AIRFIX®: the first digital postoperative chest tube airflowmetry—a novel method to quantify air leakage after lung resection

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Abstract

Objective: Prolonged air leak after pulmonary resection is a common complication and a major limiting factor for early discharge from hospital. Currently there is little consensus on its management. The aim of this study was to develop and evaluate a measuring device which allows a simple digital bedside quantification of air-leaks compatible to standard thoracic drainage systems. Patients and methods: The measuring device (AIRFIX®) is based upon a ‘mass airflow’ sensor with a specially designed software package that is connected to a thoracic suction drainage system. Its efficacy in detecting pulmonary air-leaks was evaluated in a series of 204 patients; all postoperative measurements were done under standardized conditions; the patients were asked to cough, to take a deep breath, to breathe out against the resistance of a flutter valve, to keep breath and to breathe normally. As standard parameters, the leakage per breath or cough (ml/b) as well as the leakage per minute (ml/min) were displayed and recorded on the computer.

Results: Air-leaks within a range of 0.25—45 ml/b and 5—900 ml/min were found. Removal of the chest tubes was done when leakage volume on Heimlich valve was less than 1.0 ml/b or 20 ml/min. After drain removal based upon the data from chest tube airflowmetry none of the patients needed re-drainage due to pneumothorax.

Conclusion: The AIRFIX® device for bedside quantification of air-leaks has proved to be very simple and helpful in diagnosis and management of air-leaks after lung surgery, permitting drain removal without tentative clamping.

Keywords: Airflowmetry; Pulmonary air-leaks; Pneumothorax

1. Introduction

Air-leaks continue to be the most common complication and an accepted morbidity after lung surgery. Minor leaks are generally innocuous and can be managed conservatively by chest tube drainage whereas prolonged ones, defined as those lasting more than 7 days may require further interventions resulting in a delay of discharge and thus causing additional costs [1—3].

Currently there is little consensus on the management of the latter. Published treatment modalities [4—6] including change of the degree of suction, placement of additional chest tubes, or re-drainage, chemical pleurodesis or even re-operation [4,7] are usually based on a semi-quantitative measurement or on only approximate assessment of air-loss through drainages by mere inspection.

Because of the lack of objective data on air-loss across the lung surface 'tentative treatments' often precede the adequate one.

A quantification of the air leak might help to develop treatment algorithms and to define the correct moment for drain removal, thereby reducing morbidity and treatment costs.

The intention of this project was to develop a safe, reproducible and clinically applicable system providing a digital bedside quantification of postoperative air-leaks. The device was designed to be connected in-line with the chest tube. In our patients suction drainage systems of the Buelau-type were used.

2. Patients and methods

Between July 2002 and December 2004 clinical evaluation of the AIRFIX® measurement device, developed in cooperation with the University of Technology Graz [8], was performed in 204 patients, all of whom had an air leak of at least 150 but not more than 250 ml/tidal volume after
closure of the pleural cavity following lung resection. Wedge resection \( (n = 23) \) or lobectomy \( (n = 181) \) and complete lymphadenectomy due to non-small cell lung cancer were performed. In each case intraoperative air leakage and air leakage through the drainage system after closure of the chest as well as in the further postoperative course were documented. Informed consent for intra- and postoperative airflowmetry was obtained.

After lung resection air-leaks on the lung surface were pinpointed by rinsing the lung with warm saline solution during ventilation at a maximum inspiratory pressure of 25 cmH\(_{2}\)O. Leaks scored as grade 3 (coalescent bubbles) were sutured with pledget-reinforced PDS 3-0 sutures (Johnson & Johnson, Ethicon, Hamburg, Germany) and reduced to at least grade 2 (stream of bubbles). Grade 2 leakages were covered with a collagen fleece coated with fibrinogen and thrombin coagulation factors (TachoSil \(^{\text{R}}\) Nycomed, Langebjerg, Rokskilde, Denmark), whereas grade 1 leakage (single bubbles) were mostly left to heal spontaneously.

Intraoperative quantitative spirometry was performed in all patients. The pleural cavity was closed when macroscopic leakage of no more than grade 1 or 2 was present, corresponding to less than 250 ml spirometric air-loss per tidal volume.

In patients who underwent lobectomy two chest tubes were placed, one of which was removed on the first or second postoperative day, in patients who underwent wedge resection only one tube was inserted. In all cases —12 cm continuous suction was applied by using a drainage system of the Buelau-type.

The routine procedure for air-leaks used at our division was applied until removal of the chest tubes, provided that the initial degree of air-loss was found to continuously diminish or subside, respectively, during the first three postoperative days. If the air-loss persisted unchanged beyond the 3rd day, a Heimlich valve was connected distally to the fluid catchment tank of the system (Fig. 1). If the lung remained expanded on chest-roentgenograms or if a small, stable, asymptomatic pneumothorax developed, the valve was left in place until removal of the drainage. In case of an enlarging pneumothorax or in presence of dyspnea —12 cm suction was re-established and left until the air-leak gradually subsided and disappeared or until a decision for redo-operation was made. In each patient a control chest-roentgenogram was done on the day after removal of the last drainage.

2.1. The digital chest tube airflowmeter, AIRFIX\(^{\text{R}}\) (Figs. 1 and 2)

The measuring device (AIRFIX\(^{\text{R}}\)) is based upon a ‘mass airflow’ sensor with a specially designed software package. An embedded data acquisition system digitizes the output signal of the mass airflow sensor using a 12-bit successive approximation switched capacitor ADC. The data acquisition system performs basic gain and offset calculations and continuously sends measurement values over a serial data link to a hand held processor, from which data can be transmitted to any desk PC for storage or printout. Only the netto flux into one direction (from the drainage into the ‘open’) is recorded as air-leak. The amount of air moving into the opposite direction (shift of intrapleural dead space, e.g. after lobectomy) is subtracted both from the leakage per breath and from the leakage per minute.
The flash memory of its microcontroller is in-system programmable without disassembly. Sensor and application-specific parameters are stored in the electrically erasable memory area (EEPROM) of the microcontroller. The data acquisition system operates from an unregulated power supply (primary or rechargeable batteries). A combination of switching and linear regulators boosts the overall efficiency and also provides a stable and low noise supply voltage for the mass airflow sensor. A disposable catchment tank for fluids is installed proximal to the inflow-port of the system, preventing a spilling of blood or serous fluid from the chest tube into the measuring device (Figs. 1 and 2).

2.1.1. The device manufacturer is TEUP's Ltd., Deutschlandsberg, Austria

For the measurement the inflow-port of the AIRFIX® device is connected in-line with the chest tube (Fig. 1). The drainage system is plugged to the outflow-port. If suction-based drainage systems are connected to fittings set at high negative pressure levels profuse formation of bubbles occurs in the system which may cause measuring artefacts due to the high sensitivity of the device. In such cases the degree of negative pressure at the fitting has to be reduced for the measurement or the outflow-port has to be temporarily armed with a Heimlich valve in order to establish optimal measuring conditions. The mass airflow sensor connected in-line with the chest tube was sterilized by ETO-gas after each application.

Following each measurement the data acquired can be printed in an 'airflowmetry report' to be stored with the documents of the respective patient.

2.2. Assessment of air-leakage

In each patient the presence or absence of a leakage was crudely assessed by watching the chest tubes for the passage of bubbles.

The definitive amount of leakage was displayed and recorded as ml leakage per breath (ml/b) and ml leakage per minute (ml/min).

The first measurements were scheduled on the first and on the third postoperative days. If the air-leak diminished the next measurement was done when there was no more visually detectable air-loss over the drainage. If in these cases the measurements showed no more leakage the drainage was removed, if not, daily measurements were continued until the air-leak had subsided. In cases with fistulae persisting unchanged beyond the third postoperative day regular measurements were scheduled on a daily basis. The latter were continued until the leakage diminished to less than the agreed threshold value or until re-operation.

The degree of suction during the measurements followed a standard protocol which included −20 cmH₂O, −12 cmH₂O and Heimlich valve on the first postoperative day and −12 cmH₂O and Heimlich valve during the following measurements. The patients were asked to breathe normally, to take deep breaths, to cough and to breathe out against the resistance of a flutter valve. As standard parameters, the leakage per expiration as well as the leakage per minute were displayed and recorded on the computer.

Removal of the chest tubes was done when the air-leakage volume was less than 20 ml/min or less than 1, 0 ml/b during normal breathing on Heimlich valve, this amount of air-loss being considered due to shifts in the measuring system itself.
The threshold of fluid-drainage volume over the chest-drain considered apt for removal was 250 ml/24 h.

2.3. Validation of the system

Immediately after closure of the chest the AIRFIX device was connected to the drainage system as described above. The air-leak displayed by the AIRFIX device was compared with the one shown during simultaneous intraoperative spirometry.

Daily chest-roentgenograms were taken until no further leakage could be measured. A control roentgenogram was done after removal of the last chest tube.

2.4. Statistics

Statistical analysis was performed by utilizing Student’s t-test for paired values.

3. Results

The validation of the AIR-FIX system by comparing the leakage with the one measured by intraoperative spirometry showed almost identical values (±0.5 ml/b).

A total of 7296 measurements was performed (mean: 35.76/patient, range: 28—92). The digital bed-side airflowmetry of chest tubes was performed without any complications. A measurement series (8 or 12 measurements, respectively) took 10—15 min. Depending on the suction level and the type of breathing manoeuvre air-leaks within the range of 0.25—45 ml/b or 5—900 ml/min were documented (Table 1). All single measurements of each patient were stored as airflow-report in the patient’s records.

Table 1
Range of air leakage in various breathing manoeuvres under different suction levels (ml/min)

<table>
<thead>
<tr>
<th>Suction Level</th>
<th>Normal Breathing</th>
<th>Forced Breathing</th>
<th>Cough</th>
<th>Flutter Valve</th>
</tr>
</thead>
<tbody>
<tr>
<td>−20 cmH2O</td>
<td>40—340</td>
<td>15—260</td>
<td>5—100</td>
<td>65—440</td>
</tr>
<tr>
<td>−12 cmH2O</td>
<td>65—450</td>
<td>25—350</td>
<td>10—150</td>
<td>35—350</td>
</tr>
<tr>
<td>Heimlich Valve</td>
<td>70—900</td>
<td>35—450</td>
<td>20—370</td>
<td>35—350</td>
</tr>
<tr>
<td></td>
<td>85—440</td>
<td>35—350</td>
<td>20—320</td>
<td></td>
</tr>
</tbody>
</table>

Number of measurements, N = 204.

A statistical comparison of the data obtained from measurements of identical suction levels (i.e. −20 mmHg or −12 mmHg or Heimlich valve) but during different breathing manoeuvres (i.e. normal breathing, deep breath, cough and flutter valve) showed significant differences (Figs. 3 and 4). Air-leakage was maximal in each type of breathing while applying a suction level of −20 cmH2O (p < 0.05). The difference between degrees of air-leakage was maximal when comparing −20 cm of suction to Heimlich valve (p < 0.05). Less distinct but still significant was the difference between −12 cm and Heimlich valve (p < 0.05).

Normal breathing involved the lowest leakage volume at any suction level. In contrast, coughing caused the highest leakage volume in each suction setting (p < 0.05). During application of a suction level of −12 cm or when using Heimlich valve, respectively, a higher air-leakage was found when blowing the flutter valve compared to breathing deeply (p < 0.05) (Figs. 3 and 4).

Coughing in presence of a Heimlich valve resulted in insignificantly higher air-leakage than normal breathing while applying a suction level of −20 cmH2O (p > 0.05).

In 26 out of 174 patients in whom air leakage was no longer visually detectable within 2—5 days airflowmetry showed minor, but still measurable air-loss that lasted up to 7 days.

Fig. 3. The influence of different breathing manoeuvres on postoperative air-leak using Heimlich valve (a) and the influence of increased expiratory resistance on postoperative air leakage using a flutter valve in comparison to normal breathing (b).
Based upon the measurements the decision for chest tube removal was postponed accordingly. In 31 patients an air leak was measurable beyond the 7th postoperative day. In these latter patients the time of drainage based upon the measurements was between 9 and 24 days. In four of them redo-thoracotomy was done 10—13 days postoperatively. In these four cases no change whatsoever of leakage rates on DCO 12 cm suction was found throughout the postoperative course (mean leakage rates on normal breathing: 227, 235, 247, 260 ml/min). When set on the Heimlich valve the leakage persisted at a lower level (leakage rates: 83, 86, 91, and 92 ml/min, respectively), while an expanding pneumothorax and dyspnea developed shortly after connecting the valve. On re-thoracotomy in each of the four cases a small broncho-pleural fistula was identified and closed by pledget-reinforced PDS 3-0 sutures. The further course was uneventful.

No problems whatsoever resulted from the temporary changes in suction level required during the measurement periods or from the intermittent in-line connection of the system to the chest-drain.

None of the patients required re-drainage due to recurrent pneumothorax after drain removal.

4. Comment

Air-leaks and especially persistent ones present one major problem in the postoperative course of patients undergoing lung surgery, thus constituting a major factor for prolonged hospitalization [1].

Countless surgical attempts to prevent any air leak in the first place have proved that the lung surface cannot always be sufficiently sealed. A randomized multicentre study performed by Wain et al. [9] showed intraoperative air-leaks in more than 70% of patients who had undergone pulmonary resections using standard techniques for closure of lung parenchyma.

In the postoperative course of a bronchopleural fistula the decision whether to set chest tubes on different suction levels, on water seal or on Heimlich valve is a crucial one.

In fact, the surgeon’s subjective estimation and not precise reproducible data [5] commonly determine the procedure. In this context, Cerfolio et al. [4—6] suggested the use of clear-cut algorithms for the treatment of air-leaks. In a first attempt air-leaks were detected on the basis of bubble-formation by putting the end of a Heimlich valve into a tank of water during forceful breathing or coughing. In another setting a semi-quantitative assessment was accomplished by the use of a commercially available air-leak meter integrated into a chest drainage system (Sahara Pleur-evac, Deknatel, Boston, MA, USA): the meter scores leaks from 1 to 7 with 7 being the highest. By taking several deep breaths bubbles become visible in the drainage system, where they move into one of seven chambers. The larger the leak the more chambers the bubbles move into. However, the main shortcomings of this method are its dependence on subjective interpretation of the course of bubbles and the impossibility to record, store or reproduce the test results. The problem of an enlarging pneumothorax after the reduction of the suction or after drain removal based upon these measurements still persists [4—6].

A clear-cut quantification of the air-loss from the lung surface may help to both establish and validate algorithms for management of postoperative bronchopleural fistulae and enable an exact determination of the correct time for drain removal.

In the present study, a newly developed tool for quantification of postoperative air-leaks was evaluated in patients all of whom had air-leaks on the lung surface at the end of the operation. The system was easily applicable in everyday clinical routine. No problems whatsoever emerged.
from the temporary changes in suction levels required for the measuring procedures. In contrast to the usual 'visual' assessment of air-leaks by bubbles moving through chest drains or into specially designed 'chambers' the new system also permits a quantification of the netto-air-loss, subtracting air shifts out of and into dead pleural space — a phenomenon often encountered after lobectomies [10].

Using the AIRFIX® device the influence of different breathing manoeuvres and of increased expiratory resistance as well as the influence of different suction algorithms (–20, –12 cm and Heimlich) on postoperative air leak could be demonstrated very clearly and reproducibly, underlining the fact that in cases of minor air-leak a reduction of the degree of negative intrapleural pressure will enhance healing of the fistula in most cases.

On the other hand, air-leaks were detected in cases presumed to have none by visual assessment. It cannot be stated whether or not clamping or removal of the drainage based upon visual assessment would have been ensued by enlarging pneumothorax and/or the necessity for re-drainage in these patients. When the decision for chest-tube removal was based upon strict criteria derived from the measurements, however, re-drainage was not mandatory in any patient.

A further benefit of the system is the possibility of electronical storage of the data with the option of a printout, permitting repeated objective comparative evaluations in the course.

In this study, daily chest-roentgenograms were performed in order to early diagnose a pneumothorax in the context of the setting. Our initial experience with the measuring device suggests a high degree of reliability, which may reduce the need for control chest-roentgenograms. A further reduction of costs and of discomfort for the patient may derive from the fact that the measuring system may obviate the need for tentative clamping and may thus enable an earlier discharge from hospital.

In conclusion, the AIRFIX® device fulfils many requirements for the introduction of an evidence-based algorithm for the evaluation and treatment of air-leaks, reducing morbidity, hospitalization and treatment costs. However, further studies on this issue are necessary.

**References**