Fentanyl decreases end-expiratory lung volume in patients anaesthetized with sevoflurane

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Background. In patients breathing spontaneously during anaesthesia, expiratory muscle activity can be a prominent feature. This activity is triggered or exaggerated by opioid administration, which causes a prompt increase in intra-abdominal pressure. The effect of this increased expiratory activity on end-expiratory lung volume is not described.

Methods. Nine patients having minor gynaecological procedures were studied during stable anaesthetic conditions, breathing sevoflurane (end tidal 2.6%) through a laryngeal mask airway, in a circle system. The spill valve was closed and the fresh gas flow was temporarily reduced to approximate the oxygen uptake. The volume of the reservoir bag was then measured by placing it in a hinged, wedge-shaped container. Fentanyl (0.5 μg kg⁻¹ ideal body weight) was given after 1 min of stable recording, and the change in end-expiratory volume measured after 3 min.

Results. End-expiratory lung volume decreased in all patients by 160 (111) ml (mean, SD) (P<0.01). The decrease did not relate to obesity.

Conclusions. During sevoflurane anaesthesia, fentanyl causes a rapid reduction in functional residual capacity. This is caused by increased activity of expiratory muscles and an increase in intra-abdominal pressure.

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Methods

After obtaining approval from the Lothian local research ethics committee, we distributed a leaflet to patients presenting for preoperative assessment before minor day case gynaecological surgery. We approached patients presenting for hysteroscopy, microwave ablation, thermoablation, and other intra-uterine procedures. We excluded patients who were taking opioid medication. We obtained written informed consent, noted the patients’ age, height, and weight, and found the expected body weight (for height) from standard tables.10

Anaesthesia was induced using up to 50 mg propofol i.v. followed by inhalation of sevoflurane in oxygen. After sufficient depth of anaesthesia was obtained, a laryngeal mask airway was inserted and the seal was checked. The patient breathed from a circle anaesthesia system (Aestiva 5, GE Healthcare, Hatfield, Herts, UK). The inspired gas mixture was adjusted to 50% oxygen, with sufficient sevoflurane to give an end-tidal concentration close to 2.6%. The composition of the respired gas was analysed using a Datex Ohmeda S/5 monitor (Datex-Ohmeda Division, Instrumentarium Corp., Helsinki, Finland) and the sample gas returned to the circle system after analysis. The fresh gas flow was reduced as quickly as possible, so that a flow of <500 ml min⁻¹ oxygen and sevoflurane vapour could be used. The reservoir bag of the breathing circuit was placed in a custom-built device that measured the bag movement. This consisted of a static and a moving plate. The moving plate was mounted on an axle connected to the shaft of a 1% tolerance 10 kohm potentiometer, which measured the rotation of the shaft (Fig. 1). The signal was passed to an A/D converter (Amplicon Instrunet 100B, Brighton, UK), digitized at 50 Hz, and recorded with a laptop computer.

During stable anaesthesia with minimal surgical stimulation, after cervical dilation and insertion of the instruments for hysteroscopy or microwave application, between 10 and 15 min after induction of anaesthesia, the reservoir bag was placed in the measuring device, the spill valve of the circle was closed, and the fresh gas flow adjusted so that the end-expiratory bag volume stayed nearly constant. After recording respiration for 1 min, the patient was given fentanyl 0.5 µg kg⁻¹ expected body weight i.v. as a dilute solution in approximately 5 ml of 0.9% w/v sodium chloride and the injection was flushed in with a further 5 ml of normal saline. Recording was continued for a further 4 min. The traces were analysed as in a previous study.11

The reservoir bag measurement system was calibrated by the successive injection of 20 ml aliquots of air, over the working range of the bag volume, and recording the output. A polynomial relationship was fitted to the values to allow calibration of the recorded signal (Fig. 2) using an Excel spreadsheet (Microsoft Windows, Seattle, WA, USA). The data were analysed using Graphpad Prism software and significance testing was with the Wilcoxon test.

Results

We asked 14 patients to participate and 10 agreed. The data from one patient were inadvertently lost from the computer, so we present data from nine patients. Their mean age was 30 (range 19–49) yr, height was 166 (SD 7) cm, and weight was 66 (SD 13) kg. These weights were 108% (SD 19) of predicted, with a range from 67% to 142% of predicted. At the start of the study period, the end-tidal sevoflurane concentration was 2.6% (SD 0.1) and FIO₂ 0.55 (SD 0.1). The respiratory frequency during the control measurements was 26 (SD 6) The mean dose of fentanyl given was 30 µg (SD 3).

Figure 3 shows a good example of the effects of fentanyl administration. After the administration of opioid, respiratory frequency progressively declined to 14 (SD 3) cycle min⁻¹ and the end-expiratory volume changed by a mean of 160 ml (SD 110) (P<0.01) (Fig. 4). We plotted the change in end-expiratory volume against the body weight/expected weight but found no relationship.

Pulse oximeter readings were always 98% or greater.

Discussion

To our knowledge, this study is the first to show a direct reduction in lung volume after giving small doses of opioid.
to patients breathing spontaneously during anaesthesia. In some patients, this change was substantial, and of the same order as the changes seen on induction of anaesthesia and after reversal of fentanyl with naloxone.

The body weight of patients undergoing this type of surgery varies considerably. In our patients, their weight, expressed as a fraction of the weight expected on the basis of height and age, ranged from 87% to 142%. We therefore decided at the outset to give fentanyl in relation to the expected body weight, to avoid excessive dosage of patients who were overweight. In addition, if body weight did have an effect on the change in EELV, we would have expected to have found one, since there was a large range in weight which should have allowed the influence to be apparent.

Measurement of rapid changes in absolute lung volume during clinical anaesthesia is not simple. The only practical methods are closed-circuit indicator dilution (washin) or open-circuit washout methods. Both take some time to perform, even when washout or washin are rapid. Inductance plethysmography is an attractive method, but its accuracy for prolonged measurements is limited. With careful positioning, we have used impedance plethysmography successfully to show that the FRC changes on induction of anaesthesia are exclusively caused by a reduction in ribcage dimension. Although measurements of end-expiratory lung volume do not give an absolute measure of lung volume, they provide a precise continuous direct indication of change in absolute lung volume.

The relationship between decreased FRC and increased shunting during anaesthesia is non-linear. Important increases only occur when the FRC is less than awake closing capacity. When this is the case, a further decrease in FRC caused by opioid administration may have a large effect on shunting. From the data presented by Dueck and colleagues, obtained in young, non-obese patients, a change in FRC of about 300 ml (equivalent to an approximate 6% change in FRC/TLC) would cause a 10% increase in shunt fraction. In clinical practice, we have noted that in some patients, oxygen saturation may decrease by more than that expected from a change in ventilation alone, since end-tidal oxygen concentration is usually greater than 50%. Such decreases in saturation could be explained by the onset of airway closure and development of a low ventilation/perfusion compartment in the lung, but this topic requires further formal study.

We do not yet know precisely what factors control abdominal muscle activation during anaesthesia. Freund and colleagues noted that arousal from anaesthesia was often associated with an abrupt cessation of the abdominal muscle activity. Abdominal muscle activity is also often present in patients receiving opioid analgesia after abdominal surgery where it may contribute to the reduced lung volume and impairment of oxygenation found in these patients, and in patients in intensive care, where it may interfere with mechanical ventilation. Further studies, to establish the control mechanism by which opioids exert this effect, could be useful clinically.

References

![Image of Fentanyl dose given](image_url)
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