulmonary function tests have been used to identify potential candidates for lung resection and to predict morbidity and mortality rates after surgery [1—5]. Of these, the British Thoracic Society and the European Respiratory Society have incorporated into their guidelines evaluation of FEV1, and for patients not clearly operable on the basis of spirometry, full pulmonary function tests (PFTs) including estimation of diffusion capacity of the lung for CO (DLCO), as the most firmly established tools for prediction of surgical outcome [2,3].

Quantitative radionuclide perfusion studies are commonly used to evaluate the split lung function and to predict postoperative (ppo) lung function and outcome [1,2,4—8]. However, the predicted results can be unreliable. Ladurie and Ranson-Bitker [9] found significant differences between predicted and estimated postoperative FEV1 values in 75% of patients following pneumonectomy. Despite these limitations, the radionuclide perfusion scan is strongly recommended for calculating estimated postoperative FEV1 after resection surgery in patients with low lung function [2].

The vibration response imaging (VRI) is a new technique to capture lung sounds generated by the flow of air through the lungs [10]. The VRI data can be analysed by a physician, using desktop software called the VRI O-Plan to calculate the acoustic energy derived from each pulmonary area. Computed data afford ppo values for intended lung resection at the level of a lobectomy or greater as analysed by the physician.

In this study, our primary objective was to estimate the accuracy of the predictions of ppoFEV1 (%) and ppoFEV1 (l) calculated by the VRI O-Plan software compared with postoperative spirometric measurements 4—6 weeks after surgery. In addition, we analysed, in a group of patients, the correlation between postoperative lung function predictions derived from both VRI and Q scan tests.
2. Methods

2.1. Study population and design

Over the course of 8 months, 94 patients with lung cancer, candidates for lung resections, presented to our institution and were evaluated. This study was approved by Cruces Hospital Ethics Committees and written consent was obtained from all participants.

All 94 candidates were evaluated by the VRIXP device (Deep Breeze™, Or-Akiva, Israel). All the patients with expected major lung resection (lobectomy, bilobectomy or pneumonectomy) were initially included in the study. Exclusion criteria were: smaller lung resection less than lobectomy (anatomical segmentectomy or wedge resection), factors that could interfere with recordings or sensors adhesion (body mass index less than 19, chest wall or spine deformation, hirsutism on the back, cardiac pacemaker or implantable defibrillator) [10] and postoperative morbidity (no trustworthy postoperative data) or mortality (non-obtainable postoperative data).

A total of 58 out of 94 intended resections were finally accepted for analysis. The wedge resection in patients with lung metastases from different primary tumours was the most frequent cause of exclusion (20 patients). We analysed the VRI test in patients when the performed resection was lobectomy or pneumonectomy. Three patients had postoperative mortalities due to respiratory arrest or infection.

All the subjects were evaluated with the standard preoperative functional protocol as well-known international algorithms [2,3]. Only in patients with FEV1 < 80% or 2 l, a ventilation/perfusion lung scan (V/Q) was performed.

A total of 20 patients had undergone Q scan prior to surgery. The Q scans were performed at least within 2 weeks of VRIXP recording.

PFT were obtained according to published guidelines [11] using a spirometer (Master Scope, Jaeger, Wulzburg, Germany). The postoperative tests were done with the same equipment and technique used preoperatively.

The post-resection measurements were done 4–6 weeks after surgery, when patients without complications reached their baseline, and prior to adjuvant therapy. In this way, we assured that the drop in the lung function was only due to lung resection and not because of the possible adverse effects of this treatment on the lung.

Bronchoscopy findings were reported for all the patients. In 12 (20.6%) of 58 patients, endobronchial tumours were found with bronchial obstruction.

2.2. Quantitative regional function as measured by VRIXP

Prior to VRIXP recordings, the patients were evaluated for potential inclusion in a VRIXP O-Plan analysis. Eligibility criteria included: no active pulmonary infection; not decompensated cardiac or chronic airways disease; the patient presented with the best lung function and any airway secretions were cleared by cough or other methods.

Patients’ statistics were recorded with the VRIXP device by the respiratory therapist following lung function testing. The acoustic lung imaging system quantifies breath sound measurements and depicts the findings as a dynamic image and numerical values, as described previously [10]. The energy generated by the vibrations of the lungs during inspiration and expiration is discerned by two arrays of piezoelectric sensors during 12 s of recording. Each array is comprised of 21 (seven-row array) or 18 (six-row array) piezoelectric contact sensors, attached to the posterior chest by a computer-controlled low vacuum. Digital signals are acquired at a sampling rate of 19.2 kHz and then filtered, amplified and converted into digital data. For the resulting signals from each sensor, an algorithm calculates quantitative information, displayed either as a total lung vibration signal or analysed regionally and quantitatively for upper, middle and lower sensor zones for each lung separately [10].

For the VRIXP recording process, patients were seated in the pulmonary function laboratory. Patients were instructed to inhale deeply and to exhale without force via the mouth for 12 s; with optimal breathing rate, four breathing cycles should be obtained. Recordings with artefacts were not saved, and additional recordings were performed so that there were at least three satisfactory recordings for each patient. Other parameters that required re-recording included a breathing intensity below 1.5 (as indicated in the VRIXP breathing intensity bar), less than three breathing cycles in the 12 s and ambient noise, talking or coughing by the patient during the recording. If crackles or wheezes were detected by VRIXP we verified if they correlated with dynamic image (hypervibrations) at the same time and in same area. In such cases, re-recordings were performed.

Once the three VRIXP recordings for a patient were uploaded to the O-Plan software, the physician then selected the maximum number of good-quality breathing frames to be added to the average quantitative lung data (QLD) calculations for each recording. Average QLD and standard deviation (SD) were then calculated by the software to produce the final average QLD value. The SD was used to ensure the reliability of the data; a value of the SD below 5.4 was chosen as the acceptable limit (Fig. 1).

Preoperative lung function data were entered into the software, through the user interface, and the intended surgical site was selected on the O-Plan lung resection diagram (Fig. 2). The predictions were calculated as published equations [1,2,12].

2.3. Statistical analysis

Descriptive statistics of scintigraphy measurements, quantitative VRIXP O-Plan measurements and actual FEV1 measurements are presented as mean ± standard deviation (SD).

To evaluate the relationship between ppoFEV1 predictions calculated by the O-Plan compared with the postoperative spirometric findings, we used Pearson’s coefficient (correlation). Concordance was evaluated using Lin’s concordance coefficient and the Bland and Altman test.

The Wilcoxon signed-rank test for paired data with a significance level of 5% was used to test differences between the values.

Analysis of data was performed with SPSS (version 11.5.1, SPSS Inc., Chicago, IL, USA) software.
3. Results

A total of 58 patients (44 males, 14 females; 62 ± 10 years, 41–80 years) with lung cancer underwent preoperative pulmonary function testing and VR1xp testing prior to lung resection surgery and obtained postoperative lung function testing results.

A total of 46 lobectomies (12 VATS, 14 anterolateral thoracotomy and 20 posterolateral thoracotomy) (10 right lower lobectomies, 16 right upper lobectomies, eight left upper lobectomies and 10 left lower lobectomies and two middle lobectomies) and 12 pneumonectomies (seven right pneumonectomies, five left pneumonectomies) were performed.
The majority of the patients (48/58, 82.75%) had stage I non-small-cell lung cancer (NSCLC) (15/58, 25.86% T1 and 33/58, 56.89% T2). Three (5.17%) patients had T3 with chest wall invasion, requiring additional chest wall resection. Seven (12.06%) patients went to surgery after neo-adjuvant therapy.

A total of 182 recordings were performed, and there were no adverse events with the VRI XP procedure. None of the patients experienced discomfort with the VRI XP procedure.

3.1. Baseline FEV1

The preoperative FEV1 was 2.38 ± 0.61 l; 83.68 ± 20.6% predicted. Predictions were done both for lobectomy and pneumonectomy so that we could compare postoperative spirometric follow-up with the preoperative predictions corresponding to the surgery performed.

3.2. Comparison of ppoFEV1 by VRI XP with spirometric postoperative values

The average ppo values for FEV1 were 66.7 ± 16.03% and 1.90 ± 0.53 l. The postoperative spirometric results were 63.16 ± 14.8% and 1.80 ± 0.512 l. In 94.8% (55/58) of the comparisons, the differences between VRI XP O-Plan ppo FEV1 (%) and spirometric postoperative results were less than 10%. In all the patients with endobronchial findings in bronchoscopy, the differences were less than 10%.

The average ppo values for patients who underwent pneumonectomy (12) were FEV1 (%) 48.6 ± 13.38 and FEV1 (l) 1.46 ± 0.47. The postoperative spirometric results in this subgroup were 55.6 ± 14.5% and 1.58 ± 0.47 l.

In the whole group, Pearson’s correlations for VRI and postoperative FEV1 were \( r = 0.877 \) and 0.865 for FEV1 (%) and FEV1 (l), respectively. Lin’s concordance correlation coefficient was 0.861 (FEV1%) and 0.858 (FEV1 (l)) in the same group. The Bland and Altman test showed an average of 1.771 ± 3.832 and 0.055 ± 0.282 for FEV1 (%) and FEV1 (l) (Figs. 3 and 4).

The correlation, concordance and the Bland and Altman test for FEV1 (%) in patients with lobectomies was 0.793, 0.784 and 1.772 ± 9.937, respectively. For patients with pneumonectomies, the same values were 0.792, 0.694 and 6.997 ± 9.058.

3.3. Correlations in perfusion group

Out of 20 patients with performed Q scan, seven underwent pneumonectomy (four left and three right) and 13 underwent lobectomy. Assuming pneumonectomy for all the patients, the correlation between the predictions done by VRI XP and perfusion scan was 0.74. Lin’s concordance coefficient in this group was 0.700. The Bland and Altman test shows an average of 3.099 ± 7.067. Average ppo values for FEV1 (l) were 45 ± 11% and 47 ± 13%, based on perfusion and VRI XP, respectively.

4. Discussion

In this study, we used a new technique to obtain FEV1 ppo values and demonstrated that VRI predicts with high accuracy lung function after lung resection surgery. Further, comparing VRI with the gold standard (Q scan), we have found high agreement in correlation and concordance between both techniques to predict postoperative lung function.

Several methods for predicting lung function after resection surgery have been used. These range from the simple anatomical estimation based on counting the number of segments to be removed [2], to the use of ventilation (V) and Q scans [13,14], quantitative computed tomography (CT) scans [4], and dynamic perfusion magnetic resonance imaging (MRI) [15]. Of these, the quantitative Q scan is the most commonly accepted and best validated technique that serves as the reference standard against which others are compared.

Our results are similar to those reported in previous studies with radiospirometric techniques [5,8,16]. Markos et al. [6] described significant correlations between predicted and actual values for FEV1% for pneumonectomy \( (r = 0.51) \) and for lobectomy \( (r = 0.89) \) using radionuclide techniques. In another study, quantitative CT of chest compared well to Q scan for predicting postoperative FEV1 in patients who underwent pneumonectomy \( (n = 28, r = 0.88 \text{ vs } r = 0.86) \) and lobectomy \( (n = 16, r = 0.90 \text{ vs } r = 0.80) \) [2].
This is also similar to our experience, with global correlation of 0.838 and 0.865 for FEV₁ (%) and (l), respectively.

This new technique could have universal applicability in patients who are candidates for lung resection. It is easy to perform, is non-invasive and is a radiation-free system next to the autonomy for the surgical team to convert the device to assess postoperative function in all patients.

A tendency to underestimate the postoperative spirometric values has been associated with the use of Q scan for calculating ppoFEV₁ in patients with pneumonectomies [9]. In contrast to this, our data demonstrate the same accuracy in the predictions for pneumonectomy and lobectomy using VRIₓp.

Besides being accurate, an advantage of VRI is its ease of use in practice. Due to time constraints in performing hospital procedures and the lengthy time to receive results (1—2 weeks for perfusion scans), the quick and simple VRIₓp test that provides immediate results can be regarded as a beneficial innovation in the preoperative assessment protocol.

In the past few years, many articles have been published defining the utility of this diagnostic device in different diseases. In this sense, multiple studies are available on the evaluation and reproducibility of recordings in healthy individuals [17,18], on the value of VRIₓp in subjects with various lung conditions [10], for example, in patients with pleural effusion or pneumonia [19]; patients under mechanical ventilation [10]; lung-transplant patients [20]; paediatric patients [21] and in other clinical situations in the intensive care unit (ICU) and in emergency medicine [22—24]. As Maher [17] has demonstrated in healthy subjects, the acoustic lung imaging is reproducible and can be interpreted with a high degree of accuracy by the same and different reviewers. In this study, the authors report that the quantitative measurement of acoustic recordings is highly reproducible with an intraclass correlation score of 0.86 (very good agreement). Intra-class correlations for inter-rater agreement and reproducibility were 0.61 (good agreement) and 0.86 (very good agreement), respectively.

We have studied the postoperative lung function 4—6 weeks after the operation. We know that patients who have undergone lung resection reach to their baseline later, 3—6 months after lung resection. In our hospital, adjuvant therapy begins 4—6 weeks after the surgical procedure. To avoid mistakes and to assure that the drop in the lung function was only due to lung resection and not because of possible adverse effects of the chemo- and radiotherapy in the lung (pneumonitis, pulmonary fibrosis, etc.) we decided to perform the postoperative spirometry only 4—6 weeks postoperatively.

It is important to take into account the fact that the images obtained by VRIₓp are not anatomically well delimited.

4.1. Limitations

Because of the novelty of VRIₓp application in the estimation of ppo lung function, in the design of the study, we considered the postoperative FEV₁ as our gold standard. In this way, we could compare the predictions by VRIₓp with the real objective reference, overcoming the limitations of lung Q scan, a technique that also served for comparison in a group of patients.

VRIₓp measurements are based on lung sounds. For this reason, the presence of secretions or bronchial obstruction can interfere with the results. In patients with these features, special attention must be paid to avoid possible artefacts (i.e., active manoeuvres to cough and expectorate in case of secretions).

In some patients with endobronchial obstruction, we found an increased amount of lung sounds in the dynamic image with a possible false QLD in the stricture area. In these cases, specially in partial bronchial obstruction of proximal localisation, the quantitative data could be wrongly interpreted with subsequent error in the prediction. Taking the bronchoscopic findings into account, the 12 patients of our study with endobronchial lesions were correctly evaluated, showing a difference between the predictions and the postoperative measurement always smaller than 10%. We stress the importance of taking special care in the evaluation of these patients.

Patients with special characteristics are worse candidates for this technique. For example, in cachectic patients or subjects with hirsutism in the back, the adhesion of the sensors can be difficult due to bone prominences or hair. Nevertheless, in our experience after more of 300 000 recordings in around 100 000 patients, only in two patients have the adhesion of the sensors been impossible (two cachectic patients). In patients with pacemakers or cardiac mechanic valves, the appearance of interferences in the sound recordings could be observed.

It must be kept in mind that VRIₓp measures acoustic energy, not lung perfusion or ventilation. Quantitative breath sound recording is a simple procedure that is performed by a trained staff member using a standard protocol. The technique is time saving and does not require administration of intravenous, inhaled or external radiation. Despite its relative simplicity, appropriate technical procedure needs to be followed to prevent erroneous results. Proper patient selection and preparation are crucial to avoid recording artefacts caused by ambient noise such as that arising from the proximity of air-conditioning vents. During testing, attention should be paid to the quality and amplitude of the tracings.

The interpreting clinician needs to acquire further VRIₓp interpretation skills to correctly interpret the information and to avoid errors. Interpretation of tests results must also include clinical, bronchoscopic and radiographic data, as we have previously described.

In our opinion, the VRIₓp and VRIₓp O-Plan are techniques that should be introduced in the preoperative protocols for lung resection surgery because of their good correlation with postoperative lung function. Comparison with perfusion scans also shows similar results, but as we stated before, this technique offers the advantage of reducing overall costs in the preoperative evaluation process and provides a non-invasive, promising complementary tool to pulmonary function testing.

References