Originals

Intensive Care Medicine
© Springer-Verlag 1994
Intensive Care Med (1994) 20:470–475

High fat, low carbohydrate, enteral feeding in patients weaning from the ventilator

B. van den Berg[1], **J.M. Bogaard**[1], **W.C.J. Hop**[2]

[1] Respiratory Intensive Care Unit, Room D 306, University Hospital, Rotterdam, The Netherlands
[2] Department of Epidemiology and Biostatistics, University Hospital, Rotterdam, The Netherlands

Received: 10 February 1992/Accepted: 17 March 1993

Abstract. *Objective:* To study whether high fat, low carbohydrate enteral nutrition could reduce $\dot{V}CO_2$ in patients during ventilator support and weaning from the ventilator in order to facilitate the weaning process.
Design: prospective, randomized controlled study.
Setting: Medical ICU of a university hospital.
Patients: 32 ventilator-dependent patients with a prospect of weaning from mechanical ventilation.
Interventions: high fat feeding administered to 15 patients and standard isocaloric feeding administered to 17 patients, both in a dosage of 1.5 times basal metabolic rate.
Measurements and results: Respiratory and metabolic measurements were obtained both during mechanical ventilation and weaning procedures. High fat feeding was associated with significantly lower RQ values compared with standard feeding; the mean (±SEM) RQ values during mechanical ventilation amounted to 0.91 ± 0.01 and 1.00 ± 0.02 and during weaning to 0.72 ± 0.02 and 0.86 ± 0.02 for high fat and standard nutrition respectively (both p-values < 0.001). High fat feeding reduced the CO_2-excretion both during mechanical ventilation and weaning, but only the decrease during weaning proved to be significant; the mean (±SEM) CO_2-excretion amounted to 0.177 ± 0.010 and 0.231 ± 0.011 l/min STPD for the high fat and standard feeding respectively ($p < 0.01$). No significant differences were found in the $PaCO_2$ during weaning between the two feeding groups.
Conclusion: High fat, low carbohydrate enteral feeding significantly reduced the RQ values in ventilated patients with decreases in $\dot{V}CO_2$, but in this study failed to reduce $PaCO_2$ during weaning from the ventilator.

Key words: Artificial ventilation – Respiratory failure – Enteral nutrition.

In the last decade the importance of nutritional support in mechanically ventilated patients has been underlined [1]. In patients who at first failed to wean from mechanical ventilation, the response to nutritional support was considered a prognostic sign of success of weaning [2]. However, nutritional support affects ventilation in different ways. Nutrition increases oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) due to the thermic effects of the nutrients. In patients with limited ventilatory reserves, high calorie diets in excess of energy requirements were found to precipitate respiratory distress due to increased $\dot{V}CO_2$ [3]. In particular parenteral nutrition with high carbohydrate loads resulted in markedly increased $\dot{V}CO_2$, with a respiratory quotient rising to values above 1.0 [4]. A shift from predominantly carbohydrate diets to diets with a high fat content has been suggested, to reduce respiratory quotient and $\dot{V}CO_2$ [5]. Consequently high fat, low carbohydrate nutrition would appear to be beneficial to patients with limited ventilatory reserves [6]. However, in patients with chronic obstructive pulmonary disease (COPD) conflicting results have been published about the effects of high fat, low carbohydrate feed on $PaCO_2$ [5, 7]. We studied the effects of a high fat, low carbohydrate enteral feed compared with a standard enteral nutrition in ventilator-dependent patients. Minute ventilation, $\dot{V}O_2$, $\dot{V}CO_2$ and arterial blood-gases were obtained during mechanical ventilation and periods of weaning from the ventilator.

Patients and methods

Patients

Adult patients (32) suffering from COPD, neurological illness or pneumonia in the absence of COPD, requiring mechanical ventilation and who could be fed enterally, were entered into the study. Patients were excluded from the study if they had evidence of diabetes mellitus, renal or hepatic failure, or respiratory failure without a prospect of weaning from the ventilator.

Body height and weight, percentage ideal body weight, triceps skinfold (TSF), arm muscle circumference (AMC) and serum albumin levels were obtained as measures of nutritional status. The ideal body weight for each patient's height was calculated using standard tables [8]. Arm muscle circumference was calculated according to the methods of Blackburn et al. [8]. Apache II-scores were obtained at entry of the

Correspondence to: B. van den Berg

study to assess severity of illness [9]. All patients with COPD were maintained on a stable bronchodilator regimen including theophylline and inhaled beta-stimulating drugs. The investigative protocol was approved by the institutional ethics committee, and informed consent was obtained from the patient or family in all cases.

Mechanical ventilation

The patients were on controlled ventilation through a cuffed endotracheal tube with a time-cycled ventilator (Siemens Servo-ventilator 900C, Siemens-Elema, Sweden). Mechanical ventilation using the volume-controlled mode, was adjusted to normocapnia and a PaO_2-value above 10 kPa. Mean minute ventilation was 10.8 l/min (SD 2.1), mean respiratory frequency was 16/min (SD 4).

Weaning

Weaning was performed using the continuous positive airway pressure (CPAP) mode of the Siemens Servo-ventilator. Weaning was started as soon as the patients fulfilled the following conditions:

1. mechanical ventilation with FIO_2 less than 50% and a PEEP level less than 10 cm H_2O;
2. mechanical ventilation without sedation or relaxation;
3. absence of high fever or circulatory failure;
4. serum bicarbonate level less than 28 mmol/l.

Nutrition

Patients received either a high fat, low carbohydrate feed or a standard enteral feed. The dosage prescribed was 1.5 times basal metabolic rate calculated from the tables of Harris and Benedict and was kept constant during the study.

The enteral nutrition was given through a nasogastric tube by continuous flow for 24 h per day using a Flexiflo II enteral feeding pump. As high fat, low carbohydrate enteral feed, Pulmocare (Abbott Laboratories, Amstelveen, Holland), consisting of 16.7% protein, 55.2% fat and 28.1% carbohydrates, was used. As standard enteral nutrition, Ensure Plus ® (Abbott Laboratories, Amstelveen, Holland), consisting of 16.7% protein, 30% fat and 53.3% carbohydrates, was used.

Respiratory and metabolic measurements

Respiratory minute volume ($\dot{V}E$), oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$) and respiratory quotient (RQ) were determined using an indirect calorimetric technique, described in a previous paper [10]. For these measurements the $\dot{V}E$ was obtained using the flow transducer (type Silverman) from the ventilator calibrated with a wet spirometer in series with the ventilator. For monitoring of the respiratory gases an infrared type CO_2-analyzer (Siemens, type Ultramat M) and a paramagnetic O_2-analyzer (Mijnhardt, type Oxylyzer), were used.

Alternately inspiratory and mixed expiratory gas fractions were measured using two mixing bags to avoid pressure variations influencing the gas analysis. For $\dot{V}O_2$ calculation the Haldane-correction was used [11]. Considering the influence of the FIO_2 on the accuracy of the metabolic variables, measurements were only obtained at FIO_2-values less than 45% [12]. In order to measure FIO_2 accurately, a flow-weighted mean of the inspiratory gas fraction was obtained using a continuous leak in the inspiratory line of the ventilator discharging into a mixing bag. The inspiratory gas was sampled intermittently from this mixing bag for gas analysis. During mechanical ventilation peak airway pressures were obtained in all patients using the pressure transducer from the ventilator.

Study protocol

Patients were randomly allocated to the high fat, low carbohydrate feeding (15), the remaining 17 patients to the standard nutrition. Stratification was done on basis of the nature of their underlying diseases: COPD versus neurological illness and pneumonia in the absence of COPD. At 12–24 h after the start of the nutritional support respiratory and metabolic measurements were obtained during mechanical ventilation and weaning if the patient fulfilled the criteria to start spontaneous breathing. In order to assess the ability of the respiratory muscles to cope with the respiratory workload during weaning, the maximum static inspiratory pressure (PI_{max}) was measured. If the patients did not fulfill criteria to start weaning, the measurements were done only during mechanical ventilation and were repeated two times a week.

$\dot{V}E$, $\dot{V}O_2$, $\dot{V}CO_2$ and RQ, were obtained for 1 h during mechanical ventilation. At the end of this period arterial blood-gases were measured. Subsequently weaning was started during which the measurements of $\dot{V}E$, $\dot{V}O_2$, $\dot{V}CO_2$ and RQ were continued. The weaning trial was ended when the patient was too short of breath or tired to continue. During weaning arterial blood-gases were obtained according to a fixed time-schedule: at 30 min and, as long as the patient sustained spontaneous breathing, at 1 h, 2 h and 3 h after the start of the trial. If the patient was unable to wean for 30 min, no blood-gases were obtained and the results of the weaning trial were discarded. After the weaning trial mechanical ventilation was resumed in order to rest the respiratory muscles. Subsequently after a period of rest varying from 4–6 h, the weaning trial was repeated. During the night the patients were ventilated and weaning was not attempted. The ability of the patient to breath spontaneously for 3 h was used as endpoint of the study. If the patient was unable to fulfill this condition, the study was terminated on the 15th day after the start of the nutritional support.

In order to compare the effects of the nutritional regimens, the measurements obtained in the two patient groups on the third day of the study were used.

The mean $\dot{V}O_2$, $\dot{V}CO_2$ and RQ obtained during mechanical ventilation for the two patient groups were compared to evaluate the effect of the nutritional regimens on the patients' metabolism.

The measurements obtained during the first half hour of weaning were used to evaluate the effects of nutrition on respiration, because only a limited number of the patients could sustain spontaneous breathing for periods of time longer than 30 min on the third day of the study. The values of $\dot{V}E$, $\dot{V}O_2$, $\dot{V}CO_2$ and RQ obtained during the first 30 min of weaning and the $PaCO_2$ measured at the end of that period were compared to evaluate the effect of the two nutritional regimens on respiration. In order to establish the clinical relevance of the measurements obtained during the first half hour of weaning, correlations were calculated between measurements at the first half hour and the third hour of weaning. For this purpose the measurements of all patients who could wean for 3 h were used, irrespectively of the day of the study. The median time in days, from the start of the study until the patient could breath spontaneously for 3 h during a weaning trial, was compared between the patient groups in order to evaluate the effects of nutrition on the time required to wean the patients from the ventilator.

Statistical methods

In order to compare differences in the respiratory measurements and the time required for weaning from the ventilator between the feeding groups the Mann-Whitney test was used. Two-way analysis of variance (ANOVA) was used to evaluate simultaneously differences between feeding groups and differences between patient groups according to the nature of the respiratory failure [13]. To allow for the multiple comparisons, statistical significance was tested at $p = 0.01$ instead of the conventional $p = 0.05$ [14]. For calculation of the correlations the Pearson correlation coefficient was used. Data given are means (±SEM), or indicated otherwise.

Results

Considering the results of the study, we found an imbalance between the two patient groups. Although the number of patients with COPD did not differ between the two feeding groups, an imbalance was present between the number of patients ventilated for acute-on-chronic respiratory failure due to COPD, against patients with COPD ventilated for other causes of respiratory insufficiency such as cerebral hemorrhage, cardiac failure or abdominal surgery.

In the high fat, low carbohydrate feeding group 10 out of 11 patients with COPD were ventilated for acute-on-chronic respiratory failure due to COPD, against only 5 out of 13 patients in the standard feeding group. In contrast to the patients with COPD ventilated for other causes of respiratory failure, the patients with acute-on-chronic respiratory failure were intubated and ventilated for severe hypercapnia. In the latter group hypercapnia was also present during the weaning procedures. As this imbalance substantially affected the results, two-way analysis of variance was used in order to evaluate whether the results obtained at the two nutritional regimens were related to the nature of the respiratory failure.

The patient group receiving high fat, low carbohydrate feeding and ventilated for "other causes" consisted of 5 patients: one patient with COPD, three patients with pneumonia and one patient with neurological illness. The patient group receiving standard feeding and ventilated for "other causes" consisted of 12 patients: 8 patients with COPD, 3 patients with pneumonia and one patient with neurological illness. The patient data on admission are shown in Table 1. Considering the two patient groups according to the nutritional intakes, no significant differences were found.

Neither significant difference was found in the calorie intake: 1943 ± 306 kcal per 24 h in the high fat, low carbohydrate and 2003 ± 277 kcal per 24 h in the standard feeding group (means and SD).

Measurements during mechanical ventilation

The results of the measurements obtained during mechanical ventilation at the third day of the study were compared. Measurements of 14 patients in the high fat, low carbohydrate feeding group were available, subdivided in 10 patients with acute-on-chronic respiratory failure and 4 patients ventilated for other causes of respiratory failure. In the standard feeding group measurements of 16 patients were available consisting of 5 patients with acute-on-chronic respiratory failure and 11 patients ventilated for other causes. With regard to the ventilator-settings, no differences were found comparing the FIO_2-values applied during the ventilator support the values amounted to 0.35 ± 0.01 and 0.36 ± 0.01 for the high fat, low carbohydrate and standard feeding groups respectively. The results of the respiratory and metabolic measurements are shown in Table 2. Concerning the two feeding groups a significant difference was found in RQ; the difference in $\dot{V}CO_2$ failed to reach significantly (p-values < 0.001 and 0.08 respectively). The effects of the nutritional regimens on RQ and $\dot{V}CO_2$ proved to be independent of the nature of the respiratory failure. No differences were found in minute ventilation, $\dot{V}O_2$ or $PaCO_2$. Neither differences were found comparing the peak airway pressures measured during mechanical ventilation; the peak airway pressures amounted to 27 ± 2 and 30 ± 3 cm H_2O for the high fat, low carbohydrate and standard feeding group respectively.

The ANOVA revealed a significant difference in $PaCO_2$ between the patients with acute-on-chronic respiratory failure to those ventilated for other causes. This difference proved to be independent of the type of nutrition used. The $PaCO_2$ amounted 5.5 ± 0.2 and 4.5 ± 0.2 kPa for the patients ventilated for acute-on-chronic respiratory failure and for other causes respectively ($p < .001$).

Table 1. Patient characteristics at entry into the study. Data are given are number of patients or means ± SD

	High fat, low carbohydrate feed	Standard feed
No. of patients	15	17
Male/female	10/5	13/4
Underlying conditions:		
Patients with COPD	11	13
(patients with ARF-on-CRF due to COPD)	(10)	(5)
Patients with neurological illness	1	1
Patients with pneumonia	3	3
% ideal body weight	0.95 ± 0.24	1.15 ± 0.27
Triceps skin fold mm	11.9 ± 6.9	13.4 ± 7.7
Arm muscle circumference cm	22.0 ± 3.5	24.1 ± 4.2
Serum-albumin g/l	28.6 ± 4.7	28.0 ± 5.9
Apache II score	15 ± 4	14 ± 4

ARF-on-CRF, Acute-on-chronic respiratory failure

Measurements during weaning procedures

Measurements obtained during weaning on the third day of the study were compared. Data of 12 patients in the high fat, low carbohydrate feeding group were available against those of 14 patients in the standard nutrition group. Of the 12 patients in the high fat, low carbohydrate feeding group 8 were ventilated for acute-on-chronic respiratory failure due to COPD against 5 of the 14 patients in the standard feeding group.

Comparing the two feeding groups no significant differences were found in the values of PI_{max} obtained at the start of the weaning procedures: the values amounted to -32 ± 2 and -34 ± 3 cm H_2O for the high fat, low carbohydrate feeding and standard feeding groups respectively. Neither differences were found comparing the PI_{max} values of the patient groups according to the nature of the respiratory failure.

The data of the respiratory and metabolic measurements during weaning are shown in Table 3 and Fig. 1 – 3. Significant differences between the two feeding groups were found in mean CO_2-excretion and mean RQ (p-values < 0.01 and 0.001 respectively). The differences in minute ventilation, $\dot{V}O_2$ and $PaCO_2$ were not significant. The ANOVA further revealed that no significant differences in CO_2-excretion or RQ were present when the patients with acute-on-chronic respiratory failure were compared to those ventilated for other causes. The effects of the nutritional intakes with respect to RQ and CO_2-excretion proved to be independent of the nature of the

Table 2. Respiratory and metabolic measurements during mechanical ventilation, obtained on the 3rd day of the study. Data given are means ± SEM

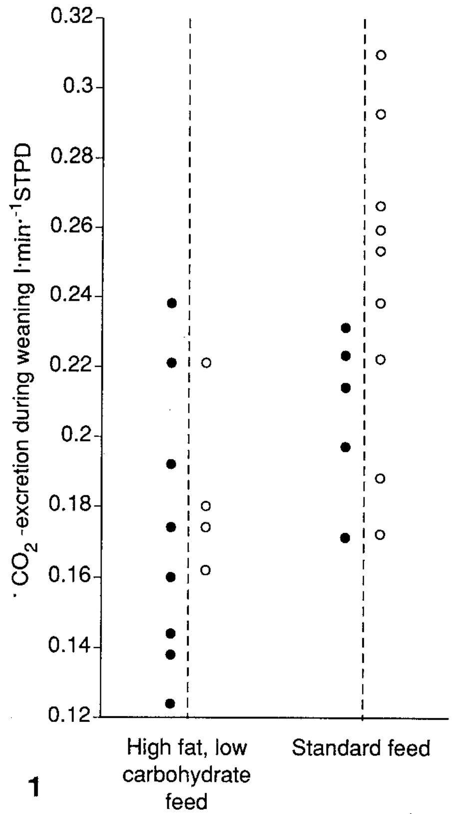
Mechanical ventilation		Min. vent. l/minBTPS	$\dot{V}CO_2$ l/minSTPD	$\dot{V}O_2$ l/minSTPD	RQ	$PaCO_2$ kPa
High fat, low carbohydrate feed	Total $n = 14$	9.9 ± 0.6	0.218 ± 0.013	0.199 ± 0.011	0.91 ± 0.01*	5.1 ± 0.3
Standard feed	Total $n = 16$	11.0 ± 0.7	0.225 ± 0.007	0.225 ± 0.008	1.00 ± 0.02*	5.0 ± 0.2

Min.vent., Minute ventilation; BTPS, body temperature pressure saturated; STPD, standard temperature pressure dry
*$p < 0.001$

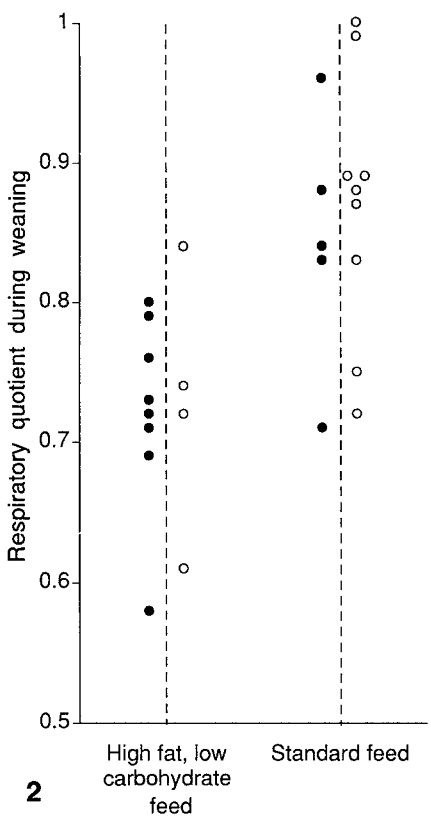
Table 3. Respiratory and metabolic measurements during weaning from the ventilator, obtained on the 3rd day of the study. Data given are means ± SEM

Weaning		Min. vent. l/minBTPS	$\dot{V}O_2$ l/minSTPD	$\dot{V}CO_2$ l/minSTPD	RQ	$PaCO_2$ kPa
High fat, low carbohydrate feed	Total $n = 12$	8.8 ± 0.9	0.244 ± 0.010	0.177 ± 0.010*	0.72 ± 0.02**	6.4 ± 0.4
Standard feed	Total $n = 14$	10.5 ± 0.8	0.271 ± 0.013	0.231 ± 0.011*	0.86 ± 0.02**	5.9 ± 0.3

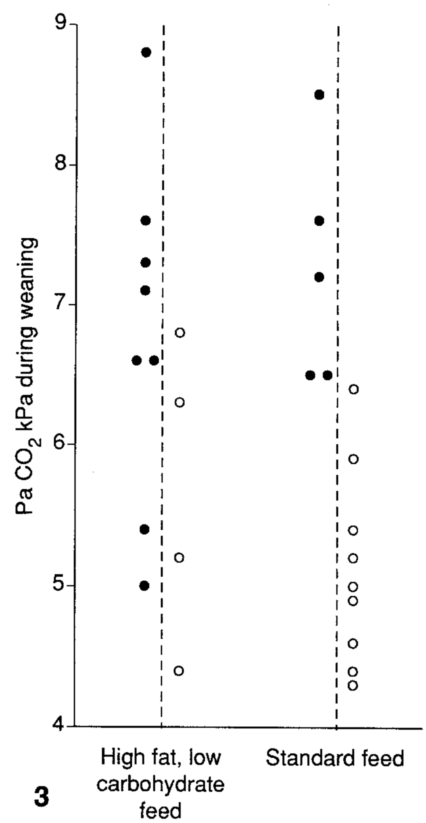
Min.vent., Minute ventilation; BTPS, body temperature pressure saturated; STPD, standard temperature pressure dry
*$p < 0.01$; **$p < 0.001$



1



2



3

Fig. 1. The values of CO_2-excretion of the individual patients during weaning off the ventilator. The values are shown according to the nutritional regimen and to the nature of the respiratory failure. ● = acute-on-chronic respiratory failure; ○ = respiratory failure due to other causes

Fig. 2. The values of RQ of the individual patients during weaning off the ventilator. The values are shown according to the nutritional regimen and to the nature of the respiratory failure. ● = acute-on-chronic respiratory failure; ○ = respiratory failure due to other causes

Fig. 3. The values of $PaCO_2$ of the individual patients during weaning off the ventilator. The values are shown according to the nutritional regimen and to the nature of the respiratory failure. ● = acute-on-chronic respiratory failure; ○ = respiratory failure due to other causes

respiratory failure. Significant differences however were found in minute ventilation and $PaCO_2$ comparing the patient groups according to the cause of the respiratory failure. These differences proved to be independent of the type of nutrition used. The mean minute ventilation amounted to 7.9 ± 0.5 against 11.5 ± 0.9 l/min BTPS and the mean $PaCO_2$ to 7.0 ± 0.5 against 5.3 ± 0.2 kPa in the acute-on-chronic respiratory failure group against the patient group ventilated for other causes (p-values < 0.01 and 0.001 respectively).

Correlations between the first half hour and the third hour of weaning were obtained in 25 patients; 11 patients in the high fat, low carbohydrate feeding group and 14 patients in the standard feeding group. Significant correlations were found in both groups for CO_2-excretion and RQ. As to the CO_2-excretion the correlation coefficients amounted to 0.83 and 0.87 ($p < 0.01$ and $p < 0.001$ respectively) for the two feeding groups. For the RQ the correlation coefficients amounted to 0.72 and 0.78 ($p = 0.01$ and $p < 0.01$ respectively).

Time required to wean off the ventilator

In two patients the endpoint of the study could not be reached; the enteral feeding had to be ended because of gastric retention in one patient in the high fat, low carbohydrate feed group and in one patient in the standard nutrition group after 3 and 7 days respectively. Both patients were ventilated for "other causes" of respiratory failure. Five patients failed to breath spontaneously for 3 h within 15 days from the start of the study; two patients in the high fat, low carbohydrate feeding group, as against three patients in the standard nutrition group. Of these patients one patient in the high fat, low carbohydrate feeding group against two patients in the standard feeding group were ventilated for acute-on-chronic respiratory failure. The median time of the study amounted to 4 days in the high fat, low carbohydrate feeding group against 6 days in the standard nutrition group: a difference which failed to reach significance.

Discussion

This study was designed to investigate the effects of a high fat, low carbohydrate enteral feeding on gas-exchange in patients during mechanical ventilation and weaning from the ventilator.

Although the stratification resulted in a comparable number of patients with COPD in both of feeding groups, subdivision into different causes of respiratory failure in the patients with COPD revealed an imbalance between the two feeding groups. Analysis of the results revealed that patients with acute-on-chronic respiratory failure due to COPD were predominantly found in the high fat, low carbohydrate enteral feeding group. It was clear that in particular in these patients hypercapnia was found during weaning from the ventilator. Consequently this imbalance had to be taken into account at the analysis of the results.

Therefore two-way analysis of variance was used in order to evaluate differences between the patient groups defined by the nutritional regimens and the nature of the respiratory failure simultaneously.

Nutritional assessment of the patients obtained at the start of the study revealed that severe malnourishment was not prominent in this study in contrast to the study of Driver et al. who found a high prevalence of malnutrition in patients with acute respiratory failure and COPS [15].

In this study the calculated basal energy expenditure according to Harris and Benedict was used in order to determine the calorie intake for each patient. Previous experience had tought us that in the disturbing environment of an intensive care unit reproducible measurements of resting energy expenditure in post-absorptive state are hard to obtain in ventilator-dependent patients who are not sedated.

Considering the metabolic measurements obtained during mechanical ventilation it must be stressed that the mode of mechanical ventilation was aimed to reduce the work of breathing of the patients to a minimum. Consequently the $\dot{V}O_2$ of the patients has also been affected by the mode of mechanical ventilation. This explains why in our study, during nutritional support, lower values of $\dot{V}O_2$ were found compared with data previously reported of spontaneously breathing patients with COPD receiving equivalent amounts of high fat, low carbohydrate and standard enteral diets [5]. Marked higher RQ values were also found in our study compared with studies of equivalent nutritional support in ambulatory spontaneously breathing patients with COPD [5, 7]. Compared with an isocaloric moderate fat diet, the high fat, low carbohydrate feeding was associated with a lower $\dot{V}CO_2$ and RQ during mechanical ventilation. This indicates that the patients receiving the high fat, low carbohydrate feeding oxidized more fat than the patients receiving the standard feeding. Only the difference in RQ however proved to be significant. Despite the difference in fat content between the two nutritional intakes, the difference in $\dot{V}CO_2$ between the two feeding groups failed to reach significance. If the difference in mean $\dot{V}CO_2$ between the two patient groups was expressed as percentage of the mean $\dot{V}CO_2$ of the standard feeding group, a reduction in $\dot{V}CO_2$ of 12% was found. In another study using equivalent nutritional support in patients with COPD a significant difference in $\dot{V}CO_2$ was found comparing high fat, low carbohydrate and standard feeding groups: the reduction in mean $\dot{V}CO_2$ was, however, 10% [5]. In contrast to our investigation, in that study a cross-over design was used, comparing the nutritional regimens in the same patient group.

No differences were found in minute ventilation of $PaCO_2$ during mechanical ventilation comparing the two feeding groups. In agreement with these results no difference was found in the peak airway pressures measured during the mechanical ventilation. The ANOVA revealed a significant higher $PaCO_2$-value during mechanical ventilation in the patient group with acute-on-chronic respiratory failure compared to those ventilated for other causes. These higher $PaCO_2$-values should be explained in terms of a lower minute ventilation and a higher dead space ventilation in the patients with acute-on-chronic respiratory failure.

During the weaning trial a significantly lower CO_2-excretion and RQ were found in the high fat, low carbohydrate feeding group. For both variables the difference between the feeding groups was similar for the patients with acute-on-chronic respiratory failure and the patients ventilated for other causes. Comparing the patients with acute-on-chronic respiratory failure to those ventilated for other causes, significantly higher $PaCO_2$-value and lower minute ventilation was found during weaning in the former group. These differences were unrelated to the nutritional regimen applied. For both CO_2-excretion and RQ significant correlations were found between the first half hour and the third hour of weaning, indicating the predictive value of the measurements at the first half hour of weaning. It is however clear, that these correlations could only be obtained in the group of patients who could sustain weaning for 3 h.

It should be discussed what value can be attached to these results in view of the short period of time studied. Clearly, the start of weaning implied considerable changes in the gas exchange of the patients. Comparing the weaning trial to mechanical ventilation an increase in $\dot{V}O_2$ was observed in all patients; a decrease in CO_2-excretion was found in the high fat, low carbohydrate feeding group against a slight increase in the standard feeding group. As a result, the RQ values decreased in all patients. The increase in $\dot{V}O_2$ is determined predominantly by the energy expenditure of the respiratory muscles of the patients. The changes in the CO_2-excretion should be elucidated in view of the increased metabolic rate and alterations in the body CO_2-pool during the weaning period. Assuming that with respect to oxidation the ratio between carbohydrate and fat did not alter during the weaning trial, the changes in the CO_2-excretion can then only be explained by an increase in the body CO_2-pool. This suggests that the CO_2-excretion did not equal the CO_2-production of the body and no steady state was present during the half hour's weaning trial. Under these circumstances, because of the unaltered diet, a relationship between the type of nutritional support and the CO_2-excretion and RQ values is however assumed, comparable to that during mechanical ventilation. Consequently, the values of CO_2-excretion and RQ may provide valuable information with respect to the effects of feeding on spontaneous breathing.

A previous study reported by Al-Saady, suggested significant reductions in $PaCO_2$ and minute ventilation in patients with high fat, low carbohydrate feeding compared with patients with standard enteral nutrition [6]. This study used enteral nutrition identical to our investigation. However, $\dot{V}O_2$ and $\dot{V}CO_2$ were not measured during this study and an improvement of pulmonary function with a decrease in dead space ventilation could not be excluded. In contrast to our investigation this study also reported a significant reduction in time spent on mechanical ventilation in the patient group on high fat, low carbohydrate enteral feeding [6]. A marked difference was however present in underlying diseases of the patients between both studies. In our study 15 out of 32 patients were ventilated for acute-on-chronic respiratory failure due to COPD against 1 of 20 patients in the study of Al-Saady [6]. In the latter study successful weaning was defined as 24 h spontaneous breathing without hypercapnia against only 3 h spontaneous breathing disregard the level of $PaCO_2$ in our study.

In conclusion high fat, low carbohydrate feeding compared with standard nutrition decreased RQ but failed to reduce $\dot{V}CO_2$ significantly in mechanically ventilated patients in this study. Comparing the two nutritional regimens, no difference could be demonstrated in the $PaCO_2$-values during weaning from the ventilator. Althoug during weaning both CO_2-excretion and RQ proved to be lower in the high fat, low carbohydrate feeding group, this type of nutrition was unable to shorten the time spent on mechanical ventilation before successful weaning was accomplished.

References

1. Driver AG, LeBrun M (1980) Iatrogenic malnutrition in patients receiving ventilatory support. JAMA 244:2195–2196
2. Larca L, Greenbaum DM (1982) Effectiveness of intensive nutritional regimes in patients who fail to wean from mechanical ventilation. Crit Care Med 10:297–300
3. Berg B van den, Stam H (1988) Metabolic and respiratory effects of enteral nutrition in patients during mechanical ventilation. Intensive Care Med 14:206–211
4. Covelli HD, Black JW, Olsen MS, Beekman JF (1981) Respiratory failure precipitated by high carbohydrate loads. Ann Intern Med 95:579–581
5. Angelillo VA, Bedi S, Durfee D, Dahl J, Patterson AJ, O'Donohue WJ (1985) Effects of low and high carbohydrate feedings in ambulatory patients with chronic obstructive pulmonary disease and chronic hypercapnia. Ann Intern Med 103:883–885
6. Al-Saady NM, Blackmore CM, Bennett ED (1989) High Fat, low carbohydrate, enteral feeding lowers $paCO_2$ and reduces the period of ventilation in artificially ventilated patients. Intensive Care Med 15:290–295
7. Goldstein SA, Thomashow B, Askanazi J (1986) Functional changes during nutritional repletion in patients with lung disease. Clin Chest Med 7:141–151
8. Blackburn GL, Benotti PN, Bistrian BR, Maini BS, Schlamm HT, Smith MF (1979) Nutritional assessment and treatment of hospital malnutrition. Infusionstherapie 6:238–250
9. Knaus WA, Draper EA, Wagner DP, Zimmerman JE (1985) Apache II: a severity of disease classification system. Crit Care Med 13:818–829
10. Stam H, Berg B van den, Versprille A (1987) A simple and accurate automated system for continuous long-term metabolic studies during artificial ventilation. Clin Phys Physiol Meas 8:261–269
11. Otis AB (1964) Quantitative relationships in steady-state gas exchange. In: Fenn WO, Rahn H (eds) Handbook of physiology, section III, Respiration Vol 1. American Physiological Society, Washington DC, pp 681–698
12. Ultman JS, Bursztein S (1981) Analysis of error in the determination of respiratory gas exchange at varying FIO_2. J Appl Physiol 50:210–216
13. Snedecor GN, Cochran WG (1967) Statistical methods. Ames lowa State Unversity Press, Iowa, pp 258–296
14. Glantz SA (1987) Primer of biostatistics. McGraw-Hill, New York, pp 88–89
15. Driver AG, McAlevy MT, Smith JL (1982) Nutritional assessment of patients with chronic obstructive pulmonary disease and acute respiratory failure. Chest 82:568–571