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Original Article

Ultrasound utilization in the diagnosis of diaphragm dysfunction compared to other modalities: A retrospective study

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ABSTRACT

Objectives: Diaphragm is dome-shaped fibro-muscular assembly, composed of central tendon surrounded by peripheral muscle fibers. It plays a significant role in respiration and maintenance of lumber spine stability. Any condition that interferes with diaphragmatic innervation, contractile muscle function or mechanical coupling to chest wall can cause diaphragm dysfunction; which is usually manifests as elevation at chest radiography. Functional imaging with M-mode ultrasonography has been used in assessment of diaphragm kinetics in a variety of normal and pathological conditions. In this study, we evaluate the departmental ultrasound accuracy in diaphragm motion assessment and compare its results with other institutional parameters.

Methods: We retrospectively reviewed the recorded laboratory investigation and chest radiograph of 163 pediatric patients. A total of 131 patients met clinical inclusion criteria for our study, patients under age of 14 years having clinical suspicion of diaphragmatic dysfunction. Patients having neuromuscular blockers, surgical plication, and phrenic nerve pacing were excluded. The mean age was 1.6 (SD 2.6) years and there were 44.3% of male and 55.7% of female patients.

Results: The data demonstrated that ultrasonography is a highly sensitive and specific diagnostic tool compared to X-ray and laboratory investigation and clinical suspicion. The second-best results were obtained by X-ray and less accurate results were obtained by laboratory investigation.

Conclusion: In proper sonographic technique; diaphragmatic ultrasound appears to be a valid and reliable diagnostic too; for diaphragmatic dysfunction. Diaphragm ultrasound may act as an imaging tool guiding rehabilitation success in diaphragmatic dysfunction cases.

Keywords: Blood gases, Diaphragm dysfunction, Diaphragm, Ultrasound, X-ray

Introduction

Diaphragm is a dome shaped fibro-muscular assembly lies at the bottom of thoracic cavity and composed of an aponeurotic tendinous central ligament surrounded by peripheral muscle fibers. Diaphragm is divided into left and right hemi-diaphragms, each with different vascular and nerve supplies.[1-5] It is innervated by two phrenic nerves originating from cervical nerve roots C3 to C5. It is a physical barrier that separates the thoracic cavity from the abdominal cavity and functions primarily involuntarily with additional voluntary control when needed. It, therefore, is considered as principal muscle of ventilation. During inspiration, it contracts along with the accessory respiratory muscles resulting in expanding thoracic cavity, decreasing intrathoracic pressure and drawing air into the lungs. With relaxation of diaphragm, predominates elastic recoiling of lungs, causes exhalation. In addition, the diaphragm also assists in emesis, urination, and defecation by increasing intra-abdominal pressure and helps prevent gastroesophageal reflux by exerting external pressure at the esophageal hiatus.[6,7]

In young children, especially in neonates, the accessory respiratory muscles are often inadequate to compensate for a failing diaphragm. This leads to respiratory muscle fatigue with poor lung expansion and variable degree of potential atelectasis and ultimately result in respiratory failure. However, in adults and older children, the accessory respiratory muscles can often compensate for the paretic or paralyzed diaphragm.[8,9] Cardiac surgery done for underlying congenital heart diseases is the most common cause of abnormal diaphragmatic motion with a prevalence ranging from 0.3 to 12.8%.[10]

Based on symptoms like unexplained dyspnea, limitation to exercise and pain in shoulder, the primary utilized diagnostic tools include physical examination, laboratory investigation, and imaging modalities. Physical examination include diaphragm excursion, which involves percussion along the posterior chest to determine the displacement range of diaphragm during deep inspiration and deep expiration. Normal diaphragmatic excursion is 5–6 cm. Diminished diaphragmatic excursion is often associated with weakness of diaphragm or its paralysis.[7,11] Laboratory investigations of arterial/venous blood gases (BG's) measure dissolved gases in and other properties of blood (pH, pCO_2, pO_2, base excess, O_2 saturation, etc.) and are most often performed on patients in critical care settings. BG's are an indication of ventilation, gas exchange and acid-base status of blood, where blood is collected either from an arterial or venous blood supply.[12-16]

Chest radiographic X-ray provides an image, which allows physicians to perceive structure and morphology of diaphragm. It clearly demonstrates the elevation of diaphragm. In normal individuals, the left hemi-diaphragm is usually located one intercostal space lower than the right hemi-diaphragm. Slight elevation of right hemi-diaphragm is associated with the presence of liver under it. If a hemi-diaphragm is weak, then the normal negative intra-pleural pressure pulls the diaphragm cranially into the thoracic cavity. Consequently, the paralyzed diaphragm appears at a higher level. If the right side is paralyzed, the distance between the right and left diaphragm will be more than two intercostal spaces, and if the left side is paralyzed, both the hemi-diaphragms will appear on the same level [Figure 1].[17] In bilateral weakness, both hemi-diaphragms will appear at a higher level and might be missed on routine chest radiographs.[5]

Diaphragm ultrasonography is a non-invasive, portable mode of imaging that eliminates the exposure to radiation and risk of transportation. It is widely used particularly in intensive care unit (ICU) where intense patient cooperation is not essential. Two ultrasound methods are characteristically used to assess diaphragmatic functions. First, the analysis of the dome excursion with M-mode approach which is well-tolerated test with a linear relationship between diaphragmatic movement and inspired volume and allows quantitative and qualitative assessment of diaphragmatic movement [Figure 2]. Second is the evaluation of diaphragmatic thickness and thickening during inspiration by analyzing the apposition zone.[1,18]

The aim of this paper was to retrospectively study and to evaluate the accuracy of departmental ultrasound in assessment of diaphragm motion and to compare its results with other institutional parameter, namely, physical examination, laboratory investigation, and chest radiograph findings. Although, other institution parameters provide sufficient information to diagnose impaired diaphragm motion, ultrasonography is considered relatively sensitive tool. The final objective of this study was to support the diagnostic superiority and reliable of ultrasonography.

Materials and Methods

Study population

Study population included pediatric patients admitted to King Abdullah Specialized Children Hospital, a tertiary hospital for pediatric patients, Ministry of National Guard Health Affairs, Riyadh, Saudi Arabia. The study was bioethically approved by the local institutional review board of King Abdullah International Medical Research Center (approval # RC19/307/R). In this study, patients were retrospectively selected in two years and half long sampling period from January 1, 2017, to June 30, 2019. Pediatric patients under 14 years from both genders having respiratory symptoms (such as dyspnea, intolerance to exercise, sleep disturbances, hypersomnia, and with a potential impact on survival) associated with clinical suspicion of diaphragm dysfunction were considered for study as per institutional criteria (for pediatric age). Data of total 133 cardiac and non-cardiac pediatric patients were selected for the study. Demographic and baseline characteristics of the study population were collected. Pediatric patients having neuromuscular blockers, surgical plication and phrenic nerve pacing were excluded from the study. Neuromuscular blocker drugs block neuromuscular transmission at neuromuscular junction, causing paralysis of the affected muscle exhibiting false positive results. Diaphragmatic plication is traditionally performed by gathering weak and flaccid diaphragm muscle and central

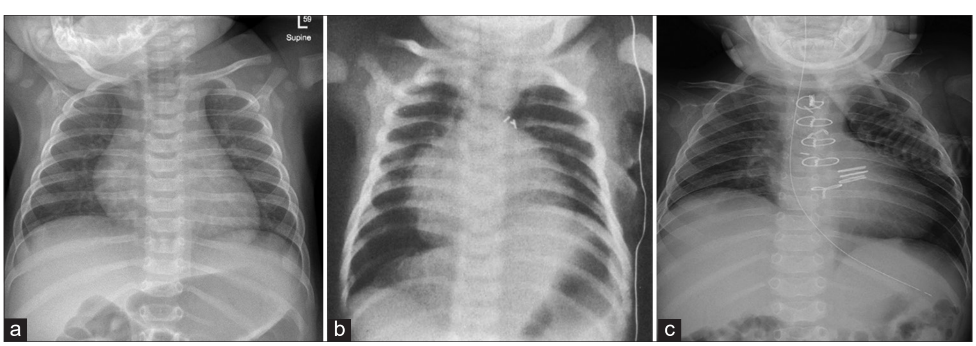

Figure 1: Chest radiograph showing: (a) Normal diaphragm appearance, (b and c) elevation of left and right hemi-diaphragm; respectively, following phrenic nerve paralysis in patients with post-cardiac surgery

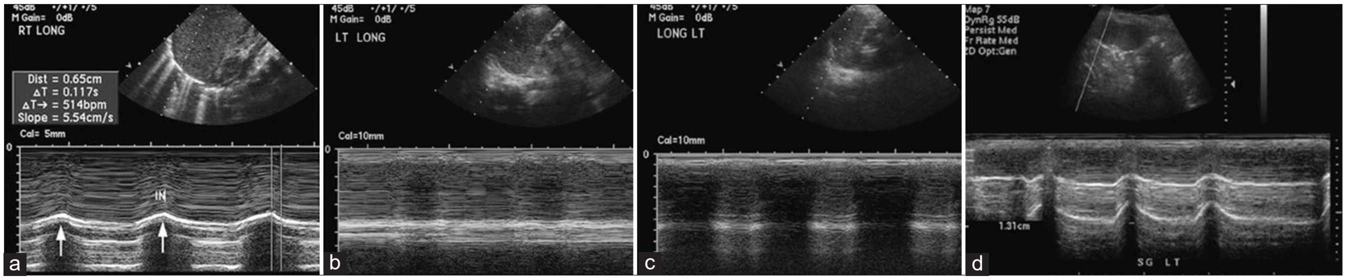

Figure 2: M-mode ultrasound showing initial and follow-up ultrasound in a 4-month-old infant having post-cardiac surgery with left diaphragmatic paralysis. (a) Normal right hemi-diaphragm with inspiratory peak above the baseline. (b) First ultrasound shows a flat line indicative of absent motion of the left hemi-diaphragm. (c) Follow-up ultrasound shows some movement of the left hemi-diaphragm during inspiration. (d) Complete recovery of left diaphragmatic paralysis is seen with return of normal inspiratory peak

tendon into pleats and sutured, lowering and tightening the hemi-diaphragm and increasing intrathoracic volume. In case of phrenic nerve pacing, the nerves are electrically stimulated using implanted electrodes to restore physiological functions of diaphragm. Diaphragmatic plication and phrenic nerve pacing often interfere in diaphragm movement assessment by exhibiting false negative results.[19-25]

As per organization structure, pediatric patients having respiratory symptoms associated with clinical suspicion of diaphragm dysfunction were diagnosed based on review of patient clinical history, physical examination with emphasis on the diaphragm excursion and laboratory investigation by arterial/venous BGs test. On suspicion of either unilateral or bilateral diaphragmatic dysfunction, the patients were subjected to imaging modalities including chest radiograph and diaphragmatic ultrasound. Results of diaphragm dysfunction diagnosis on both right and left hemi-diaphragms are presented.

Statistical analysis

Raw data were processed by following the best practices for raw data management to identify any inaccuracies or incompleteness in advance of the statistical analysis. To accomplish this task, all interval variables were checked and summarized in terms of maximum and minimum values. Minimum and maximum values were checked and compared against the nominal maximum and minimum value of each variable, and variables with implausible values were flagged. All variables were summarized and reported for the study using descriptive statistics. Interval variables were summarized and reported in terms of n, %, mean, and standard deviation. Categorical variables were summarized and reported in terms of frequency distribution. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and 95% confidence interval (CI) were calculated to assess the predictive accuracy. About 95% CI was calculated to assess the predictive accuracy of the diagnostic ultrasounds, chest radiograph, clinical suspicion, and laboratory investigation, relative to the clinical diagnosis results (with clinical diagnosis representing the gold standard measurement for the unknown true outcome status).

For all analyses, ultrasound reports, clinical suspicion, and chest radiograph reports were classified into two levels namely "Abnormal" and "Normal." The findings such as paralysis and paresis from ultrasound and clinical suspicion results were categorized as "Abnormal." However, the low and high findings from chest radiograph report were considered "Abnormal." All statistical analyses were done using SAS software version 9.4 or higher (SAS Institute, Cary, NC, USA).

Table 1: Demographic and baseline characteristics of patients investigated for diaphragmatic dysfunction (n=131). Data shown are frequencies; *n* (%) or mean±SD

Variables	*n* (%) or Mean±SD
Gender	
Female	58 (44.3)
Male	73 (55.7)
Age in years	1.6±2.6
Background	
Cardiac	97 (74.0)
Non-cardiac	34 (26.0)
pH (Normal range 7.35–7.45)	7.4±0.1
$PaCO_2$ (Normal range 35.0–45.0 mmHg)	48.0±12.2
PaO_2 (Normal range 75–100 mmHg)	58.5±29.9
Bicarbonate (HCO_3-; Normal range 22–26 mmol/L)	29.3±5.5
O_2 Sat. (Normal range 95–100%)	83.4±17.5
Lab. Result	
Acute metabolic acidosis	1 (0.8)
Acute metabolic alkalosis	13 (9.9)
Acute respiratory acidosis	3 (2.3)
Acute respiratory alkalosis	4 (3.1)
Compensated metabolic alkalosis	14 (10.7)
Compensated respiratory acidosis	41 (31.3)
Compensated respiratory alkalosis	1 (0.8)
Mixed disorders	9 (6.9)
Normal	26 (19.8)
Partly compensated metabolic alkalosis	6 (4.6)
Partly compensated respiratory acidosis	9 (6.9)
Partly compensated respiratory alkalosis	4 (3.1)

Results

From a total of 163 pediatric patients under the age of 14 years having clinical suspicion of diaphragmatic dysfunction, a total of 131 met clinical inclusion criteria for our study. The mean age was 1.6 (SD 2.6) years and there were 44.3% of male and 55.7% of female patients. A summary of demographic and baseline characteristics detailed in Table 1.

Table 2 summarizes the results of ultrasound, clinical suspicion, laboratory investigation and chest radiograph of right side hemi-diaphragm. There were 102 reports classified as normal by clinical diagnosis, out of which 45.1% of reports were correctly identified as normal by clinical suspicion, 9.8% were identified as paresis by clinical suspicion, and 45.1% were classified as paralysis. Out of 11 identified paralysis cases by clinical diagnosis, only one report (9.1%) was classified as paresis, whereas 10 (90.9%) reports were correctly classified as paralysis by clinical suspicion. Out of 18 clinically diagnosed paresis cases, 15 (83.3%) were identified as paralysis by clinical suspicion, whereas 3 (16.7%) reports were correctly identified as paresis. The results identified by clinical suspicion and clinical diagnosis were significantly different ($P < 0.0001$). Similar trend was seen for ultrasound and clinical diagnosis reports. The chest radiograph and laboratory investigation reports were not significantly different with clinical diagnosis reports.

Table 3 summarizes results of ultrasound, clinical suspicion, laboratory investigation, and chest radiograph of the left side hemi-diaphragm. Out of 90 clinically diagnosed normal reports, 35 (38.9%) reports were correctly classified as normal by clinical suspicion, 84 (93.3%) by ultrasound, and only 26 (28.9%) by X-ray. 45 (50.0%) reports were identified as paralysis by clinical suspicion and X-ray, and only one (1.1%) by ultrasound. The results obtained by clinical suspicion and ultrasounds were significantly different from clinical diagnosis. The chest radiograph and laboratory investigation reports were not significantly different with clinical diagnosis.

Table 4 summarizes the classification results of ultrasound, clinical suspicion, and X-ray in predicting clinical diagnosis on the right hemi-diaphragm. The ultrasound yielded 96.6% sensitivity and 90.3% PPVs, 99% NPV, and 97.1% specificity. The ultrasound results produced perfect classification for discriminating between clinical diagnosis results with accuracy of 96.95% and precision of 90.32%. The sensitivity and PPV for clinical suspicion were 100% and 34.1%, whereas, only 27.6% of sensitivity and 29.6% of PPV achieved by chest radiograph. The specificity and NPV were 45.1% and 100% for clinical suspicion, 81.4% and 79.8% for chest radiograph, respectively. The clinical suspicion and chest radiograph results produced poor classification for discriminating between clinical diagnosis results with accuracy of 57.25% and 69.47% and precision of 34.12% and 29.63%, respectively.

Table 2: Results of comparing right hemi-diaphragm dysfunction diagnosis by clinical suspicion, laboratory investigation, ultrasound, and X-ray. Data shown are frequencies; *n* (%) and Fisher's exact test calculated *P*-values

Parameters	Category	Clinical diagnosis				*P*-value
		Normal *n*=102	Paralysis *n*=11	Paresis *n*=18	Overall *n*=131	
Clinical Suspicion	Normal	46 (45.1)	-	-	46 (35.1)	<0.0001
	Paralysis	46 (45.1)	10 (90.9)	15 (83.3)	71 (54.2)	
	Paresis	10 (9.8)	1 (9.1)	3 (16.7)	14 (10.7)	
Lab. Result	Normal	18 (17.6)	4 (36.4)	4 (22.2)	26 (19.8)	0.505
	Acute respiratory acidosis	2 (2.0)	1 (9.1)	-	3 (2.3)	
	Acute respiratory alkalosis	4 (3.9)	-	-	4 (3.1)	
	Acute metabolic acidosis	-	1 (9.1)	-	1 (0.8)	
	Acute metabolic alkalosis	10 (9.8)	1 (9.1)	2 (11.1)	13 (9.9)	
	Partly compensated respiratory acidosis	6 (5.9)	1 (9.1)	2 (11.1)	9 (6.9)	
	Partly compensated respiratory alkalosis	4 (3.9)	-	-	4 (3.1)	
	Partly compensated metabolic alkalosis	4 (3.9)	-	2 (11.1)	6 (4.6)	
	Compensated respiratory acidosis	33 (32.4)	2 (18.2)	6 (33.3)	41 (31.3)	
	Compensated respiratory alkalosis	1 (1.0)	-	-	1 (0.8)	
	Compensated metabolic alkalosis	13 (12.7)	1 (9.1)	-	14 (10.7)	
	Mixed disorders	7 (6.9)	-	2 (11.1)	9 (6.9)	
Ultrasound	Normal	99 (97.1)	-	1 (5.6)	100 (76.3)	<0.0001
	Paralysis	1 (1.0)	8 (72.7)	-	9 (6.9)	
	Paresis	2 (2.0)	3 (27.3)	17 (94.4)	22 (16.8)	
X-Ray	Normal	83 (81.4)	7 (63.6)	14 (77.8)	104 (79.4)	0.359
	Paralysis	14 (13.7)	4 (36.4)	3 (16.7)	21 (16.0)	
	Paresis	5 (4.9)	-	1 (5.6)	6 (4.6)	

Table 3: Results of comparing left hemi-diaphragm dysfunction diagnosis by clinical suspicion, laboratory investigation, ultrasound, and X-ray. Data shown are frequencies; *n* (%) and Fisher's exact test calculated *P*-values

Parameters	Category	Clinical Diagnosis				*P*-value
		Normal *n*=90	Paralysis *n*=14	Paresis *n*=27	Overall *n*=131	
Clinical Suspicion	Normal	35 (38.9)	1 (7.1)	1 (3.7)	37 (28.2)	<0.0001
	Paralysis	45 (50.0)	12 (85.7)	17 (63.0)	74 (56.5)	
	Paresis	10 (11.1)	1 (7.1)	9 (33.3)	20 (15.3)	
Lab. Result	Normal	21 (23.3)	-	5 (18.5)	26 (19.8)	0.517
	Acute respiratory acidosis	3 (3.3)	-	-	3 (2.3)	
	Acute respiratory alkalosis	3 (3.3)	1 (7.1)	-	4 (3.1)	
	Acute metabolic acidosis	1 (1.1)	-	-	1 (0.8)	
	Acute metabolic alkalosis	6 (6.7)	2 (14.3)	5 (18.5)	13 (9.9)	
	Partly compensated respiratory acidosis	5 (5.6)	2 (14.3)	2 (7.4)	9 (6.9)	
	Partly compensated respiratory alkalosis	4 (4.4)	-	-	4 (3.1)	
	Partly compensated metabolic alkalosis	6 (6.7)	-	-	6 (4.6)	
	Compensated respiratory acidosis	26 (28.9)	7 (50.0)	8 (29.6)	41 (31.3)	
	Compensated respiratory alkalosis	1 (1.1)	-	-	1 (0.8)	
	Compensated metabolic alkalosis	9 (10.0)	1 (7.1)	4 (14.8)	14 (10.7)	
	Mixed disorders	5 (5.6)	1 (7.1)	3 (11.1)	9 (6.9)	
Ultrasound Report	Normal	84 (93.3)	1 (7.1)	3 (11.1)	88 (67.2)	<0.0001
	Paralysis	1 (1.1)	12 (85.7)	-	13 (9.9)	
	Paresis	5 (5.6)	1 (7.1)	24 (88.9)	30 (22.9)	
X-Ray	Normal	26 (28.9)	3 (21.4)	8 (29.6)	37 (28.2)	0.278
	Paralysis	45 (50.0)	11 (78.6)	14 (51.9)	70 (53.4)	
	Paresis	19 (21.1)	-	5 (18.5)	24 (18.3)	

Table 4: Comparative results of the right hemi-diaphragm dysfunction diagnosis by clinical suspicion, ultrasound, and X-ray

Tests	TP	FP	FN	TN	Sen (95%CI)	Spec (95%CI)	PPV (95%CI)	NPV (95%CI)	Accu	Prec
Clinical suspicion Report versus Clinical Diagnosis	29	56	0	46	100.0 (99.91, 100)	45.1 (54.29, 98.55)	34.1 (43.98, 97.84)	100.0 (99.94, 100)	57.25	34.12
Ultrasound Report versus Clinical Diagnosis	28	3	1	99	96.6 (99.15, 99.91)	97.1 (98.92, 99.80)	90.3 (96.37, 99.31)	99.0 (99.76, 99.97)	96.95	90.32
X-ray Report versus Clinical Diagnosis	8	19	21	83	27.6 (43.54, 94.68)	81.4 (87.59, 99.31)	29.6 (46.28, 94.77)	79.8 (86.24, 99.29)	69.47	29.63

TP: True positive, FP: False positive, FN: False negative, TN: True negative, Sen: Sensitivity, Spec: Specificity, CI: Confidence interval, PPV: Positive predictive value, NPV: Negative predictive value, Accu: Accuracy, Prec: Precision

Table 5: Comparative results of the left hemi-diaphragm dysfunction diagnosis by clinical suspicion, ultrasound, and X-ray

Tests	TP	FP	FN	TN	Sen (95%CI)	Spec (95%CI)	PPV (95%CI)	NPV (95%CI)	Accu	Prec
Clinical suspicion Report versus Clinical Diagnosis	39	55	2	35	95.1 (98.46, 99.70)	38.9 (48.62, 98.16)	41.5 (51.05, 98.33)	94.6 (98.30, 99.67)	56.49	41.49
Ultrasound Report versus Clinical Diagnosis	37	6	4	84	90.2 (95.92, 99.30)	93.3 (96.82, 99.58)	86.0 (93.19, 99.07)	95.5 (98.13, 99.68)	92.37	86.05
X-ray report versus clinical diagnosis	30	64	11	26	73.2 (83.87, 98.49)	28.9 (38.22, 97.60)	31.9 (41.22, 97.87)	70.3 (81.99, 98.28)	42.75	31.91

TP: True positive, FP: False positive, FN: False negative, TN: True negative, Sen: Sensitivity, Spec: Specificity, CI: Confidence interval, PPV: positive predictive value, NPV: Negative predictive value, Accu: Accuracy, Prec: Precision

Table 5 depicts the classification results of ultrasound, clinical suspicion, and chest radiograph in predicting clinical diagnosis on the left hemi-diaphragm. The ultrasound showed 90.2% sensitivity and 86.0% PPV, 95.5% NPV, and 93.3% specificity. Results showed little high variability in comparison to classification results obtained for the right hemi-diaphragm. The ultrasound results produced good classification for discriminating between clinical diagnosis results with accuracy of 92.37% and precision of 86.05%. The sensitivity and PPV for clinical suspicion were 95.1% and 41.5%, whereas 73.2% of sensitivity and 31.9% of PPV were achieved by chest radiograph. The specificity and NPV were 38.9% and 94.6% for clinical suspicion, and only 28.9% and 70.3% for chest radiograph, respectively. The clinical suspicion and chest radiograph results produced poor classification for discriminating between clinical diagnosis results with accuracy of 56.49% and 42.75% and precision of 41.49% and 31.91%, respectively.

Figure 3 summarizes the accuracy results of clinical suspicion, ultrasound, and chest radiograph with clinical diagnosis performed on the left and right side hemi-diaphragm.

Discussion

The term, diaphragmatic dysfunction includes eventration, paresis and paralysis.[6] Eventration is a permanent elevation of entire or part of the hemi-diaphragm caused by thinning.[6,7,26,27] Diaphragmatic paresis would be the partial loss of muscle strength to generate necessary pressure for adequate ventilation.[26,28] While paralysis means the total absence of this capacity. Diaphragmatic paralysis can arise from either weakness of the muscle itself or damage to its nerve supply. Depending on the severity of the paralysis and whether it is unilateral or bilateral, patients can have varied clinical manifestations such as dyspnea, intolerance to exercise, sleep disturbances, hypersomnia, and with a potential impact on survival.[4,5] A patient may be asymptomatic, often diagnosed during investigation of unexplained dyspnea or, occasionally, after the casual finding of a diaphragmatic elevation in an imaging radiograph performed for another purpose for unrelated aliment, while another may be ventilator dependent.[5,29]

Diaphragmatic dysfunction is still a matter of concern after cardiothoracic surgery, especially among young children and neonates. The prevalence of diaphragmatic dysfunction after cardiothoracic surgery in children varies from 0.3 to 12.8%.[10] Timely diagnosis of abnormal diaphragmatic motion is essential for patient in immediate post-operative period to minimize potential risk and to ascertain appropriate therapeutic approach. The diagnosis of diaphragm dysfunction can be done by laboratory investigation, diaphragmatic ultrasonography and chest radiograph.

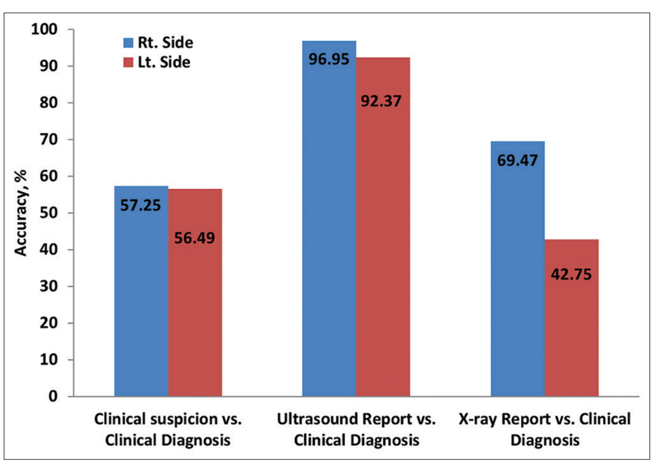

Figure 3: Summary of accuracy results of clinical suspicion, ultrasound, and chest radiograph with clinical diagnosis performed on the left and right side hemi-diaphragm.

Our retrospective study demonstrates the accuracy of ultrasonography as 96.95% on right side and 92.37% on the left side in diagnosing diaphragmatic dysfunction. Ultrasonography proved to be highly sensitive and specific diagnostic tool over chest radiograph and clinical suspicion approach. The second-best results were obtained by chest radiograph and prove to be more efficient in diagnosis of right hemi-diaphragm dysfunction. Slightly less accurate results were obtained by clinical suspicion as compared to chest radiograph.

Diaphragmatic ultrasound has some limitations. First, ultrasound systems have inherent resolution limits (usually 0.1 mm). In addition, the assessment of the left hemidiaphragm can be problematic. However, taking extra precautions during the diaphragmatic ultrasound examination (e.g., placing the patient in the supine position and rotating the transducer) can help overcome these limitations. Furthermore, because ultrasound is an operator-dependent examination, repeated training can improve accuracy. Moreover, although diaphragmatic ultrasound has been shown to have a steep learning curve when applied in healthy subjects, few studies have evaluated how to develop the appropriate skills. One study, involving a pediatric population, found that 4 h of hands-on diaphragmatic ultrasound training focused on the recognition of normal and abnormal diaphragmatic motion resulted in high concordance between the diaphragmatic ultrasound findings reported by a trainee and those reported by a pediatric intensivist.[30,31]

Conclusion

Diaphragmatic ultrasound appears to be a valid and reliable diagnostic tool for diagnosis of abnormal diaphragmatic motion. At present, the more emphasis should be given to use of ultrasonography due to its non-invasive and non-radiating characteristics, and convenient portability that eliminates risk of transportation. Thus, ultrasound assessment should be part of the diagnostic checklist, particularly in ICU where patient's cooperation is not essential. Diaphragm ultrasound may act as an imaging tool guiding rehabilitation success in diaphragmatic dysfunction cases.

Authors Declaration Statements

Ethical approval and patients consent

All procedures performed in the studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Availability of data and materials

The data used in this study are available and will be provided by the corresponding author on a reasonable request.

Competing interests

The author declared no conflict of interests.

Funding statement

This study is self-funded.

Author contribution

A.S.J. designed the study, prepared the manuscript, the statistical analysis, and the interpretation of results.

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