A randomized trial of automated versus conventional protocol-driven weaning from mechanical ventilation following coronary artery bypass surgery

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Abstract

Objective: The Siemens servo 300 A ventilator has an automode function that allows automated weaning of patients from mechanical ventilation. Spontaneous breathing triggers the ventilator. After two spontaneously triggered breaths, the ventilator automatically changes from mandatory mechanical ventilation to spontaneous ventilation. If spontaneous breathing or triggering does not occur, the Siemens servo 300 A ventilator changes from spontaneous ventilation back to mandatory mechanical ventilation. We compared the effects of automated versus conventional protocol-driven weaning on the time until extubation in patients undergoing coronary artery bypass graft (CABG) surgery. In addition, we studied the effects of the mode of weaning on hemodynamic and physiologic parameters.

Methods: Twenty consecutive male patients without respiratory disease scheduled for CABG at the University Hospital of Regensburg were entered into the study. Patients were randomized to postoperative ventilation with the Siemens 300 A/automode ventilator (group A, n = 10) or with the Siemens 300 ventilator (group B, n = 10). All patients were weaned from ventilation according to a standardized protocol.

Results: On average, patients in group A were younger and had lower pulmonary artery pressure (PAP) and higher cardiac output compared to patients in group B. However, patients in group A had longer ischemic and bypass times compared to patients in group B. Postoperative use of analgesia and sedation were similar in both groups. Time from tracheal intubation until extubation was 2 h shorter in patients assigned to automode ventilation compared to patients assigned to conventional ventilation (mean time group A 7.9 h, group B 10.0 h; p = 0.069). Peak airway pressure was reduced by 2 cm H2O at the beginning of spontaneous ventilation in group A compared to group B. After extubation, cardiac index showed a greater increase in patients assigned to group A compared to those in group B.

Conclusions: Automode ventilator weaning trended toward more rapid extubation than did conventional protocol-driven ventilation in conjunction with a standardized weaning protocol. Physiologic and hemodynamic factors were better in patients using automode ventilation compared to patients using conventional ventilation. Automode ventilation was well tolerated and did not induce significant adverse effects.

Keywords: Automode ventilation; Conventional protocol-driven ventilation; Coronary artery bypass surgery; Cardiovascular—pulmonary interactions; Time until extubation

1. Introduction

Despite of a variety of modern ventilators, weaning patients from mechanical ventilation utilizes a significant amount of health care resources in an intensive care unit [1].

Even though the majority of mechanically ventilated patients can be rapidly transferred from mandatory ventilation to spontaneous breathing, the efficacy of this process partly depends on the experience of health care workers who are supervising or assisting with the weaning process. Standard ventilators are unable to automatically change modes back and forth between mandatory mechanical ventilation and spontaneous ventilation, depending on the patients’ alertness. Ventilator changes are typically made by respiratory therapists, nurses, or physicians.

Protocol-guided weaning of mechanical ventilation has been proposed [2] to improve weaning and decrease the time of mechanical ventilation. However, weaning typically occurs in an intensive care unit where the time between patient...
observations may be irregular and delays in making the appropriate ventilator setting changes to spontaneous ventilation may occur. Ideally, mechanical ventilation mode would automatically change modes back and forth between mandatory mechanical ventilation and spontaneous ventilation, depending on the patients’ alertness. Siemens has developed a new ventilator generation called Siemens servo 300 A, which has an automode function. The automode function enables the patient to initiate a ventilator mode change. When a patient on mandatory mechanical ventilation starts to breathe spontaneously, the Siemens servo 300 A is triggered. After two spontaneously triggered breaths, the ventilator mode changes automatically from mandatory to spontaneous ventilation. If the patient does not continue to trigger the Siemens servo 300 A, the ventilator mode changes again automatically from spontaneous to mandatory mechanical ventilation.

Duration and intensity of mechanical ventilation is influenced by many factors such as the duration of the operation, the anesthesia, the clinical condition, the mode of ventilator therapy, and the method of weaning from mechanical ventilation. Following coronary artery bypass graft (CABG) surgery, many patients may not be physiologically ventilated or not breathing in concert with the ventilator during a weaning process, leading to a greater work of breathing. Inefficient ventilation may lead to a decrease in cardiac output because of mechanical ventilation and cardiovascular system interactions [3]. In patients with impaired cardiovascular function after cardiac surgery, further compromise could adversely affect patient outcomes. In this pilot study, we compared the automode method of weaning versus conventional protocol-driven ventilation in patients after CABG. We wanted to find out whether a new ventilator system could shorten the time until extubation.

2. Methods

The study was approved by the human studies committee of the University of Regensburg. During June and July of 1997, we recruited consecutive patients who were scheduled to undergo CABG. Patients were selected for CABG based on angiographic and clinical criteria. All patients had pre-operative pulmonary history and pulmonary function data collected. Pulmonary function (Master Lab, Fa. Jäger) and room air blood gases (ABG) were performed using standard techniques. All spirometry values reported are prebronchodilator, and the percent of normal predicted values was determined using standard equations. Patients with a history suggestive of respiratory disease or an FEV1 ≤70% were excluded from the study. Twenty patients were eligible for the study.

Eligible patients were randomized in blocks of two prior to undergoing CABG. Only one single automode ventilator was available for use. Thus, two patients undergoing surgery on the same day were randomized either to the Siemens 300 A/automode ventilator (group A) or to the conventional Siemens 300 ventilator (group B) using a slips of paper in a box technique which was our procedure to randomize the patients. Once the automode ventilator was again ready for use, two more patients could again be randomized. This procedure was repeated until 20 patients, 10 in group A and 10 in group B, had entered the study.

Anesthesia was induced in a standard technique with fentanyl (150 µg/kg of body weight before bypass), pancuronium and etomidate, adapted to the patients body weight. Swan Ganz pulmonary artery catheterization and arterial catheterization were performed according to standard techniques after induction of anesthesia. During the operation, patients received intravenous fentanyl (25 µg/kg of body weight every 30 min after bypass) and inhaled forense.

CABG was performed in a standard fashion through a median sternotomy with cardiopulmonary bypass. In all patients the saphenous vein(s) was used for revascularization. In addition, all patients, except for two in group B, had internal mammary artery grafting performed.

Postoperatively, all patients received analgesic therapy with piritramid, an opioid derivate. In addition, three patients in group A and one patient in group B received pethidin for pain control. Sedative drugs were not used, except for two patients in group A who were briefly treated with intravenous sedative drugs after admission to the ICU.

Cardiovascular support drugs consisted of dopamine, dobutamine, nitroglycerin, isoproterenol, and norepinephrine. These drugs were administered according to standard practice.

After surgery, patients were admitted to the cardiac surgery intensive care unit (ICU). Patients randomized to group A were ventilated with the Siemens 300 A/automode ventilator and patients randomized to group B were conventionally ventilated with the Siemens ventilator 300. Upon arrival to the ICU, the ventilator settings in both groups were set to pressure regulated, volume controlled (PRVC) with a tidal volume (VT) of 10 ml/kg of body weight. The inspiration to expiration time was set on 1:1, which was standard practice in our clinic. The upper pressure limit in both groups was set on 30 cm H2O. In addition, group A had the automode function set to ‘on.’ All patients were then weaned from mechanical ventilation and extubated according to standardized criteria (Table 1 and Fig. 1). The target of partial arterial pressure of carbon dioxide (PaCO2) was less than 45 mmHg during the weaning process in both groups and was one of the criteria necessary for extubation (Fig. 1).

Mechanical ventilation period was divided into three different phases based on patient assessments (Fig. 1). During the initial postoperative mandatory mechanical ventilation phase, both nonalert groups had PRVC ventilation, with the automode set to ‘on’ in group A.

After initial FIO2 weaning per protocol (spontaneous ventilation I in Fig. 1), all ventilator changes in group A were

<table>
<thead>
<tr>
<th>Initial PaO2</th>
<th>Absolute reduction in FIO2</th>
</tr>
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<tbody>
<tr>
<td>&gt;200 mmHg</td>
<td>0.20 (drop by 20% in FIO2)</td>
</tr>
<tr>
<td>150–200 mmHg</td>
<td>0.15</td>
</tr>
<tr>
<td>110–149 mmHg</td>
<td>0.10</td>
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<tr>
<td>0–109 mmHg</td>
<td>0.05</td>
</tr>
<tr>
<td>&lt;90 mmHg</td>
<td>0 (no change)</td>
</tr>
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</table>

ABG was drawn every hour until extubation.
Group A: automode ventilation

**Action**

Ventilator Mode (set by ICU Physician): PRVC-automode on

**Phases/Assessment**

MANDATORY VENTILATION

Meets criteria for weaning:
- Able to trigger ventilator
- Opens eyes
- Moves extremities upon request

Remains alert:
- For at least 45 minutes of a 60 minute period

SPONTANEOUS VENTILATION I

Meets criteria for fully alert:
- Triggers ventilator
- Opens eyes
- Moves extremities
- Doesn’t fall asleep

SPONTANEOUS VENTILATION II

Meets criteria for extubation:
- Alert
- RR ≤ 25 breaths/minute
- FIO2 ≤ 40%
- PEEP ≤ 5 cm H2O
- PSV ≤ 10 cm H2O
- PaO2 (FiO2 0.4) ≥ 80 mm Hg
- PaCO2 ≤ 45 mm Hg

**Group B: conventional ventilation**

**Action**

Ventilator mode (set by ICU Physician): PRVC

**Source of ventilator change:**

Automatic Ventilator Mode: PRVC-automode on

**Source of ventilator change:**

Therapist Ventilator mode: SIMV 5 breaths/minute/PSV 10 cm H2O

**Source of ventilator change:**

Automatic Ventilator mode: PRVC-automode on

**Source of ventilator change:**

Therapist Ventilator mode: CPAP 5 cm H2O

Extricate

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the ventilator support. Arterial blood gases were obtained at regular intervals according to the protocol. Pulmonary and cardiac physiologic data, use of analgesic and sedative drugs, time to extubation and adverse events including arrhythmias and blood loss over the chest tubes were assessed and documented by the ICU nurses and physicians.

We used the cardiac index (CI) and the mixed venous saturation (SVO2) as the main parameters to describe the postoperative function of the cardiovascular system because these parameters have been demonstrated as good indicators of cardiovascular function in ventilated patients [3,4]. One hour after extubation, the last measured cardiovascular results were obtained and the pulmonary artery catheter was then removed. Five days after extubation, each patient underwent repeat pulmonary function testing.

Statistical analyses were performed using SPSS version 6.1 (SPSS, Inc. Chicago, IL, USA) for the Macintosh. Continuous data are expressed as mean ± SD. Categorical data are expressed as counts or proportions. Two-tailed Wilcoxon rank-sum tests were used to compare continuous data between groups A and B. To compare paired continuous data within groups, two-tailed Wilcoxon signed-rank tests were used. Box plots, stratified by group, were used to demonstrate the time to extubation data. Kaplan–Meier analyses and the log rank test was used to compare the time to extubation between groups A and B. Cox proportional hazards analysis was used to control for baseline differences between the groups, using time to extubation as the outcome variable. The independent effect of group assignment (Wald chi-square test) on outcome (time to extubation), adjusted for other significant univariate factors, was assessed. Statistically significant differences were defined as p < 0.05. A sample size of 20 patients, 10 in each group, was arbitrarily chosen for this pilot study.

3. Results

Baseline preoperative and intraoperative characteristics of patients using the Siemens 300 A/automode ventilator (group A) and patients using the Siemens 300 ventilator in conjunction with a weaning protocol (group B) are demonstrated in Table 2. Patients in group A were an average of 11 years younger than patients of group B. Preoperative pulmonary function was similar between patients in groups A and B. Mean pulmonary artery pressure (PAP) was 4 mmHg lower and cardiac index was slightly higher in group A compared to group B, though the mixed venous oxygen saturation was similar between the groups.

The average number of venous coronary anastomoses was similar between groups A and B. All patients in both groups, except for two patients in group B, were revascularized using the left internal mammary artery. The average ischemic time was 32 min longer and the bypass time was accordingly prolonged by 19 additional minutes in group A compared to group B. Furthermore, the operating time of group A patients was longer compared to group B patients (mean time group A 3.8 h, group B 3.0 h; p = 0.075). Thus, patients in group A received a higher cumulative dose of fentanyl compared to patients in group B (mean dose of fentanyl group A 1.76 mg, group B 1.50 mg; p = 0.086).

Upon arrival to the ICU after CABG, each patient was ventilated with a volume-controlled mode (PRVC) and weaning took place per protocol. The average peak airway pressures were similar between groups A and B (19 ± 3 cm H2O vs 18 ± 2 cm H2O; p = 0.11). One hour into spontaneous ventilation I, the average peak airway pressure in group A was 2 cm lower than that of group B (20 ± 3 cm H2O vs 22 ± 4 cm H2O; p = 0.07). One hour into spontaneous ventilation II, the average peak airway pressures were similar between groups A and B (17 ± 5 cm H2O vs 16 ± 2 cm H2O; p = 0.934). Group A showed no significant change in the average peak airway pressure when comparing data between spontaneous ventilations I and II. However, group B showed significant change in the average peak airway pressure when comparing data between spontaneous ventilations I and II. Arterial blood gas parameters (PaO2 and PaCO2) between groups A and B were comparable and not statistically different throughout weaning.

There were no significant differences in SVO2 between groups A and B, and in group A patients showed a higher CI than group B.

Table 2
Preoperative and intraoperative patient characteristics

<table>
<thead>
<tr>
<th></th>
<th>Group A (automode ventilation) (n = 10)</th>
<th>Group B (conventional ventilation) (n = 10)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preoperative</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (year)</td>
<td>54 ± 9</td>
<td>66 ± 4</td>
<td>0.002*</td>
</tr>
<tr>
<td>VC%</td>
<td>97 ± 12</td>
<td>91 ± 15</td>
<td>0.198</td>
</tr>
<tr>
<td>FEV1,%</td>
<td>103 ± 14</td>
<td>97 ± 16</td>
<td>0.289</td>
</tr>
<tr>
<td>PaO2 (mmHg)</td>
<td>73 ± 8</td>
<td>76 ± 12</td>
<td>0.450</td>
</tr>
<tr>
<td>PaCO2 (mmHg)</td>
<td>39 ± 3</td>
<td>37 ± 4</td>
<td>0.307</td>
</tr>
<tr>
<td><strong>Postintubation/anesthesia, before surgery</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean PAP (mmHg)</td>
<td>18 ± 3</td>
<td>23 ± 4</td>
<td>0.018*</td>
</tr>
<tr>
<td>CI (l/min/m2)</td>
<td>3.4 ± 0.7</td>
<td>3.0 ± 0.4</td>
<td>0.140</td>
</tr>
<tr>
<td>SVO2 (mmHg)</td>
<td>79 ± 3</td>
<td>78 ± 5</td>
<td>0.650</td>
</tr>
<tr>
<td><strong>Intraoperative</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of anastomoses</td>
<td>2.9 ± 1.0</td>
<td>2.7 ± 0.8</td>
<td>0.684</td>
</tr>
<tr>
<td>Bypass time (min)</td>
<td>104 ± 26</td>
<td>85 ± 21</td>
<td>0.162</td>
</tr>
<tr>
<td>Ischemic time (min)</td>
<td>67 ± 16</td>
<td>49 ± 15</td>
<td>0.019*</td>
</tr>
</tbody>
</table>

Values expressed as mean ± SD. VC: vital capacity; FEV1: forced expiratory volume in 1 s; PaO2: partial pressure of arterial oxygen with FIO2 = 0.21; PaCO2: partial pressure of arterial carbon dioxide with FIO2 = 0.21; PAP: pulmonary artery pressure; CI: cardiac index; SVO2: mixed venous arterial oxygen.

p < 0.05.
patients after extubation (3.9 ± 0.5 l/min/m² vs 3.3 ± 0.5 l/min/m²; p = 0.005).

Patients in groups A and B received similar doses of analgesic. The mean dose of Dipidolor (piritramid) after surgery was similar in groups A and B (10.5 ± 3.5 mg vs 12.8 ± 6.9 mg; p = 0.673). We found no significant differences between both groups concerning cardiovascular support drugs.

The duration of mechanical ventilation ranged in all patients from 4 to 13 h. The average time to extubation was 2 h shorter in group A patients compared to patients in group B (7.9 ± 2.4 h vs 9.9 ± 1.9 h; p = 0.069; Figs. 2 and 3). Age, mean pulmonary artery pressure, ischemia time, operating time, and cumulative doses of fentanyl were different between the groups despite of randomization. Controlling for these variables, Cox regression analysis, using time to extubation as the outcome variable (mean time in each group needed to have 50% of the cohort extubated) still showed a trend toward prolonged ventilation using the conventional mode compared to the automode (Model chi-square 10.6, p = 0.031; group B hazard ratio 1.23, 95% CI 0.59—2.56, p = 0.585).

No complications associated with surgery or weaning occurred. All patients survived to be discharged from the hospital. The mean postoperative hospital length of stay was similar in both groups (group A = 9.5 days and group B = 9.4 days).

Five days after surgery/extubation, pulmonary function tests were repeated (Table 3). There were no statistically significant differences between groups A and B, though group B had a slightly higher FEV1% of predicted. In both groups, the VC% of predicted, the FEV1% of predicted, and the PaO2 were similar.

![Fig. 2](image-url) Boxplots of time spent on the mechanical ventilator for group A (automode ventilation) or group B (conventional ventilation) following coronary artery bypass grafting. Boxes demonstrate the mean value (horizontal line in the box) and the 25th and 75th percentiles (lower and upper boundaries); whiskers extend to the last case within 1.5 box lengths away from the box edge; outlier and extreme cases are not present.

![Fig. 3](image-url) Kaplan—Meier plot of time spent on the mechanical ventilator, stratified by randomized group assignment to group A (automode ventilation) or group B (conventional ventilation) ventilation following coronary artery bypass grafting. Where the dotted line crosses each curve, the mean time of extubation is located (group A 7.9 h and group B 10.0 h). Log rank p = 0.08.

**Table 3**
Pulmonary function and arterial blood gas results (room air) 5 days after extubation/surgery

<table>
<thead>
<tr>
<th></th>
<th>Group A (automode ventilation) (n = 10)</th>
<th>Group B (conventional ventilation) (n = 10)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC% predicted</td>
<td>56 ± 11</td>
<td>57 ± 17</td>
<td>0.820</td>
</tr>
<tr>
<td>FEV1% predicted</td>
<td>54 ± 11</td>
<td>62 ± 18</td>
<td>0.150</td>
</tr>
<tr>
<td>PaO2 (mmHg)</td>
<td>57 ± 2</td>
<td>57 ± 4</td>
<td>0.344</td>
</tr>
<tr>
<td>PaCO2 (mmHg)</td>
<td>33 ± 3</td>
<td>34 ± 4</td>
<td>0.820</td>
</tr>
</tbody>
</table>

Values are expressed as mean ± SD. VC: vital capacity; FEV1: forced expiratory volume in 1 s; PaO2: partial pressure of arterial oxygen with FIO2 = 0.21; PaCO2: partial pressure of arterial carbon dioxide with FIO2 = 0.21.
significantly \((p < 0.001)\) reduced after surgery compared to preoperative baseline, but these changes were similar in both groups.

4. Discussion

Patients without a previous history of lung disease scheduled for coronary artery bypass surgery were randomized to postoperative ventilation with the Siemens 300 A ventilator with automode function (group A) or to conventional Siemens 300 ventilation. Possibly due to the small number of patients or the quasi-randomization procedure, there were some baseline differences between both groups. The patients in group A were younger, had lower mean preoperative pulmonary artery pressure, had longer ischemic time, had a longer duration of the operation, and got higher cumulative doses of fentanyl during the operation compared to patients in group B. A longer operation is associated with patients receiving more anesthesia which may influence the time to extubation. All the other pre- and intraoperative parameters were similar. Postoperative dosages of analgesia and sedation were also similar between the groups and weaning was performed according to a standardized protocol.

The study demonstrated that the time from tracheal intubation until extubation was 2 h shorter for patients in group A compared to patients in group B.

Weaning patients from mechanical ventilation is usually conducted in an empirical manner [5]. Over 40% of total ventilator time may be consumed by the weaning process. Thus, weaning patients from ventilation constitutes a major portion of the workload in an intensive care unit [1].

Despite the use of various criteria for weaning [6,7], it is often difficult to determine the ideal time of extubation for each patient. Efforts have been made to solve the problem of weaning patients from mechanical ventilation. Kooler et al. [2] showed that protocol-guided weaning of mechanical ventilation was safe and led to extubation more rapidly than physician-directed weaning. In a Multicenter trial, Esteban et al. compared different methods of weaning patients from mechanical ventilation. They concluded that a once-daily trial of spontaneous breathing led to extubation about three times more quickly than intermittent mandatory ventilation and about twice as quickly as pressure-support ventilation [5]. Viseshwara et al. [8] reported their results of a of long-term patient-triggered synchronized assisted ventilation in infants compared to infants receiving conventional ventilation. Infants receiving patient-triggered synchronized assisted ventilation showed a statistically significant decrease of the duration of ventilation.

Other efforts to automate weaning from mechanical ventilation have been reported by several groups using different techniques [9–11]. All these studies indicate that more automatic weaning from mechanical ventilation shortens the duration of weaning, decreases the time to extubation, and lessens the cardiovascular interactions resulting from mechanical ventilation.

Roth et al. [12] compared the effects of patient-triggered automatic switching between mandatory and supported ventilation (Automode) to synchronized intermittent mandatory ventilation in the postoperative weaning period of neurosurgical patients. They found a trend (not significant) to shorter weaning times. These results are comparable to our results in patients after CABAG.

In addition to evaluating whether such an automated mechanism has any influence on the duration of weaning from mechanical ventilation, we assessed whether there are benefits concerning cardiovascular—pulmonary interactions.

Positive airway pressure may result in complex cardiovascular interactions with a decrease in cardiac output as mentioned by Pinsky [3]. In our study, the peak airway pressure was slightly higher in group B at the beginning of spontaneous ventilation I. At the other time points of weaning, the mean peak airway pressures were not statistically different. The cardiac indexes of both groups were not statistically different during weaning from mechanical ventilation, though group A had a higher average cardiac index compared to group B. These results are similar to those presented by Roth et al. [12]. However, after extubation, the mean cardiac index of group A was significantly higher than that of group B. Automated ventilation may have had a positive influence on the cardiovascular system, especially in these patients after coronary artery bypass surgery. Even if the cardiovascular response to weaning from mechanical ventilation may vary according to the type of surgery as mentioned by De Backer et al. [13], this is no contradiction to the statement of our study. On the contrary, De Backer et al. showed in their study an influence of weaning from mechanical ventilation on the cardiovascular system with an increase of the Cardiac index in patients after cardiac surgery [13].

There were no significant differences between groups A and B in postoperative lung function. Both groups showed a significant decrease in lung function after surgery. Both VC% of predicted and FEV1% of predicted decreased postoperatively by one-third to one-half of their preoperative values. These results are comparable to those published by Shenkman et al. [14] who showed that pulmonary functions deteriorate significantly more than 3 months after cardiac surgery.

This pilot study was limited by its small number of patients and is only generalizable to men without underlying respiratory disease undergoing CABG. The nonblinded treatment assignment and post-randomization data collection may have introduced bias, but much of the weaning was automated (group A) or protocol driven (groups A and B) and ‘objective’ endpoints were used. Nevertheless the data, especially the 2-h difference between groups A and B in time to extubation as well as the significantly higher cardiac index in group A patients after extubation, demonstrated a marked trend to a benefit for patients automatically ventilated. A study of larger magnitude is necessary to validate these early results concerning the time to extubation in comparison to conventional methods of weaning. Furthermore, a larger study may also discover that the rate of cardiovascular complications, such as ischemia and arrhythmias may differ due to differences in modes of weaning. If this could be confirmed by larger studies, it could also be important for patients administered to fast-track cardiac anesthesia as described for example by Wong et al. [15]. In their study, not only increased age but also atrial arrhythmia were risk factors of delayed extubation.
In summary, we conclude that automode ventilator weaning from mechanical ventilation is safe, easy, and may lead to more rapid extubation compared to conventional ventilation in patients after CABG. Furthermore, we hypothesize that reduction in peak airway pressure during spontaneous ventilation and better performance of the cardiovascular system lead to improved patient outcomes. Larger studies in more diverse populations are indicated.

References