

Can Gastric Tonometry be Used to Determine Weaning Failure?

Gastrik Tonometri Weaning Başarısızlığını Belirlemek İçin Kullanılabilir mi?

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Abstract

Aim: Despite the advances, weaning from mechanical ventilation is an important problem in the daily operation of intensive care units (ICUs). The aim of this study was to measure the changes in intramucosal pH (pHi) and PCO₂ of gastric juice (PiCO₂) and to determine the value of these variables in order to predict weaning failure in ICU patients.

Material and Methods: Forty (20 male, 20 female) patients considered ready to be weaned from mechanical ventilation (MV) were studied. All patients were on pressure support MV for at least 2h before the weaning trial. PiCO₂ was determined with a tonometer and monitor. At the beginning of the weaning, MV was discontinued and extubation was performed after 2h of T-piece trial. Patients were followed for at least 24h.

Results: While 28 patients were successfully weaned, weaning failed in 12 patients. The initial SaO₂ levels were significantly higher in successful cases (p<0.05). In the successful group, initial PiCO₂ levels were lower than those in the failure group (39.70±13.03 and 47.01±10.95), but this difference was not statistically significant (p>0.05). pHi (7.319±0.12 and 7.12±0.21 p=0.002) and SaO₂ levels (96.87±2.83 and 93.92±3.47, p<0.05) were found significantly low at the post-weaning 6th h in the failure group. PiCO₂ was high in the failure group, but this difference was not significant (46.39±16.92 and 63.01±30.14, p>0.05). The best parameters showing weaning failure were initial PaCO₂, final pHi, final PiCO₂ levels and ΔpHi.

Conclusion: Weaning failure was associated with gastric intramucosal acidosis. It was found that there was an increase in PiCO₂ or a decrease in pHi in patients with weaning failure. However, predictive values of gastric tonometric measurements were not sufficient to decide on reintubation. The results obtained after 6th h did not give further information about weaning failure. Thus, a follow-up period consisting of 6 h may be adequate to assess weaning outcomes. (Yoğun Bakım Derg 2010; 3: 55-9)

Key words: Gastric tonometry, weaning failure, mechanical ventilation, gastric intramucosal acidosis

Received: 18.03.2010

Accepted: 02.12.2010

Özet

Amaç: Tüm gelişmelere rağmen mekanik ventilasyondan ayrılma yoğun bakım ünitelerinde önemli bir sorundur. Bu çalışmanın amacı intramukozal pH (pHi) ve gastrik sıvının pCO₂ (PiCO₂) daki değişiklikleri ölçmek ve YBÜ hastalarındaki weaning başarısızlığının belirleyicisi olarak bu değişkenlerin önemini araştırmaktır.

Gereç ve Yöntemler: Mekanik Ventilasyondan (MV) ayrılmaya hazır olduğu düşünülen kırk hasta (20 erkek, 20 kadın) çalışmaya alındı. Tüm hastalar weaning çalışmasından önce en az 2 saat için basınç destekli MV da tutuldu. PiCO₂ bir tonometre ve monitor ile değerlendirildi. Weaningin başlangıcında, MV sonlandırıldı ve 2 saatlik T tüp çalışması sonrası ekstübasyon uygulandı. Hastalar en az 24 saat için izlendi.

Bulgular: 28 hasta başarı ile ayrılırken 12 hastada weaning başarısız oldu. Başlangıç SaO₂ seviyeleri başarılı vakalarda önemli derecede yüksekti (p<0.05). Başarılı grupta, başlangıç PiCO₂ seviyeleri başarısız gruptakilerden düşüktü (39.70±13.03 ve 47.01±10.95). Fakat bu fark istatistiksel olarak önemli değildi (p>0.05). pHi (7.319±0.12 ve 7.12±0.21 p=0.002) ve SaO₂ seviyeleri (96.87±2.83 ve 93.92±3.47, p<0.05) başarısız grupta weaning sonrası 6. saatte önemli derecede düşük bulundu. PiCO₂ başarısız grupta yüksekti, fakat bu fark önemli değildi (46.39±16.92 ve 63.01±30.14, p>0.05). Weaning başarısızlığını gösteren en iyi parametreler başlangıç PaCO₂, son pHi, son PiCO₂ seviyeleri ve ΔpHi idi.

Sonuç: Weaning başarısızlığı gastrik intramukozal asidoz ile ilişkilidir. Weaning başarısızlığı olan hastalarda PiCO₂ de bir artma veya pHi de bir azalma olduğu bulundu. Bununla birlikte, gastrik tonometrik ölçümlerin belirleyicilik değerleri reentübasyon kararı vermek için yeterli değildi. 6. saatten sonra gözlenen sonuçlar weaning başarısızlığı hakkında fazla bilgi vermedi. Bundan dolayı, weaning gidişatını değerlendirmek için 6 saatlik bir izlem periyodu yeterli olabilir. (Yoğun Bakım Derg 2010; 3: 55-9)

Anahtar sözcükler: Gastrik tonometre, gastrik intramukozal asidoz, mekanik ventilasyon, weaning başarısızlığı

Geliş Tarihi: 18.03.2010

Kabul Tarihi: 02.12.2010

Introduction

Despite the advances, weaning from mechanical ventilation is an important problem in daily operations of intensive care units (ICUs). The weaning period can represent more than 40% of the mechanical ventilation duration. As reported in different series, weaning failure varies widely (1-4). Several pathophysiological determinants of weaning failure have been identified, including inadequacy of pulmonary gas exchange, cardiovascular dysfunction, disturbance in respiratory muscle performance, and psychological factors (5). A stepwise reduction of

the mechanical ventilatory support is a widespread weaning strategy to gradually transfer the work of breathing (WOB) from the ventilator to the respiratory muscles. It has been reported that, under certain pathologic conditions, spontaneous ventilation increases the respiratory oxygen (O₂) demand from 1% to 3% up to 25% to 40% of the total O₂ consumption (6-9). In critically ill patients, and especially in those with chronic obstructive pulmonary disease (COPD), the oxygen cost of breathing is increased during the weaning process and may increase the proportion of total body O₂ delivery required by respiratory muscles to meet ventilation requirements (10, 11). This increased O₂ cost of

2. Ulusal Dahili ve Cerrahi Bilimler Yoğun Bakım Sempozyumu. 1-3 Ekim 2005, Ankara, Türkiye

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doi:10.5152/dcbbybd.2010.07

breathing is met by an increase in blood flow to respiratory muscles, resulting in a blood flow diversion from other tissues, and may lead to hypoperfusion in some areas (12).

Thus, during low cardiac output states, septic shock, and hypoxemia, the blood flow to the skin, kidneys, and the splanchnic area decreases to favor of respiratory muscle perfusion (13-15). Gastric intramucosal pH (pHi) is considered to be an indirect estimation of the mesenteric perfusion and oxygenation (16-18). An association between weaning failure and gastric intramucosal acidosis has been reported in previous works, suggesting that pHi could be a useful predictor of weaning outcome (19-22).

Mohsenifar and coworkers used the PCO_2 of gastric juice ($PiCO_2$) and calculated pHi as an early indicator of weaning success or failure during a weaning trial in 29 critically ill patients. Patients who could not be weaned had a substantially reduced pHi during a 30-min weaning trial, whereas no change was observed in patients who were successfully weaned (19). Bouachour and coworkers found patients with weaning failure to have had lower pHi before the weaning period, while the patients were still on ventilatory support (20).

The aim of this study was to measure the changes in pHi and $PiCO_2$ along with other common respiratory and hemodynamic variables during weaning, and to determine the value of these variables to predict weaning failure in ICU patients.

Methods

Patients

This prospective study was conducted between July 2001 and June 2003 in the Medical and Pulmonary ICUs of the University Hospital in Central Anatolia, Turkey. Forty (20 male, 20 female) consecutive patients who were considered ready to be weaned from mechanical ventilation were studied. Patients who were on mechanical ventilation for less than 24 h were not included in this series. The study protocol was approved by the Institutional Review Board. An informed consent was obtained from the family or, when possible, from the patient.

All intubated and mechanically ventilated patients were eligible for the study when the following criteria were fulfilled: improvement of the underlying causes of acute respiratory failure; hemoglobin ≥ 9 g/dl; absence of vasoactive drugs; Glasgow coma scale ≥ 13 ; $PaCO_2 \leq 55$ mm Hg; $PaO_2 > 60$ mm Hg with fractional inspired oxygen (FiO_2) < 0.4 ; positive end-expiratory pressure (PEEP) < 5 cm H_2O ; negative inspiratory force (NIF) < -20 cm H_2O ; Rapid Shallow Breathing Index (RSBI) (f/Vt) < 100 (23).

Exclusion criteria for this study were: abdominal surgery; gastrointestinal bleeding; and clinically documented gastroesophageal reflux.

Data Obtained and Study Design

Demographic characteristics (age, gender, history) and clinical data (e.g., body temperature, arterial blood pressure, blood gases and general laboratory and ventilatory parameters) were recorded on the day of the study. The study protocol consisted of three phases: mechanical ventilation, weaning period, and post extubation period.

Mechanical ventilation: All eligible patients were on pressure support mechanical ventilation (SIEMENS Servo 300, SWEDEN) for at least 2 h before the weaning trial. Gastric PCO_2 was determined with a tonometer (Datex-Ohmeda Division, Instrumentarium Corp. Finland) and a monitor (Datex-Ohmeda Tonocap, Finland). All patients received histamine receptor (H_2) antagonists by continuous intravenous infusion. Enteral nutrition was stopped 6 h before the beginning of the study protocol. After nasogastric insertion, the position of the balloon in the stomach was checked radiographically before the inflation with 2.5 ml of room air. After 10-min $PiCO_2$ was measured. An arterial blood sample was anaerobically obtained simultaneously for the determination of

arterial pH, blood gases, and bicarbonate concentration (HCO_3^-) (BGA-865 CHIRON DIAGNOSTIC, BAYER, GERMANY). Gastric intramucosal pH was calculated by monitor from $PiCO_2$, blood pH and HCO_3^- .

Weaning period: At the beginning of the weaning, mechanical ventilation was discontinued and patients breathed spontaneously for 3 min without supplemental O_2 . Included patients breathed spontaneously through a T-piece supported by supplemental O_2 and gas humidification for the remaining period of the weaning trial. Weaning failure (unsuccessful) was defined as one or more of the following criteria: (1) arterial O_2 saturation (SaO_2) $< 90\%$ ($< 80\%$ in patients with COPD) and/or $PaO_2 < 55$ mm Hg; (2) $f > 35$ breaths/min; (3) systolic blood pressure < 80 mm Hg or > 200 mm Hg ($\pm 20\%$ of the value in mechanically ventilated patients with documented hypotension or hypertension); (4) heart rate > 140 beats/min ($\pm 20\%$ of the value in mechanically ventilated patients with previous tachycardia); or (5) clinical signs of spontaneous breathing intolerance (diaphoresis; excessive use of accessory respiratory muscles or thoracic-abdominal discoordination; decrease of consciousness; and agitation) (23).

Arterial blood gases were obtained from all patients during the weaning trial, because no patients failed before 2 hours of weaning. For the patients with weaning failure, these measurements were used for the calculation of pHi and functional indices. In the patients with weaning success, or extubation success, measurements of tonometry and arterial blood gases at 2nd, 6th, 10th and 24th h were used for analysis. The results of the arterial blood gas analysis, but not those of gastric tonometry, were available for the physician responsible for the evaluation of the weaning trial.

Postextubation period: Extubation was performed after 2 h of T-piece trial in the absence of weaning failure criteria. Patients were followed for at least 24 h, and the patients who needed ventilatory support were classified as extubation failure. The possible cause of the extubation failure was noted and the patients were analyzed separately.

Statistical Analysis

Means were compared between two groups by unpaired Student's *t* test. Measurements of the tonometry were compared between the two groups and over time (mechanical ventilation and weaning period) with paired Student's *t* test. Mann-Whitney U and Wilcoxon tests were used for non-parametric measurements. To identify the optimal cut off values between the patients with weaning success and failure, receiver operating characteristics (ROC) curve analyses were employed. The results of this analysis were reported with a 95% confidence interval (95% CI). All data were processed with MedCalc for Windows 95-demo version. The level of significance was set at 5% (all two-tailed) and data were reported as counts or mean \pm standard deviation.

Results

Forty patients (20 male and 20 female) were included in the study. Mean age of the patients was 57.75 ± 16.74 years. Basic characteristics of the patients were given in Table 1. While 28 patients were successfully weaned from ventilation, weaning was unsuccessful in 12 patients. Age, mean duration of ventilation and APACHE II scores were similar in both groups. The initial SaO_2 levels were significantly higher in successful cases ($p < 0.05$). In the successful group, $PiCO_2$ levels were lower (39.70 ± 13.03) than those in the failure group (47.01 ± 10.95), but this difference was not statistically significant ($p > 0.05$).

Weaning failure developed at the 2nd hour after weaning in 4 patients, 10th hour in 2 patients, 20th hour in 4 patients and 24th hour in 2 patients. Four of these patients died during the study period. At the post weaning 2nd h, there was an increment in $PiCO_2$ and a decrease in pHi

Table 1. Basic characteristics of the patients before weaning

Parameter	Successful n:28	Unsuccessful n:12	p
Age (year)	57.75±17.17	57.75±16.44	1.0
Duration of ventilation (h)	116.92±91.38	113.66±57.90	0.91
NIF (cm H ₂ O)	-35.71±9.2	-33.08±7.22	0.38
APACHE II	26.64±5.82	26.50±8.10	0.95
PaO ₂ (mm Hg)	100.32±24.35	80.9±14.39	0.14
PaCO ₂ (mm Hg)	35.09±10.26	40.39±9.52	0.13
pH	7.32±0.56	7.44±0.054	0.49
SaO ₂ (%)	97.22±1.93	94.73±3.56	0.007
HCO ₃ (mEq/L)	23.98±6.27	26.14±7.19	0.34
FiO ₂ (%)	39.28±3.77	40.0±0	0.52
f (breaths/min)	21.64±5.27	24.56±6.43	0.21
Peak airway pressure (PAP) (mm Hg)	16.21±4.96	16.91±4.87	0.68
Mean arterial pressure (MAP) (mm Hg)	88.92±14.02	90.0±10.67	0.704
Vt (L/min)	0.489±0.12	0.496±0.087	0.85
f/Vt	47.9±20.78	50.35±18.08	0.72
Heart rate (beat/min)	95.96±14.91	92.66±11.03	0.49
PiCO ₂ (mm Hg)	39.70±13.03	47.01±10.95	0.09
pHi	7.36±0.13	7.39±0.09	0.54

Table 2. Post weaning 2nd h values

Parameter	Successful n:28	Unsuccessful n:12	p
PaO ₂	95.96±33.20	82.55±28.40	0.23
PaCO ₂	37.33±13.35	44.21±12.26	0.15
pH	7.42±0.065	7.41±0.047	0.36
SaO ₂	95.99±3.66	94.45±4.02	0.24
HCO ₃	24.42±7.01	27.45±6.36	0.208
FiO ₂	25.71±9.59	27.5±6.21	0.55
f (breaths/min)	24.64±4.87	26.66±3.82	0.209
MAP	90.89±13.67	89.08±13.32	0.701
Heart rate	95.96±14.91	92.66±11.03	0.54
PiCO ₂	49.200±18.81	55.80±20.52	0.32
pHi	7.29±0.17	7.29±0.07	0.95

levels in both groups. However, no parameters were significantly different between the groups (Table 2). During the study period, PiCO₂ continued to increase and pHi continued to decrease in the failure group. This resulted in augmentation of the differences between the groups. pHi and SaO₂ levels were found as significantly low at the post-weaning 6th h in the failure group. PiCO₂ was high in the failure group, but this difference was not significant (Table 3).

Arterial pH levels were significantly low, and PaCO₂ levels were significantly high at the post-weaning 10th h in the failure group (p=0.002, p=0.05; respectively). PiCO₂ was high in the failure group, but this difference was not significant. However, PiCO₂ continued to increase in the failure group (Table 4). Post-weaning 24th h values were not statistically evaluated, since there were only 2 patients in the failure group.

Initial and final pH, PaCO₂, pHi and PiCO₂ values before reintubation were compared. While there were no significant changes in the successful group, pH and pHi significantly decreased and PaCO₂ significantly increased in the failure group. Final PiCO₂ was also high in the failure group, but this difference was not significant (Table 5).

ROC analysis was performed to find threshold (cutoff) values. The threshold value for pHi was >7.44 (sensitivity=41.7%; specificity=82%)

before weaning, and <7.39 (sensitivity=100%; specificity=25%) at the post-weaning 2ndh. These values for PiCO₂ were >33 mm Hg (sensitivity=75%; specificity=50%), and >42.4 mm Hg (sensitivity=83.3%; specificity=39.3%), respectively. Thresholds values for some other parameters were given in Table 6.

The best parameters showing weaning failure were found to be initial PaCO₂, final pHi, final PiCO₂ levels and ΔpHi. However, there were no significant differences between the post-weaning 6thh pHi (0.64) or PiCO₂ (0.67) and final pHi (0.63) or PiCO₂ (0.69) AUCs (p=0.86, p=0.80, respectively).

Discussion

Gastric pH and PiCO₂ are altered during regional hypoperfusion (22, 24). Dysoxia as a result of decreased mesenteric O₂ supply leads to local acidosis and increased PiCO₂ (16, 22, 25). The high WOB and the adrenergic response during weaning can induce intestinal hypoperfusion due to commensurate increase in blood flow to respiratory muscles (22, 26-28). This leads to an accumulation of CO₂ in the splanchnic region after ventilator support is withdrawn and patients have to breathe spontaneously during the weaning trial (22).

Table 3. Post weaning 6th h values

Parameter	Successful n:28	Unsuccessful n:8	p
PaO ₂	102.92±28.89	83.81±18.79	0.088
PaCO ₂	38.11±13.59	41.73±13.54	0.51
pH	7.41±0.062	7.41±0.049	0.98
SaO ₂	96.87±2.83	93.92±3.47	0.019
HCO ₃	21.82±7.71	26.93±6.07	0.48
FiO ₂	25.35±6.92	27.50±7.07	0.44
f (breaths/min)	24.57±4.93	23.50±3.66	0.57
MAP	90.1±15.64	85.87±15.63	0.50
Heart rate	95.46±12.05	93.87±13.92	0.75
PiCO ₂	46.17±13.68	57.41±22.97	0.09
pHi	7.319±0.12	7.12±0.21	0.002

Table 4. Post weaning 10th h values

Parameter	Successful n:28	Unsuccessful n:6	p
PaO ₂	90.10±21.72	83.18±24.37	0.49
PaCO ₂	37.63±12.14	49.46±18.23	0.05
pH	7.41±0.053	7.32±0.088	0.002
SaO ₂	95.58±3.74	92.50±5.76	0.107
HCO ₃	23.83±7.64	26.56±6.86	0.42
FiO ₂	24.64±6.37	25±8.36	0.97
f (breaths/min)	24.28±4.6	28.33±8.77	0.66
MAP	91.42±12.29	87.66±17.72	0.53
Heart rate	94.21±14.79	95.16±8.23	0.88
PiCO ₂	46.39±16.92	63.01±30.14	0.068
pHi	7.34±0.16	7.268±0.066	0.26

Table 5. Initial and final pH, PaCO₂, pHi and PiCO₂ values before reintubation

Parameter	Successful n=28			Unsuccessful n=12		
	Initial	Final	p	Initial	Final	p
pH	7.43±0.05	7.41±0.07	0.195	7.44±0.05	7.38±0.08	0.022
PaCO ₂	35.09±10.26	38.40±15.52	0.128	40.39±9.50	47.50±10.41	0.016
pHi	7.37±0.14	7.33±0.16	0.257	7.39±0.10	7.25±0.16	0.038
PiCO ₂	39.70±13.03	46.87±20.27	0.077	47.01±10.96	57.53±19.36	0.107

Several studies have been performed to predict the role of gastric tonometry in determining weaning success. However, the results are controversial. Mohsenifar and coworkers measured pHi and PiCO₂ during a weaning. A pHi<7.30 before a weaning attempt or a decrease by 0.009 or more during weaning was successful in determining weaning failure, with a 100% predictive value (19). This pHi threshold was confirmed by Bouachour et al. during a weaning, pHi was found ≤7.30 in patients who failed in weaning and >7.30 in patients who were successfully weaned, with 100% sensitivity and specificity. The investigators showed that PiCO₂ was higher in the failure group during the assist-control ventilation. The authors concluded that measurement of pHi (or PiCO₂) represents a simple and accurate index to predict the weaning outcome in COPD patients (20). Maldonado et al. showed that an increase in PiCO₂ was associated with weaning failure in a group of patients with acute respiratory failure (22).

Bocquillon et al. showed that pHi values significantly decreased during the first hours of weaning in both successful and unsuccessful weaning groups. However, pHi was continued to decrease in the failure group. A similar trend was observed in PiCO₂. PiCO₂ values increased significantly during the first hours of weaning in both groups, but, pHi

continued to increase in the failure group. The investigators showed that PiCO₂ was higher in the failure group at the 2nd h of ventilation. The authors concluded that these changes were related to PaCO₂ (21). In a study by Hurtado and coworkers, pHi values in both initial and final evaluations were found low, and PiCO₂ were found high. The threshold values were for pHi ≤7.30 (with 88% sensitivity, 82% specificity) and for PiCO₂ ≥40 mm Hg (with 100% sensitivity, 55% specificity) (29). The authors concluded that weaning failure was associated with gastric intramucosal acidosis, and pHi and PiCO₂ may be helpful to predict weaning outcome. Uusaro et al. found that a 1-h stress test improved the accuracy of the predictive values of PiCO₂ (30).

This present study has both similarities and dissimilarities to those in literature. These similarities and dissimilarities probably result from the characteristics of patients, follow-up duration and the methods of gastric tonometry. The initial PiCO₂ levels were higher in unsuccessful cases, but this difference was not statistically significant (p>0.05). pHi levels decreased and PiCO₂ levels increased during the postweaning 2nd h in both groups, but, these changes improved at the 6th h in the successful group, and continued until the 10th h in the failure group. These results were similar to those in the study by Bocquillon et al. (21). The initial and final pHi

Table 6. Threshold values for some parameters

Parameter	Cutoff	Sensitivity	Specificity	+LR	-LR	AUC
		(%95 CI)	(%95 CI)			
Initial pH	>7.45	58.3 (27.8-84.7)	67.9 (47.7-84.1)	1.81	0.61	0.56
Initial PaCO ₂	>29.4	91.7 (61.5-98.6)	50.0 (30.7-69.3)	1.83	0.17	0.66
ΔpHi	>1.64	75.0 (42.8-94.2)	53.6 (33.9-72.5)	1.62	0.47	0.56
Final pHi	≤7.32	83.3 (51.6-97.4)	57.1 (10.7-44.9)	1.94	0.29	0.63
Final PiCO ₂	>47	75.0 (42.8-94.2)	67.9 (47.7-84.1)	2.33	0.37	0.69

+LR: Positive likelihood ratio -LR: Negative likelihood ratio, ΔpHi : Difference between the initial and final pHi values

and gastric PiCO₂ values before the reintubation were compared. While there were no significant changes in the successful group, pHi significantly decreased in the failure group. Similarly, PiCO₂ levels increased in the failure group, but these changes were not statistically significant. When 24th h values of the successful group were compared with final values of the failure group before reintubation, threshold values for pHi to predict of weaning failure were found ≤7.32 (with 83.3% sensitivity, 57.1% specificity), and for PiCO₂ >47 (with 75% sensitivity, 67.9% specificity). However, the final and 6th h AUC values were not statistically different.

The explanations of these results were as follows: The results in both groups were similar in the first 2 hours at postweaning period, since respiratory effort, O₂ consumption and production of CO₂ increased. Thereafter, respiratory effort, O₂ consumption, production of CO₂ and respiratory muscle perfusion improved in patients who adapted to spontaneous respiration and had adequate gas exchange. However, negative events continued in the failure group. This led to the difference between the groups during the following hours. Short and long-term analyses might have been inadequate or unnecessary; since there were no significant differences in the early period and the changes after the 6th h were similar.

In conclusion, weaning failure was associated with gastric intramucosal acidosis. It was found that there was an increase in PiCO₂ or a decrease in pHi in the patients with weaning failure; However, predictive values of gastric tonometric measurements were not adequate to decide to reintubate. The physicians' observations are also important. The results obtained after the 6th h did not give additional information about weaning failure. Thus, a follow-up period consisting of 6 h might have been adequate to assess weaning outcomes.

Conflict of Interest

No conflict of interest is declared by authors

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