INTRODUCTION

Pneumonia is the single largest infectious cause of death in children worldwide. Pneumonia killed 920 136 children under the age of 5 in 2015, accounting for 16% of all deaths of children under five years old ***(WHO, 2016).***

Diagnosis of community acquired pneumonia (CAP) is done clinically but with poor diagnostic specificity ***(Harris et al., 2011; Shah et al., 2010).***

Chest X-ray (CXR) is considered as the first imaging step for further evaluation. Even though plain radiographs have small amounts of radiation dose exposure about 0.01-1.5 mSv, children are more susceptible to nondeterministic stochastic effects of radiation than adults ***(Park and Jung, 2016; Gargani and Picano, 2015).***

In addition, the interpretation of CXR findings is dependent on the quality of the film and the expertise of the reader ***(Williams et al., 2013; Wingerter et al., 2012).***

The use of ultrasound for the evaluation of the lung is relatively recent. Lung ultrasound (LUS) is inexpensive, portable and non-ionizing imaging tool. It is relative easy to teach ***(Solomon and Saldana, 2014).*** The various studies had shown that LUS performs well in adults ***(Chavez et al., 2014; Ye et al., 2015).***

Lung ultrasound (LUS) is being increasingly studied in children and neonates in various thoracic conditions ***(Chen et al., 2015; Cattarossi, 2013).***

In light of increasing awareness of radiation exposure risks in children, we designed a study to define the LUS characteristics of pneumonia in children at presentation and to compare these LUS findings with the CXR findings to determine if LUS could serve as a useful alternative to CXR.

Aim of the Work

The aim of this study is to evaluate the ultrasound efficiency in the assessment of pneumonia in paediatric age group as compared to chest x-ray.

Chapter 1

NORMAL SONOGRAPHIC ANATOMY OF THE CHEST

In the typical appearance of a normal chest on US, the chest wall is visualized as multiple layers of echogenicity representing muscles and fascia. Reverberation artifacts beneath the pleural lines imply an underlying air-filled lung (Fig.1) ***(Bolliger et al., 2009).***

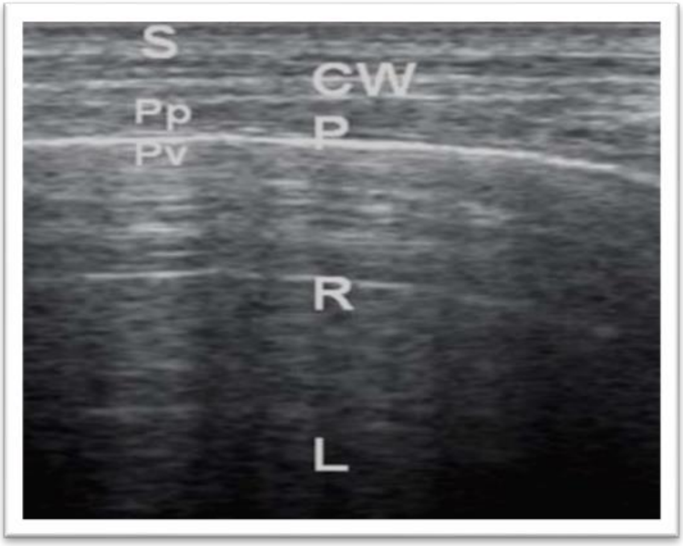

Figure (1): The typical appearance of a normal chest on US by transverse image through the intercostal space with high frequency probe.: S_Skin; CW_chest wall; P_pleura; Pp_parietal pleura; Pv_visceral pleura; L_lung; R_reverberation artifact ***(Bolliger et al., 2009).***

The pleura situated posterior (below) to the ribs appear as white curved lines with a dark shadow behind. This is known as the “Bat sign” (Fig.2). In a longitudinal view the bat sign identifies the upper and lower ribs (the wings of the bat) and, a little deeper, the pleural line (the back of the bat) ***(Prithviraj and Suresh, 2014).***

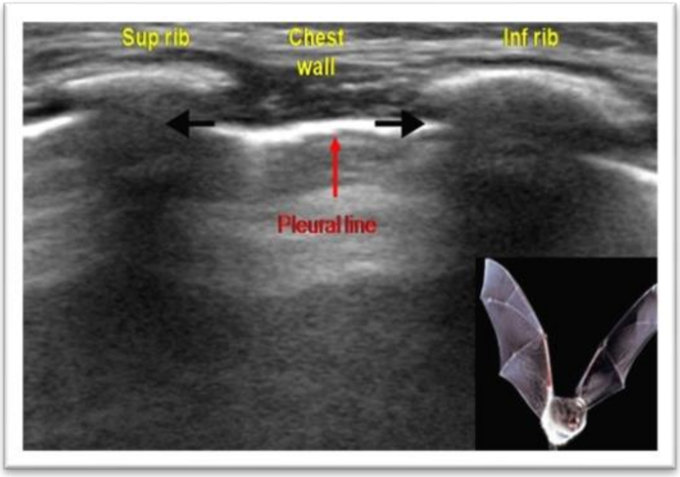

Figure (2): Bat sign ***(Prithviraj and Suresh, 2014).***

The normal ribs appear as hyperechoic surfaces with prominent acoustic shadows beneath the ribs. Approximal 0.5 cm below the ribs shadows, the visceral and parietal pleura appear as an enchogenic bright line named pleural lines (Fig.3) ***(Piette et al., 2013).*** During respiratory movement, the two pleural lines glide with each other and is referred to as the "Gliding sign". Loss of this sign can be seen in pneumothorax or diffuse pleural thickening ***(Liao et al., 2013).***

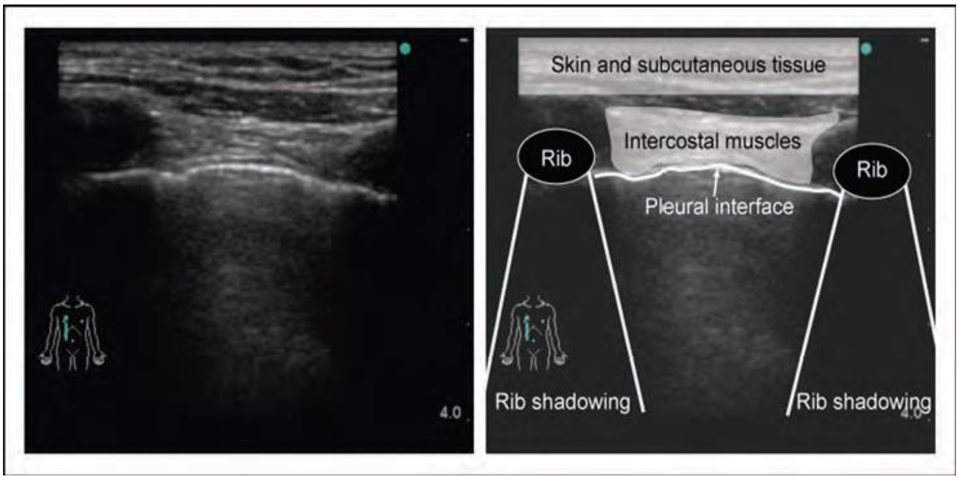

Figure (3): Typical lung ultrasound image showing normal ribs ***(Piette et al., 2013).***

Diaphragm

The diaphragm is best examined through the lower intercostal spaces and is seen as an echogenic line, 1 mm thick, above the liver and spleen. Normal downward movement of the diaphragm should be seen on inspiration ***(Koh et al., 2002)***. As a general rule, when the patient is sitting, the diaphragm is located caudad to the 9th rib ***(Mayo and Doelken, 2006)***.

Table (1): Normal findings in chest sonography ***(Prithviraj & Suresh, 2014)***

Pleural line.
Bat wing sign.
Sliding lung.
A-lines.
Lung pulse.
B lines/Comet tails.

Sonographic Artifacts

1. A line Artifact (Fig. 4)

The A line artifact is the single or multiple horizontal reflections of the pleural interface. They are present in a normal lung as well as in the presence of a pneumothorax when the lung sliding is abolished ***(Piette et al., 2013).***

They result from the intense reflection between the surfaces of contact of soft tissue and air-filled lung. Therefore, their depth is a multiplicative of the distance between skin and pleural line ***(Stefanidis et al., 2011).***

In contrast to the comet-tail artifact, A-lines do not slide back and forth with respirations. These lines are best visualized with a lower-frequency probe (3–5 MHz) ***(Lichtenstein, 2014).***

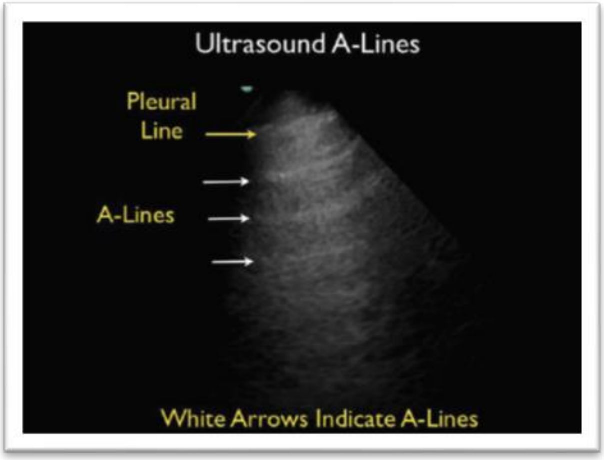

Figure (4): A-lines in normal chest US ***(Piette et al., 2013).***

2. B-line (comet tail) Artifact (fig. 5)

Comet-tails or "B-lines" are defined as hyperechoic reflections which originate only from and travel roughly perpendicular to the pleural line of the lung. They have a narrow base and form a ray spreading away from the transducer towards the bottom of the screen and synchronously move with lung respiration ***(Volpicelli and Gargani, 2013).***

B-lines are caused by the reflections of the ultrasound beam between the alveolar air and the fluid of the interlobular septa ***(Turner and Dankoff, 2012).***

It occurs when sound waves pass through the superficial soft tissues and cross the pleural line encountering a mixture of air and water (as in pulmonary edema, pneumonia, lung contusion, acute respiratory distress syndrome, etc.) giving rise to discrete laser-like vertical hyperechoic reverberation artifacts ***(Prithviraj and Suresh, 2014).***

The number of B lines depends on the degree of lung aeration loss, and their intensity increases with inspiratory movements. When several B lines are visible the term "Lung rocket`s" is used ***(Stefanidis et al., 2011).***

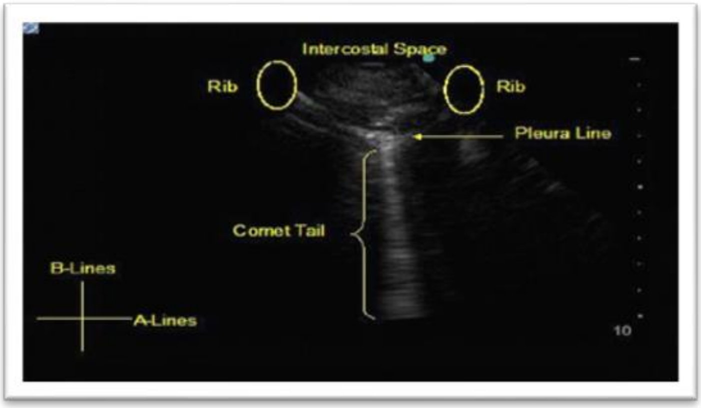

Figure (5): Comet-tail artifact ***(Piette et al., 2013).***

3. The V- lines (Fig. 6)

The V-line sign is a result of the fluid acting as an acoustic window to enable visualization of vertebral bodies and posterior thoracic wall, thus confirming the presence of pleural fluid. When scanning a patient in a supine position using a low frequency sector probe in the coronal/longitudinal plane, laterally on the torso at the level of the diaphragm, typical sonographic pattern of the vertebral bodies caudal to the diaphragm is seen. This series of intermittent echogenic foci with acoustic shadows is visible because sound waves are transmitted to the vertebral bodies by the acoustic windows of the liver (or spleen) and kidney. Above the diaphragm, the vertebral line ends abruptly as aerated lung does not permit transmission of sound waves to the posterior thoracic structures including the vertebral bodies and proximal posterior ribs. Instead, a black acoustic shadow or 'lung curtain' is seen, where no posterior structures can be visualized unless there is fluid providing acoustic window ***(Atkinson et al., 2012).***

This line is seen in supine patients above the diaphragm in the presence of pleural fluid. The posterior thoracic cage (vertebral bodies and posterior ribs) is seen as an echogenic line extending cephalad to the diaphragm due to transmission of ultrasound waves through fluid to the posterior thoracic cavity. This V-line sign can help to differentiate between fluid and air as the cause of the dark echo-poor area seen above the diaphragm with normal lung and with pleural effusions ***(Atkinson et al., 2012).***

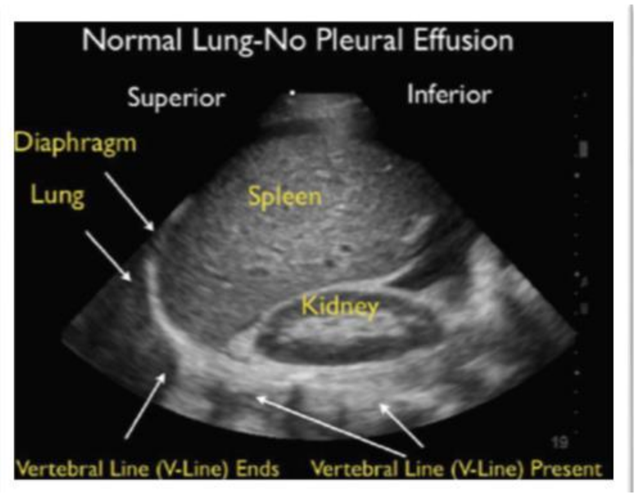

Figure (6): V-Lines: Normal US of the thoracic cavity. Vertebral line is noted to end above the diaphragm, caused by the presence of intervening lung and lack of fluid ***(Lobo et al., 2014).***

4. Lung curtain (Fig. 7)

This term refers to the edge of normal lung artifact visible at the costophrenic angles. On inspiration, the descent of lung artifact transiently obscures deeper structures, such as liver, spleen and kidneys, reminiscent of a theatre curtain drawn shut to hide the stage behind it. As such, liver and diaphragm are seen covered by lung during inspiration. Lung curtain may be higher than expected with hemidiaphragm elevation, lower in patients with hyperinflation, paradoxical in hemidiaphragm paralysis, and altered or even absent in pleural effusion ***(Hew & Heinze, 2012).***

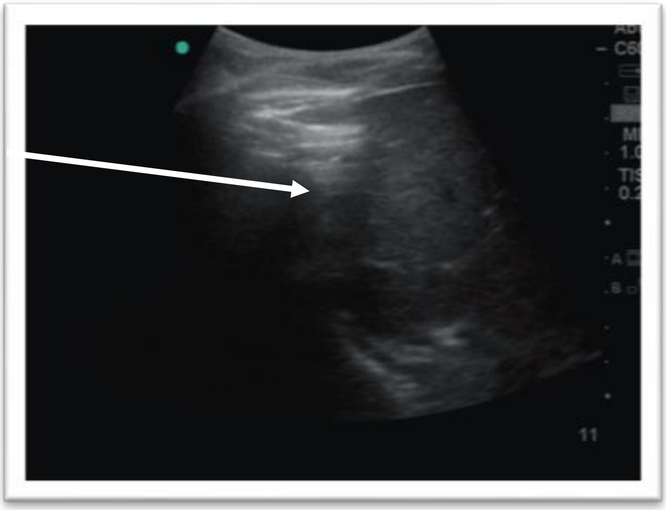

Figure (7): Lung curtain. The arrow indicates the caudal descent of the ‘lung curtain’ during inspiration about to obscure the ultrasound view of the liver ***(Hew & Heinze, 2012).***

5. Seashore Sign (Fig. 8 & 9)

Seashore sign is a dynamic sign of normal lung. It is described as a complex picture of parallel lines representing the static thoracic wall and sandy 'granulous' pattern below the pleural line. It's created by the movement of the two layers of the pleura, which represents the normal pulmonary parenchyma ***(Stefanidis et al., 2011).***

The sign is seen in time-motion mode, and characterized by motionless parietal tissue over the pleural line and a homogeneous granular pattern below it ***(Belaid et al., 2007).***

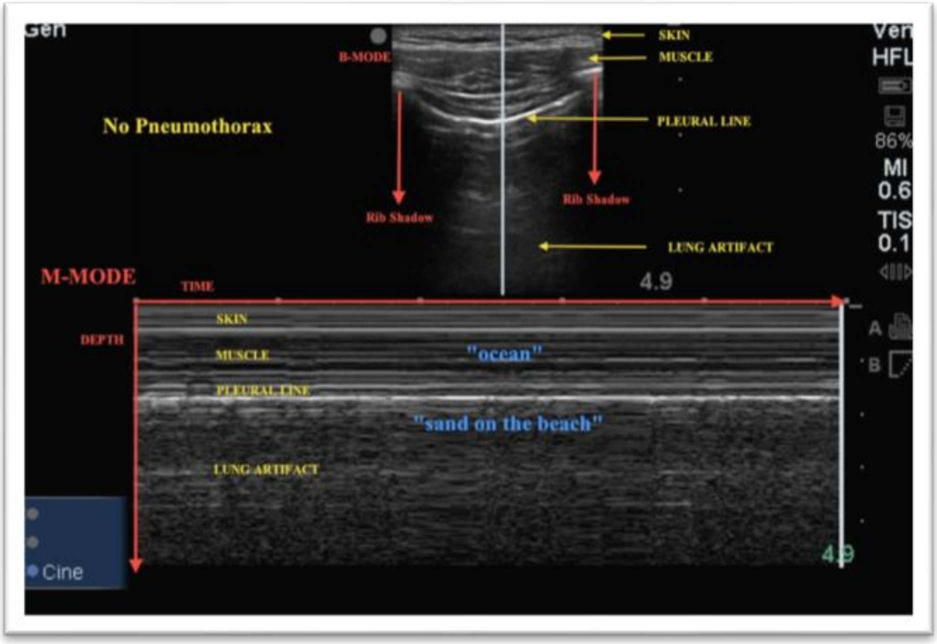

Figure (8): Seashore sign B & M-mode ***(Stefanidis et al., 2011).***

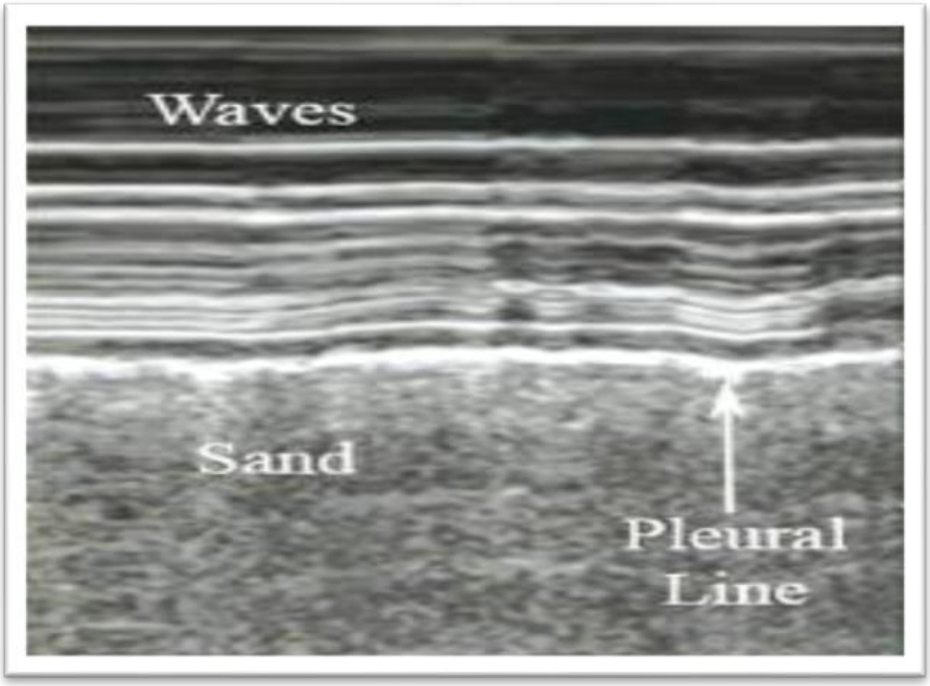

Figure (9): Seashore sign ***(Stefanidis et al., 2011).***

Table (2): Line patterns seen in lung ultrasound and their corresponding clinical significance ***(Atkinson et al., 2012)***

Line Pattern	Clinical significance
A lines	A lines are ultrasound artifacts that are not related to any Pathology These lines are horizontal in the ultrasound field and regularly spaced. They represent the ultrasound waves reflecting off of the pleural lining rather than returning directly back to the probe. This finding can be seen in normal lungs
B lines	B lines are pathologic findings related to alveolar interstitial syndrome. These lines are vertical and narrow, which project from the pleural lining to the edge of the ultrasound field. They are hyper-echogenic, distinct, and resemble either rays of sun shining through clouds or ‘comet tails’. When there are multiple B lines in the image, they are described as ‘lung rockets’
Z lines	These can be seen in healthy patients as well as in those with pneumothorax. They resemble B lines but are shorter, broader, and not as clearly defined. They do not project to the edge of the ultrasound window but still arise from the pleural line.
E lines	Seen in subcutaneous emphysema or in the presence of echogenic foreign bodies. These can be best described as comet tail artifacts that are superficial to the pleural lining.
V line	Seen in supine patients in the presence of pleural fluid. The posterior thoracic cage (vertebral bodies and posterior ribs) is seen as an echogenic line extending cephalad to the diaphragm due to transmission of ultrasound waves through fluid to the posterior thoracic cavity.

Doppler

The wide application of recent advances in chest ultrasound has enabled color Doppler ultrasound (CDUS) to be used in evaluating thoracic lesions. Clinically, CDUS is helpful in assessing vessel signals within the thoracic lesions, differentiating lung cancers from benign lesions, assessing the neovascularity of lung cancers, diagnosing congenital vascular abnormalities (pulmonary sequestration and arteriovenous malformation), and avoiding the complication of US-guided needle biopsy injury to the great vessels ***(Hsu, 2007).***

The CDUS “fluid color sign” can be used to detect minimal pleural effusion in thoracocentesis, and the CDUS “pulmonary artery vessel signal” is useful in predicting pulmonary benign lesions. Though CDUS still has some limitations in its capability to image vessel signals, the development of power Doppler US (US angiography) has improved images of vessel signals without angle limitation, and the newly developed dynamic flow US produces superior imaging quality with less color noise and blooming effect ***(Hsu, 2007).***

Color flow Doppler needs to be used cautiously as it produces artifacts with respiratory movement and experience is needed to interpret it ***(Islam and Tonn, 2009).***

Specific Anatomy in Children

In children, the thymus is larger compared with the rest of the thorax during the first year of life. Fortunately, the thymus has a characteristic echotexture, with regular linear and punctate echogenicities that allows its confident recognition and differentiation from mediastinal pathology (fig.10). The normal pleural space contains a tiny amount of fluid, but fluid