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Effect of different modes of ventilation on diaphragmatic excursion in mechanically ventilated patients: ultrasonographic assessment

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ABSTRACT

Objective: Ultrasonographic assessment of the effect of different modes of mechanical ventilation on diaphragmatic excursion and consequently its effect on weaning of mechanical ventilation, total ventilatory days, hospital stay and mortality.

Patients and methods: This study was carried out on 61 mechanically ventilated adult patients of both genders who were admitted to Critical Care Medicine Department in Alexandria main university hospital over a period from 1/6/2014 to 30\11\2014. All patients were subjected to complete medical and surgical history taking, complete physical examination and daily ultrasonographic assessment of diaphragmatic excursion.

Results: Diaphragmatic dysfunction was detected in 16 patients (72.2%) of patients on CMV, 12 patients (54.5%) of patients on assisted MV in comparison to only 2 patients (11.1%) of patients on spontaneous MV ($P<0.001$). Patients who developed diaphragmatic dysfunction had a mean total ventilatory days 9.23 ± 2.46 days, mean hospital stay 17.80 ± 7.57 days, mortality rate 26.7%, primary weaning failure rate 50% and secondary weaning failure rate 40.9% while Patients who did not develop diaphragmatic dysfunction had a mean total ventilatory days 4.71 ± 1.90 days, mean hospital stay 7.81 ± 2.14 days, mortality rate 6.5%, primary weaning failure rate 3.4% and secondary weaning failure rate 6.9%. ($P1 < 0.001$ $P2 <0.001$ $P3 = 0.043$ $P4 <0.001$ respectively).

Conclusion: Mechanical ventilation induces diaphragmatic dysfunction which is significantly higher with controlled and assisted mechanical ventilation modes than spontaneous modes. Ventilator induced diaphragmatic dysfunction is associated with higher rates of primary and secondary weaning failure, more ventilatory days, longer hospital stay and higher mortality rate.

Key words: Mechanical Ventilation; Diaphragmatic Dysfunction; Weaning Failure.
Abbreviations: CMV=controlled mechanical ventilation, ICU= intensive care unit, VIDD= ventilator induced diaphragmatic dysfunction, CPAP=continuous positive airway pressure.

INTRODUCTION

Sonographic evaluation of the diaphragm has recently started to gain popularity in the intensive care unit (ICU) as specific needs for assessing diaphragmatic function in many clinical situations. (1-5). Ultrasonography can assess the characteristics of diaphragmatic movement such as amplitude, force and velocity of contraction, special patterns of motion and changes in diaphragmatic thickness during inspiration. (6, 7).

These sonographic diaphragmatic parameters can provide valuable information in the assessment and follow up of patients with diaphragmatic weakness or paralysis, in terms of patient–ventilator interactions during controlled or assisted modalities of mechanical ventilation, and can be potentially helpful to understand post-operative pulmonary dysfunction or weaning failure from mechanical ventilation. (7, 8)
The aim of the work is to evaluate diaphragmatic excursion using ultrasonography in mechanically ventilated patients on different modes of ventilation and its change overtime.

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Patients and Methods

This study was carried out on 61 adult patients of both genders who were admitted to Critical Care Medicine Department in Alexandria main university hospital over a period of six months.

All haemodynamically stable adult Patients who required mechanical ventilation with positive end-expiratory pressure level ≤ 5 cm H_2O were included in the study.

Some patients were excluded for reasons as: history of diaphragmatic or neuromuscular disease, use of any muscle-paralyzing agent, aminoglycosides and corticosteroids, morbid obesity (body mass index > 40), current thoracostomy, pneumothorax or pneumomediastinum, declined consent, or respiratory rate ≥ 30 breaths/min.

All patients included in the study were subjected after admission to the followings:

- Complete history taking including medical and surgical history.
- Complete physical examination.
- Chest ultrasonography using ultrasound unit, digital ultrasonic imaging system Model DP3300, (SHELZHEN MINDRAY) biomedical electronic CO.LTD with macro convex probe 2.5-5 MHZ :

1. Patients on all modes of ventilation were included and trends in changes in diaphragm excursion within groups (Controlled modes, assisted modes and spontaneous modes) were determined.
2. Daily ultrasonographic images of the diaphragm by placing Probe over one of the lower intercostal spaces in the right anterior axillary line for the right diaphragm and the left midaxillary line for the left diaphragm with the probe fixed on the chest wall during respiration, the ultrasound beam was directed to the hemidiaphragmatic domes at an angle of not < 70°.
3. Diaphragmatic excursion was measured once per day as soon as possible after consent granted and continued until weaning trial whatever it resulted in successful or failed weaning, discharge or death, whichever came first.
4. All measurements were performed during tidal breathing at 6–12 mL/kg, excluding smaller or deeper breaths.
5. Ultrasonographic diaphragmatic dysfunction was diagnosed if an excursion was < 10 mm or negative.

- Outcome parameters included :
  1. Successful weaning
  2. Primary weaning failure
  3. Secondary weaning failure
  4. Total ventilation time
  5. Length of hospital stay
  6. Mortality

Results

Patients were divided into three main groups;

Table-1. Effect of different modes of mechanical ventilation on diaphragmatic excursion

	Mode of mechanical ventilation						χ^2	p
	Controlled (n = 21)		Assisted (n = 22)		Spontaneous (n = 18)			
	No.	%	No.	%	No.	%		
Diaphragm dysfunction								
No	5	23.8	10	45.5	16	88.9	16.821*	<0.001*
With	16	72.2	12	54.5	2	11.1		
Sig. bet. grps	p_1 = 0.137, p_2 = 0.004*, p_3 <0.001*							

Table-2. Association of mode of mechanical ventilation with outcome of patients

	Mode of mechanical ventilation						χ^2	^{MC}p
	Controlled (n = 21)		Assisted (n = 22)		Spontaneous (n = 18)			
	No.	%	No.	%	No.	%		
Outcome								
Died	6	28.6	4	18.2	0	0.0	5.853*	0.034*
Survived	15	71.4	18	81.8	18	100.0		
Successful weaning	4	26.7	8	44.4	16	88.9	15.697*	0.002*
Primary weaning failure	7	46.7	4	22.2	1	5.6		
Secondary weaning failure	4	26.7	6	33.3	1	5.6		
Sig. bet. grps	p_1 =0.376, p_2 =0.021*, p_3 =0.001*							

Group I: patients on controlled mechanical ventilation modes, Group II: patients on Assisted mechanical ventilation modes and Group III: patients on spontaneous mechanical ventilation mode. Patients were further divided into two groups; Group A: patients without diaphragmatic dysfunction and Group B: patients with diaphragmatic dysfunction.

Among patients on controlled modes 5 patients (23.8%) did not develop diaphragmatic dysfunction while 16 patients (72.2%) developed diaphragmatic dysfunction as shown in table (1).

Among patients on assisted modes 10 patients (45.5%) did not develop diaphragmatic dysfunction while 12 patients (54.5%) develop diaphragmatic dysfunction as shown in table (1).

Among patients on spontaneous modes 16 patients (88.9%) did not develop diaphragmatic dysfunction while only 2 patients (11.1%) developed diaphragmatic dysfunction as shown in table (1).

Controlled and assisted modes were associated with significantly higher rates of diaphragmatic dysfunction than spontaneous modes while there was no significant difference regarding diaphragmatic dysfunction between controlled and assisted modes as shown in table (1). Regarding total ventilatory days among the three groups; it ranged from 5.0 to 13.0 days with a mean 8.95 ± 2.16 days in controlled modes group, it ranged from 5.0 to 13.0 days with a mean 8.09 ± 2.35 days in assisted modes group, while ranged from 2.0 to 4.0 days with a mean 3.17 ± 0.79 days in spontaneous modes.

Regarding hospital stay among the three groups; it ranged from 5.0 to 38.0 days with a mean 17.43 ± 8.74 days in patients on controlled modes, it ranged from 5.0 to 26.0 days with a mean 13.05 ± 5.60 days in patients on assisted modes and it ranged within 4.0 – 11.0 days with a mean 6.83 ± 1.58 days in patients on spontaneous modes.

Controlled and assisted modes were associated with significantly more ventilatory days and longer hospital stay than spontaneous modes while there was no significant difference between controlled and assisted modes.

Regarding association of different modes of mechanical ventilation with mortality; 6 patients (28.6%) on controlled modes died 4 patients (18.2%) on assisted modes died, while no patients (0.0%) on spontaneous modes died so mortality was significantly higher with controlled and assisted modes than spontaneous modes with no significant difference between controlled and assisted modes regarding mortality as shown in table (3).

Among surviving patients on controlled modes only 4 patients (26.7%) were successfully weaned, 7 patients (46.7%) suffered from primary weaning failure and 4 patients (26.7%) suffered from secondary weaning failure as shown in table (3).

Among surviving patients on assisted modes of mechanical ventilation 8 patients (44.4%) were successfully weaned, 4 patients (22.2%) suffered from primary weaning failure and 6 patients (33.3%) suffered from secondary weaning failure as shown in table (3).

Among surviving patients on spontaneous mode of 16 patients (88.9%) were successfully weaned, one patient (5.6%) suffered from primary weaning failure and another one patient (5.6%) suffered from secondary weaning failure as shown in table (3).

So weaning failure rates were significantly higher with controlled and assisted modes than spontaneous modes while there was no significant difference between controlled and assisted modes

Regarding total ventilatory days; it ranged from 2.0 to 9.0 days with a mean 4.71 ± 1.90 days in patients who did not develop diaphragmatic dysfunction, while it ranged from 3.0 to 13.0 days with a mean 9.23 ± 2.46 days in patients who developed diaphragmatic dysfunction. Diaphragmatic dysfunction group was associated with significantly more ventilatory days than non-diaphragmatic dysfunction group.

Regarding hospital stay; it ranged from 4.0 to 13.0 days with a mean 7.81 ± 2.14 days in patients who did not develop diaphragmatic dysfunction while it ranged from 5.0 to 38.0 days with a mean 17.80 ± 7.57 days in patients who developed diaphragmatic dysfunction. Diaphragmatic dysfunction group was associated with significantly longer hospital stay than non-diaphragmatic dysfunction group.

Among patients who developed diaphragmatic dysfunction 8 patients (26.7%) died while among patients who did not develop diaphragmatic dysfunction 2 patients (6.5%) died. Diaphragmatic dysfunction group was associated with significantly higher mortality than non-diaphragmatic dysfunction group.

Among patients who developed diaphragmatic dysfunction and survived only 2 patients (9.1%) were successfully weaned, 11 patients (50.0%) suffered from primary weaning failure and 9 patients (40.9%) suffered from secondary weaning failure. while among patients who did not develop diaphragmatic dysfunction and survived 26 patients (89.7%) were successfully weaned, one patient (3.4%) suffered from primary weaning failure and 2 patients (6.9%) suffered from secondary weaning failure so Diaphragmatic dysfunction group was associated with significantly higher rates of weaning failure than non-diaphragmatic dysfunction group.

DISCUSSION

In our study, patients on controlled mechanical ventilation (CMV); 5 patients (23.8%) did not develop diaphragmatic dysfunction while 16 patients (72.2%) developed diaphragmatic dysfunction. Patients on assisted modes; 10 patients (45.5%) did not develop diaphragmatic dysfunction while 12 patients (54.5%) developed diaphragmatic dysfunction. Patients on spontaneous mode of mechanical ventilation; 16

patients (88.9%) did not develop diaphragmatic dysfunction while only 2 patients (11.1%) developed diaphragmatic dysfunction. Controlled and assisted modes were associated with significantly higher rates of diaphragmatic dysfunction than spontaneous modes while there was no significant difference regarding diaphragmatic dysfunction between controlled and assisted modes.

Sassoon et al (9) measured in vivo and in vitro diaphragm contractile and morphological properties in 30 sedated mechanically ventilated rabbits and concluded that diaphragmatic contractility did not decrease with continuous positive airway pressure (CPAP) but decreased to 63% after 1 day of CMV and to 49% after 3 days of CMV due to significant myofibril damage occurred in the diaphragm which is consistent with our findings.

Mrozek et al, (10) studied contractile properties of the diaphragm in 18 healthy adult male mice which were assigned to three groups; Group I rats were mechanically ventilated with CMV for 6 hours, group II rats were on CPAP of 2-4 cm H2O for 6 hours and group III rats which were a control group with no specific intervention. They concluded that controlled MV leads to a severe impairment of diaphragmatic contractility.

In the study of Jung et al, (11) Two groups of six anesthetized piglets were ventilated during a 72 hours period. Piglets in the CMV group were ventilated without spontaneous ventilation, and piglets in the adaptive support ventilation (ASV) group were ventilated with spontaneous breaths. After 72 h of ventilation, diaphragmatic contractility decreased by 30% of its baseline value in the CMV group, whereas it did not decrease in the ASV group. Although CMV was associated with an atrophy of the diaphragm (evaluated by mean cross-sectional area of both the slow and fast myosin chains), atrophy was not detected in the ASV group. Consistently with our results they concluded that maintaining diaphragmatic contractile activity by using the spontaneous mode may protect the diaphragm against the deleterious effect of prolonged controlled mandatory ventilation.

Same results were obtained by Levine et al, (12) who concluded that combination of 18 to 69 hours of complete diaphragmatic inactivity and controlled mandatory ventilation results in marked atrophy and dysfunction of human diaphragm myofibers after obtaining biopsy specimens from 22 brain-dead organ donors who underwent controlled mechanical ventilation.

Sassoon et al (13) assessed in-vitro diaphragmatic contractile function in 18 sedated rabbits which were randomized equally into control animals, those with 3 days of assisted ventilation, and those with 3 days of CMV. They found that diaphragmatic force decreased by 14% with assisted ventilation and 48% with CMV. From that they could conclude that assist-control mechanical ventilation attenuates ventilator-induced diaphragmatic dysfunction (VIDD) which is non-concordant with our results, it may be because of the difference between both studies in ventilatory days and sample size.

Conclusion

- MV induces diaphragmatic dysfunction which is significantly higher with Controlled and assisted mechanical ventilation modes in comparison to spontaneous modes.
- VIDD is associated with higher rates of primary and secondary weaning failure, more ventilatory days, longer hospital stay and higher mortality rate.
- Controlled and assisted mechanical ventilation modes are associated with higher rates of primary and secondary weaning failure, more ventilatory days and longer hospital stay in comparison to spontaneous modes.

Conflict of Interests:

Authors declare that there is no conflict of interests regarding the publication of this paper.

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