The Efficacy of Postoperative Incentive Spirometry Is Influenced by the Device-Specific Imposed Work of Breathing*

Josef Weindler, MD; and Ralph-Thomas Kiefer, MD

Study objectives: The study evaluated the impact of the additional imposed work of breathing (WBimp) generated by two different spirometers on postoperative incentive spirometry performance in patients at high risk and moderate risk for postoperative pulmonary complications (PPCs). Additionally, we investigated whether maximal inspiratory pressure (PImax) is an easy estimate of the WBimp imposed by incentive spirometers.

Design: Prospective, randomized, single-blind clinical trial.

Setting: ICU of a university hospital.

Interventions and measurements: Thirty male patients were assigned to a group at high risk for PPCs (group A; inspiratory capacity [IC], < 1.6 L) or to a group at moderate risk for PPCs (group B; IC, 1.6 to 2.5 L) after upper-abdominal, thoracic, or two-cavity surgery. On the first or second postoperative day WBimp, IC, and PImax were recorded without spirometers (baseline) and during incentive spirometry with the Mediflo spirometer (Medimex; Hamburg, Germany) (high WBimp) and the Coach spirometer (Kendall; Neustadt, Germany) (low WBimp) using a pneumotachograph. In group A, the baseline and the ICs for both spirometers only differed slightly. In group B, the IC was significantly reduced for the Mediflo (p < 0.05), which imposed a WBimp twice as high as the Coach (p < 0.01). Pmax was significantly increased for both the Mediflo and the Coach (p < 0.01). Pmax was positively correlated with WBimp (r = 0.8).

Conclusions: Incentive spirometers differ considerably in their additional Wbimp with a potential impact on the efficacy of postoperative incentive spirometry performance. PImax might be an easy clinical estimate for the WBimp during incentive spirometry. Incentive spirometers with low WBimp permit increased maximal sustained inspiration and, thus, enhanced incentive spirometry performance, and, therefore, it might be more suitable for use in postoperative respiratory care.

(CHEST 2001; 119:1858–1864)

Key words: incentive spirometry; inspiratory capacity; maximal sustained inspiration; respiratory care; work of breathing

Abbreviations: IC = inspiratory capacity; PImax = maximal inspiratory pressure; PPC = postoperative pulmonary complication; WBimp = imposed work of breathing

Recovery from major surgery is primarily endangered by postoperative pulmonary complications (PPCs), eg, atelectasis, pneumonia, or pulmonary dysfunction, which remain the major causes of postoperative morbidity and mortality.\textsuperscript{1,2} Taking into consideration that effective therapy of postoperative respiratory disorders still is difficult, the importance of effective prophylactic and therapeutic respiratory training must be emphasized. At present, incentive spirometry is used clinically as part of the routine prophylactic and therapeutic regimen in perioperative respiratory care. However, the efficacy of incentive spirometry still is controversially discussed.\textsuperscript{2,3}

Since the first incentive spirometer was constructed by Bartlett et al\textsuperscript{1} in the 1970s, many different types of incentive spirometers have been developed. In general, the incentive spirometer is activated by an inspiratory effort, that is, breathing is visualized by an uplifted plate or ball in a transparent cylinder during sustained inspiration. On a calibrated scale on the cylinder, the uplifted plate or ball on the spirometer displays either the inspired volume (a volume-oriented incentive spirometer) or the generated flow (a flow-oriented incentive spirometer).\textsuperscript{4}

Surprisingly, little is known about differences in
construction and function between various types of incentive spirometers and about their potential impact on therapeutic efficacy. One clinically relevant parameter is the additional imposed work of breathing (WBimp) generated by different incentive spirometers, which might directly influence incentive spirometry performance. However, until the date of this study, the clinical relevance of the device-specific additional WBimp had remained to be investigated. Therefore, two incentive spirometers, differing in their WBimp, were compared with respect to postoperative incentive spirometry performance in patients at risk for PPCs.

**Materials and Methods**

**Patients**

After the study was approved and written informed consent was obtained, 30 male patients were included in the study after undergoing elective upper-abdominal, thoracic, or two-cavity surgery. To avoid the influence of well-known, significant, gender-specific differences in functional respiratory parameters, only male patients were included in the study. Depending on postoperative inspiratory capacity (IC) and the subsequent risk for PPCs, patients were assigned to a group of patients at high risk for PPCs (group A; postoperative IC, < 1.6 L; n = 15) or to a group of patients at moderate risk for PPCs (group B; postoperative IC, 1.6 to 2.5 L; n = 15). Patients at low risk for PPCs (postoperative IC, > 2.5 L) were not included because they did not significantly benefit from postoperative incentive spirometry. Patients experiencing relevant preoperative pulmonary disease (eg, obstructive or restrictive lung disease) who were identified by preoperative body plethysmography and by obvious abnormalities in preoperative arterial blood gas analyses were excluded. All measurements were performed in the late afternoon of the first or second postoperative day. An experienced respiratory therapist monitored the respiratory training to ensure the efficacy of the incentive spirometry. The patients were blinded from the type of spirometer in use. Measurements were performed only in patients who were not sedated (Tables 1, 2).

All measurements were performed with a diagnostic device (Transferscreen; Erich Jaeger GmbH; Hoechberg, Germany) equipped with a pneumotachograph and pressure transducers that allow the measurement of functional respiratory parameters and the calculation of the physiologic work of breathing based on inspiratory pressure changes, detected with an esophageal balloon. To calculate the additional WBimp using the incentive spirometers, the pressure transducers were placed between the patient and the incentive spirometers. Before all measurements, the diagnostic device was calibrated according to ambient temperature and pressure, saturated.

**Incentive Spirometers**

To compare the impact of the WBimp on incentive spirometry performance, we chose a device with a high WBimp (Mediflo; Medimex; Hamburg, Germany) and a device with a low WBimp (Coach; Kendall; Neustadt, Germany). The choice also was influenced by the fact that these incentive spirometers are commonly used in our country.

**Mediflo:** The Mediflo is a flow-oriented incentive spirometer with high additional WBimp. Corresponding to the inspiratory flow, a ball is uplifted and kept suspended by the sustained inspiratory flow. The flow rate can be regulated between 200 mL and 1,200 mL. Postoperatively, the vital capacity is significantly reduced, and, thus, a significant reduction of the achievable inspiratory flow during sustained slow inspiration must also be expected. Therefore, a flow of 200 mL was chosen for all measurements. To make the ball rise and keep it suspended, the patient has to produce a high inspiratory pressure. The ball serves as visible feedback of the inspiratory flow and indicates the obtained flow on a calibrated scale on the transparent cylinder of the spirometer (Fig 1, 2).

**Coach:** The Coach is a volume-oriented, technically more sophisticated incentive spirometer. On two calibrated scales, the inspired volume (0 to 1,000 mL) as well as the inspiratory flow are displayed by plates, which are lifted up and kept suspended by the sustained inspiration. Compared to the Mediflo, considerably lower inspiratory pressure and WBimp are required. The Coach possesses a one-way valve to prevent contamination of the system during expiration (Fig 1, 2).

**Experimental Setup**

For the experiments, the incentive spirometers were integrated into the pneumotachograph with the patients blinded to which spirometer they were connected to. By integrating a one-way valve, inspiration was directed through the incentive spirometer and expiration over the valve. To avoid an additional resistance by the mouthpiece and tubing of the incentive spirometers, these were disconnected before integration in the diagnostic device (the Transferscreen). The inspiratory pressure was directly measured with the pneumotachograph integrated into the mouthpiece.

Every patient received inspiratory training with the Mediflo as well as with the Coach. To exclude an effect of sequencing, the

**Table 1—Biometrical Data of Group A, at High Risk for PPCs, and Group B, at Moderate Risk for PPCs**

<table>
<thead>
<tr>
<th>Group</th>
<th>Age, yr</th>
<th>Height, cm</th>
<th>Weight, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (n = 15)</td>
<td>50.3 ± 14.7</td>
<td>173 ± 6.1</td>
<td>75.0 ± 16.0</td>
</tr>
<tr>
<td>B (n = 15)</td>
<td>51.7 ± 12.7</td>
<td>172 ± 3.8</td>
<td>66.4 ± 8.1</td>
</tr>
</tbody>
</table>

*Values given as mean ± SD.

**Table 2—Surgical Procedures Performed in Group A Patients, at High Risk for PPCs, and Group B Patients, at Moderate Risk for PPCs**

<table>
<thead>
<tr>
<th>Type of Surgery</th>
<th>Procedures</th>
<th>Group A (n = 15)</th>
<th>Group B (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdominal</td>
<td>Cholecystectomy</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Whipple procedure</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Gastrectomy</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Anus praeter</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Duodenoejejunostomy</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pancreatic surgery</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Explorative laparotomy</td>
<td>—</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Liver surgery</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Thoracic</td>
<td>Explorative thoracotomy</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Segmental lung resection</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>Two-cavity</td>
<td>Esophageal resection</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Esophageal rupture</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

*Values given as No.
two incentive spirometers were used in a randomized order. Primarily, the patient’s maximal inspiration, the normal expiration, and the WBimp of the system were recorded without an incentive spirometer as a baseline measurement. After a 10-min rest period, the same values were recorded for the first incentive spirometer. After another 45-min rest period, the baseline values for the second spirometer were recorded. All measurements were performed twice.

**IC**

IC, defined as the maximal volume of inspiration after a normal expiration, is an indicator for the expansion capacity of the lung. Postoperatively, IC is decreased more significantly in patients after upper-abdominal and thoracic surgery. The extent of the postoperative reduction of IC allows the identification of patients at risk for pulmonary complications.1,4

**Maximal Inspiratory Pressure**

Maximal inspiratory pressure (P\text{\text{max}}) is an important indicator for assessing the strength of inspiratory muscles, especially for diagnosis and follow-up in patients with neuromuscular or traumatic deficiencies. In patients with decreased respiratory muscular strength because of emphysema, thoracic deformations, or drug effects, P\text{\text{max}} is used as a diagnostic parameter. Furthermore, during mechanical ventilation it is used as a criterion for successful weaning and extubation. P\text{\text{max}}, in the clinical setting, can be easily measured. The correlation between P\text{\text{max}} and WBimp was tested, hypothesizing that P\text{\text{max}} might be an easy estimate for the WBimp of an incentive spirometer. All P\text{\text{max}} measurements were performed at functional residual capacity.

**WBimp**

The additional WBimp was calculated by integrating the area of inspiratory pressure times the inspiratory volume using the diagnostic device (Transferscreen).5 The WBimp of the system was recorded at baseline before the integration of the incentive spirometers. During incentive spirometry, the device creates an additional respiratory resistance that needs to be overcome by the patient. After integration of the incentive spirometers into the diagnostic device, the WBimp values of the devices were measured (Fig 2).

**Statistical Analysis**

Statistical analysis was performed with a statistical software package (Statistical Package for Social Sciences; SPSS; Chicago, IL). Distribution analysis was performed using the Kolmogorov-Smirnov test. For normal distributed data, analysis of variance was performed followed by the Student’s \( t \) test. Data not normally distributed were analyzed with the Mann-Whitney \( U \) test. \( \alpha \) was set for all tests at 5%. The relationship between P\text{\text{max}} and WBimp was calculated as the Pearson product moment correlation.

**RESULTS**

**Biometric Data**

In each group, 15 patients were included. Both groups were very comparable concerning mean (± SD) age (group A, 50.3 ± 14.7 years; group B, 51.7 ± 12.7 years), mean height (group A, 173 ± 6.1 cm; group B, 172 ± 3.8 cm), and mean weight (group A, 75 ± 16.0 kg; group B, 66.4 ± 8.1 kg). The observed differences were not significant (Table 1).

**IC**

In group A, the mean baseline IC (1.26 ± 0.18 L) and the mean ICs using the Mediflo (1.32 ± 0.45 L) or the Coach (1.29 ± 0.33 L) differed only slightly, and results were not statistically significant. In group B, the mean baseline IC (1.95 ± 0.1 L) did not significantly differ from the IC measured using the Coach (1.89 ± 0.33 L). The Mediflo however,
caused a significant reduction (1.6 ± 0.39 L; p < 0.05) in IC compared to baseline and the Coach (Table 3 and Fig 3).

P_{\text{max}}

The lowest P_{\text{max}} values were found during baseline measurement, with no significant difference between the groups (group A, 0.19 ± 0.07 kPa; group B, 0.24 ± 0.1 kPa). The P_{\text{max}} values using the Mediflo in both groups significantly increased (group A, 0.99 ± 0.36 kPa; group B, 0.98 ± 0.4 kPa) compared to baseline values and those using the Coach (group A, 0.43 ± 0.13 kPa; group B, 0.49 ± 0.24 kPa; p < 0.01; Table 3 and Fig 4).

WB_{\text{imp}}

The additional WB_{\text{imp}} was lowest at baseline (group A, 0.32 ± 0.09 J/L; group B, 0.33 ± 0.13 J/L). WB_{\text{imp}} significantly increased using the Mediflo (p < 0.01) and the Coach (p < 0.01) compared to baseline. WB_{\text{imp}} values for the Mediflo were approximately twice those of the Coach (group A, 1.0 ± 0.31 vs 0.51 ± 0.18 J/L, respectively; group B, 1 ± 0.33 vs 0.53 ± 0.19 J/L, respectively; Table 3 and Fig 4).

Correlation of P_{\text{max}} and WB_{\text{imp}}

To test the hypothesis that the P_{\text{max}} allows the estimation of the WB_{\text{imp}} of an incentive spirometer, the correlation between these two variables was calculated. The coefficient of r = 0.8 indicates a close relationship between P_{\text{max}} and WB_{\text{imp}}.

**DISCUSSION**

The therapeutic efficacy of incentive spirometry is controversially discussed in the literature.\(^\text{3,7--14}\) However, manifold variables, whether patient-related (eg, age, constitution, or concomitant pulmonary disease) or care-related (eg, type of surgery, anesthesia, or analgesia), are supposed to have an impact on the efficacy of respiratory care and yielded inconsistent results. Clinical observations indicate that not every patient will benefit from respiratory care. Schwieger et al\(^6\) demonstrated the lack of benefit of postoperative incentive spirometry in patients with an American Society of Anesthesiology physical status of I or II undergoing elective cholecystectomy. Hall and colleagues\(^14\) compared incentive spirometry and chest physiotherapy for the prevention of pulmonary complications after upper abdominal surgery and found them to be equivalent. Christensen et al\(^15\) compared the efficacy of chest physiotherapy with chest physiotherapy and positive expiratory pressure, and compared chest physiotherapy with both positive expiratory pressure and inspiratory resistance after upper-abdominal surgery. There were no statistically significant differences in the incidence of PPCs. The authors, however, postulate that insuffi-
cient self-administration of the respiratory training might be a possible explanation. Celli and colleagues\textsuperscript{16} compared intermittent positive-pressure breathing, incentive spirometry, and deep-breathing exercises in a monitored postoperative regimen in patients who had undergone abdominal surgery with no treatment in control subjects. For monitored incentive spirometry, the authors reported a significantly lower incidence of PPCs and significant shorter hospital stays.\textsuperscript{16} Hall et al\textsuperscript{7} showed that incentive spirometry was the most efficient prophylaxis against pulmonary complications in high-risk patients after abdominal surgery. In summary, there is growing evidence in more recent studies that incentive spirometry is effective. However, its effectiveness depends on the selection of patients, careful instruction, and supervision of patients during respiratory training. Furthermore, the combination of incentive spirometry with chest physiotherapy, early mobilization, and sufficient analgesia improves the efficiency of perioperative incentive spirometry.\textsuperscript{7–11,17,18}

Surprisingly, to date only very few studies concerned with incentive spirometry focused on the technical aspects of different incentive spirometers and their potential impact on clinical incentive spirometry performance. During incentive spirometry, an additional WBimp is generated by the device that depends on constructional characteristics such as the diameter of the spirometer cylinder and the shape and weight of the plate or ball that is lifted by the inspiratory effort. The patient has to overcome this additional WBimp by increased inspiratory effort. So far, only two reports\textsuperscript{4,5} demonstrated important technical and functional differences between the devices. Mang et al\textsuperscript{4} tested different volume and flow-oriented spirometers in the laboratory, simulating typical conditions of the postoperative period (ie, vital capacity, \(\leq 2.5\) L; inspiratory flow, \(\leq 1\) L/s). The authors noted significant discrepancies between the measured inspiratory flow necessary for effective incentive spirometry and that indicated by the manufacturer (deviations of 25 to 50\% for three flow-oriented devices. In two volume-oriented devices, deviations of \(\pm 10\%\) between the volumes measured in the laboratory and the volumes indicated on the

<table>
<thead>
<tr>
<th>Device</th>
<th>Group A</th>
<th>Group B</th>
<th>Group A</th>
<th>Group B</th>
<th>Group A</th>
<th>Group B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>1.26 ± 0.18</td>
<td>1.95 ± 0.1</td>
<td>0.32 ± 0.09</td>
<td>0.33 ± 0.13</td>
<td>0.19 ± 0.07</td>
<td>0.24 ± 0.1</td>
</tr>
<tr>
<td>Coach</td>
<td>1.29 ± 0.33</td>
<td>1.89 ± 0.33</td>
<td>0.51 ± 0.18\†</td>
<td>0.53 ± 0.19\†</td>
<td>0.43 ± 0.13\†</td>
<td>0.49 ± 0.24\†</td>
</tr>
<tr>
<td>Mediflo</td>
<td>1.32 ± 0.45</td>
<td>1.60 ± 0.39\†</td>
<td>1.0 ± 0.31\†</td>
<td>1.0 ± 0.33\†</td>
<td>0.99 ± 0.36\†</td>
<td>0.98 ± 0.41\†</td>
</tr>
</tbody>
</table>

*Values given as mean ± SD.

\(\dagger p < 0.01.

\(\ddagger p < 0.05.

Figure 3. IC. Results for baseline (without the spirometers), the Coach and the Mediflo for group A (patients at high risk for PPCs) and group B (patients at moderate risk for PPCs) and significant differences (mean ± SD). \(\dagger p < 0.05.

Clinical Investigations in Critical Care
scales of the spirometer were reported. In a further laboratory report, Mang et al\textsuperscript{5} reported significant differences in the WBimp between different incentive spirometers and postulated a potential clinically relevant effect on incentive spirometry primarily in patients at risk for inspiratory muscle fatigue. However, to date and to our knowledge, the impact of the WBimp on incentive spirometry performance in the clinical setting remains to be investigated. The physiologic total work of breathing when breathing through the nose at rest was determined to be 0.73 J/L.\textsuperscript{19} In the postoperative period, however, the work of breathing is assumed to be significantly increased, because of dystelectasis and atelectasis, weakened muscular tone of the abdominal and chest-wall inspiratory muscles, or the accumulation of airway secretions.\textsuperscript{13} Thus, at least in theory, the high additional WBimp generated by an incentive spirometer might compromise spirometry performance, especially in patients with severely impaired respiratory function.\textsuperscript{4,5}

Indeed, our results indicate that incentive spirometry adds a considerable WBimp (Coach: group A, 69%; group B, 72%; Mediflo, to 136% of the physiologic work of breathing). These clinically obtained results are in good accordance with those observed in the laboratory.\textsuperscript{5} A limitation of our study is, however, that the total work of breathing of the patients during incentive spirometry was not measured. In the spontaneously breathing patient, the work of breathing only could have been measured by introducing an esophageal balloon, which seemed to be an inappropriate and risky procedure in patients in their first postoperative days.

Surprisingly, the additional WBimp generated by the Mediflo did not affect the maximal inspired volume of patients in group A, who had severely impaired respiratory function. A significant reduction of the maximal inspired volume was observed in the patients in group B, who had only moderately impaired respiratory function. Furthermore, it is remarkable that in group A the higher WBimp generated by the Mediflo did not lead to a decrease in the IC. This might possibly indicate that in the case of a patient with severely impaired respiratory function and a very low IC (as in group A), a more distinct increase in additional WBimp might be necessary for a further decrease in IC. An explanation might be that a then critically reduced IC leads to respiratory insufficiency and that immediately compensatory mechanisms are triggers to avoid respiratory failure. Prestretching of the respiratory muscles at a low IC also might lead to increased contractility, allowing the fibers to perform at a higher work of breathing level. However, with increased IC the gain in contractility by muscular prestretching is reduced because of a worsened ratio between the prestretching and the increase in muscular contractility. Furthermore, increased work of breathing leads to an increase in the contraction length of the respiratory muscles and subsequently to a decrease in maximal inspiration.\textsuperscript{20}

Regarding the fact that maximal sustained inspiration is a crucial factor for the recruitment of non-ventilated alveoli, spirometers with a low additional WBimp might nevertheless be more beneficial for postoperative respiratory training.\textsuperscript{5,12,13} The question of whether low inspiratory pressures would be beneficial cannot be answered by this study. However, a greater inspiratory pressure may enable increased retractive forces by the transmural pressure to re-open collapsed alveoli, thus leading to an increased recruitment of alveoli.\textsuperscript{7,20}

**Conclusion**

In conclusion, different types of incentive spirometers differ considerably in their additional WBimp in the clinical setting. These differences seem to be clinically relevant because of their impact on postoperative incentive spirometry performance. Thus, incentive spirometers with a low additional WBimp allow improved maximal sustained inspiration and
therefore might be more suitable for postoperative respiratory training. Additionally, when considering the efficacy of incentive spirometry in clinical trials, it is assumed that the type and properties of the incentive spirometer also may be of importance.

The observed good correlation between the \( P_{\text{im} \text{ax}} \) during incentive spirometry and the additional \( \text{WBimp} \) might be clinically helpful to estimate the device-specific \( \text{WBimp} \) by the simple measurement of \( P_{\text{im} \text{ax}} \).

ACKNOWLEDGMENT: We are indebted to Joan Robertson-Hoehne for language assistance and copyediting the article.

REFERENCES
5. Mang H, Obermayer T, Weindler J. Comparison of inspiratory work of breathing through six different spirometers. Respir Care 1988; 33:955–964