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Metabolic gas exchange during gynaecological laparotomy and laparoscopy

The purpose of this study was to evaluate metabolic gas exchange change during surgery performed with general anaesthesia. Metabolic gas exchange was measured continuously (Deltatrac®) during 33 gynaecological laparotomies and 22 laparoscopies performed during anaesthesia with propofol, fentanyl and vecuronium in mechanically ventilated patients. In both groups of patients, oxygen consumption ($\dot{V}O_2$) increased rapidly after skin incision (5–8% after 5 min, $P < 0.01$) and further increased during the surgical procedure (7% at 15 min in the laparoscopy group, $P < 0.001$ and 15% at 60 min in the laparotomy group, $P < 0.0001$). Carbon dioxide production ($\dot{V}CO_2$), on the other hand, showed different patterns in the two groups. It is concluded that a dynamic development of $\dot{V}O_2$ was seen during surgery suggesting that continuous measurement of $\dot{V}O_2$ might be used to evaluate the metabolic response evoked by surgical intervention.

L'objet de cette étude est d'évaluer les modifications des échanges gazeux métaboliques au cours d'une chirurgie réalisée sous anesthésie générale. Les échanges gazeux métaboliques sont mesurés continuellement (Deltatrac®) au cours de 33 laparotomies et de 22 laparoscopies gynécologiques. Ces interventions sont réalisées sous une anesthésie au propofol, fentanyl et vecuronium associée à une ventilation mécanique. Dans les deux groupes de patientes, la consommation d'oxygène ($\dot{V}O_2$) augmente rapidement après l'incision cutanée (5–8% après 5 min, $P < 0.01$) et ensuite pendant la réalisation de la chirurgie (7% à 15 min. dans le groupe laparoscopie, $P < 0.001$ et 15%

à 60 min. dans le groupe laparotomie, $P < 0.0001$). D'autre part, la production d'anhydride carbonique ($\dot{V}CO_2$) présente des profils différents dans les deux groupes. On en conclut qu'une augmentation active de la $\dot{V}O_2$ est observée pendant la chirurgie suggérant la possibilité d'une mesure continue de $\dot{V}O_2$ pour évaluer la réponse métabolique à la chirurgie.

In man, metabolic rate can be measured by means of oxygen consumption ($\dot{V}O_2$) as O_2 is consumed in energy creating processes. Trauma is known to increase $\dot{V}O_2$ ¹ but during anaesthesia $\dot{V}O_2$ is decreased.^{2–5} Thus, during surgery, $\dot{V}O_2$ reflects the net effect of surgical trauma and anaesthesia on metabolism. During surgery performed with general anaesthesia and muscle relaxation, easily measurable signs of autonomic activity, such as increases of blood pressure, heart rate or the occurrence of sweating and lacrimation are generally used to monitor anaesthesia. However, repeated measurements of $\dot{V}O_2$ might be used as an additional monitoring tool.

Today commercially available devices for measurements of metabolic gas exchange allow continuous online measurements of $\dot{V}O_2$ as well as carbon dioxide production ($\dot{V}CO_2$).⁶ The present study was undertaken in order to investigate the dynamics of $\dot{V}O_2$ and $\dot{V}CO_2$ during two different surgical procedures performed during general anaesthesia.

Methods

Fifty-five patients scheduled for gynaecological laparotomies ($n = 33$) and laparoscopies ($n = 22$) were included in the study. All patients gave informed consent and the study was approved by the local Ethics Committee.

All patients received premedication with 0.1 mg · kg⁻¹ diazepam *po* and 1 mg · kg⁻¹ pethidine *im* one hour before anaesthesia. Five to ten minutes before the induction of anaesthesia 2 µg · kg⁻¹ fentanyl was given, *iv*. Anaesthesia was induced by an infusion of 2 mg · kg⁻¹ propofol administered by syringe pump over 30 sec.

Anaesthesia was maintained by a continuous infusion of propofol at a rate of 10 mg · kg⁻¹ · hr⁻¹ for ten minutes and then reduced to 8 mg · kg⁻¹ · hr⁻¹ for 10 min and

Key words

CARBON DIOXIDE: elimination, production;

METABOLISM: oxygen consumption;

OXYGEN: consumption;

SURGERY: gynaecological.

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then maintained at $6 \text{ mg} \cdot \text{kg}^{-1} \cdot \text{hr}^{-1}$ until the skin had been closed. The tracheas of all patients were intubated and the lungs were mechanically ventilated during anaesthesia using an oxygen/air mixture providing 30% oxygen (measured by Ultima, Datex Instr Corp, Helsinki, Finland). Vecuronium, $0.1 \text{ kg} \cdot \text{kg}^{-1}$ was given to provide muscle relaxation. Neither nitrous oxide nor volatile agents were given.

In the laparotomy group hysterectomy, with or without salpingo-oophorectomy, was performed in the majority of cases although in two patients ovarian tumours were removed and three patients underwent tuboplasty.

In the laparoscopy group, 2–3 L CO_2 were inflated into the abdominal cavity before sterilization or diagnostic procedures were performed using percutaneous techniques.

Metabolic gas exchange was measured by a commercial indirect calorimetry device Deltatrac (Datex Instr Corp, Helsinki, Finland). The lungs were mechanically ventilated using a non-rebreathing system providing a minute ventilation of approximately $100 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. The minute ventilation was adjusted to achieve normocapnia as evaluated by end-tidal CO_2 measurements (Ultima, Datex Instr Corp, Helsinki, Finland). The Deltatrac monitor was connected to the ventilator in such a way that FiO_2 was measured at the end of the inspiratory tube and VE , FECO_2 and FEO_2 were measured at the end of the expiratory tube.

The fraction of CO_2 in the expired gas (FECO_2) was measured by an infrared sensor and corrected for the O_2 concentration. The O_2 concentration was measured both in a sample of the inspired (FiO_2) and in the expired (FEO_2) gases by a differential paramagnetic O_2 -analyser. Automatic calibration of both O_2 - and CO_2 -analysers were carried out every ten minutes. The expiratory flow (VE) was measured by an air dilution method in which expired gas passed through a mixing chamber and then was drawn into a $45 \text{ L} \cdot \text{min}^{-1}$ fixed flow generator. The volume flow through a turbulent restrictor was measured by the pressure drop over the resistor. The $\dot{\text{V}}\text{O}_2$ was calculated as $\text{VE}(\text{FiO}_2 - \text{FEO}_2)$ and $\dot{\text{V}}\text{CO}_2$ as $\text{VE} \times \text{FECO}_2$ assuming FiCO_2 to be negligible. The measurements performed over a five-minute period were averaged by the monitor.

The Deltatrac metabolic monitor has recently been validated in a study using butane combustion in conjunction with ventilation in a lung model.⁶ The relative errors for $\dot{\text{V}}\text{O}_2$ measurements at comparable FiO_2 was 0.8–3.4%. The metabolic monitor used in the present study was validated by alcohol burning inside a glass container specially designed for the metabolic monitors: the alcohol burning test showed a variation in $\dot{\text{V}}\text{O}_2$ and $\dot{\text{V}}\text{CO}_2$ of <2% when applied for four hours. The metabolic monitor

was further calibrated with a standard gas of 95% O_2 and 5% CO_2 , both before and after each measurement period. No measurements showing a difference between the two calibrations of >1% were included in the study. Two patients were deleted from the study for this reason.

The continuous gas exchange measurements were initiated at least 15 min after the tracheal intubation in order to avoid the 18% increase in $\dot{\text{V}}\text{O}_2$ seen shortly after intubation.⁷ This time lag has also been reported to eliminate the difficulties regarding measurements of gas exchange during changes in FEN_2 .² After 15 min of anaesthesia the nitrogen body stores are in steady state so that the relative error between computed and measured $\dot{\text{V}}\text{O}_2$ is <3%. For details see discussion by Viale *et al.*² Baseline data on metabolic gas exchange were measured during the two minutes prior to skin incision during general anaesthesia. Metabolic gas exchange was thereafter measured continuously each minute as long as surgery was performed. Mean values for each five-minute interval were calculated and the percental change from baseline is presented in the figures.

Systolic blood pressure (SBP) and heart rate were measured by an automatic non-invasive blood pressure recorder and an ECG-monitor every five minutes. Oesophageal temperature was measured every five minutes in the first ten patients enrolled in the study and was found to decrease 0.5 – 0.9° after 60 min of surgery.

Changes in gas exchange and haemodynamic variables were assessed by the ANOVA for repeated measures. Dunnett *t* test was applied to evaluate differences between certain means. Two-tailed significance values were given with $P < 0.05$ regarded as sufficient.

Results

Except for age ($P < 0.05$) there were no differences between the groups in demographic data or in basal variables. (Table I).

Laparotomy group

Rapid increases in both SBP and $\dot{\text{V}}\text{O}_2$ were seen during the first five minutes of surgery in the laparotomy group (both $P < 0.0001$). The SBP and $\dot{\text{V}}\text{O}_2$ continued to increase and reached their initial peaks within 10 to 15 min (+25% and +12% above baseline, respectively). Thereafter both variables declined slightly but remained considerably elevated (minimal levels +14% and +6% above baseline, $P < 0.01$ compared with the early peak levels). From 30 to 60 min a gradual increase in both SBP and $\dot{\text{V}}\text{O}_2$ were seen ($P < 0.01$ compared with minimal levels seen at 20 to 30 min).

On the other hand $\dot{\text{V}}\text{CO}_2$ declined gradually to –14% below baseline at 50 min ($P < 0.0001$).

The heart rate was unaffected during the first 20 min

TABLE I Basic characteristics in the studied groups given as mean $\pm$ SD

	Laparotomy group	Laparoscopy group
<i>n</i>	33	22
Age (yr)	46 $\pm$ 12	32 $\pm$ 8.6
Height (cm)	164 $\pm$ 37	166 $\pm$ 5
Weight (kg)	68 $\pm$ 12	67 $\pm$ 70
Measured basal $\dot{V}O_2$ (ml $\cdot$ min ⁻¹)	160 $\pm$ 35	168 $\pm$ 37
Measured basal $\dot{V}CO_2$ (ml $\cdot$ min ⁻¹)	169 $\pm$ 35	176 $\pm$ 32
Basal systolic blood pressure (mmHg)	101 $\pm$ 17	97 $\pm$ 21
Basal heart rate (beats $\cdot$ min ⁻¹)	82 $\pm$ 14	77 $\pm$ 12

of surgery and thereafter decreased gradually. This late reduction in heart rate was significant at 40 to 60 min, compared with baseline ($P < 0.05$). Data are presented in Table II.

Laparoscopy group

Similar increases in SBP and $\dot{V}O_2$ as seen in the laparotomy group were found in the laparoscopy group during the 15 min long procedure. The increase in $\dot{V}O_2$ (+8%) was, however, smaller than that seen in the laparotomy group ($P < 0.05$), but still significant ($P < 0.001$). In this study group $\dot{V}CO_2$ did not decline, but increased ($P < 0.006$). The heart rate was not changed in the laparoscopy group (Table III).

Discussion

In the present study metabolic gas exchange showed a dynamic pattern during surgery performed with general anaesthesia. A rapid increase in $\dot{V}O_2$ was seen after skin incision and was followed by a more gradual rise in oxygen consumption during gynaecological laparotomy. In the case of laparoscopy only an initial increase in $\dot{V}O_2$ could be detected, probably as a consequence of the shorter surgical procedure.

There are very few data on the dynamics of the metabolic gas exchange during surgery. In one study, in patients undergoing mastoidectomy or thyroidectomy, a 4% increase in $\dot{V}O_2$ was induced by skin incision.⁸ However, contrary to the present findings $\dot{V}O_2$ was reported to decrease during the operative course. In another study, involving gastrointestinal surgery patients, an increase in $\dot{V}O_2$ similar to that found in the present study was seen in patients during anaesthesia with benzodiazepine/fentanyl, but this surgically-induced change in oxygen consumption was blunted in patients in whom N_2O or halothane was added to the intravenous anaesthetic agents.² Thus, it suggests that both the type of surgery and the depth of anaesthesia influence oxygen consumption.

TABLE II Systolic blood pressure (SBP), heart rate, $\dot{V}O_2$ and $\dot{V}CO_2$ during 60 min of gynaecological laparotomy. Means $\pm$ SD

Variable	$\dot{V}O_2$ (ml $\cdot$ min ⁻¹)	$\dot{V}CO_2$ (ml $\cdot$ min ⁻¹)	Heart rate (beats $\cdot$ min ⁻¹)	SBP (mmHg)
Baseline	160 $\pm$ 35	169 $\pm$ 35	82 $\pm$ 14	101 $\pm$ 17
5 min	172 $\pm$ 35	165 $\pm$ 22	80 $\pm$ 12	123 $\pm$ 26
10 min	173 $\pm$ 35	162 $\pm$ 21	81 $\pm$ 17	126 $\pm$ 28
15 min	174 $\pm$ 37	159 $\pm$ 22	81 $\pm$ 13	122 $\pm$ 25
20 min	173 $\pm$ 37	156 $\pm$ 22	82 $\pm$ 21	118 $\pm$ 23
25 min	171 $\pm$ 35	151 $\pm$ 22	78 $\pm$ 11	117 $\pm$ 21
30 min	173 $\pm$ 36	150 $\pm$ 22	77 $\pm$ 10	116 $\pm$ 21
35 min	175 $\pm$ 38	148 $\pm$ 22	78 $\pm$ 17	118 $\pm$ 22
40 min	177 $\pm$ 39	149 $\pm$ 21	75 $\pm$ 11	123 $\pm$ 24
45 min	180 $\pm$ 39	150 $\pm$ 21	75 $\pm$ 12	123 $\pm$ 25
50 min	179 $\pm$ 40	147 $\pm$ 19	74 $\pm$ 12	120 $\pm$ 24
55 min	179 $\pm$ 35	151 $\pm$ 18	74 $\pm$ 12	121 $\pm$ 27
60 min	181 $\pm$ 41	153 $\pm$ 19	73 $\pm$ 12	123 $\pm$ 26

TABLE III Systolic blood pressure (SBP), heart rate, $\dot{V}O_2$ and $\dot{V}CO_2$ during 15 min of gynaecological laparoscopy. Means $\pm$ SD

Variable	$\dot{V}O_2$ (ml $\cdot$ min ⁻¹)	$\dot{V}CO_2$ (ml $\cdot$ min ⁻¹)	Heart rate (beats $\cdot$ min ⁻¹)	SBP (mmHg)
Baseline	168 $\pm$ 37	176 $\pm$ 32	77 $\pm$ 12	97 $\pm$ 21
5 min	175 $\pm$ 38	178 $\pm$ 34	80 $\pm$ 13	113 $\pm$ 20
10 min	179 $\pm$ 40	187 $\pm$ 35	76 $\pm$ 11	117 $\pm$ 24
15 min	184 $\pm$ 38	189 $\pm$ 31	79 $\pm$ 12	123 $\pm$ 22

In a study comparing the effects of neurolept/ N_2O versus halothane anaesthesia on $\dot{V}O_2$ a decrease in $\dot{V}O_2$ of 35–40% was seen after 30 min of anaesthesia.³ Ten minutes after skin incision a rise in $\dot{V}O_2$ by 15–16% was noted. This increase was accompanied by a substantial increase in circulating adrenaline levels. These findings might be taken as evidence that the increase in sympathetic activity induced by the initiation of surgery caused a rapid increase in $\dot{V}O_2$ as seen in the present as well as in previous studies.

After the initial peak in $\dot{V}O_2$ (and SBP) a temporary decline was found in the present study. This temporary reduction was followed by a gradual rise in $\dot{V}O_2$ during the rest of the laparotomy procedure. A similar time course has previously been described by Viale *et al.* during benzodiazepine/fentanyl anaesthesia.² The late gradual rise in $\dot{V}O_2$ during the laparotomies may be caused by different mechanisms. First, the maintenance dose of propofol may have been insufficient to counteract the metabolic effects of the surgical trauma. Secondly, fentanyl was given at the beginning of surgery and the effect of this analgesic drug may have passed by the end of surgery as suggested by Westenskow and Jordan.⁴ Thirdly, the metabolic response to surgical trauma involves several neuro-endocrine features, such as activation

of the sympathetic and the renin-angiotensin systems as well as increased secretion of hormones from the adrenal cortex. The potency and time course of the different features involved in the metabolic response to surgical trauma might induce late increase in $\dot{V}O_2$. Thus a task for the future is to relate the dynamics of $\dot{V}O_2$ during surgery to the secretion of various hormones involved in the response to surgical trauma.

On the other hand, $\dot{V}CO_2$ gradually decreased during the first 50 min of surgery in the laparotomy group. The same phenomenon was noted in two recent studies^{2,5} and was attributed to alveolar hypoventilation leading to an excess carbon dioxide elimination in expired gas for the first 50 min. After this period, the CO_2 stores in the body were probably in steady state. Thus, longer surgical interventions than in the present study should be investigated in order to clarify the effects of surgery on $\dot{V}CO_2$.

Laparoscopy has been regarded as a minor event as the skin incision is small and the duration of the procedure is short. However, a study evaluating the hormonal response during gynaecological laparoscopies showed that both the serum concentrations of glucose and cortisol, as well as growth hormone, were increased at the end of the relatively short operation.⁹ In the present study, $\dot{V}O_2$ increased rapidly in the laparoscopy group, but less than in the laparotomy group suggesting that laparoscopy is not as stressful as laparotomy. In the laparoscopy group an increase, instead of a decrease, in $\dot{V}CO_2$ was seen despite the use of similar ventilation criteria. This phenomenon could probably be explained by the insufflation of CO_2 into the abdominal cavity during the laparoscopy increasing the levels of $PaCO_2$ and thereby CO_2 elimination in alveolar gas.¹⁰

The parallel changes in blood pressure and $\dot{V}O_2$ suggest that during surgery with general anaesthesia the cardiovascular response to metabolic changes is preserved. However, as heart rate was not effected in the same manner as blood pressure it is unknown if the increase in blood pressure was due to an increase in cardiac output or an increase in the peripheral resistance. Thus, further studies with simultaneous measurements of $\dot{V}O_2$ and more detailed measurements of cardiovascular function are therefore needed to investigate this matter.

In conclusion, a dynamic development of $\dot{V}O_2$ was seen during surgery. This finding suggests that continuous measurement of $\dot{V}O_2$ might be used to evaluate the metabolic response evoked by surgical intervention.

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