

Bilateral Diaphragm Paralysis: A Challenging Diagnosis

Martha E Billings MD, Moira L Aitken MD, and Joshua O Benditt MD

Introduction

Bilateral diaphragm paralysis is a rare cause of unexplained respiratory failure. Although it is a known complication of cardiothoracic surgery, it is often under-recognized and diagnosis is frequently delayed.¹ It should be considered in patients with low lung volumes on imaging, progressive hypercapnia, and pronounced dyspnea in the supine position.² Pulmonary function tests reveal a restrictive process; the maximum inspiratory pressure (MIP) is reduced. It can be very challenging to definitively diagnose. Fluoroscopic sniff test, which is 90% sensitive for the diagnosis of unilateral diaphragm paralysis, can provide misleading results when bilateral diaphragm paralysis is present. Measurement of transdiaphragmatic pressure with gastric and esophageal balloon placement is the only reliable method to accurately diagnose this disorder.³ We report a case of recurrent hypercapnia, supine dyspnea, and respiratory failure for 2 months prior to diagnosis and treatment of bilateral diaphragm paralysis.

Case Summary

A 22-year-old woman with congenital aortic stenosis developed persistent dyspnea and inability to wean from mechanical ventilation after surgical repair of an ascending aortic aneurysm. She had undergone multiple repairs of her aortic stenosis, beginning in infancy with valvulotomy. She underwent aortic valve replacement at age 5. At age 20 she required the Konno procedure (aortic valve replacement and enlargement of the aortic annulus, ascending aorta, and left-ventricular outflow tract to treat

subaortic stenosis) with placement of a St Jude valve. The Konno procedure resulted in the development of a dilated ascending aortic aneurysm.

Prior to her aneurysm repair she had no dyspnea, chest pain, orthopnea, or exercise limitations, and could walk up 15 flights of stairs. She underwent a modified Bentall procedure, in which the aortic root and ascending aorta are replaced with a Dacron graft. The surgery was complicated by hemorrhage with associated hypotension prior to initiation of cardiopulmonary bypass. She had multiple postoperative complications, including stroke, seizures, and acute renal failure. She underwent tracheostomy 2 weeks after surgery because of persistent respiratory failure.

While on the surgical service she was unable to wean from the ventilator, despite multiple trials over 6 weeks. She reported dyspnea that worsened to the feeling of suffocation with lying flat. She complained that she was unable to sleep because of shortness of breath. She denied chest pain but noted difficulty with taking deep breaths and the feeling that her chest was tight. She had no lower-extremity swelling. She denied cough, difficulty swallowing or speaking, or aspiration. She reported difficulty with deep coughing and clearing secretions.

She had no other medical history. She was taking warfarin, epoetin alfa, aspirin, lansoprazole, labetalol, citalopram, and levetiracetam, as well as oxycodone and zolpidem as needed. She was married but had no children. She rarely drank alcohol and never smoked. She had no family history of congenital heart disease or lung disease.

Her examination was notable for tachypnea with rapid, shallow breathing. She was an obese young woman who appeared very anxious. Cardiac examination revealed tachycardia and mechanical valve sounds, but no murmurs or gallops. She had normal jugular venous pressure. On auscultation her upper lobes were bilaterally clear, but lung sounds were diminished one-third up posteriorly, with associated dullness to percussion. This did not change with inspiration. She had no lower-extremity edema.

Her bedside MIP was -16 cm H₂O. Her arterial blood gas values while receiving oxygen (4 L/min via nasal cannula) were pH 7.35, P_{CO₂} 63 mm Hg, P_{O₂} 121 mm Hg, and bicarbonate 34 mEq/L. She had a normal thyroid stimulating hormone level. Chest radiograph showed low lung

Martha E Billings MD, Moira L Aitken MD, and Joshua O Benditt MD are affiliated with the Division of Pulmonary and Critical Care Medicine, Department of Medicine, University of Washington, Seattle, Washington.

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Correspondence: Martha E Billings MD, Division of Pulmonary Critical Care, Box 359762, Harborview Medical Center, 325 9th Avenue, Seattle WA 98104. E-mail: mebillin@u.washington.edu.

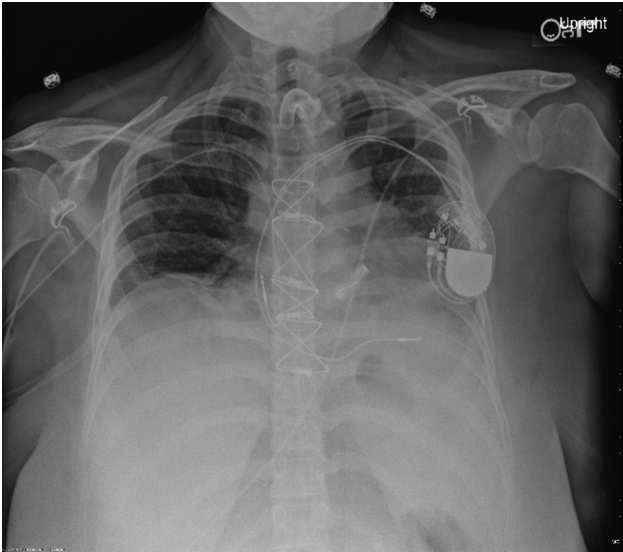


Fig. 1. Chest radiograph reveals low lung volumes and basilar atelectasis.

volumes and bibasilar opacification (Fig. 1). Her echocardiogram showed normal left-ventricular function and no substantial valvular insufficiency. Computed tomogram revealed bilateral linear atelectasis of the bases, but no pleural effusions. Diaphragm fluoroscopy via the sniff test was interpreted as normal by an experienced chest radiologist.

Two months into the hospital course, her providers requested a pulmonary consultation for evaluation of dyspnea and persistent mechanical ventilation requirement. Suspicion for bilateral diaphragm paralysis was high, given her history of new-onset orthopnea, low lung volumes, very low MIP, and absence of valvular or ventricular heart failure to explain her dyspnea. Esophageal and gastric balloon pressure measurements revealed a transdiaphragmatic pressure of zero with tidal breathing and the maximal inspiratory maneuver. The gastric pressure (P_{ga}), which should become more positive during inspiration, showed a negative deflection parallel to the esophageal pressure (P_{es}), which confirmed bilateral diaphragm paralysis (Fig. 2).

The patient was started on noninvasive ventilation (NIV) the following night, with immediate results; with NIV she was able to sleep and no longer had the sensation of severe dyspnea when flat. She was transferred from the intensive care unit the next day and was quickly transitioned to rehabilitation, where her tracheostomy was removed. Several months later she continued to have evidence of diaphragm dysfunction. In clinic, her MIP was -40 cm H_2O . Spirometry revealed an upright forced vital capacity of 1.27 L (38% of predicted), which decreased to 0.68 L (17% of predicted) when supine, which is a decrease of 46%, consistent with persistent bilateral diaphragm paralysis. Her end-tidal CO_2 was 38 mm Hg in clinic, which was down from 63 mm Hg on initial evaluation. The pa-

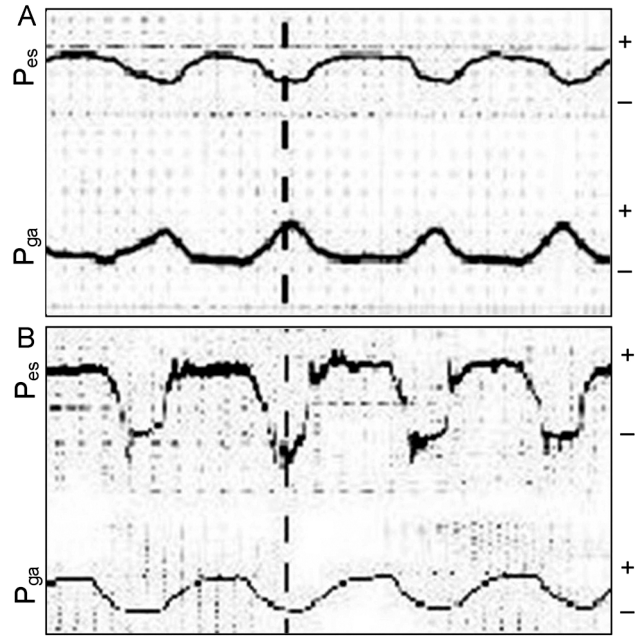


Fig. 2. A: Normal esophageal pressure (P_{es}) and gastric pressure (P_{ga}) measurements. The dashed line indicates inspiration. Note the deflection in opposite directions of P_{es} and P_{ga} during inspiration. B: P_{es} and P_{ga} measurements in a patient with diaphragm paralysis. The dashed line indicates inspiration. Note the deflection in the same direction of P_{es} and P_{ga} during inspiration. In this case the transdiaphragmatic pressure ($P_{ga} - P_{es}$) is zero because the pressure deflections are moving in the same direction.

tient is currently home, walking daily around her neighborhood, and using NIV when she sleeps.

Discussion

Bilateral diaphragm paralysis develops after injury to the phrenic nerve and certain other neuropathies and myopathies (Table 1). Most commonly the etiology is never found.² Phrenic-nerve paralysis can develop after blunt cervical trauma, neck manipulation, cardiothoracic surgery or radiation. Some idiopathic cases are due to neuralgic amyotrophy, associated with brachial plexus neuropathy (Parsonage-Turner syndrome) or possibly a post-viral neuropathy such as herpes zoster. Diaphragm paralysis may also result from myopathies, such as dermatomyositis, limb-girdle muscular dystrophy, mixed connective tissue disease, acid maltase deficiency, malnutrition, or amyloidosis. Neuropathic diseases such as poliomyelitis, multiple sclerosis, amyotrophic lateral sclerosis, and Guillain-Barré syndrome may also lead to diaphragm paralysis.⁴ In this patient the injury occurred during her thoracic surgery; the mechanism was probably phrenic-nerve injury due to sternal retraction or hypothermia injury with cardioplegia.⁵

Bilateral diaphragm paralysis has a unique presentation of dyspnea, orthopnea, and reduced MIP, but is challeng-

BILATERAL DIAPHRAGM PARALYSIS: A CHALLENGING DIAGNOSIS

Table 1. Causes of Diaphragmatic Paralysis

Neuropathies	
Central nervous system lesion	
Amyotrophic lateral sclerosis	
Multiple sclerosis	
Spinal cord transection	
Poliomyelitis	
Cervical spondylosis	
Peripheral nervous system lesion	
Parsonage-Turner brachial plexus neuropathy	
Guillain-Barré syndrome	
Idiopathic neuralgic amyotrophy	
Peripheral neuropathy secondary to diabetes	
Chronic inflammatory demyelinating polyneuropathy	
Phrenic nerve dysfunction	
Cardiac surgery hypothermia injury and stretching	
Blunt trauma	
Tumor, aneurysm, or goiter compression	
Post-viral phrenic neuropathy	
Idiopathic phrenic neuropathy	
Cervical chiropractic manipulation	
Myopathies	
Limb-girdle muscular dystrophy	
Acid maltase deficiency	
Hypothyroidism or hyperthyroidism	
Dermatomyositis	
Systemic lupus erythematosus	
Mixed connective-tissue disease	
Malnutrition	
Vitamin B6 and B12 deficiency	
Amyloidosis	
Idiopathic myopathy	

ing to diagnose. Patients typically note symptoms of intense dyspnea when recumbent. Pulmonary function tests reveal a restrictive pattern, with a reduced vital capacity of approximately 55% of predicted and residual volume of 45% of predicted (Table 2).⁶ Characteristically, patients have a supine decrease in forced vital capacity of up to 40%, caused by displacement of the abdominal contents because gravity shifts the diaphragm cephalad.⁴ A unique symptom is dyspnea with immersion in water. Chest compliance is decreased and the elastic work of breathing increases with increased hydrostatic pressure on the chest and abdomen. With immersion there is a mean vital capacity decrease of 34% in patients with bilateral diaphragm paralysis, compared to less than 10% in normals.⁷ Patients also typically have an abnormal MIP, to greater than -60 cm H₂O, often near -20 cm H₂O. Patients also have profound sleep disturbances from worsening supine respiratory dysfunction, and loss of thoracic muscle tone during rapid-eye-movement sleep.⁶ This leads to nocturnal hypoxia, hypercapnia, and symptoms of daytime somnolence, morning headaches, and anxiety, all of which were seen in this patient.

Table 2. Pulmonary Function Test Abnormalities in Bilateral Diaphragm Paralysis

Forced expiratory volume in the first second (% predicted)	50
Vital capacity (% predicted)	45
Supine vital capacity (%)	Decrease ≥ 40
Total lung capacity (% predicted)	55
Residual volume (% predicted)	55
Functional residual capacity (% predicted)	60
Maximum inspiratory pressure (cm H ₂ O)	-10 to -20
Transdiaphragmatic pressure (cm H ₂ O)	40–10

(Adapted from Reference 6.)

Fluoroscopic sniff test, although sensitive and specific for unilateral diaphragm paralysis, is not sensitive for, and is frequently misinterpreted as bilateral diaphragm paralysis. The cephalad movement of the ribs as the accessory muscles contract can give the false appearance of caudad displacement of the diaphragm. Thus, as in this case, it may appear as if the diaphragm is moving with respiratory effort and produces a false negative result.

Transdiaphragmatic pressure measurements with balloon-tipped esophageal and stomach catheters is the accepted standard test for diagnosis of diaphragm paralysis. The catheters are placed transnasally into the stomach and esophagus (Fig. 3). A catheter in the stomach measures P_{ga} . Transducers in the lower third of the esophagus measure P_{es} , which reflects pleural pressure (transdiaphragmatic pressure = $P_{ga} - P_{es}$).³ During normal inspiration, P_{es} becomes more negative as pleural pressure drops, whereas P_{ga} rises as abdominal contents are compressed with the diaphragm descending. The pressure tracings should move in opposite directions (Fig. 2A). With complete diaphragm paralysis, the P_{es} and P_{ga} move in the same directions and transdiaphragmatic pressure is zero (Fig. 2B). Maneuvers such as sniff can increase the sensitivity of this test.

Electromyography of the diaphragm and phrenic-nerve-conduction-velocity testing are also diagnostic of diaphragm paralysis.¹ Electromyography and nerve-conduction studies are more useful in distinguishing the etiology of the paralysis (eg, myogenic vs neurogenic, demyelinating vs denervation).⁶ Electromyography and nerve-conduction studies are often used early for initial diagnosis, but these are more invasive than diaphragm pressure measurements and require a skilled operator.

Recovery can occur over months to years, depending on the cause of paralysis. Hypothermia injury to the phrenic nerve is reversible, usually over several months.⁵ Idiopathic neuralgic amyotrophy or viral neuropathy may recover over years. Many cases of idiopathic phrenic-nerve paralysis never resolve.⁸ Neuromuscular causes of diaphragm

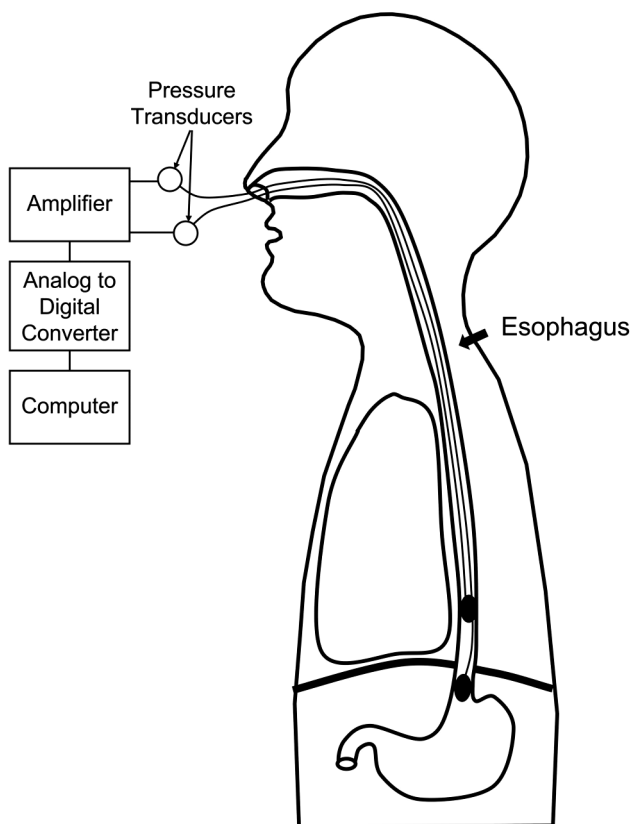


Fig. 3. Schematic of setup and placement of sensors to measure esophageal, gastric, and transdiaphragmatic pressures.

paralysis are most often permanent. The median delay in diagnosis is reportedly 2 years (range 6 wk to 10 y).¹ Delay is more common in ventilator-dependent patients.

Treatment is supportive while awaiting recovery. Patients often develop progressive hypercapnia and hypoxia due to atelectasis and reduced vital capacity.⁴ Nocturnal hypoventilation is treated via positive-pressure ventilation. With isolated diaphragm paralysis and no other neuromuscular impairment, NIV is preferred to invasive mechanical ventilation. Nocturnal bi-level NIV via nasal or face mask without tracheostomy was recently adopted.¹ This preserves patient independence and improves quality of life. Phrenic-nerve pacing requires a functional nerve, so it cannot be used if the cause of diaphragm paralysis is phrenic-nerve

injury. The procedure has had some success in patients with spinal-cord injury but requires an invasive thoracotomy. Recently, surgeons developed a laparoscopic approach to placement of intramuscular electrodes in the diaphragm, with early encouraging results. In one investigational series, 3 of 5 tetraplegics were able to achieve ventilator independence.⁹

Bilateral diaphragm paralysis should be considered in cases of new-onset dyspnea that is most severe in the supine position. The diagnosis should be suspected in patients with neuropathic and myopathic diseases, recent trauma or surgery to the neck or chest, and in patients without apparent risks. Clues to prompt transdiaphragmatic pressure measurement are low lung volumes, reduced MIP, and a supine drop in vital capacity. Although diaphragm paralysis may be permanent, treatment with nocturnal NIV may restore patients to near-normal functional status and improve quality of life.

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