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P0.1/PIMax: an index for assessing respiratory capacity in acute respiratory failure

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Abstract. We studied airway occlusion pressure (P0.1) and maximal inspiratory pressure (PIMax) in 10 healthy volunteers (Group A), 10 early postsurgical cardiac patients on spontaneous breathing (Group B), 10 patients mechanically ventilated for ARF (Group C), 10 patients weaning from mechanical ventilation after ARF (Group D) and 10 patients extubated after post-ARF (Group E). We calculated the index P0.1/PIMax in an attempt to link the ventilatory demands and muscle ventilatory reserve. We found that the sensitivity and specificity in diagnosing the need for either full (C), partial (D) or no ventilatory support (A, B, E) by means of the P0.1 were C = (50%, 95%), D = (70%, 72%) and A+B+E = (83%, 90%) respectively. When the index P0.1/PIMax was used they were C = (90%,100%), D = (80%,87%) and A+B+E = (86%,90%). We conclude that the index P0.1/PIMax increases the reliability of P0.1 alone to correctly classify the patients that will need either full, partial or no ventilatory support in ARF.

Key words: Airway occlusion pressure – Maximal inspiratory pressure – Acute respiratory failure – Mechanical ventilation

Since the introduction of mechanical ventilation as a vital support for patients with acute respiratory failure (ARF), many clinical parameters have been explored as useful markers for needing mechanical ventilation. Several physiological variables have been recommended as predictors of patient's ability to wean [1]. The airway pressure in the first 100 ms of an occluded inspiration (P0.1) has been shown to reflect the degree of discharge of the respiratory centre, both in normal subjects and in ARF patients [2–4]. However, the change in P0.1 in the face of the development of respiratory muscle fatigue is quite variable. In some very sick and weak patients, the ability to perform muscle contraction in response to neural activation is impaired; in these patients the measured P0.1 could be low despite a high respiratory centre output due to the impaired muscle function.

The aim of the study was to elucidate whether the falsely low P0.1 in fatigued patients could be corrected taking into account that PIMax is a marker of the ability to develop force. We conducted this study exploring the usefulness of the index P0.1/PIMax to predict the need for mechanical ventilatory support.

Material and methods

We studied 50 subjects classified in 5 groups according to their clinical condition. Groups were different in the degree of pulmonary function abnormality ranging from normality to severe pulmonary damage. Group A included 10 healthy volunteers of our ICU team representing the normal population. Group B included 10 post-cardiac surgery patients after extubation in the postoperative period, representing mild thoraco-pulmonary limitation. Group C included 10 ARF patients receiving full mechanical ventilatory support in the assist control mode. This was ordered by ICU physicians on the basis of standard clinical criteria, e.g. hypoxemia, hypercapnia, haemodynamic disturbances or shock. Group D included 10 ARF patients in the recovery period, who were being weaned using partial ventilatory support (SIMV greater than 10 mandatory cycles/min) due to their inability to sustain spontaneous breathing. Group E included 10 patients who were successfully extubated. Clinical data of the patients are shown in Table 1.

We measured airflow with a heated Fleisch no. 2 pneumotachograph (HP 47304A) and airway pressure by means of a differential pressure transducer (HP 270). Volume was obtained by electronic integration of the flow signal (HP 8815A). This measurement system was attached to the proximal port of the endotracheal tube (Groups C and D) or to a tight facial mask in spontaneously breathing subjects (Groups A, B, and E).

We measured standard parameters of ventilatory pattern (V_t, RR, T_i, T_{tot}) and we calculated derived parameters, namely V_t/T_i, $P0.1/V_t/T_i$ and P0.1/PIMax.

The tracheal occlusion determinations were made by occluding the inspiratory limb of a Hans-Rudolph valve by means of a manually activated latex balloon. We calculated P0.1 as the average of five occlusion manoeuvres.

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Table 1. Clinical data

Patients no.	Age (years)	Sex	Condition	FiO_2	PEEP cmH_2O	pH	PaO_2 mmHg	$PaCO_2$ mmHg
Group B								
1	61	M	CABG	0.28	–	7.36	68	43
2	46	M	CABG·COPD	0.35	–	7.44	74	36
3	58	F	Mitral surgery	0.30	–	7.40	77	40
4	50	M	CABG	0.35	–	7.43	87	39
5	58	M	Mitral surgery	0.24	–	7.50	108	33
6	56	M	CABG	0.35	–	7.41	68	39
7	72	F	CABG	0.35	–	7.40	75	36
8	52	F	Mitral surgery	0.21	–	7.40	89	31
9	58	F	CABG	0.30	–	7.41	90	36
10	59	M	CABG	0.50	–	7.39	104	43
mean	57			0.32		7.41	84	37
SD	7			0.08		0.04	14	4
Group C								
11	68	M	Pancreatitis	0.50	10	7.49	86	26
12	42	M	Mediastinitis	0.40	0	7.36	73	38
13	54	M	Meningitis	0.40	5	7.47	100	30
14	54	M	Staph. sepsis	0.35	5	7.49	108	31
15	68	M	COPD·Pneumonia	0.40	5	7.50	105	26
16	43	F	Septic shock	0.30	5	7.46	163	28
17	60	M	COPD	0.40	0	7.45	80	43
18	43	F	Peritonitis	0.30	5	7.45	107	29
19	65	M	COPD·Pneumonia	0.40	5	7.48	67	34
20	67	F	Mediastinitis	0.40	7	7.50	119	30
mean	56			0.38	5	7.47	101	31
SD	11			0.05	3	0.04	27	5
Group D								
21	20	M	Kyphoscoliosis	0.40	10	7.47	77	33
22	59	F	COPD·Pneumonia	0.30	4	7.36	81	46
23	69	F	COPD	0.30	5	7.56	90	28
24	65	M	Head injury	0.30	0	7.43	155	28
25	65	M	COPD·Pneumonia	0.50	8	7.50	72	26
26	65	M	COPD·CABG	0.30	5	7.44	71	26
27	78	M	Chest trauma	0.40	0	7.47	77	42
28	72	F	Heart failure	0.30	0	7.48	94	30
29	43	F	Peritonitis	0.35	6	7.42	106	35
30	43	F	Pneumonia	0.35	0	7.45	162	37
mean	58			0.35	4	7.46	98	33
SD	17			0.07	4	0.05	33	7
Group E								
31	27	M	Head injury	0.30	–	7.43	80	36
32	78	M	COPD	0.35	–	7.38	82	50
33	53	F	Septic shock	0.32	–	7.42	161	39
34	56	M	Pancreatitis	0.40	–	7.34	119	36
35	73	F	Brain haemorrhage	0.30	–	7.50	113	26
36	20	M	Pneumonia	0.35	–	7.36	60	47
37	68	M	Gastrectomy	0.30	–	7.50	108	34
38	56	M	Pancreatectomy	0.30	–	7.45	95	36
39	62	M	COPD·Pneumonia	0.30	–	7.42	121	36
40	69	F	COPD·Pneumonia	0.30	–	7.39	80	33
mean	55			0.32		7.42	102	37
SD	19			0.03		0.05	28	7

CABG: coronary artery bypass graft
COPD: chronic obstructive pulmonary disease

PIMax measurements were made by a standard technique in the cooperative patients. Patients were required to exhale to residual volume. They then performed a forced inspiratory manoeuvre, whilst the inspiratory limb remained occluded, and sustained the effort for a few seconds. In the uncooperative patients we performed the method described by Marini et al. [5]. By selectively occluding the inspiratory limb of a Hans-Rudolph valve, patients were forced to expire close to residual volume. We calculated PIMax as the average of 5 PIMax manoeuvres.

In patients requiring ventilatory support, we performed all the measurements after disconnecting them from the ventilator for 10 min. In all patients measurements were performed during room air breathing.

The statistical method was a one way analysis of variance test for comparison between groups. We calculated the sensitivity (true positive/true positive+false negative) and specificity (true negative/true negative+false positive) both for P0.1 and P0.1/PIMax to correctly classify the subjects as required total support (C), partial support (D) or no support (A,B,E).

Table 2. The results obtained from each group of patients expressed as mean ± SD

Groups	P0.1 cmH_2O	PIMax cmH_2O	P0.1/PIM %	R.R. c/min	T_I s	T_E s	T_{TOT} s	V_T ml	V_T/T_I ml/s	$P0.1/V_T/T_I$ cm/L/s
A	1.3±0.6	87±12	1.4±0.8	15±3	1.9±0.6	2.5±0.6	4.4±1.1	646±150	365±119	3.3±1.3
B	2.8±1.1	46±15	6.2±2.0	23±4	1.1±0.2	1.5±0.4	2.7±0.5	489±133	433±87	6.5±2.5
C	7.6±3.4	38±13	20.1±4.9	41±4	0.6±0.1	0.9±0.1	1.5±0.2	312±103	534±167	15.0±6.9
D	5.5±1.8	51±11	10.9±2.7	29±4	0.9±0.1	1.3±0.3	2.1±0.4	393±162	453±160	13.4±5.6
E	3.4±1.3	64±12	5.5±2.2	25±5	1.1±0.3	1.4±0.4	2.5±0.5	467±152	438±123	7.9±3.2
ANOVA (F)	17.2	22.6	63.7	53.8	21.3	23.2	29.1	7.7	2.0	11.9

Results

The results of the study are shown in Table 2 and summarized in Figs. 1 and 2. We found significant differences in V_t, RR, T_i, T_{tot}, P0.1 and PIMax between groups, but only P0.1 and P0.1/PIMax clearly differentiated patients by their ability to sustain spontaneous breathing. We found no significant correlation between P0.1 and PIMax ($r = 0.33$, $p < 0.15$). The most useful P0.1 values for classifying the patients were P0.1 greater than 7 cmH_2O for patients requiring total ventilatory support (Group C), P0.1 between 7 and 4 cmH_2O for patients needing partial ventilatory support (Group D) and P0.1 lower than 4 cmH_2O for patients able to breathe spontaneously (Groups A,B and E). We found the best P0.1/PIMax indicators of the need of mechanical ventilation to be P0.1/PIMax greater than 15% for Group C, P0.1/PIMax between 15% and 8% for Group D, and P0.1/PIMax lower than 8% for patients able to breathe spontaneously (Groups A, B and E). The sensitivity and specificity of each test for these levels are shown in Table 3.

Discussion

The results of this study show that the reliability of P0.1 as an index of the severity of ARF can be increased by taking into account PIMax as a marker of the respiratory muscles' working ability and, as a consequence, the need for machine support. The PIMax allows identification of severe ARF patients who failed to show high P0.1 values due to muscle fatigue.

Since the clinical introduction of mechanical ventilation as a vital organ support, many physiological parameters have been used in an attempt to define which patients will need this kind of treatment. Tachypnoea of high degree, metabolic acidosis, life threatening hypoxaemia and

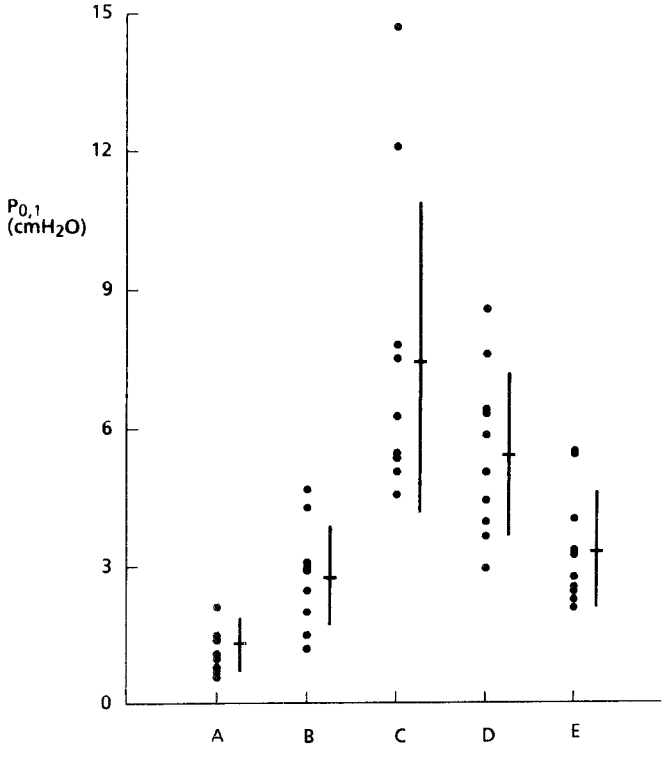

Fig. 1. Individual P0.1 values, mean and standard deviation for each group

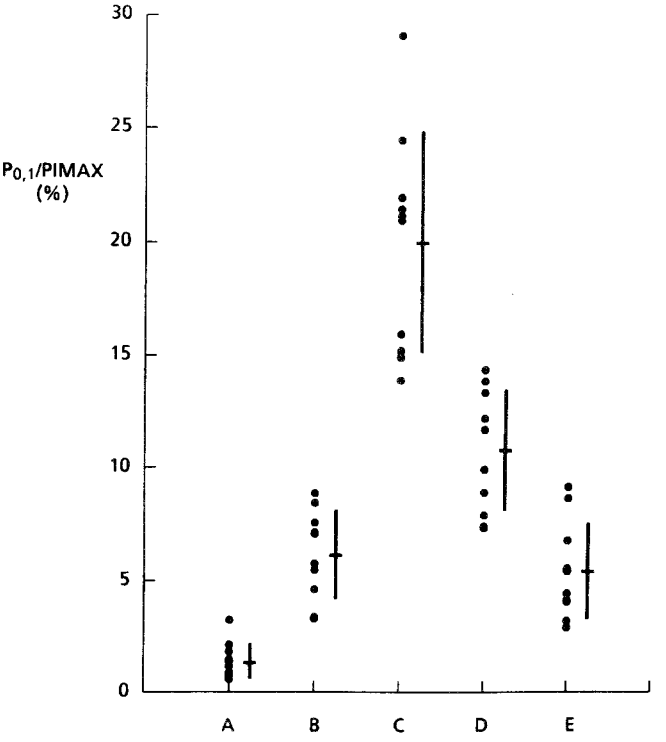

Fig. 2. Individual P0.1/PIMax values, mean and standard deviation for each group

Table 3. The diagnostic accuracy of P0.1/PIMax in distinguishing patients needing: no support (A, B, E), total support (C) or partial support (D)

		A+B+E	C	D
P0.1	sensitivity %	83	50	70
	specificity %	90	95	72
P0.1/PIMax	sensitivity %	86	90	80
	specificity %	90	100	87

shock are the commonest indicators of need for mechanical ventilation. Moreover, during the last decade, great attention has been focused upon the characteristics of the respiratory muscles as a ventilatory pump. Clinical parameters of muscular impairment like recruitment of accessory muscles and paradoxical or alternans breathing have been reported as indicators of impending ventilatory failure.

Minute ventilation was originally used as a measure of the respiratory centre output, but it has the major disadvantage of being influenced by respiratory system resistance and compliance, which may cause variations in ventilation that do not reflect variations in the activity of the respiratory centres.

In 1975, Whitelaw et al. [2] described the usefulness of P0.1 as an index of the respiratory centre output, which is unaffected by respiratory system resistance and compliance or by vagal volume-related reflex activity. Since the first description, many investigators have defined changes in P0.1 under very different conditions: ARF [4], chronic obstructive pulmonary disease [3], acute or chronic respiratory diseases, the weaning period [7] and nonpulmonary diseases [8]. Recently, the change in P0.1 induced by hypercapnia [9] and the spontaneous evolution of P0.1 [10, 11] have been advocated as good predictors of the ability to wean.

It is well known that the relationship between the stimulus of the inspiratory muscles and the pressure they develop in an isometric contraction depends on lung volume and configuration of the chest. This has been explained by the length-tension relationship of the inspiratory muscles, which governs the relationship between stimulus and tension, and by changes in the shape of the chest wall, which governs the relation between tension and pressure.

Our study has focussed on the possibility that those patients showing low P0.1 values in response to elevated output of the respiratory centre should represent muscle fatigue or weakness. Our results support this contention. The superior reliability of P0.1/PIMax over P0.1 is mostly due to the increased sensitivity and specificity in correctly classifying severe ARF patients with a low but needing total ventilatory support.

Several details of our study deserve mention. In the measurement of PIMax we used two different methods. In the co-operative patients the standard manoeuvre was performed. In uncooperative patients we used the modification that has been recently proposed by Marini et al. [5], in an attempt to standardize measurements between them. They attached a unidirectional valve to the airway, allowing expiration but preventing inspiration. This ensured that inspiration began at a low lung volume, which is important to achieve maximum pressure. Secondly, they standardized the period of occlusion to 20 s, as maximal effort occurred within this period. The pressures were about one-third more negative with this technique compared to the non-standardized approach. The coefficient of variation for PIMax with this technique has been reported to be $17\% \pm 10.4\%$, slightly greater than those previously reported in co-operative patients. Marini et al. suggest that three PIMax determinations represent a reasonable compromise between precision and pragmatism in the clinical setting [5]. In fact, in our study, uncooperative patients mainly belonged to Group C, whereas only patients 24 and 28 in Group D were unable to co-operate with the manoeuvre. All patients in Groups B and E and healthy volunteers were able to correctly perform the PIMax manoeuvre.

Murciano et al. [12] have shown that there are differences when occlusion pressure were measured at the mouth and the tracheal tube. These differences were mainly due to the modification of compliance of the oropharynx in COPD patients. In our study, we measured both P0.1 and PIMax via a tight facial mask in spontaneously breathing subjects. The incidence of COPD in this population was very low and the fact that underestimation, if it existed, should affect P0.1 greater than PIMax, probably increase the usefulness of the index P0.1/PIMax.

The lack of correlation between P0.1 and P0.1/PIMax allows us to reject criticism that the index P0.1/PIMax is a mathematical artifact without clinical significance. The use of an isometric parameter (PIMax) to predict ventilatory inability (performance) may provoke some criticism with regard to the physiological significance of this index. Indeed, the use of a parameter of performance (maximal voluntary ventilation) is more immediately comprehensible, but ARF patients are frequently unable to perform the manoeuvre.

We found significant differences between groups in the following commonly used ventilatory weaning parameters: tidal volume, respiratory rate, T_i, T_{tot} and V_t/T_i [13], but all of them failed to discriminate the need for ventilatory support.

Our results are in accordance with some previous studies [9] showing patients with low P0.1 who failed to be weaned. Moreover, our results can be compared to other studies [11] that failed to demonstrate any correlation between PIMax and the success of weaning. In contrast, Murciano et al. [10] found that their patients were able to generate high P0.1 values (8 cmH_2O on average) despite electromyographic signs of fatigue. Despite the lack of data on PIMax in their patients we may speculate that such patients could have an inapparent respiratory centre output greater than that expressed by P0.1 of 8 cmH_2O, but prevented by muscle ineffectiveness.

In conclusion, our results suggest that the use of the index P0.1/PIMax increases the reliability of P0.1 in detecting the need for mechanical ventilatory support, mainly in patients with some degree of respiratory muscle fatigue or weakness.

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