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Improved bronchial cleansing in intensive care patients with a new double-lumen catheter

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Abstract *Objectives:* A new double lumen catheter with a small channel for application of rinsing solution in deeper parts of the endobronchial tree was developed and its efficiency was tested in two trials.
Design: Comparison of the new catheter in 2 controlled studies with the traditional way of suctioning and with conventional endotracheal lavage in a randomized block design.
Setting: Intensive care unit of a university hospital.
Patients: In the first study, endobronchial cleansing with the new catheter was compared to the traditional way of suctioning in 12 long-time ventilated patients. In the second study, 28 ventilated patients received either conventional lavage or lavage with the new catheter.
Interventions: In the first trial the bronchial system of each patient was suctioned 25 times with a conventional technique or cleansed by using the new catheter. In the second study, patients alternatively received conventional lavage 88 times or lavage 88 times with the new catheter.
Measurements and results: Drained secretions averaged 0.84±0.28 ml using conventional cleaning as compared to 11.02±0.84 ml with the new catheter. This was accompanied by a significant ($p<0.001$) increase in PaO_2 of 24.20±7.90 mmHg after 10 min compared to nearly unchanged PaO_2 after normal suctioning. In the second study, suctioned volume was 2.48±0.21 ml using conventional endotracheal lavage and 10.55±0.47 ml using the new catheter. Use of the double-lumen catheter induced a significant increase in PaO_2 by 30.90±3.90 mmHg within 10 min. The changes in PaO_2 correlated with the drained volume.
Conclusion: Both studies show that suctioning with the new double lumen catheter allows drainage of a larger volume of secretions and results in a greater improvement of oxygenation.

Key words Tracheobronchial lavage · Endobronchial suctioning · Artificial ventilation · Effectiveness of suctioning · New double-lumen catheter

Introduction

Intubated, ventilated patients are generally unable to cough up effectively their bronchial secretions and therefore regular cleansing is necessary. 30% of resuscitated patients have aspirated and must be suctioned [1]. However, grave complications may result from this procedure. Hypoxia [2], arrhythmias, bradycardia or asystole [3, 4] as well as a decrease in pulmonary compliance and an increased resistance [2] are described. In order to overcome this situation different techniques of preoxygenation, on-ventilator suctioning by using special adaptors or special techniques for artificial respiration have been recommended. Endobronchial cleansing with a common catheter has only small effects on pulmonary ventilation parameters and on arterial oxygen saturation. Nevertheless, this procedure has been recommended especially in cases of airway obstruction [5–8]. Also the effectiveness of traditional tracheobronchial lavage with application of rinsing solution into the endotracheal tube is unsatisfactory. Usually this procedure requires that artificial respiration must be interrupted. The amount of aspirated secretions is usually small and the effect of application of isotonic saline is questionable [5].

In order to improve this traditional technique a new double-lumen catheter, more suited to bronchial lavage in the shortest possible time, was developed. The catheter was tested in 2 studies in artificially ventilated patients and compared to normal suctioning and the traditional technique of bronchial lavage. Especially the effect of these different maneuvers on arterial blood gases was investigated.

Methods and materials

In the present study a newly developed disposable catheter of approximately 55 cm length was investigated. It is a tube with two channels running in parallel to each other whereby the diameter of the larger one corresponds to that of a conventional suction catheter (Fig. 1). Its proximal funnel end can be connected with any suction source. The second channel of approximately 1 to 2 mm diameter runs parallel and has a luer hub which thus can be connected with a syringe. Through this channel rinsing fluid can be administered endobronchially under high pressure. Subsequently, the bronchial mucus can be drained through the large lumen of the catheter. Side eyes in the distal end prevent invaginations and damages of the bronchial mucosa. Thus the rinsing solution can deeply be applied into the bronchi of the intubated patient and no backflow to the respirator is possible. Also bronchial lavage can be performed without interruption of respiration.

Via an inlet at the connector of the respiration tube the dual lumen catheter is introduced by one person under sterile conditions and without any change of the respiration mode. The rinsing fluid is applied to the bronchial system through the application channel with high flow speed, using a 10 ml syringe. Subsequently, the liquefied secretions are removed through the suction channel. Then the catheter is withdrawn and the connector closed. Time between installation of saline in the bronchial system and aspiration was kept at about 1–2 s.

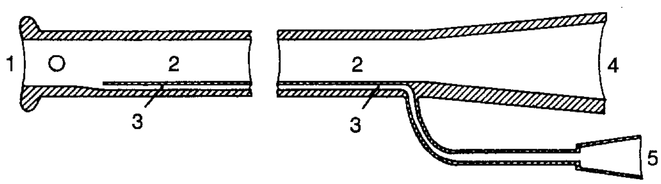

Fig. 1 Longitudinal section of the double-lumen catheter. *1* catheter tip with aspiration orifice (Aero-Flo-tip); *2* suction channel; *3* application channel; *4* connector cone for aspiration; *5* Syringe connector (Luer)

For investigating the effect of bronchial lavage with this new catheter two studies were performed in which it was compared to normal suctioning or bronchial lavage in a traditional manner.

In the first study one of the following treatment regimens was administered in a randomized sequence. Endobronchial secretions were suctioned by use of a normal suction catheter of 14 Fr 25 times or endobronchial system was cleansed with the double-lumen catheter 25 times. For endobronchial lavage with the new catheter 10 ml isotonic saline solution was used. Each of the 12 investigated patients received both treatments alternatively 2–3 times. Time between suctioning or lavage was exactly 1 h. For comparison of two methods it is necessary to keep intervals constant although the frequency of suctioning is normally determined by clinical signs. However some authors recommend endobronchial suctioning at constant time intervals, e. g. every hour [9]. All patients of our studies were intubated and artificially ventilated. The mean age of the 12 patients was 63.00±12.80 years and 9 were ventilated after cardiopulmonary resuscitation.

In the second study, bronchial lavage with the double lumen catheter was compared with a conventional endotracheal drainage. There were 28 patients disconnected from the respirator 88 times; 10 ml of an isotonic saline were aimlessly applied into the tracheal tube by means of a syringe and the rinsing fluid was distributed by ventilation with a respiration bag. Subsequently a sterile suction catheter of 14 Fr was introduced into the bronchial system and secretions were drained under slow withdrawal of the catheter. Disconnection from the respirator and application of the rinsing solution took an average of 8 s and distribution with a respiration bag averaged 10 s. Alternatively patients were cleansed with the double lumen catheter 88 times. Time between the procedures was 1 h. 10 ml isotonic saline were applicated during continued ventilation and liquefied secretions drained afterwards. Each intubated and artificially ventilated patient was treated with both methods 3–4 times. The mean age of the patients was 67.00±8.80 years, 9 patients were ventilated because of cardiopulmonary resuscitation, 7 had a myocardial infarction and 7 respiratory failure of various origins.

In both studies, ventilation was performed by a Siemens-respirator (Servo B, Servo C). Patients were intubated with a tube of size 7.5 or 8.0. All suction catheters had a size of 14 Fr. Negative pressure during suction procedures was –0.7 bar. All patients had an arterial catheter in the femoral arteria for blood pressure monitoring and blood gas analyses. Arterial samples for blood gas analysis were taken before suctioning, immediately after the procedure and after 1, 3, 5, 10, 15 min and sometimes also at 60 min.

Analysis was done using an ABL 3 (Radiometer) immediately after taking the arterial blood samples. In order to see the effect of endobronchial suctioning or lavage on arterial blood gases patients were not hyperoxygenated or hyperventilated before either procedure. In all patients, time for lavage, volume of drained secretions, ECG, blood pressure, ventilating pressure and pulmonary function parameters were monitored. For randomization in both studies a randomized block design was used. Each patient received the three rival treatments on successive occasions, the order of administration being determined randomly. For statistical analysis, Students *t*-test for pairs was used after checking for normal distribution of the collected values. Means and standard errors were calculated for all data and are provided in this manuscript. Studies were carried out in accordance with the Declaration of Helsinki.

Results

Study 1

Comparison of normal suctioning and lavage with the new double-lumen catheter showed the following results: On average endobronchial suctioning with a normal catheter could be finished within 21.00 ± 0.58 s. Respiration was interrupted for 15 s. Endobronchial cleansing during continous ventilation with the double lumen catheter took 24.00 ± 1.67 s. The suctioned volume was 0.84 ± 0.28 ml with common suctioning and 11.02 ± 0.84 ml using the new method of endobronchial lavage (Fig. 2). The difference was highly significant ($p < 0.001$).

During suctioning with a normal catheter PaO_2 fell -21.11 ± 2.79 mmHg (19%) ($n = 25$). In contrast cleansing the bronchial system during continuous ventilation with the double lumen catheter PaO_2 decreased by only -6.76 ± 4.59 mmHg (7%) ($n = 25$). As a result of interrupted ventilation there was a decrease in PaO_2 of -11.80 ± 6.4 mmHg after 1 min and -6.00 ± 5.92 mmHg after 15 min (Fig. 3). In contrast lavage with the double-lumen catheter was followed by a significant increase in PaO_2 of 10.60 ± 4.80 mmHg after 1 min and 27.6 ± 8.08 mmHg after 15 min. The increase of arterial PO_2 was 29% compared to a statistically significant ($p < 0.001$) decrease of 6% after normal suctioning. Arterial CO_2 increased slightly after normal aspiration whereas 10 and 15 min after cleansing with the double lumen catheter a significant ($p < 0.001$) decrease of about 2.40 mmHg was observed (Table 1).

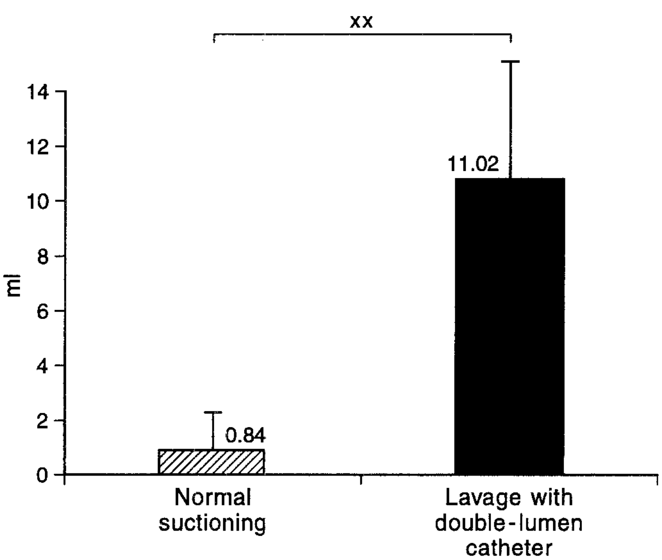

Fig. 2 Drained secretions ($n = 25$) per suction performance with a normal suction catheter (14 Fr, -0.7 bar) and lavage with a double-lumen catheter ($n = 25$) (xx = $p < 0.001$)

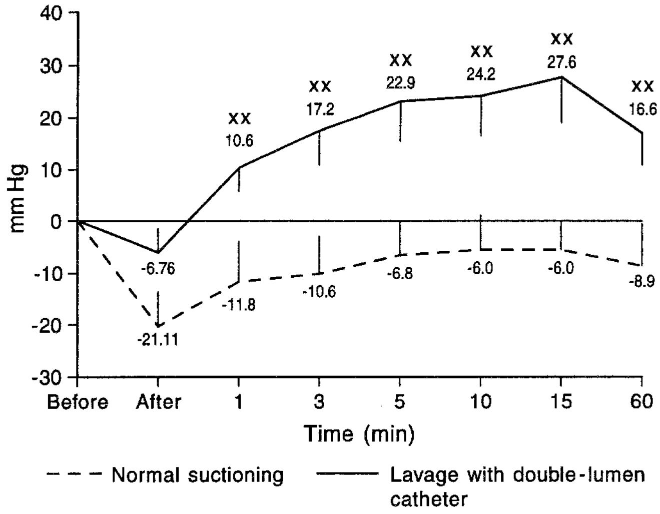

Fig. 3 Change in PaO_2 after endobronchial suctioning ($n = 25$) with a normal catheter (14 Fr, -0.7 bar) and after local lavage of the bronchial system with 10 ml isotonic saline via a double-lumen catheter ($n = 25$)

Study 2

In this series of investigations the double-lumen catheter was compared to traditional endobronchial lavage. The traditional manner of bronchial lavage took 38.23 ± 1.29 s; 8 s were used for application of saline-solution, about 10 s for ventilation with a respiration bag and 21 s for suctioning, withdrawing and closing the adaptor. Interruption of artificial respiration caused severe hypoxia with a decrease in PaO_2 up to -25.94 ± 2.29 mmHg compared to -1.04 ± 4.99 mmHg after lavage with the new catheter. The difference was statistically significant ($p < 0.001$, $n = 80$). Consequently a marked decrease of effective compliance was registered during lavage in the traditional manner (-16.30 ± 2.21 ml/cmH_2O below the initial value immediately after lavage, -11.40 ± 1.35 ml/cmH_2O after 1 min and -3.40 ± 2.11 ml/cmH_2O after 10 min below). Immediately after lavage with the new catheter, effective compliance fell -6.90 ± 2.19 ml/cmH_2O and was -6.90 ± 2.37 ml/cmH_2O after 1 min and -0.60 ± 1.89 ml/cmH_2O below the initial value after 10 min. The differences between on-ventilator lavage with the double-lumen catheter and off-ventilator lavage were highly significant ($p < 0.001$, $n = 46$). Ventilation pressure profiles showed that artificial respiration during lavage with the double-lumen catheter is not interrupted. Inspiration pressure, expiration pressure and inspiratory and expiratory resistance did not change while using the double lumen catheter. On the contrary, during traditional lavage inspiratory pressure increased by an average of 3.50 ± 1.32 mmHg. Compared to the double-lumen catheter the difference was statistically significant ($p < 0.001$).

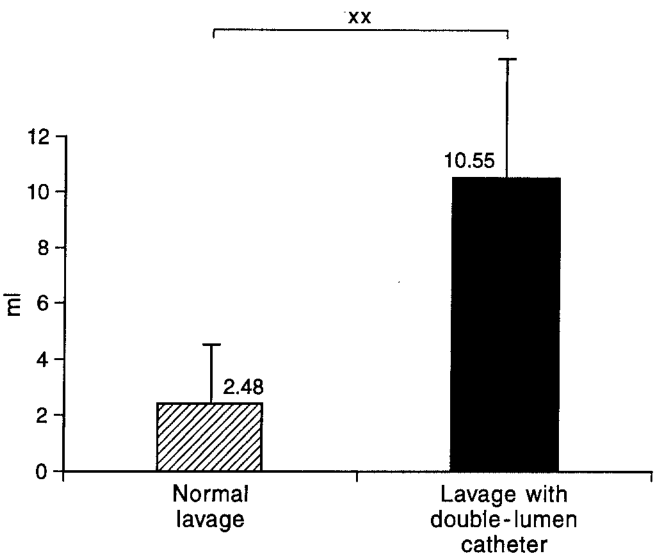

Fig. 4 Drained secretions ($n = 88$) per suction performance after lavage with 10 ml isotonic saline in a traditional manner and after lavage with a double-lumen catheter ($n = 88$) (xx = $p < 0.001$)

The suctioned volume was 2.48 ± 0.21 ml using endobronchial lavage in the traditional manner and 10.55 ± 0.47 ml using the double-lumen catheter (Fig. 4). The differences were statistically significant ($p < 0.001$).

After normal endobronchial suctioning or lavage in the traditional manner we saw no improvement of arterial PO_2. There was a decrease of PaO_2 1 min after traditional lavage of -15.30 ± 2.98 mmHg and -13.40 ± 2.60 mmHg after 15 min. Lavage with the double-lumen catheter was followed by a significant ($p < 0.001$) increase in PaO_2 of 21.80 ± 3.73 mmHg after 1 min and 31.5 ± 3.96 mmHg after 15 min (Fig. 5). Even 60 min after lavage with the new method PaO_2 was 13.9% higher than before ($p < 0.001$). The effects were independent from the kind of ventilation. Even in patients with high positive endexpiratory pressures (PEEP > 10) the same results were observed. The correlation coefficient between the amount of suctioned secretions and the change in PaO_2 within 10 min after lavage or suctioning was 0.63 ($p < 0.0001$) (Fig. 6). The X intercept shows that drained secretions less than 2.6 ml are not followed by an increase in PaO_2. The change of arterial oxygen saturation was equivalent to PaO_2. Arterial CO_2 increased slightly after traditional lavage (Table 1) whereas 10 and 15 min after cleansing with the double-lumen catheter a significant decrease in $PaCO_2$ ($p < 0.001$) was observed. As another indicator of hyperventilation after lavage with the new catheter base excess fell significantly from 0.25 to 0.1 mmol/l.

In both studies suctioning or lavage were performed without any complications. ECG showed no arrhythmias

Table 1 Arterial blood gas analysis before and after endobronchial lavage or suctioning. (Statistical comparison to corresponding values: * = $p < 0.01$, ** = $p < 0.001$, t-test)

Study 1: Normal suctioning – Lavage with dual lumen catheter ($n = 25$)

Time	$PaCO_2$ (mmHg) Normal suctioning	$PaCO_2$ (mmHg) Lavage with dual lumen catheter	HCO_3 (mmol/l) Normal suctioning	HCO_3 (mmol/l) Lavage with dual lumen catheter	BE (mmol/l) Normal suctioning	BE (mmol/l) Lavage with dual lumen catheter
Before	32.1	33.0	21.3	21.5	−1.6	−1.6
After	34.6	33.5	22.0	21.6	−1.3	−1.6*
1 min	33.1	32.8	21.5	21.4	−1.8	−1.7
3 min	32.8	32.3	21.7	21.4	−1.5	−1.4
5 min	32.4	31.8	21.3	21.0	−1.9	−1.7
10 min	32.7	30.6**	21.5	20.6*	−1.7	−2.1
15 min	32.3	30.8**	21.6	21.1	−1.6	−1.8

Study 2: Traditional lavage – Lavage with dual lumen catheter ($n = 88$)

Time	$PaCO_2$ (mmHg) Traditional lavage	$PaCO_2$ (mmHg) Lavage with dual lumen catheter	HCO_3 (mmol/l) Traditional lavage	HCO_3 (mmol/l) Lavage with dual lumen catheter	BE (mmol/l) Traditional lavage	BE (mmol/l) Lavage with dual lumen catheter
Before	33.2	34.7	23.0	23.5	−0.3	0.25
After	38.7	37.6	22.3	23.3	0	0.1**
1 min	35.4	34.3*	23.4	23.5*	−0.1	0.3**
3 min	35.2	33.6**	23.4	23.5	−0.2	0.1**
5 min	35.0	33.6**	23.3	23.4**	−0.2	0.1**
10 min	34.5	33.0**	23.1	23.3	−0.2	0.1**
15 min	34.4	33.2**	23.0	23.4**	−0.2	0.2**

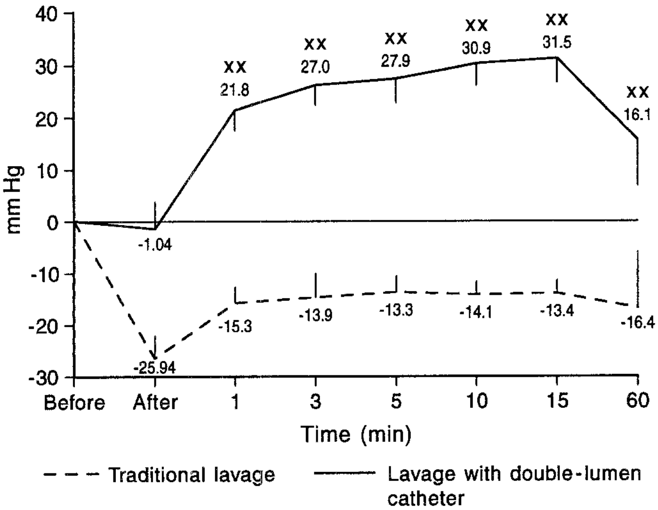

Fig. 5 Changes in PaO_2 after endobronchial lavage in a traditional manner ($n = 88$) and after local lavage of the bronchial system using the double-lumen catheter ($n = 88$) (xx = $p < 0.001$)

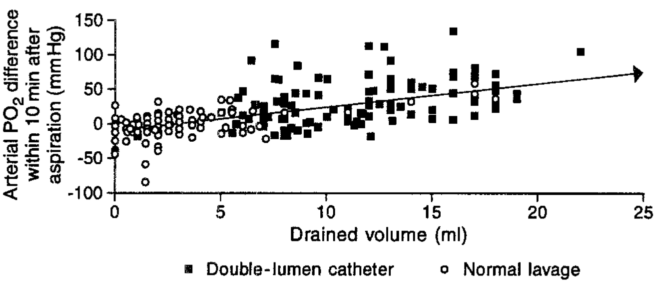

Fig. 6 Correlation between volume of drained secretions during endobronchial suctioning and change of PaO_2 within 10 min. Correlation coefficient is $r = 0.634$ ($p < 0.001$) with x-intercept 2.61

or pathological signs other than those related to the underlying illness. Pulse rate increased by 3 beats per minute during suctioning and systolic blood pressure rose up to 5.2 mmHg. Diastolic blood pressure after lavage in the traditional manner was 6.2 mmHg higher than before and 2.6 mmHg higher after cleansing with the dual lumen catheter. There were no significant differences of change of blood pressure and pulse rate between the used methods.

Discussion

A new double-lumen catheter for endobronchial cleansing was developed. In two studies it was compared to the common way of endobronchial suctioning and to a traditional manner of lavage. Hypoxia as a result of interruption of ventilation could partly be avoided by cleansing the bronchial system during continuous ventilation. The drained volume by normal suctioning was on average only 0.84 ml compared to 11.04 ml after endobronchial lavage with the double-lumen catheter. Normal suctioning did not change the arterial blood gases. Endobronchial lavage with the new catheter, however, was followed by a significant increase in PaO_2 up to 24.20 mmHg after 10 min. Interruption of ventilation for traditional lavage caused a decrease in PaO_2 of -25.94 mmHg. After application of 10 ml isotonic saline only 2.48 ml were suctioned. There was no increase in PaO_2. On the contrary, hypoxia could be avoided by lavage of the bronchial system with the new double-lumen catheter, drained secretions rose up to 10.55 ml and lavage was followed by an increase of PaO_2 of about 30 mmHg. A strong correlation between drained volume and increase of PaO_2 could be demonstrated.

Hypoxia during endobronchial suctioning or lavage is a common complication of these procedures. In previous studies we saw a decrease of PaO_2 by 4.9 mmHg and of saturation by 3% even when using a swivel adaptor. This is underlined by investigations of Brown et al. [3] who found that even the use of special adaptors cannot completely prevent oxygen desaturation. Restriction of airways and disturbances of laminar air flow during suctioning may be at least in part be responsible. When ventilation is interrupted we saw a severe decrease in PaO_2, especially after the traditional way of lavage. It takes nearly 15 min before PaO_2 increases to the initial level. This is confirmed by several other studies [10, 11]. For prevention several different techniques are recommended. The use of swivel adaptors is one way to minimize the arterial oxygen desaturation [12, 13]. Other possibilities are the use of different methods of preoxygenation [14–17] or high frequency ventilation [18]. Our investigations show that during suctioning without any prevention of hypoxia PaO_2 decreases by an average of more than 20 mmHg. This is accompanied by a decrease in effective compliance. Hyperoxygenation-techniques were not used in our studies as the effect of different manners of cleansing and suctioning on the arterial blood gas analysis should be investigated. In accordance with published studies our results show that the use of a special adaptor, a closed system or hyperoxygenation is necessary to prevent hypoxemia and resulting problems.

The amount of drained secretions by normal suctioning is low. Event the effectivity of endobronchial lavage in the traditional way is doubtful. Suctioned volume is normally small as described by Hanley et al. [5]. Even greater volumes of rinsing solutions do not improve ventilation and raise PaO_2 [19]. Normally, endobronchial instillations will sprinkle only the trachea and the main bronchi [5] but not the peripheral parts of the bronchial tree. So bronchial cleansing in the traditional manner cannot be recommended [7]. In our study the suctioned volume was not as high as the applicated rinsing solution and the change of blood gases was not convincing. Bronchoscopic lavage is more successful but it needs more personnel and time and the availability of several bronchoscopes. Therefore bronchoscopic lavage cannot be recommended for routine suctioning. This is the background for our efforts to develop a new double-lumen catheter.

According to the law of Hagen-Poisieulle velocity of flow depends on the diameter of a channel. So the small application channel of the double-lumen catheter allows to place rinsing solution in the deep parts of the bronchial system where thickened secretions are liquefied and can be drained without inducing cough. Respiration must not be interrupted and swivel adaptors or methods of hyperoxygenation can be used. Thus suctioned volume was significantly higher than as compared to normal suctioning or bronchial lavage in the traditional manner.

Normal suctioning or lavage do not significantly increase PaO_2 only a few investigations have shown a slight increase in this parameter using a combination of different methods of hyperoxygenation [20]. After lavage with the double-lumen catheter we saw a statistically significant increase in PaO_2 and a decrease in $PaCO_2$. This difference maintained significantly even after 1 h. It was independent from the pattern of ventilation or positive end-expiratory pressure. An increase in PaO_2 and a decrease in the $PaCO_2$ indicate improvement of ventilation. The strong correlation (0.63) between suctioned volume and the change in PaO_2 10 min after the procedure demonstrates that the effectiveness of endobronchial lavage or suctioning depends on the volume of drained secretions. Endobronchial lavage with the new double lumen catheter improves bronchial ventilation and oxygenation of arterial blood. As no side effects, cardiopulmonary disturbances or other problems were seen this method can be recommended for rinsing the bronchial system in long term artificially respirated patients.

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