Sonographic evaluation of normal diaphragmatic thickness and excursion in Malaysia paediatric population: A single-institution cross-sectional study

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ABSTRACT

Introduction: Diaphragmatic dysfunction is often under-diagnosed as clinical presentation is non-specific and reference values for normal diaphragmatic excursion are inadequate. The rationale of this study is to provide a normal reference value of diaphragmatic excursion and thickness in Malaysia's paediatric population using M-mode sonography, as no previous local data are available to our knowledge.

Materials and methods: A total of 119 healthy infants and children fulfilling our inclusion and exclusion criteria were recruited. They were divided into three groups according to age – 0–2 years old in group 1; 2–6 years old in group 2; 6–12 years old in group 3. Sonography B-mode was used to assess bilateral diaphragmatic thickness and M-mode to assess diaphragmatic excursion during quiet spontaneous respiration.

Results: In our paediatric population, the normal right and left diaphragmatic thickness were 2.0 mm ± 0.5 and 2.0 mm ± 0.5 for group 1; 2.5 mm ± 0.8 and 2.4 mm ± 0.6 for group 2; 2.7 mm ± 0.7 and 2.5 mm ± 0.5 for group 3, respectively. The normal right and left diaphragmatic excursion were 7.7 mm ± 2.5 and 7.3 mm ± 2.6 for group 1; 11.5 mm ± 3.8 and 10.6 mm ± 3.8 for group 2; 13.8 mm ± 3.9 and 12.9 mm ± 3.3 for group 3, respectively (data presented in mean ± standard deviation). There were no significant differences between two genders for each group. Significant positive correlation between age, weight, height, and body surface area with bilateral diaphragmatic thickness and excursion were detected in all studied population. The percentage difference between excursions of both hemidiaphragm was below 40%.

Conclusions: M-mode sonography is the modality of choice for diaphragmatic kinetics especially in paediatric population. This study provides normal sonographic reference value of diaphragmatic excursion and thickness in the Malaysian paediatric population as well as percentile curves for right diaphragmatic excursion plotted against body weight. The availability of this data will aid in the diagnosis of diaphragmatic dysfunction and hence immediate intervention for better recovery.

KEYWORDS:
M-mode sonography; Normal diaphragmatic thickness; Normal diaphragmatic excursion; Diaphragmatic excursion against body weight; Paediatric

INTRODUCTION

Diaphragms are pair of essential organs that mankind could not live without. However, diaphragmatic dysfunction is often under-diagnosed or missed as it has non-specific clinical presentations, especially in paediatric population who may not be able to communicate their symptoms.[1] Diaphragmatic dysfunction or paralysis can lead to negative clinical repercussions if untreated, or even negative impact on survival in severe cases.[2]

Congenital and Pathology Conditions of Diaphragm

Congenital diaphragmatic abnormality includes aplasia or hypoplasia, accessory diaphragm, eventration, and hernias. Aplasia or hypoplasia of diaphragm is very rare and usually not compatible with life.[3] Accessory diaphragm or duplication of fibromuscular part of diaphragm is also rare and almost always occurs on the right.[4] On the other hand, eventration and hernia of diaphragm are relatively more common. Eventration of diaphragm is due to the congenital absence of muscle fibers and usually occurs on the anteromedial aspect of the right hemidiaphragm. Bochdalek hernia is the most common type of congenital hernia. Other type of hernia includes Morgagni and hiatal hernias.[5-7]

The pathological causes of diaphragmatic dysfunction or paralysis in paediatric population include phrenic neuropathy, catheter placement, birth injury, cardiac surgery, resection of thoracic tumours, liver transplantation, or high impact polytrauma.[5,8] In the study conducted by Epelman et al., cardiac surgery such as heart transplantation were the most common source of diaphragmatic injury.[9] Other rare causes such as Lyme disease or West Nile virus were also reported.[5,10] Primary diaphragmatic tumour is very rare in children but secondary metastasis deposition on the diaphragm contributing to dysfunction is possible.[6]

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Imaging of the Diaphragm

Imaging of the diaphragm can be divided into anatomical or functional. Chest radiograph is the most commonly performed thoracic imaging for both adult and paediatric populations; however, it only shows the anatomical position of diaphragm and is a poor predictor of normal diaphragmatic motion.[9]

The capability of computed tomography (CT) and magnetic resonance imaging (MRI) in producing multiplanar imaging and high soft tissue resolution is the choice of imaging for diaphragmatic anatomy.[11] Despite that, CT and MRI are subject to motion artefact which is difficult to control in paediatric population. The use of sedation during CT or MRI may alter the breathing pattern and result in inaccurate measurement of diaphragmatic kinetics.

Sonographic imaging is more frequently utilised for the assessment of diaphragmatic kinetics, especially in paediatric population due to its non-invasive nature. Both MRI and ultrasound have the dual benefit in assessing diaphragm's anatomy and functionality. However, ultrasound is more widely available in all centre and less sophisticated compared to MRI in operation.

Traditionally, fluoroscopy is the key imaging tool for functional assessment of diaphragm by direct visualization of the diaphragmatic kinetics during quiet respiration and sniffing manoeuvre.[5] Patient's full co-operation is vital in succeeding this examination, which is deemed unfavourable in paediatric population. This requirement in addition to the downside of ionising radiation have automatically excluded the paediatric population as a choice of diaphragmatic examination.

The actual gold standard for functionality assessment of the diaphragm is by measuring the transdiaphragmatic pressure generated by phrenic nerve stimulation. This is not practical as it is time-consuming and necessitates specialised equipment.[2] Hence, ultrasound is still nominated as the imaging of choice for both anatomical and functional assessment of diaphragm, be it in adult or paediatric population.[9,12] Nonetheless, sonographic examination is limited to operator's skill and experiences.

The rationale for this study is to provide a normal reference value of diaphragmatic thickness and excursion in Malaysia paediatric population. The current available reference values are mostly done in adult population and derived from a study in foreign countries with restricted population, which limit global generalisation. The availability of these data will be useful for the diagnosis of diaphragmatic dysfunction and hence immediate intervention for better recovery.

MATERIALS AND METHODS

This was a cross-sectional study conducted from January 2020 to December 2021 at Universiti Kebangsaan Malaysia Medical Centre. Subjects were selected by convenience sampling from patient population who came for routine ultrasound screening of the cranial or urinary system. Sample size was calculated using $n = \left[\frac{Z\sigma}{\Delta}\right]^2$, based on the formula by Lwanga SK et al.[13]

We included Malaysian infants and children aged between 0 and 12 years old with normal growth parameters in this study. They were divided into three age groups, where Group 1 was children aged 0 to 2 years old; Group 2 was children aged 2 to 6 years old; and Group 3 was children aged 6 to 12 years old. Preterm babies more than 36 weeks of pregnancy were included in this study provided their growth parameters were within normal limits with no prior history of oxygen dependency. The exclusion criteria were children with active respiratory disease; congenital heart disease; neurological disease; hepatosplenomegaly; post liver or spleen removal; previous history of thoracic or abdominal surgery; failure to thrive; obesity, and those ventilated patients.

Ethical issues

Ultrasound examination is non-invasive and non-ionizing, thus will not contribute to any radiation risk. Full written consent was taken from subject's parent or caretaker prior to examination. Ethical approval for this study has been obtained from the local institution Research and Ethics Committee with the ethical approval code of FF-2020-164.

Protocol for Sonographic Evaluation of Diaphragm

The basic information such as gender, age (calculated to the nearest month based on date of birth to date of examination), ethnicity, weight (kg), and height (cm) of each subject was recorded prior to the examination. We used Toshiba Aplio 500 or GE Logiq S8 ultrasound machine in our centre to perform this study. The 5–10 MHz linear transducer was used for infant and 3–5 MHz curvilinear transducer was used for children. Study was performed during quiet spontaneous respiration in supine position.

Both diaphragms were assessed using brightness mode (B-mode) first to locate the diaphragm, then motion mode (M-mode) for the amplitude. The transducer was fixed throughout examination between midclavicular and anterior axillary line in subxiphoid or intercostal area. Using liver and spleen as acoustic window, diaphragm was identified as an echogenic line above them. Once quiet regular breathing has been identified, we froze the sonogram. Diaphragm thickness was taken as the perpendicular distance between the pleural and peritoneal reflections or simply the perpendicular distance of the echogenic line in B-mode.[1,8,12]

To measure the diaphragmatic excursion, M-mode was utilised with the cursor place almost perpendicular to the diaphragm to obtain the maximum amplitude. During inspiration, the normal diaphragm contracts and moves caudally toward the transducer, which will create an upward motion of the M-mode tracing. On the other hand, during expiration, the diaphragm moves cephalad and away from the transducer, creating a downward motion of the M-mode tracing, as shown in Figures 1–4. Diaphragmatic excursion was taken as a perpendicular distance between the upper border of inspiration and lower border of expiration in M-mode.[1,8,12]

Two sets of data were obtained by the same trained operators (a qualified medical officer and a radiologist) for each patient and the readings were then averaged. Chest radiograph was scrutinised if available to ensure no diaphragmatic elevation

or eventration in the studied population. Data collected were tabulated and analysed using SPSS version 26.0. The difference in excursion between both hemidiaphragm was calculated using the formula $\frac{(V1-V2)}{\frac{(V1+V2)}{2}}$ x 100, where V1 was the mean of right diaphragmatic excursion and V2 was the mean of left diaphragmatic excursion.

RESULTS

We recruited a total of 119 healthy infants and children in this study, with the largest sample size number of 64 in group 1, 24 subjects in group 2, and 31 subjects in group 3. Table I shows the mean anthropometric data for all groups (age, gender, weight, height, body surface area, and body mass index). As Malaysia is a multiracial country, a variety of races were included in this study.

The normal reference value of the diaphragmatic thickness and excursion in the studied population were depicted in Table II, where the normal right and left diaphragmatic thickness were 2.0 mm ± 0.5 and 2.0 mm ± 0.5 for group 1; 2.5 mm ± 0.8 and 2.4 mm ± 0.6 for group 2; 2.7 mm ± 0.7 and 2.5 mm ± 0.5 for group 3, respectively. The normal right and left diaphragmatic excursion were 7.7 mm ± 2.5 and 7.3 mm ± 2.6 for group 1; 11.5 mm ± 3.8 and 10.6 mm ± 3.8 for group 2; 13.8 mm ± 3.9 and 12.9 mm ± 3.3 for group 3, respectively (data presented in mean ± standard deviation). From the values obtained, we concluded that the minimal diaphragmatic excursion was 4.0mm. In Table III, we compared the difference of diaphragmatic thickness and excursion between male and female. Using Independent T-test, no significant difference was detected between two genders.

Table IV shows the correlation between sonographic measurement of diaphragmatic kinetics and anthropometric data using Pearson correlation coefficient test. There were positive correlation between age, weight, height, and body surface area with diaphragmatic thickness and excursion. Thus, we plotted the percentile curve for normal right diaphragmatic excursion against body weight in the studied population, as shown in Figure 5. The 5th to 95th percentiles of right diaphragm excursion according to body weight were depicted in Table V.

In this study, the percentage difference of excursion between both hemidiaphragm across all three groups was in the range of 0–39% with mean of 13.8%. Thereby we concluded that the difference of excursion between both hemidiaphragm was always below 40%.

DISCUSSION

Diaphragm is responsible for three fourth increment of lung volume during quiet breathing. However, diaphragmatic dysfunction is often under-diagnosed as clinical presentation is non-specific and normal diaphragmatic excursion reference value are inadequate. Diaphragmatic dysfunction can be unilateral or bilateral, although the latter will require ventilation assistance. Paediatric population is more vulnerable to diaphragmatic dysfunction compared to adult in view of their poorly developed intercostal muscle with increased mobility of mediastinum. Hence, they are at higher risk of developing complication from diaphragmatic dysfunction, namely atelectasis, pneumonia, or ventilation failure.[5,9,14]

Sonographic evaluation of diaphragm is the most optimum imaging method in paediatric population. In this study, we have utilised both subxiphoid and intercostal methods to assess the diaphragm. However, in both methods, only the posterior hemidiaphragm was assessed in our study. The most challenging part in this study was patient's full co-operation during ultrasound assessment. In order to get the minimum normal diaphragmatic excursion value, patient were proposed to have quiet breathing as per resting phase. However, the infants were usually active during scan and required distraction with toys or music. Contrarily, the older children may manipulate their breathing during study but were more amenable. Thus, most of the values obtained were during "active quiet breathing" rather than "very quiet breathing". At times, we had to abandon the study if patient was inconsolable.

Based on earlier study done by Urvoas et al. (1994), diaphragm excursion for children during quiet breathing always exceeded 4 mm and the differences of excursion between both hemidiaphragm are always below 50%.[8] Another similar but more recent study with larger sample size done by El-Halaby et al. in Egypt (2015) concluded that the lowest value for diaphragmatic excursion from all groups was more than 4 mm, with significant positive correlations found between excursion of the right hemidiaphragm and body weight in all age groups from their study.[1] From the data we compiled, the minimum diaphragmatic excursion in paediatric population was 4 mm, which is identical to El-Halaby et al and Urvoas et al's studies. Comparing the normal references value provided by El-Halaby with our data, the mean diaphragmatic thickness was smaller in our population by 1 to 3 mm. We postulated that this could be due to smaller body habitus in our Malaysian paediatric population compared to Egyptian paediatric population. As stated in anthropometric data in El-Halaby et al's study, the mean weight in each group was 1–2 kg heavier and the mean height in each group was 1–4 cm taller compared to our Malaysian population of the same age groups. Thus, the difference in normal reference value of diaphragmatic thickness of two different population of similar age group can be explained and supported by the positive correlation between weight and height with bilateral diaphragmatic thickness as per Table IV.

In reverse, the mean diaphragmatic excursions were higher in our Malaysian paediatric population by 10–20% (1–3 mm) compared to Egyptian paediatric population. This could be partly attributed to the "active quiet breathing" as described above. Diaphragmatic excursion can vary depending on subject's voluntary inspiratory effort, position, abdominal contents, body mass index, underlying neuromuscular disorder, previous history of thoracic or abdominal surgery, and presence of mechanical ventilations.[15-17] Any structural abnormality of the diaphragm such as congenital diaphragmatic hernia can also contribute to a skewed data.[2]

Table I: Anthropometric data in studied population

Characteristic	Group 1 (n= 64)	Group 2 (n= 24)	Group 3 (n= 31)
Age (months)	6.4 ± 6.4	42.1 ± 12.2	104.7 ± 23.7
Gender (female–male)	21 - 43	10 - 14	11 - 20
Weight (kg)	6 ± 2.5	14.3 ± 2.7	28.2 ± 9.5
Height (cm)	60.9 ± 11.6	96.3 ± 9.9	129.0± 9 11
Body surface area (m^2)	0.3 ± 0.1	0.6 ± 0.1	1.0 ± 0.2
Body mass index (kg/m^2)	15.8 ± 2.5	15.4 ± 2.4	16.5 ± 4

Data are presented as mean ± standard deviation where applicable.

Table II: Normal reference values of the diaphragmatic thickness and excursion in the studied populations

	Group 1 (n= 64)	Group 2 (n= 24)	Group 3 (n= 31)	*p*[a]
Right diaphragmatic thickness (mm)	2.0 ± 0.5 (1.2 – 3.3)	2.5 ± 0.8 (1.4 – 4.0)	2.7 ± 0.7 (1.5 – 5.0)	<0.001
Left diaphragmatic thickness (mm)	2.0 ± 0.5 (0.9 – 3.1)	2.4 ± 0.6 (1.5 – 3.2)	2.5 ± 0.5 (1.2 – 3.4)	<0.001
Right diaphragmatic excursion (mm)	7.7 ± 2.5 (4.1 – 15.3)	11.5 ± 3.8 (6.3 – 20.7)	13.8 ± 3.9 (8.3 – 22.0)	<0.001
Left diaphragmatic excursion (mm)	7.3 ± 2.6 (4.0 – 14.4)	10.6 ± 3.8 (6.2 – 19.6)	12.9 ± 3.3 (8.2 – 21.2)	<0.001

Data are presented as mean ± standard deviation (range).
[a]p value using independent T-test.

Table III: Differences in gender on diaphragmatic thickness and excursion in studied populations

	Right Diaphragmatic Thickness (mm)			Left Diaphragmatic Thickness (mm)			Right Diaphragmatic Excursion (mm)			Left Diaphragmatic Excursion (mm)		
Group	Male	Female	*p*[a]	Male	Female	*p*[a]	Male	Female	*p*[a]	Male	Female	*p*[a]
1	2.0 ± 0.5	2.0 ± 0.5	0.946	1.9 ± 0.6	2.0 ± 0.5	0.288	7.5 ± 2.2	8.1 ± 3.1	0.468	6.7 ± 1.8	8.6 ± 3.5	0.191
2	2.5 ± 0.8	2.3 ± 0.9	0.605	2.4 ± 0.7	2.3 ± 0.4	0.622	10.9 ± 4.3	12.3 ± 3.0	0.354	9.7 ± 3.8	11.7 ± 3.6	0.205
3	2.6 ± 0.6	2.7± 0.9	0.901	2.6 ± 0.5	2.4 ± 0.6	0.369	13.5 ± 3.9	14.2 ± 4.1	0.618	13.0 ± 3.3	12.8 ± 3.5	0.861

Data are presented as mean ± standard deviation.
[a]p value using independent T-test.

Table IV: Correlation between sonographic measurement of diaphragmatic thickness and excursion with anthropometric data (all groups)

	Right diaphragmatic thickness (mm)		Left diaphragmatic thickness (mm)		Right diaphragmatic excursion (mm)		Left diaphragmatic excursion (mm)	
	r	*p*	r	*p*	r	*p*	r	*p*
Age (month)	0.48	<0.001	0.46	<0.001	0.63	<0.001	0.66	<0.001
Weight (kg)	0.52	<0.001	0.51	<0.001	0.65	<0.001	0.62	<0.001
Height (cm)	0.51	<0.001	0.49	<0.001	0.70	<0.001	0.66	<0.001
Body surface area (m^2)	0.54	<0.001	0.53	<0.001	0.68	<0.001	0.66	<0.001

r and *p* using Pearson correlation coefficient test.

Table V: Right diaphragmatic excursion by percentile and body weight

Bode weight (kg)	Right diaphragmatic excursion (mm)						
	5th	10th	25th	50th	75th	80th	95th
<5	0.3	0.7	1.7	3.5	5.2	5.6	6.6
5–10	0.7	1.4	3.6	7.2	10.7	11.4	13.6
10–15	1.0	2.0	5.0	10.0	14.9	15.9	18.9
15–20	1.2	2.4	6.0	12.1	18.1	19.3	22.9
20–25	1.4	2.7	6.8	13.6	20.3	21.7	25.8
25–30	1.5	2.9	7.3	14.6	21.9	23.4	27.8
30–35	1.5	3.1	7.7	15.4	23.1	24.6	29.2
35–40	1.6	3.2	8.0	16.0	23.9	25.5	30.3
40–45	1.7	3.3	8.3	16.5	24.8	26.4	31.4
45–50	1.7	3.4	8.6	17.2	25.8	27.5	32.7
50–55	1.8	3.6	9.1	18.1	27.2	29.0	34.4
55–60	1.9	3.9	9.7	19.4	29.1	31.1	36.9
60–65	2.1	4.2	10.6	21.2	31.9	34.0	40.4

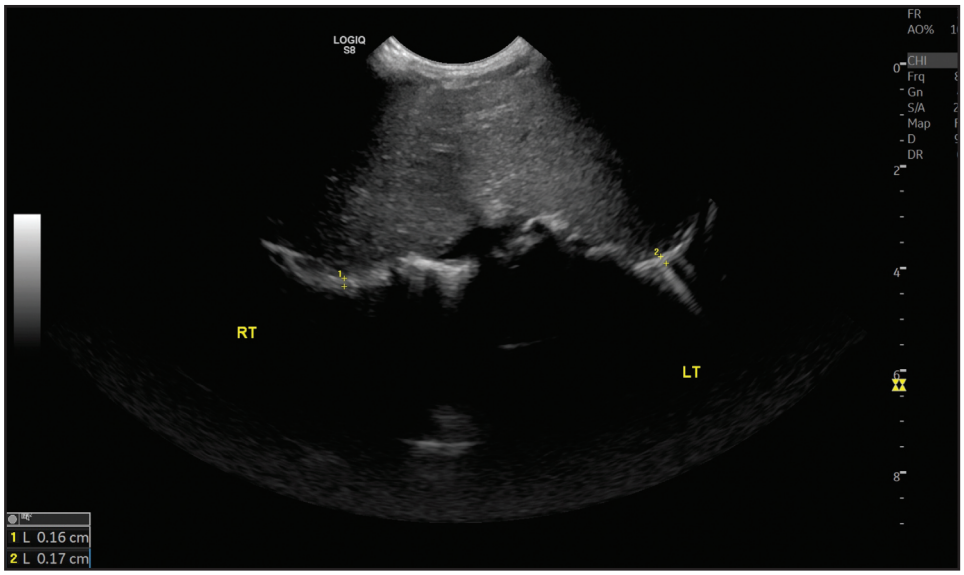

Fig. 1: Measurement of bilateral diaphragm thickness in subxiphoid view using B-mode by placing curvilinear transducer below the sternum and angle cranially. This allows visualisation of both hemidiaphragm as an echogenic line above liver and spleen at the same setting.

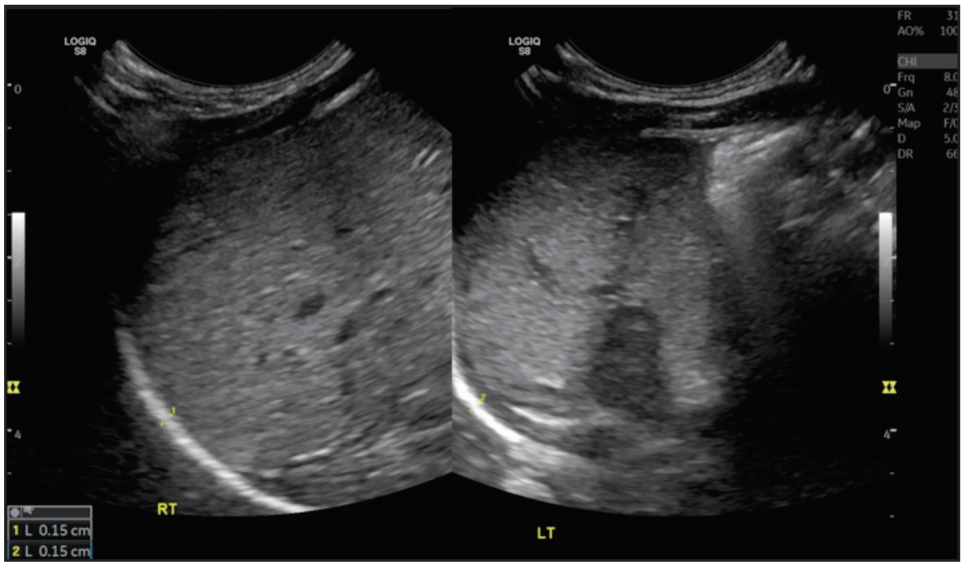

Fig. 2: Measurement of bilateral diaphragm thickness in intercostal view (between midclavicular and anterior axillary line) using B-mode and curvilinear transducer with liver and spleen as acoustic window.

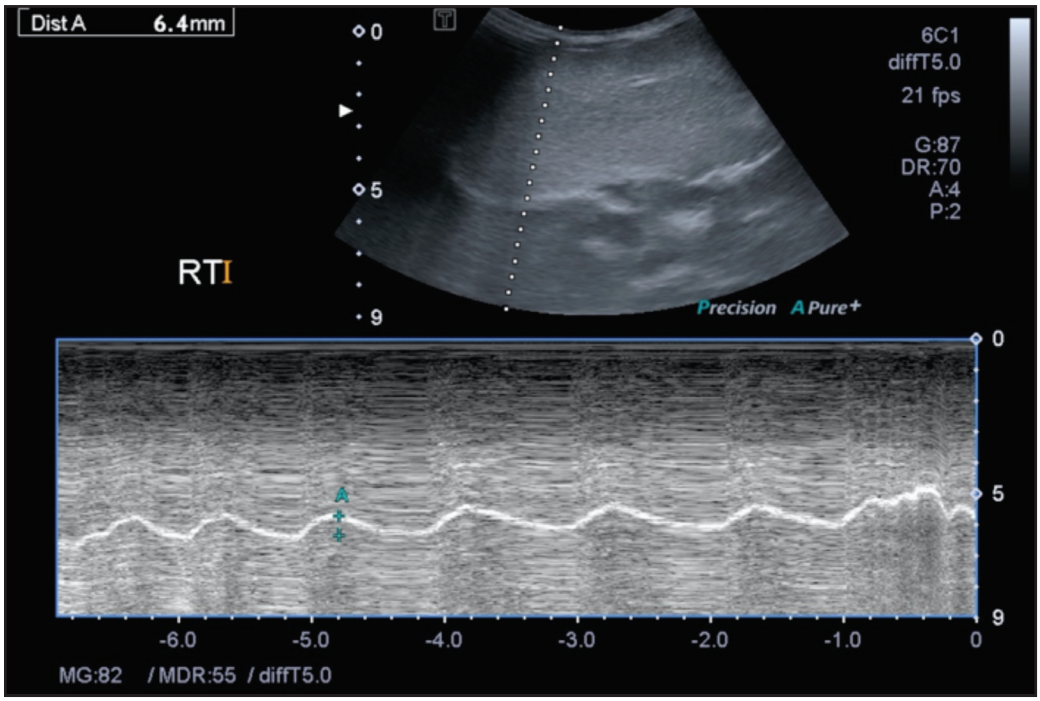

Fig. 3: Measurement of right hemidiaphragm excursion in subxiphoid view using M-mode and curvilinear transducer once regular breathing waves are established. M-mode cursor should be placed almost perpendicular to the diaphragm to obtain maximum amplitude.

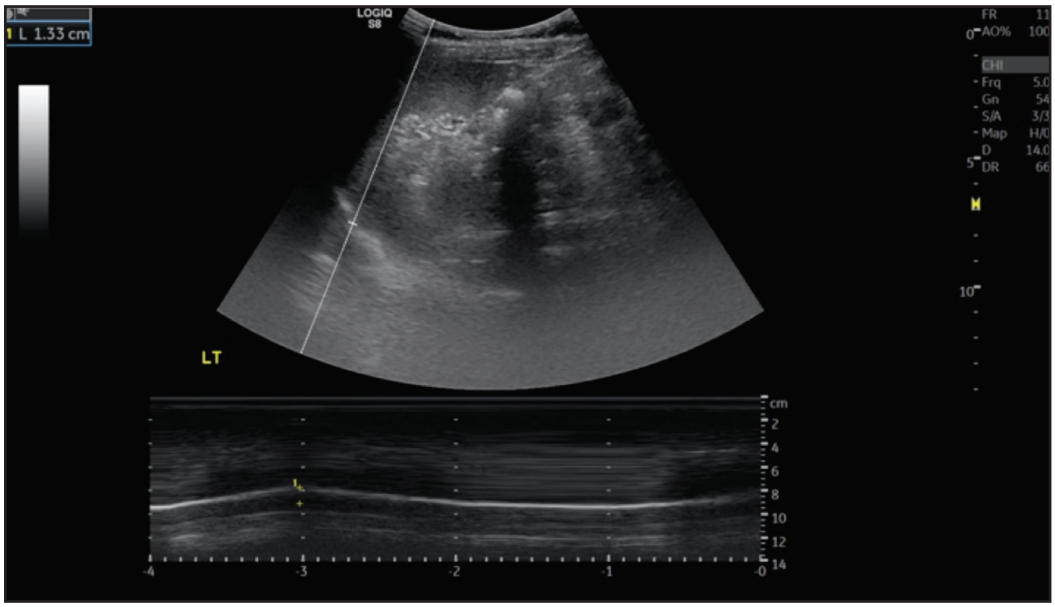

Fig. 4: Measurement of left hemidiaphragm excursion in intercostal view (between midclavicular and anterior axillary line) using M-mode and curvilinear transducer.

Hence, we have adapted these variables into our exclusion criteria to minimise misinterpretation. Nonetheless, we have to consider operator's technique and bias during sonography assessment as part of the consequences as diaphragm kinetics can alter if measures at different ultrasound beam position and direction.

As per El-Halaby et al's study, we have established that there is no gender difference for diaphragmatic excursion and thickness. Among the data we have summarised, the subject's age, weight, height, and body surface area were proportional to their diaphragmatic thickness and excursion. These findings were in accordance with the result from El-Halaby et al as well as Rehan and McCool's studies, where positive correlation between weight and height with diaphragmatic kinetics were determined.[1,18]

Both hemidiaphragm should move simultaneously and symmetrically in a normal subject. Any discrepancy should raise the suspicion of diaphragmatic dysfunction or

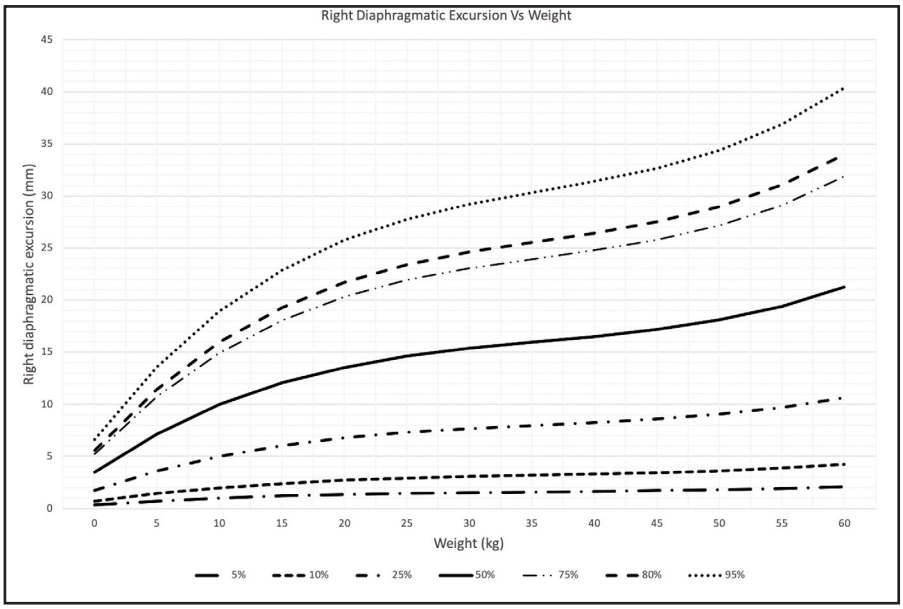

Fig. 5: Percentile curve for normal right diaphragmatic excursion plotted against body weight in the studied populations.

paradoxical movement of diaphragmatic paralysis.[5,8] As stated in Urvoas et al's study, the differences of excursion between both hemidiaphragm were always below 50% with a mean of 30% and range of 5–47%. In our study, the percentage difference of excursion between both hemidiaphragm was in the range of 0–39% with a mean of 13.8% across all studied groups, which supported Urvoas et al's statement. We have concluded that it is generally safe to exclude diaphragmatic dysfunction if the difference between two diaphragmatic excursion is less than 40%.

Having said that, the potential of misinterpretation when there is bilateral diaphragmatic paralysis must be kept in mind and counter-checked with the provided normal reference range. Alternatively, the examiner can place a hand at the patient's chest while observing the diaphragmatic excursion with M-mode sonography. During normal inspiration, the chest should rise and diaphragm would move caudally toward the transducer, creating an upward motion in M-mode tracing. The reverse applied during normal expiration. Paradoxical breathing occurs when chest rise and M-mode tracing are not synchronised.[8] This sonographic assessment should only be done during spontaneous breathing to provide accurate result, thus any ongoing mechanical ventilation need to be temporarily disconnected with continuous monitoring and expert care on standby.[5,9]

We plotted the percentile curve for normal right diaphragmatic excursion against body weight based on the data we have collected in Malaysian paediatric population. We hope that the availability of these graphs and values would provide a guide in diagnosing diaphragmatic dysfunction for our fellow paediatrician and radiologist.

CONCLUSION

Sonography M-mode assessment of diaphragmatic kinetics should be the modality of choice for the paediatric population. This study provides normal sonographic reference value of diaphragmatic excursion and thickness in the Malaysian paediatric population as well as percentile curves for diaphragmatic excursion plotted against body weight. The availability of this data will aid in the diagnosis of diaphragmatic dysfunction and hence immediate intervention for better recovery.

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