



# Does it make difference to measure diaphragm function with M mode (MM) or B mode (BM)?

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## Abstract

Diaphragm dysfunction occurs in mechanically ventilated subjects. Recent literature suggests that diaphragm thickening fraction (DTF) measured by ultrasound can be useful to predict weaning outcome. However, there is no standardized approach in the measurement of diaphragm thickness (DT) and limited data exists comparing different measurement techniques of diaphragm thickness (M mode-MM or B mode-BM). The goal of this study was to compare MM with BM in the measurements of DT and excursion in the ICU subjects. DT measurements were obtained from the right diaphragm during tidal and maximal inspiratory breathing. Three measurements of the DT were taken both in MM and BM and their mean values were calculated. DT was measured during inspiration and expiration and DTF was calculated. Excursion of diaphragm was also measured with MM and BM during tidal and maximal inspiratory breathing. Bias and agreement between the two measurement methods were evaluated with Bland and Altman test. Sixty-two subjects were enrolled in the study. While 25 (40%) subjects were receiving invasive mechanical ventilation, 14 (23%) subjects ventilated noninvasively. There were no significant difference between the measurement results of MM and BM. BM and MM tidal diaphragm measurements during the inspiratory ( $0.3 \pm 0.08$  and  $0.31 \pm 0.08$  cm;  $P=0.022$ ), expiratory ( $0.24 \pm 0.07$  and  $0.24 \pm 0.07$  cm;  $P=0.315$ ) phases and tidal DTF were ( $27 \pm 16$  and  $31 \pm 14\%$ ,  $P=0.089$ ) respectively. Results of our study suggests that except tidal inspiratory diaphragm thickness, all thickness and excursion measurements with MM and BM are very compatible with each other. Further studies are necessary to confirm our results and to standardize the measurements of diaphragm.

**Keywords** Diaphragm ultrasound · Point of care ultrasound (POCUS) · Intensive care unit (ICU) · Respiratory failure · Mechanical ventilation

## 1 Introduction

Diaphragm is the main muscle of breathing and assessment of its thickness and excursion are important in detecting dysfunction and exhaustion [1]. Diaphragm dysfunction (DD) is associated with respiratory insufficiency and poor outcomes

[2]. Clinical trials in the last decade have drawn attention to the relationship between DD and mechanical ventilation in intensive care unit (ICU) subjects. They have shown that most frequent cause of DD acquired in ICU is invasive mechanical ventilation [3]. DD is a very common condition, causing to prolonged mechanical ventilation and longer stay in ICU. Clinically significant DD is observed nearly 60–80% of mechanically ventilated subjects [4]. Decrement in diaphragm muscle mass and contractility are reported in previous studies even in as early as 48 h after starting mechanical ventilation [5, 6]. DD has different definitions according to ultrasonographic measurements of diaphragm such as diaphragmatic thickening fraction (DTF) of less than 20–30% during tidal breathing and a diaphragmatic excursion less than 10 mm from end-expiration to end-inspiration [7].

Functional status of diaphragm can be assessed by various methods such as chest radiography, fluoroscopy, pulmonary function test, electromyography and magnetic

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phrenic nerve stimulation [8]. Among them ultrasonography (US) is preferred recently because it is easy to perform, cost effective, non-radiating, non-invasive bedside tool for assessment of diaphragm function [9]. Recent findings suggest that diaphragm dysfunction is related with weaning failure and is associated with worse prognosis at the time of liberation from mechanical ventilation [4, 10, 11]. On the other hand despite these developments, the measurement method and cut off values for diaphragm dysfunction are not standardized yet. For example, it is not certain that should we use diaphragm thickness, diaphragm thickening fraction or diaphragm excursion as the criterion of DD. In addition, in some studies, while measurements related to the diaphragm during weaning period are made when the subject is connected to the ventilator, in other studies it is done during spontaneous breathing trial. Lastly there is no certainty that measurements should be made with M Mode (MM) or B Mode (BM). Previous inferior vena cava (IVC) studies showed that, translational changes during the respiration negatively affect the maximum and minimum dimensions of the IVC, and with respiratory motion IVC can be displaced under the probe and measured outside the area where the diameter values should be measured [12]. The similar problem may also happens during diaphragm measurements. Diaphragm function can be evaluated by diaphragm thickness, thickening fraction and excursion, and these parameters can be measured with both MM or BM. In previous studies both mode were used widely [13–16]. The diaphragm moves in the caudal direction relative to the probe during inspiration and especially in MM, this movement may cause that the diaphragm thickness or excursion to be measured at different locations during inspiration and expiration.

The aim of this study is to investigate whether the measurements of diaphragm thickness, thickening fraction and excursion influenced by use of MM or BM.

## 2 Methods

### 2.1 Study population, data collection and measurements

This observational study was carried out at Gazi University School of Medicine, Department of Pulmonary Critical Care Medicine. The study protocol was approved by the ethics committee of our institution (28.12.2015/166). Sixty-two subjects age  $\geq 18$  years old who were consecutively admitted to the ICU were included in the study. The inclusion criteria were stable hemodynamic status, no administration of sedative agents or neuromuscular blocking agents  $> 24$  h before enrollment and ability to sustain pressure support ventilation for at least 15 min. The exclusion criteria were the presence

of pneumothorax, pregnancy, anatomical malformation of the diaphragm a history of either neuromuscular disease or thoracic surgery and poor image quality. Subject's age, diagnosis, comorbidities, duration of mechanical ventilation, length of ICU and hospital stay, acute physiology and chronic health evaluation (APACHE II) score on admission, Body Mass Index (BMI), arterial blood gas analysis parameters and Glasgow Coma Scale (GCS) were recorded. Diaphragm measurements were performed during the first week of ICU stay in 50 subjects. In seven intubated and 5 non-intubated subjects measurements were performed 7 days after ICU admission. Pressure support mode was used during the study period and was set in order to provide a tidal volume of 6–8 ml/kg of ideal body weight, without any sign of respiratory distress or discomfort. End-expiratory pressure was set as 5 cm H<sub>2</sub>O. Measurements were performed while subjects were in semi-recumbent position and were not receiving sedation or neuromuscular blocking agents. A standart ultrasound machine, Vivid-Q (GE Healthcare), was used for ultrasonographic evaluations with a linear probe (7.5–10 MHz) and a low-frequency (1–5 MHz) sector probe. In general, the liver provides an excellent ultrasound window, so that the right side gives better view than the left side. Therefore all measurements were performed on the right side. All researchers who applied ultrasonographic measurements were experienced in diaphragm USG (GG has 4 years experience with more than 300 diaphragm examination and BSK has 2 years experience with about 150 examination). For the measurement of DT, diaphragm was visualized by placing the transducer perpendicular to the chest wall in the eighth or ninth intercostal space, between the anterior axillary and the midaxillary lines, to observe the zone of apposition (ZOA). For evaluation of diaphragmatic excursion, the probe was placed below the right subcostal margin in the mid-clavicular line. BM and MM were then used to display diaphragm excursion and three subsequent measurements were recorded. Measurement of diaphragm excursion were made according to technic described by Skaarub et al. [17]. Several images of the diaphragm were captured and stored, including at least three at the point of maximum thickening at maximum inspiratory level and than resting tidal volume. Both BM and MM images were recorded for thickening and excursion measurements. Paradoxical motion was defined as diaphragm moving away from the transducer (with MM) during inspiration. Measurements were performed by the two intensivists. To measure DT with MM and BM, the same screen was used (Fig. 4). When BM and MM images are seen on the same screen, expiratory diaphragm thickness was measured by both BM and MM. Inspiratory and expiratory measurements of thickness were performed carefully at the same part of the diaphragm. MM measurements were performed on the MM screen and thin part was measured as expiratory thickness and thick part was measured as

inspiratory thickness. Physicians were blinded to measure of each other. To determine inter-observer reliability, each physician evaluated previously recorded three consecutive MM and BM measurements of tidal expiratory thickness and tidal excursion in 15 subjects. Their means were calculated and used in the ICC analysis. The DTF was calculated as percentage from the following formula: Thickness at peak inspiration – Thickness at end expiration/Thickness at end expiration  $\times 100$  [5]. In addition to these analysis we compared DD rates according to BM and MM measurements of the diaphragm. Our DD definition was that: existence of at least 2 of the following 3 criteria; Tidal expiratory diaphragm thickness  $< 2$  mm, tidal diaphragm excursion  $< 10$  mm and tidal DTF  $< 20\%$  [7].

## 2.2 Statistical analysis

We used SPSS software (version 22.0) to carry out statistical analyses. Continuous variables were described as mean  $\pm$  standard deviation or median (interquartile range) depending on whether distribution was normal or not. Data distribution was analyzed using a Kolmogorov–Smirnov test. P values lower than 0.05 were considered as statistically significant. The averages were compared with the Student's t test. We used Chi square test and Kappa statistic in order to compare DD rates according to BM and MM measurements. Pearson correlation coefficient was used for correlation coefficient calculations ( $r$ ). Agreement and bias between the two measurement methods (MM and BM) for thickening and excursion measurements were evaluated with Bland and Altman test. Intra-class correlation coefficient (ICC) was used for the assessment of inter-observer reliability. ICC greater than 0.7 was taken to indicate a strong correlation. The evaluation was carried out with SPSS statistical programme.

## 3 Results

Table 1 shows the demographic characteristics of the subjects. Seventeen subjects (27%) were female. Mean age was  $68 \pm 17$  years. Twenty-five (40%) subjects received invasive mechanical ventilation, 14 (23%) subjects received noninvasive mechanical ventilation during the ICU stay. Three subjects had tracheostomy and 5(8%) subjects had paradoxical breathing. During the MM measurements, the diaphragm moved and slid slightly away from the transducer during inspiration in nine subjects. The mean duration of mechanical ventilation was  $23 \pm 26$  days, mean length of ICU stay was  $20 \pm 23$  days and mean hospital stay was  $25 \pm 24$  days. BM and MM tidal diaphragm measurements during the inspiratory ( $0.3 \pm 0.08$  and  $0.31 \pm 0.08$  cm;  $P = 0.022$ ), expiratory ( $0.24 \pm 0.07$  and  $0.24 \pm 0.07$  cm;  $P = 0.315$ ) phases and DTF were ( $27 \pm 16$  and  $31 \pm 14\%$ ;

**Table 1** Demographic characteristics of the subjects ( $n = 62$ )

Age, years (mean $\pm$ SD)	$68 \pm 17$
APACHE II Score (mean $\pm$ SD)	$23 \pm 8$
Body mass index, kg/m <sup>2</sup> (mean $\pm$ SD)	$25 \pm 6$
Glasgow Coma Scale (mean $\pm$ SD)	$9 \pm 4$
Sex: female, n (%) / male, n (%)	17 (27%) / 45 (73%)
Arterial blood gas analysis, n (mean $\pm$ SD)	
pH	$7.39 \pm 0.08$
PO <sub>2</sub> , mmHg	$83 \pm 30$
PCO <sub>2</sub> , mmHg	$44 \pm 16$
HCO <sub>3</sub> , mEq	$25 \pm 7$
SaO <sub>2</sub> , %	$93 \pm 8$
Admission diagnosis, n (%)	
COPD	34 (55%)
Sepsis	24 (39%)
Renal	10 (16%)
Pulmonary	61 (98%)
Cardiac	7 (11%)
Gastrointestinal	1 (1.6%)
Neurologic	3 (5%)
Rheumatologic	1 (1.6%)
ARDS	4 (7%)
Comorbidities, n (%)	
Pulmonary	45 (73%)
Cardiac	34 (55%)
Gastrointestinal	2 (3%)
Neurological	11 (18%)
Endocrinological	6 (10%)
Malignancy	12 (20%)
Renal	5 (8%)
Rheumatologic	1 (1.6%)
Immunosuppression	10 (16%)

*n* number, APACHE II acute physiologic and chronic health evaluation, SD standard deviation, ICU intensive care unit, kg kilogram, m<sup>2</sup> square meter, COPD chronic obstructive pulmonary disease, ARDS acute respiratory distress syndrome

$P = 0.089$ ) respectively. BM and MM maximum inspiratory diaphragm measurements during the inspiratory phase ( $0.33 \pm 0.08$  and  $0.35 \pm 0.09$  cm;  $P = 0.167$ ) and DTF were ( $34 \pm 22$  and  $34 \pm 22\%$ ,  $P = 0.983$ ) respectively. BM and MM tidal diaphragm excursion measurements were ( $1.3 \pm 0.8$  and  $1.4 \pm 0.9$  cm;  $P = 0.369$ ), BM and MM maximum inspiratory diaphragm excursion measurements were ( $1.8 \pm 1.3$  and  $2.1 \pm 1.5$  cm;  $P = 0.195$ ) respectively Table 2. Table 3 summarizes the reference values of diaphragm thickness and excursion measured with BM and/or MM in the mechanically ventilated subjects and healthy volunteers in previously published studies. Despite existence of different degree diaphragm movements relative to the ultrasound transducer secondary to respiratory movement, there was no significant difference between the measurement results of MM and BM.

**Table 2** Measurements of diaphragm at maximum inspiratory and tidal respiratory with B mode and M mode

Parameters	Paired t test	Pearson correlation	Bland–Altman		
			One sample agreement	Linear regression BIAS	
Tidal inspiratory thickness, cm (n:58)	P=0.022	r=0.79	P=0.0001	Mean difference P=0.022 −0.017±0.106	LR P=0.849
BM	0.3±0.08				
MM	0.31±0.08				
Tidal expiratory thickness, cm (n:57)	P=0.315	r=0.86	P=0.0001	Mean difference P=0.315 −0.005±0.072	LR P=0.861
BM	0.24±0.07				
MM	0.24±0.07				
Maximum inspiratory thickness, cm (n:38)	P=0.167	r=0.72	P=0.0001	Mean difference P=0.167 −0.015±0.123	LR P=0.553
BM	0.33±0.08				
MM	0.35±0.09				
Tidal TF, % (n:57)	P=0.089	r=0.53	P=0.0001	Mean difference P=0.089 −3.35±28.7	LR P=0.441
BM	27±16				
MM	31±14				
Maximum inspiratory TF, % (n:38)	P=0.983	r=0.42	P=0.008	Mean difference P=0.983 0.08±46.25	LR P=0.811
BM	34±22				
MM	34±22				
Tidal diaphragmatic excursion, cm (n:28)	P=0.369	r=0.67	P=0.0001	Mean difference P=0.369 −0.12±1.38	LR P=0.552
BM	1.3±0.8				
MM	1.4±0.9				
Maximum inspiratory diaphragmatic excursion, cm (n:21)	P=0.226	r=0.80	P=0.0001	Mean difference P=0.226 −0.24±0.88	LR P=0.260
BM	1.8±1.3				
MM	2.1±1.5				

*n* number, *BM* B mode, *MM* M mode, *p* probability, *r* correlation coefficient, *LR* linear regression, *TF* thickening fraction, *cm* centimeter

In general there was good agreement and no proportional bias between the measurements of 2 modes ( $P > 0.05$ ). But there was not good agreement in the measurement of tidal inspiratory thickness.

When we compared DD rates according to BM and MM measurements of the diaphragm, there was no statistically significant difference between the DD rates across the modes' measurements. Rate of DD in the whole study group was 21% (11/52) and 8% (4/52) according to BM and MM measurements respectively ( $P = 0.628$ ). Kappa statistics was also showed no statistically significant disagreement across the modes ( $P = 0.845$ ).

Figure 1a–c show Bland–Altman graphics of tidal inspiratory thickness, maximum inspiratory thickness and tidal expiratory thickness, Fig. 2a and b show Bland–Altman graphics of tidal thickening fraction and maximum inspiratory thickening fraction, Fig. 3a and b show Bland–Altman graphics of tidal excursion and maximum inspiratory excursion, respectively. Figures 4a, b and 5 show measurement methods of thickness and excursion via BM and MM, respectively. Table 3 summarizes the reference values of diaphragm thickness and excursion measured with BM and/or MM in the mechanically ventilated subjects and healthy volunteers in previously published studies. In inter-observer

**Table 3** The reference values of diaphragm thickness and excursion in ultrasound assessment

Study of subgroup	B-Mode		M-Mode	
	Diaphragm thickness (mm)	Excursion (mm)	Diaphragm thickness (mm)	Excursion (mm)
Healthy volunteers				
Gottesman 1997 [36]	2.7 ± 0.5			
Bousseges 2009 [37]				29 ± 6
Testa 2011 [38]				18.4 ± 7.6
Voyvoda 2012 [39]				16 (6–37)
Vivier 2012 [25]	2.6 (2.1–3.0)			
Carrillo-Esper 2016 [40]	1.6 ± 0.4			
Laviola 2018 [41]	2.5 ± 0.4			
Boussuges 2018 [15]				30 ± 11
Boccatonda 2019 [42]				15 ± 6
Zhu 2019 [43]	1.6 ± 0.4			14.8 ± 2.6
Fayssol 2019 [44]			1.5 (1.3–1.9)	32 (19–36)
Spadaro 2019 [45]				16 (12–18)
Mechanically ventilated subjects				
Schepens 2015 [46]	1.9 ± 0.4			
Goligher 2015 [47]			2.4 ± 0.8	
Yoo 2016 [48]	2.8 (2–3.5)			16.9 (10.6–19.6)
Theerawit 2018 [49]				13.5 ± 6.5
Pirompanich 2018 [50]	2.4 ± 0.9			
Vivier 2019 [51]			2.5 ± 1.1	14 ± 7
Rittayamai 2019 [52]				24.9 ± 8.4

*mm* millimeter

reliability analysis of all the measurements, ICC coefficients were 0.96 for tidal expiratory thickness in BM, 0.96 for tidal expiratory thickness in MM, 0.95 for tidal diaphragmatic excursion in BM, 0.94 for tidal diaphragmatic excursion in MM, respectively ( $P < 0.05$ ).

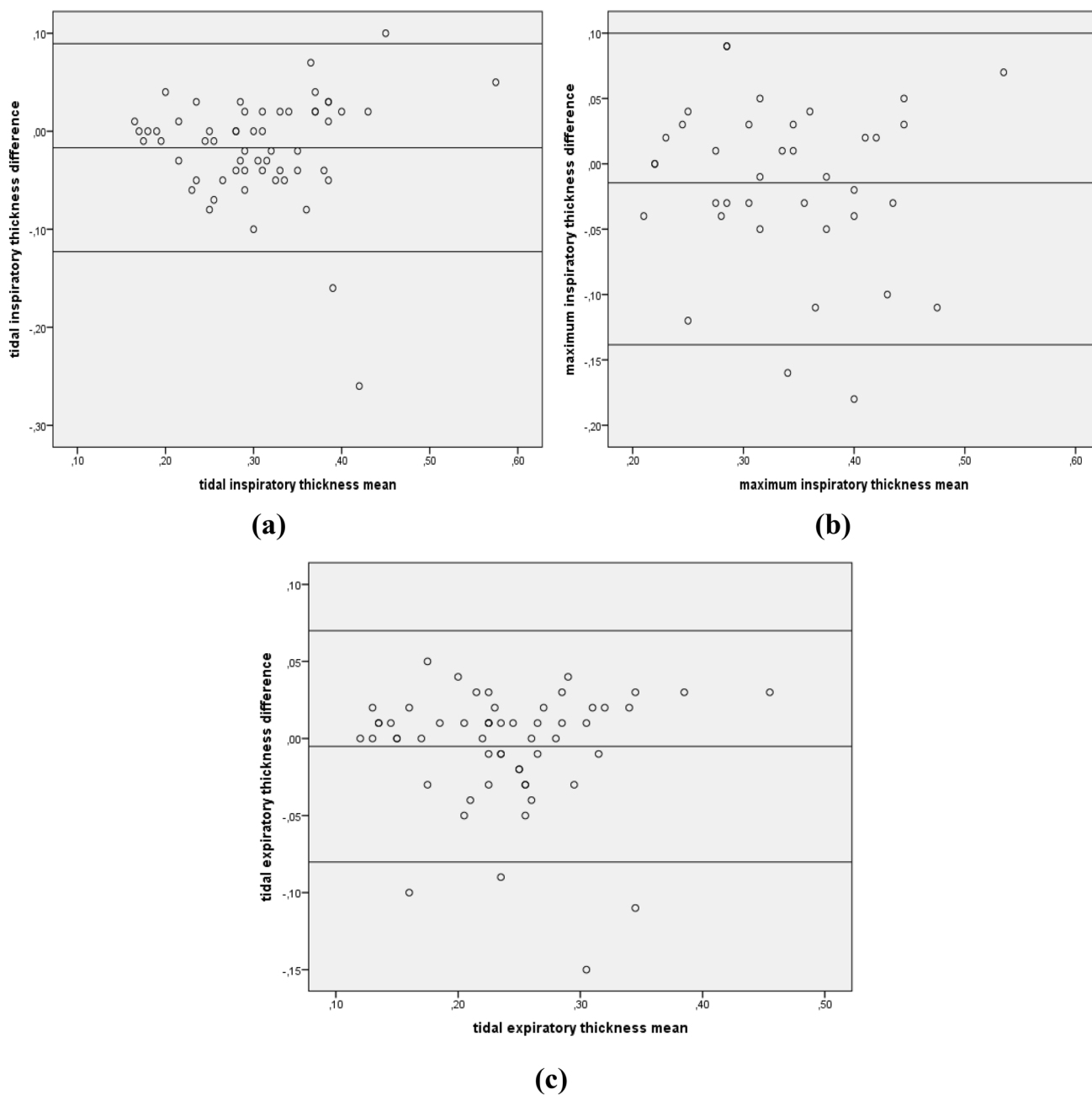
## 4 Discussion

In this study, our results showed that BM and MM measurements of expiratory thickness of diaphragm, maximum inspiratory thickness, tidal and maximum inspiratory DTF and excursion were significantly correlated, there were good agreement between each other and there was no bias among the measurements. There was no significant difference in the evaluation of DD incidence according to measurements with both modes. These results suggest that in the ICU subjects both BM and MM can be used to measure diaphragm. Only diaphragm thickness measured during tidal inspiration varied between MM and BM (disagreement) but bias was not detected between MM and BM measurements. However, the difference in tidal inspiration was too small to be clinically significant and it was not influenced the TF calculation results. Diaphragm BM or MM thickness evaluation is a feasible, reproducible and non-invasive technique to assess

diaphragm activity and to evaluate the impact of mechanical ventilation on subject's diaphragm in terms of anatomical changes and muscle strength. When we examined the literature, we saw that both BM and MM was used to measure thickness and excursion of diaphragm. But, in the majority of diaphragm ultrasound studies diaphragm thickness measured by BM ultrasound imaging [18, 19]. MM is used more frequently to measure the excursion [20, 21]. In our study, we determined the success rate of diaphragm imaging as 85% and this ratio was compatible with the literature [22].

We summarized ultrasound studies evaluating diaphragm dysfunction in Table 3. In these studies measurement of diaphragm thickness, thickening fraction and excursion were assessed with B mode and/or M mode. But we could not find any study specifically comparing MM with BM in thickness and excursion measurements.

In the Lerolle's study excursion during maximal inspiratory effort found to be well correlated with transdiaphragmatic pressures in subjects requiring prolonged mechanical ventilation after cardiac surgery and excursion of  $< 2.5$  cm was a predictor of prolonged intubation [23]. Kim et al. was defined diaphragmatic dysfunction as tidal excursion of less than 10 mm or presence of diaphragmatic paradoxical movement. It has been emphasized that POCUS should be done in order to evaluate diaphragm dysfunction



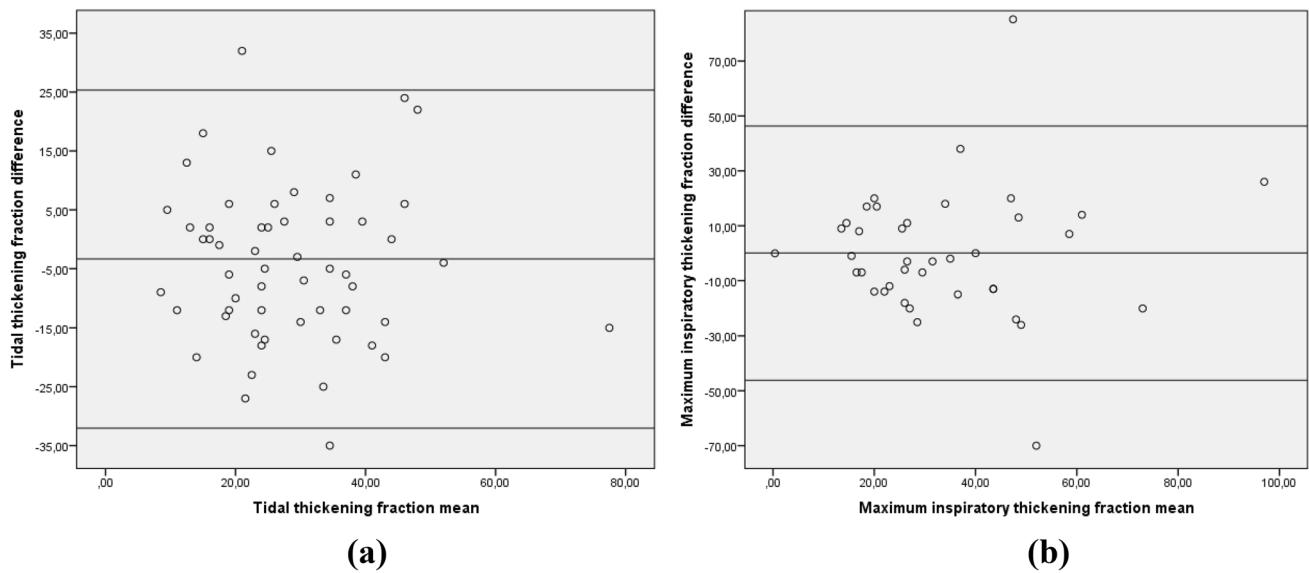
**Fig. 1** **a** Bland–Altman graphics of tidal inspiratory thickness. **b** Bland–Altman graphics of maximum inspiratory thickness. **c** Bland–Altman graphics of tidal expiratory thickness

for difficult weaning [24]. Vivier et al. concluded that the use of MM ultrasonography to assess muscle function and contribution to respiratory burden is an useful, non-invasive and reproducible method [25]. Goligher et al., evaluated the feasibility, reproducibility and validity of diaphragm thickness measurements to assess inspiratory effort in mechanically ventilated subjects. They concluded that M-Mode technique may be employed to reliably detect

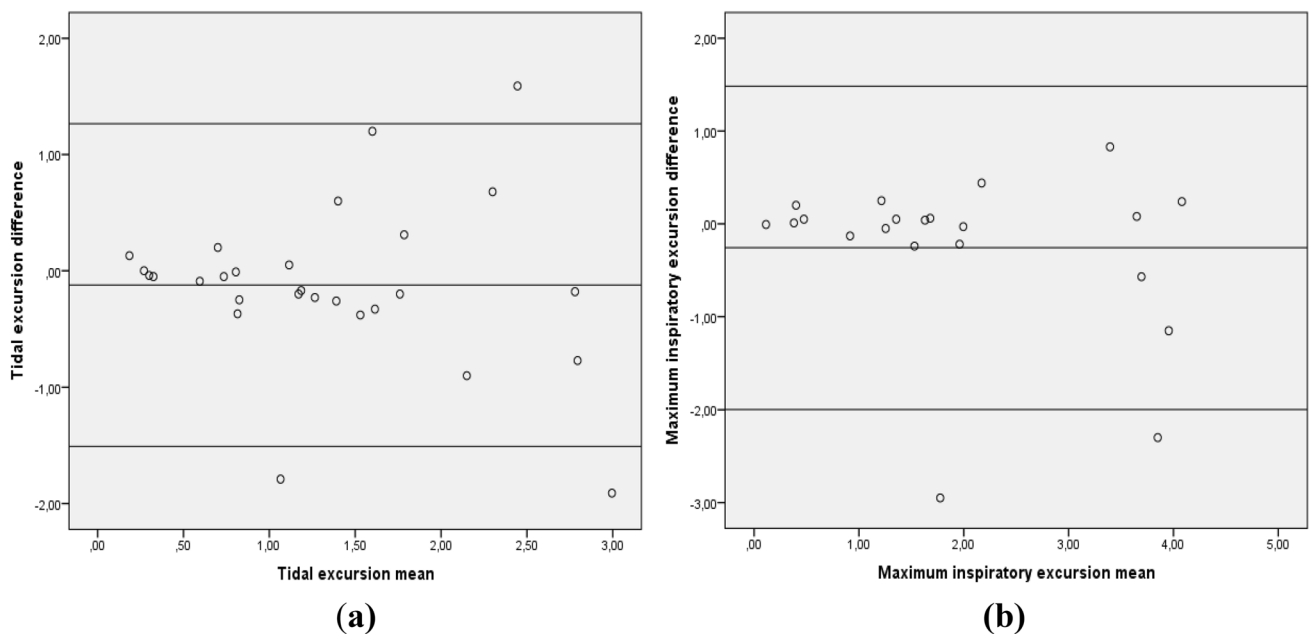
diaphragmatic atrophy over time and to assess diaphragm contractile activity in ventilated subjects [26].

Some concerns about the diaphragm sonography have to be pointed out in clinical practice. Although M mode can be used to measure thickness and has the advantage of capturing multiple breaths within one image allowing for easier comparison, it has some limitations such as failure to visualize precise anatomy of diaphragm, wider variability





**Fig. 2** **a** Bland–Altman graphics of tidal thickening fraction. **b** Bland–Altman graphics of maximum inspiratory thickening fraction



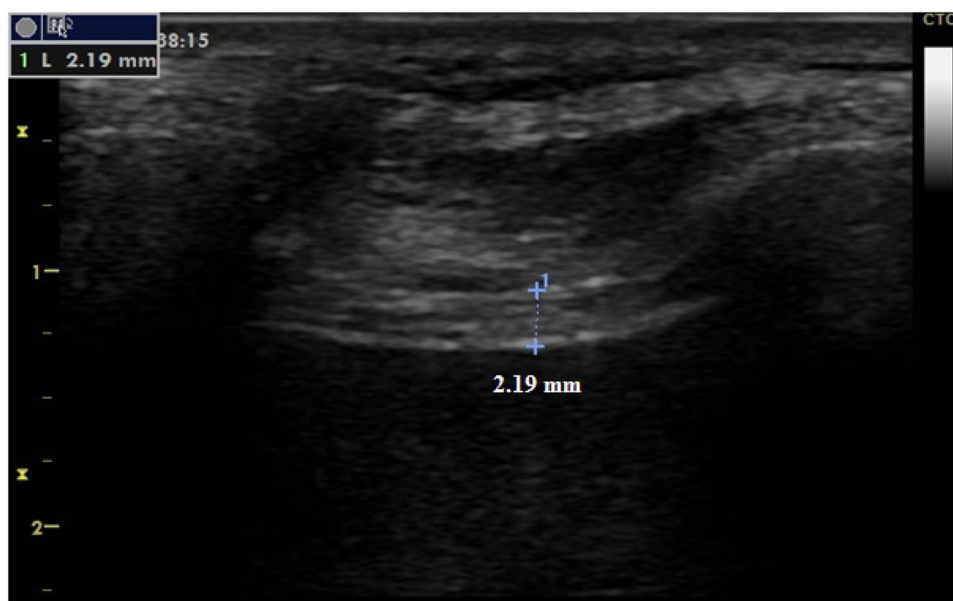
**Fig. 3** **a** Bland–Altman graphics of tidal excursion. **b** Bland–Altman graphics of maximum inspiratory excursion

in measuring muscle thickness, the potential to overestimate diaphragm muscle thickness and an inability to discriminate between excursion resulting from extrinsic mechanical positive pressure and intrinsic diaphragm contractility [26–28]. BM ultrasound provides good anatomical view of the muscle and with its adjacent structures to measure thickness both at inspiration and expiration, a more detailed visualization of the diaphragm in two dimensions in comparison with MM and morphometry overcomes the limitations of displacement

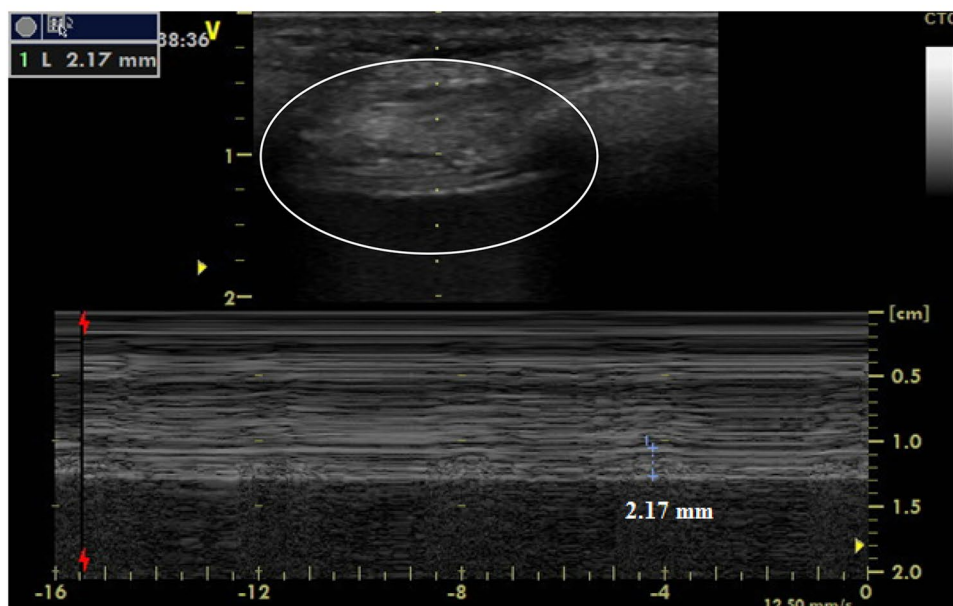
ambiguities by representing only active diaphragm contraction [26, 29–31]. According to Houston's study direct visualization of diaphragm and measuring its thickness by BM ultrasound provides a best method for detection of unilateral or bilateral paralysis in subjects with clinical suspicion of diaphragm dysfunction [32].

Diaphragm motion and thickness may be different from one location to the other; to avoid this limitation, it is essential to perform the ultrasound exam using identical

**Fig. 4** Measurements of diaphragm thickness with BM (a zoomed in appearance of the area in the circle in b) and MM (b)



(a)



(b)

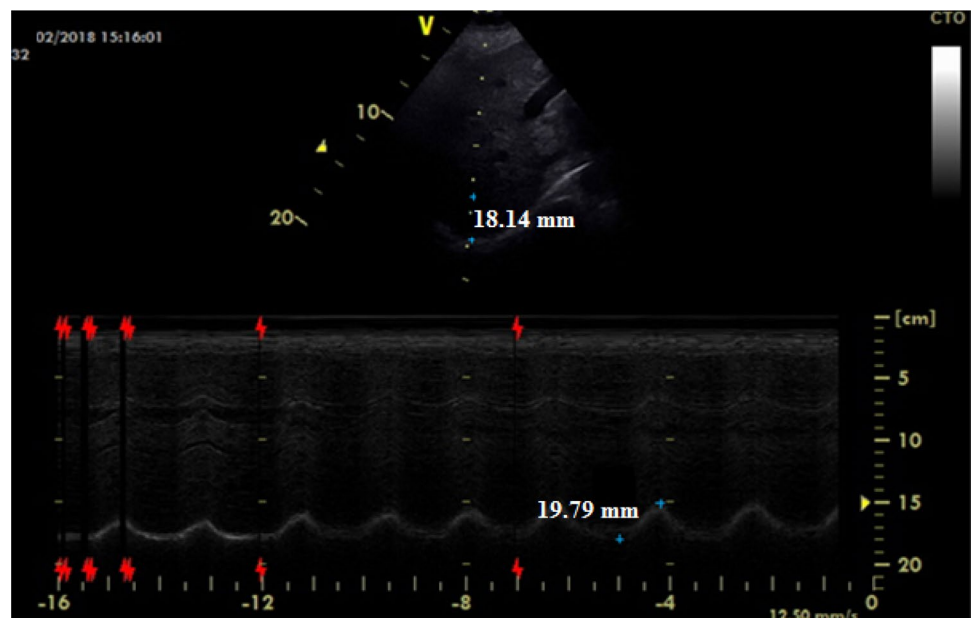
ultrasound beam position and direction. Especially motion variations are more pronounced for MM. The measurement is easy but there is a high risk that taking thickness measurements in different parts of the diaphragm during inspiration and expiration.

Sometimes diaphragm borders can not be detected clearly when its' thickness is measured with MM. In our study, we obviously observed in our nine subjects that, during MM recordings of diaphragm thickness diaphragm slid rigorously under the MM cursor and we could not excluded this effect during our MM measurements even during tidal measurements. Probably for these reasons in our study

we found significant disagreement between MM and BM measurements of diaphragm thickness during inspiration. In IVC measurement studies, this problem was documented very well in previous studies. For this reason it is recommended to measure the respiratory variability of IVC with BM instead of MM [33, 34]. In this regard, there are no studies on diaphragm, but there are IVC studies. Movement of the IVC occurs mediolaterally and craniocaudally during respirophasic ultrasound with collapse of the vessel occurring off axis from the true vertical. This has led to offer in methodological approaches to IVC measurement supporting BM and discouraging MM [12, 35].



**Fig. 5** Measurements of diaphragm excursion with BM and MM



There is no standardized method to evaluate diaphragm thickness, thickening fraction and excursion. Results of our study suggest that there might be some small differences between BM and MM measurements of inspiratory diaphragm thickness.

Although the measurement of diaphragm inspiratory and expiratory thicknesses with BM can be seen as a logical solution in the repeated measurements, it is more difficult to do this and standardize the excursion measurements. The main reason is difficult to standardize the depth of subject's breathing (especially if intubated in intensive care). Secondly, with deep breathing, during the excursion the diaphragm domes not only move cranial and caudal, but also slide laterally. Thus, during the measurement with the MM, the diaphragm is continuously displaced and makes measurement very difficult from the same location.

#### 4.1 Limitations of the study

The limitation of the study was that some of the subjects are intubated, some are not intubated and the number of intubated subjects was low and for this reason incidence of DD could not be evaluated in this important subgroup.

#### 4.2 Conclusion

Results of this study suggest that except inspiratory diaphragm thickness all thickness and excursion measurements with MM and BM are very compatible with each other and incidence of DD measured by both modes were similar.

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#### Compliance with ethical standards

**Conflict of interest** The authors alone are responsible for the content and writing of the manuscript. The authors report no conflicts of interest.

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