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Original Article

Diaphragmatic paralysis: the use of M mode ultrasound for diagnosis in adults

T Lloyd*[,1], Y-M Tang[1], MD Benson[1] and S King[1]

[1]*Department of Radiology, Princess Alexandra Hospital, Wooloongabba, Brisbane, Queensland, Australia*

Study Design: Retrospective, case series.
Objectives: To evaluate the use of M mode ultrasonography in the evaluation of diaphragmatic paralysis in adults.
Setting: Radiology department, Princess Alexandra Hospital, Brisbane, Australia.
Methods: Ten patients who were referred for evaluation of suspected diaphragmatic paralysis were evaluated using M mode ultrasound.
Results: Three of the patients who were scanned demonstrated normal diaphragmatic movement. The M mode trace demonstrated normal movement of the diaphragm bilaterally with quiet respiration and a sharp upstroke on the sniff test (indicating normal caudal movement of the diaphragm). Six patients were found to have a unilateral diaphragmatic paralysis. Four of these patients were noted to have a raised hemi-diaphragm on chest radiography. Of the two who did not have a raised hemi-diaphragm on chest radiography, one was permanently ventilated. The M mode trace of the paralyzed side showed no active caudal movement of the diaphragm with inspiration and abnormal paradoxical movement (ie cranial movement on inspiration) particularly with the sniff test.
Conclusion: M mode ultrasonography is a relatively simple and accurate test for diagnosing paralysis of the diaphragm, in the adult population. It can be performed, if necessary, at the bedside and can be easily repeated if paralysis is not thought to be permanent.
Equipment: Philips ATL Sono CT 5000 using a 2–5 MHz curved linear transducer.
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Keywords: ultrasonography; diaphragm; paralysis; adult

Introduction

Motion mode (M mode) ultrasonography, allows evaluation of movement and accurate measurements in moving structures. M mode ultrasonography is gaining favor in the medical literature for evaluation of the suspected paralyzed diaphragm in the pediatric population.[1–3] There does not however appear to be a similar consensus in the adult population as to how to evaluate the suspected paralyzed diaphragm. Methods used include plain radiography, fluoroscopy, B mode ultrasound and M mode ultrasound. Respiratory function tests and transthoracic pressure studies are also used.[4]

We report our experience with using M mode ultrasonography and propose that this is a fast, easy and accurate method of evaluating diaphragmatic movement that should be further studied in the adult population.

Materials and methods

Patients

From October 2002 to May 2005, 10 patients were referred for evaluation of suspected diaphragmatic paralysis, and examined using M mode ultrasound. Suspicion of diaphragmatic palsy was raised either by the mechanism of injury (eg high spinal cord injury), symptoms of dyspnea and orthopnea, or the presence of a raised hemi-diaphragm on chest radiography. The age at initial examination ranged from 16 to 61 years (average 30 years). Nine of the patients were male and one female.

*Correspondence: T Lloyd, Department of Radiology, Princess Alexandra Hospital, Ipswich Road, Wooloongabba, Brisbane, Queensland 4102, Australia

We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers/animals were followed during the course of this research.

We declare that the content of this manuscript is original and that it has not been published or accepted for publication, either in whole or in part, in any form. We declare that no part of the manuscript is currently under consideration for publication elsewhere.

Technique
Patients were imaged using a Philips ATL Sono CT 5000 using a 2–5 MHz curved linear transducer. Patients were scanned supine; in the case of ventilated patients it was necessary to briefly disconnect the ventilator to assess the patients' spontaneous respiratory efforts. The patients were asked to breathe comfortably and to sniff when requested. Patients were scanned intercostally in the anterior axillary line with the probe angled cranially so as to have the diaphragm as close as possible to 90 degrees to the probe. The liver was used as a window on the right while the spleen was used on the left. The M mode line of sight was angled to obtain the maximal diaphragmatic excursion. If unilateral paralysis was suspected the normal side was scanned first. M mode was performed in conjunction with conventional brightness-mode (B mode) grey-scale ultrasound.

The M mode charts movement against time along the M mode line giving a linear analogue of the motion of the object being studied, in this case the diaphragm. Normal inspiratory diaphragmatic movement is caudal, with the corresponding M mode trace being upwards as the diaphragm moves toward the probe, the expiratory trace is downwards as the diaphragm moves away from the probe (ie cranially). The inspiratory phase of respiration is noted by a preceding pause in the trace not present before the expiratory phase. The phase of respiration can also be noted and recorded by the sonographer. A normal sniff is demonstrated as a sharp upstroke on the screen, whereas a paralyzed diaphragm will either demonstrate absent movement or paradoxical (ie cranial) movement.

For the purposes of our study only the direction of diaphragm excursion was noted, we did not take measurements of the range of excursion.

Results

The results are summarized in Table 1.

Normal examination (Figures 1 and 2): Three patients scanned demonstrated normal diaphragmatic move-

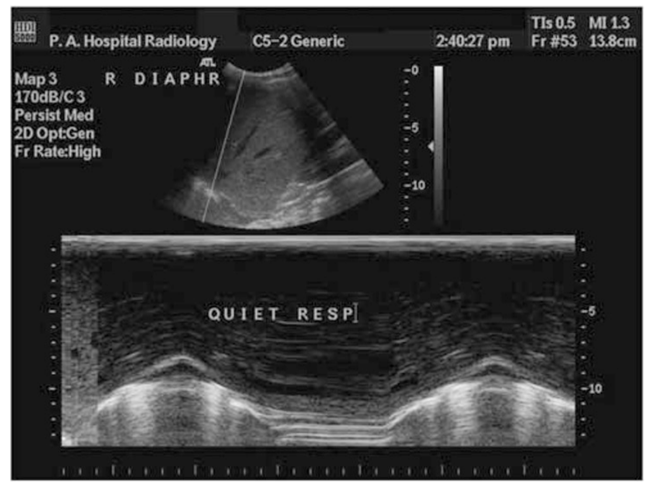

Figure 1 M mode ultrasound trace of normal diaphragm movement. Normal trace of diaphragmatic movement. In inspiration, movement is caudal, with the corresponding M mode trace being upwards as the diaphragm moves toward the probe. In expiration, the M mode trace is downwards as the diaphragm moves away from the probe

Table 1 Summary of details and findings on all subjects

Subject	*Sex*	*Age (years)*	*Reason for suspicion*	*Chest X-ray findings*	*Findings with M mode US*
1	M	26	C6 fracture tetraplegia	High L hemi-diaphragm on CXR	L diaphragmatic paralysis
2	M	61	Dyspnoea when swimming or standing in deep water	High R diaphragm on CXR	R diaphragmatic paralysis
3	M	16	C5 incomplete tetraplegia	No CXR abnormalities	No abnormality seen
4	M	31	C4 incomplete tetraplegia	No CXR abnormalities	No abnormality seen
5	F	23	Disseminated encephalomyelitis	No CXR abnormalities	R diaphragmatic paralysis
6	M	51	Mixed connective tissue disease, loss of lung volume, paradoxical respiratory movements	Both diaphragms raised on CXR	Normal diaphragmatic movement bilaterally
7	M	29	Attempted suicide by hanging, incomplete C3 tetraplegia	Raised R hemi-diaphragm on CXR	R diaphragmatic palsy
8	M	18	Complete C2 tetraplegia, pushbike accident	No CXR abnormalities (ventilated)	L diaphragmatic palsy. Second scan done due to increasing time off ventilator no improvement
9	M	28	Complete C2 tetraplegia, ventilator dependant	No CXR abnormalities (ventilated)	Bilateral palsy with paradoxical movement
10	M	17	Multi trauma, R brachial plexus injury	Raised R diaphragm on CXR	R diaphragmatic palsy with paradoxical movement

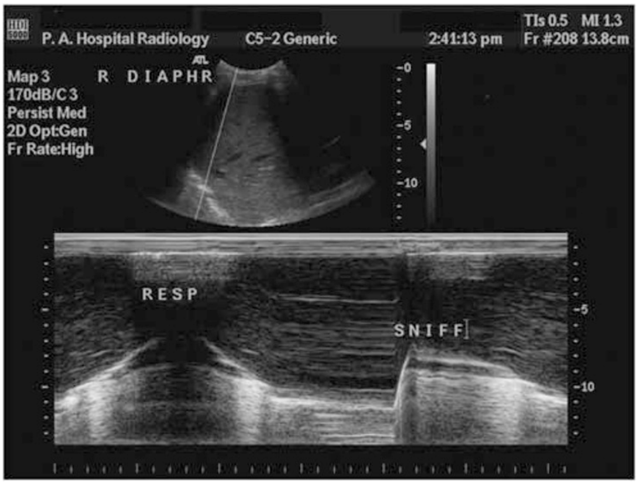

Figure 2 M mode ultrasound trace of normal diaphragm movement. In a normal diaphragm a sharp upstroke is demonstrated when the patient sniffs

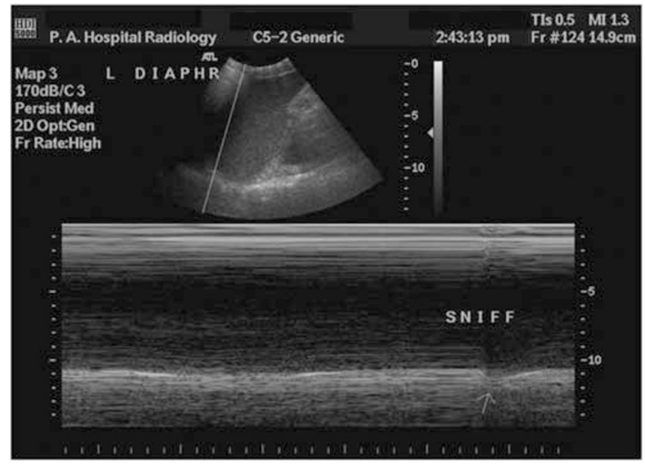

Figure 4 M mode ultrasound trace of paralyzed diaphragm. In a paralysed diaphragm, there is paradoxical (ie cranial) or absent movement when the patient sniffs

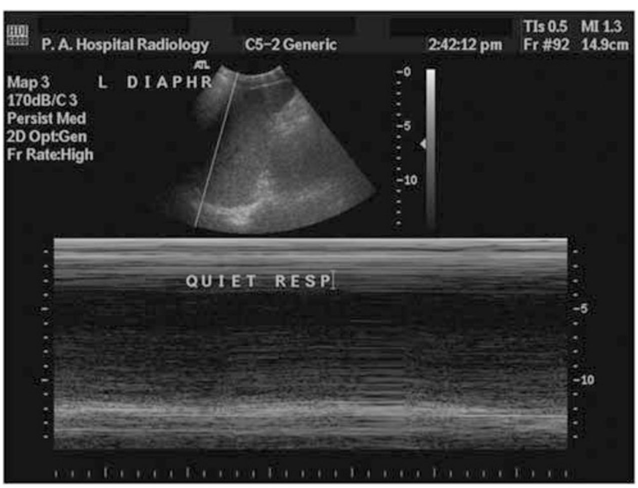

Figure 3 M mode ultrasound trace of paralyzed diaphragm. A paralysed diaphragm demonstrates absent movement with respiration

ment. The M mode trace demonstrated caudal movement of the diaphragm bilaterally (towards the top of the screen) and a sharp upstroke on the sniff test.

Diaphragmatic paralysis (Figures 3 and 4): Six patients were found to have evidence of a unilateral diaphragmatic paralysis. This was owing to high cervical spine injury ($n=3$), brachial plexus injury ($n=1$) disseminated encephalomyelitis ($n=1$) and idiopathic ($n=1$). Four of these patients were noted to have a raised hemi-diaphragm on CXR. Of the two who did not have a raised hemi-diaphragm on CXR, one was permanently ventilated.

M mode tracing of movement on the normal side demonstrated caudal movement with inspiration and a sharp upstroke on the sniff test. The M mode trace of the paralyzed side showed no active caudal movement of the diaphragm with inspiration and paradoxical movement (ie cranial movement on inspiration) particularly with the sniff test. No measurements of diaphragmatic excursion were taken.

One patient had evidence of bilateral diaphragmatic paralysis. This patient's M mode trace showed paradoxical movement bilaterally with inspiratory effort. His chest X-ray did not show raised diaphragms, though it should be noted that he was permanently ventilated.

The sensitivity of Chest X-ray was 66.6% for unilateral paralysis and 57% for paralysis in general.

Discussion

The diaphragm is the principal muscle of respiration. In concert with the other accessory muscles of respiration it enlarges the chest cavity on inspiration, allowing the lung to passively inflate owing to the negative intra-thoracic pressure. When the diaphragm relaxes, the intrathoracic pressure rises, and air is forced out of the chest. If one or both of the hemi-diaphragms is paralyzed, the negative pressure created at inspiration by the other muscles of respiration causes the diaphragm to passively move cranially, as opposed to its normal active caudal movement. Methods of evaluation of the suspected paralyzed diaphragm focus on either observing the direction of movement or measuring the pressure in the chest.

Fluoroscopy has traditionally been the modality of choice for imaging of the suspected paralyzed diaphragm (the default gold standard). Houston *et al*,[5] however, noted a number of limitations to this modality; it requires patient cooperation and the ability of the patient to maintain themselves upright, involves a significant radiation dose and is a subjective method, with results difficult to reproduce. Some of the techniques that a patient uses to compensate for the lack of diaphragm function (for example, forced expiration to the point that the elastic recoil of the lung and thoracic cavity causes lung expansion and passive diaphragm movement) can mistakenly simulate diaphragm function using fluoroscopy. It has also been noted by Young and Simon,[6] that fluoroscopy images the highest portion of the diaphragm (the anterior third) which is the least mobile part of the diaphragm.

B mode ultrasound has been studied both in comparison with fluoroscopy and by itself. Houston *et al*[5] found that quantitative measurements of diaphragm movement using ultrasound, when compared to fluoroscopy, were a superior method of diagnosis. This method, however, was also limited by the necessity of patient cooperation and the ability of the patient to take a deep breath. Gottesman and McCool[7] described using the thickness of the diaphragm and the degree of thickening during active respiration as an indirect measure of diaphragm functioning, using the rational that a skeletal muscle (such as the diaphragm) will thicken during contraction. This method relies on the paralyzed diaphragm becoming atrophic, which limits its use in the acute setting.

M mode ultrasound for evaluation of diaphragmatic movement abnormalities has previously been described, most notably in the pediatric population,[1–3] including a recent large series of 278 pediatric patients by Epelman *et al*.[2] Riccabona *et al*[3] compared conventional ultrasonography with M mode in 50 patients, and found that only M mode enabled adequate documentation for comparison with follow-up examinations, although assessment was only semi-quantitative.

Gerscovich *et al*[8] studied M mode ultrasonography for diaphragm movement abnormalities for adults and children. In addition to direction of travel of the diaphragm in the phases of respiration, they also gave a normal range of movement for diaphragm excursion. While this would seem to be of value, particularly in determining if a patient had reduced rather than absent diaphragm movement, the range of movement noted by the authors in their cohort of healthy volunteers seems too wide to be of practical value (eg 1.67–9.2 cm on deep inspiration). In addition, it was noted by the authors that the range of motion varies with sex and body weight, and by deduction it would seem that for the measure to be useful it would have to be calibrated to the size and sex of the patient, requiring a far larger cohort to be analyzed. This could be a subject for further research in the area.

As noted in the technique section above, we did not measure the range of diaphragm excursion in our patients, this would however be of particular value when reassessing the same patient for change in their status.

M mode ultrasonography has been reported as a useful technique that is not yet in general use worldwide, having received some attention in the adult population, but primarily being a modality used in the pediatric population. Our experience would suggest that M mode sonography is a valuable technique in the adult population that deserves further study. There are several advantages of M mode ultrasound over the other imaging technologies used to evaluate movement of the diaphragm including the use of non-ionizing radiation, the need for only active breathing (ie not ventilated) without requiring the patient to take deep breaths and while the ability to 'sniff' is helpful, it is not essential to the study. It is fast, taking approximately 5 min with an experienced operator, and can be done by the bedside on the ward or in intensive care. It also provides a documentation which can be compared to follow-up studies at a later date to assess progress (particularly if measurements of excursion are made), removing the subjectivity of the study.

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