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## Protracted Respiratory Failure in a Case of Global Spinal Syringomyelia and Chiari Malformation Following Administration of Diazepam: Illustrative Case

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## Protracted respiratory failure in a case of global spinal syringomyelia and Chiari malformation following administration of diazepam: illustrative case

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**BACKGROUND** Syringomyelia is defined as dilation of the spinal cord's central canal and is often precipitated by skull base herniation disorders. Although respiratory failure (RF) can be associated with skull base abnormalities due to brainstem compression, most cases occur in pediatric patients and quickly resolve. The authors report the case of an adult patient with global spinal syringomyelia and Chiari malformation who developed refractory RF after routine administration of diazepam.

**OBSERVATIONS** A 31-year-old female presented with malnutrition, a 1-month history of right-sided weakness, and normal respiratory dynamics. After administration of diazepam prior to magnetic resonance imaging (MRI), she suddenly developed hypercapnic RF followed MRI and required intubation. MRI disclosed a Chiari malformation type I and syrinx extending from C1 to the conus medullaris. After decompressive surgery, her respiratory function progressively returned to baseline status, although 22 months after initial benzodiazepine administration, the patient continues to require nocturnal ventilation.

**LESSONS** Administration of central nervous system depressants should be closely monitored in patients with extensive syrinx formation given the potential to exacerbate diminished central respiratory drive. Early identification of syrinx in the context of Chiari malformation and hemiplegia should prompt clinical suspicion of underlying respiratory compromise and early involvement of intensive care consultants.

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**KEYWORDS** syringomyelia; Arnold-Chiari malformation; diazepam; respiratory failure; central sleep apnea; central respiratory drive

Chiari malformations (CMs) are herniation disorders of the posterior fossa and hindbrain.<sup>1</sup> Type 1 Arnold-Chiari Malformation (ACM1) is the most common variant, characterized by herniation of the cerebellar tonsils below the foramen magnum (McRae line), reduced posterior fossa size, and varying degrees of syringomyelia.<sup>1,2</sup> Co-occurrence of CM and syringomyelia has an estimated incidence of 69% in adults and 40% in children.<sup>3,4</sup> Other associations of syringomyelia include tethered spinal cord in pediatric patients, spinal neoplasms, trauma, and delayed presentation following meningitis.<sup>4</sup>

Although usually located between C2 and T9, syrinxes have been reported to extend into the upper brainstem and descend as low as the conus medullaris.<sup>4</sup> Nevertheless, the exact mechanism governing syrinx formation is still relatively unknown.<sup>5</sup> Early proposals suggested that hindbrain-related syrinxes filled through the obex between the fourth ventricle of the brain and the central canal of the spinal cord via either arterial pulsation or Valsalva-induced venous pressure waves.<sup>5</sup> More recently, it has been suggested that perivascular spaces allow cerebrospinal fluid to penetrate the spinal

**ABBREVIATIONS** ABG = arterial blood gas; ACM1 = type 1 Arnold-Chiari Malformation; CM = Chiari malformation; CSA = central sleep apnea; HD = hospital day; ICU = intensive care unit; LTAC = long-term acute care; MRI = magnetic resonance imaging; MUSC = Medical University of South Carolina; PaCO<sub>2</sub> = partial pressure of carbon dioxide; PAO<sub>2</sub> = partial pressure of oxygen; PEG = percutaneous endoscopic gastrostomy; POD = postoperative day; RF = respiratory failure.

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cord parenchyma, with the herniated tonsils found in patients with ACM1 additionally trapping this fluid and driving it into the cord through these spaces to create a syrinx.<sup>5</sup>

Syringomyelia is most often identified incidentally but can present with pain and temperature insensitivities specifically in the upper extremities.<sup>4</sup> Rare reports have been published of syrinx and CM presenting with respiratory failure (RF), although most of these cases have occurred in children.<sup>6,7</sup> In the following report, we detail the case of an adult female patient with compensated respiratory function presenting with global spinal syrinx and CM who developed RF and protracted central sleep apnea (CSA) after anxiolytic administration.

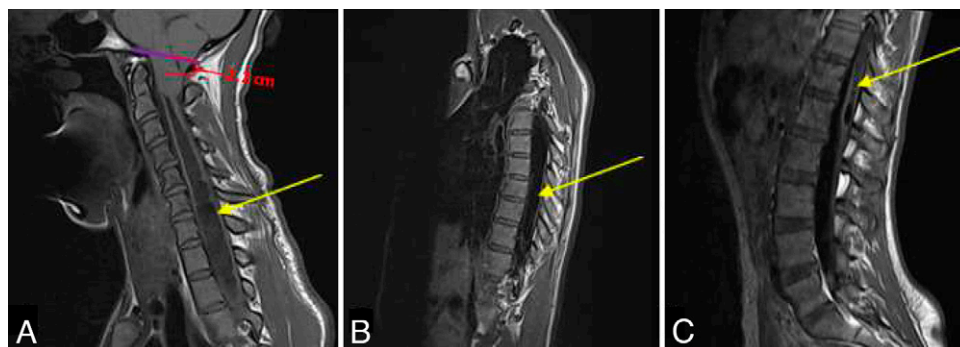
### Illustrative Case

A 31-year-old female presented to an outside hospital with malnutrition and a 1-month history of right-sided weakness. Six days prior to admission, she reported the development of a right foot drop that led to a fall. Her past medical history included celiac disease and mild scoliosis. Magnetic resonance imaging (MRI) of the brain was performed and revealed a type I CM and tonsillar herniation measuring 2.2 cm.

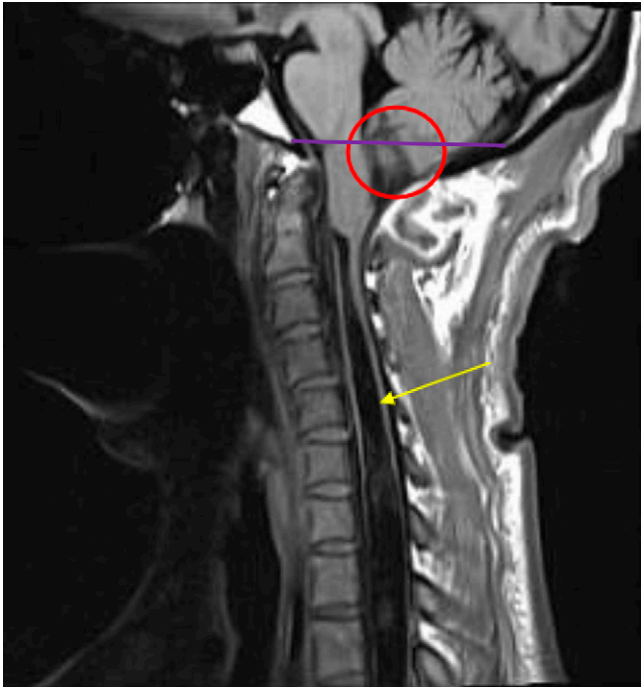
The patient was transferred to the Medical University of South Carolina (MUSC) for further evaluation. At admission, the patient displayed good respiratory effort with a rate of 17 breaths per minute, normal oxygen saturation on room air, and no accessory muscle use. On neurological examination, cranial nerves II–XII were intact. Muscle strength was 2/5 for deltoid, wrist extension, and iliopsoas on the right; 3/5 for biceps, dorsiflexion, extensor hallucis longus, and plantar flexion on the right; 4/5 for triceps and quadriceps on the right; and 3/5 hand grip bilaterally. With muscle strength in the upper extremities recorded as deltoid/biceps/triceps/wrist extension/hand grip and strength in the lower extremities recorded as iliopsoas/knee extension/dorsiflexion/extensor hallucis longus/plantar flexion, muscle strength on initial examination strength was recorded as 2/3/2/4/3 in the right upper extremity, 5/5/5/5/3 in the left upper extremity, 2/4/3/3/3 in the right lower extremity, and 5/5/5/5/5 in the left lower extremity. Serum bicarbonate measured 34 mmol/L, chloride 84 mmol/L, creatinine 0.3 mg/dL, and blood urea nitrogen/Cr ratio <20. Thus, dehydration with contraction alkalosis was favored diagnostically over signs for chronic hypoventilation.

A new MRI was planned, and due to the patient's concern for claustrophobia, two doses of 5 mg of intravenous diazepam were administered separated by 2 hours prior to the scans. Cervical, thoracic, and lumbar spine MRI performed for surgical planning identified a syrinx extending from C1 to the conus medullaris (Fig. 1). After the MRI, the patient became somnolent and subsequently developed acute RF with a CO<sub>2</sub> of 146 mm Hg on arterial blood gas (ABG) examination as well as O<sub>2</sub> of 125 mm Hg, pH of 7.09, and bicarbonate of 44.3 mmol/L, indicating an acute-on-chronic respiratory acidosis. Despite administration of flumazenil, the patient continued to experience respiratory distress, resulting in endotracheal intubation and transfer to the neuroscience intensive care unit (ICU). The following day, on hospital day (HD) 3, she underwent Chiari decompression with a suboccipital craniectomy and C1 laminectomy (Fig. 2). The patient remained intubated after surgery and was unable to be weaned from the ventilator; two extubation trials were failed due to the development of acute hypoxic RF after each extubation. After the failure of the second extubation trial, a tracheostomy and a percutaneous endoscopic gastrostomy (PEG) tube placement were performed.

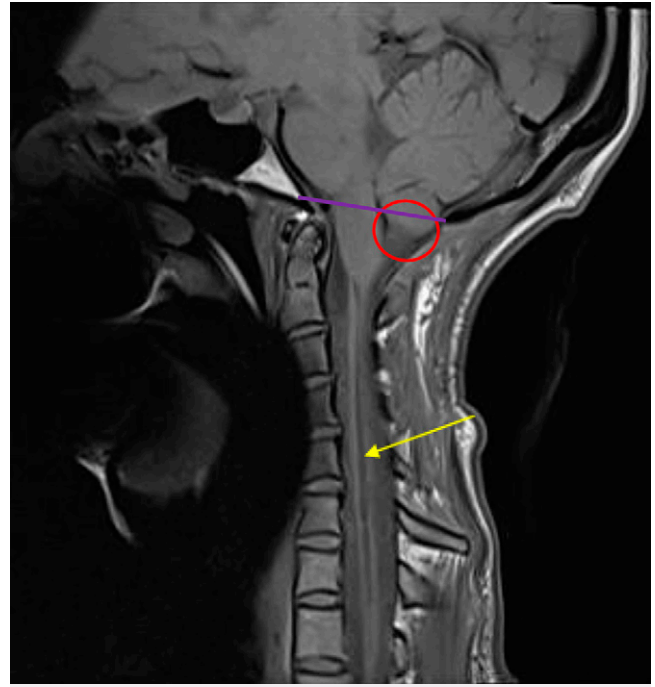
Posttracheostomy, the patient showed steady improvement in ventilation status and was slowly weaned to a tracheostomy collar. She was deemed stable for transfer to the floor on HD 25, where her tracheostomy was managed and eventually weaned to smaller cannulas. Before transfer to a long-term acute care (LTAC) facility on HD 34, she continued to display CSA despite successful Chiari decompression. Two months after transfer to LTAC, the patient presented to an outside hospital with abdominal pain and was found to have peritonitis complicated by ileus and aspiration pneumonia, resulting in the removal of the PEG tube. During her treatment for peritonitis, she became unresponsive and was intubated. After another extubation trial failed due to continued RF, the patient was returned to MUSC for escalation of care, where she underwent repeat tracheostomy and PEG tube placement. The pulmonology service was eventually consulted due to several nighttime apneic events, leading to a diagnosis of CSA. They noted elevated CO<sub>2</sub> of 70 mm Hg on ABG with an O<sub>2</sub> level of 102 mm Hg, a bicarbonate of 39.4 mmol/L, and a pH of 7.36 5 months after decompression surgery (Fig. 3). The pulmonology team recommended transfer to the ICU for initiation of nighttime ventilation. Using synchronized



**FIG. 1. A:** Preoperative T1 cervical MRI demonstrating an ACM1 with a 2.2-cm tonsillar herniation (basionopisthion line displayed in purple) and a hyperintense region spanning from C1 to the conus medullaris representing a syrinx (arrow). **B:** Preoperative T1-weighted thoracic MRI demonstrating a hyperintense region spanning from C1 to the conus medullaris representing a syrinx (arrow). **C:** Preoperative T1-weighted lumbar MRI demonstrating a hyperintense region spanning from C1 to the conus medullaris representing a syrinx (arrow).



**FIG. 2.** POD 2 T1-weighted cervical MRI after Chiari decompression, suboccipital craniectomy, and C1 laminectomy, highlighting successful decompression (*circle* indicates area of previous herniation, basion-opisthion line displayed in *purple*) and slight decrease in cervical spine syrinx (*arrow*).



**FIG. 3.** Four-month postoperative (POD 132) T1-weighted cervical MRI highlighting successful decompression (*circle* indicates area of previous herniation, basion-opisthion line displayed in *purple*) and significantly smaller syrinx compared to POD2 (*arrow*).

intermittent mandatory ventilation at a rate of 18 breaths per minute, tidal volume of 310 mL, pressure support of 10 cm H<sub>2</sub>O over a positive end expiratory pressure of 8 cm H<sub>2</sub>O on 21% fraction of inspired O<sub>2</sub>, the patient tolerated nocturnal ventilation well. She displayed normal CO<sub>2</sub> levels on nocturnal invasive mechanical ventilatory support throughout the remainder of her hospital course and was eventually discharged home on postoperative day (POD) 179.

Three months after her second discharge (POD 277), the patient reported needing nocturnal home ventilation for 2 to 3 hours at night (and no pulmonary complaints during the day or night when off ventilation). A pulmonology consultation attributed her need for nocturnal ventilation to severe respiratory muscle weakness. Fifteen months after initial development of RF, the patient was entirely independent in activities of daily living, and her PEG tube was removed because of adequate weight gain. Additionally, the patient's nocturnal RF had resolved, and her ABG was within normal limits with partial pressure of carbon dioxide (PaCO<sub>2</sub>) 44 mm Hg and partial pressure of oxygen (PaO<sub>2</sub>) 89 mm Hg, allowing for the removal of the tracheostomy tube on POD 458. Since then, the patient has had no reported complaints of respiratory distress or apnea. However, the patient continues to use noninvasive ventilation nightly and on the most recent follow-up (POD 664) displayed permanent right-sided hemiparesis.

#### Patient Informed Consent

The necessary patient informed consent was obtained in this study.

## Discussion

### Observations

RF is caused by decompensated gas exchange within the respiratory system and is further divided into type 1 and type 2 based on the measured levels of oxygen and carbon dioxide.<sup>8,9</sup> Type 1 RF, or hypoxic RF, occurs when oxygen cannot be adequately provided to the body for necessary metabolic functions, resulting in a PaO<sub>2</sub> less than 60 mm Hg and PaCO<sub>2</sub> being either normal or decreased.<sup>9</sup> Type 2 RF, or hypercapnic RF, occurs whenever CO<sub>2</sub> is inadequately released due to a failure in the respiratory system, resulting in a greater than normal CO<sub>2</sub> of more than 45 mm Hg.<sup>9</sup> RF can occur if any component of the respiratory system, such as the muscles of respiration, chest wall, respiratory tracts, or the central and peripheral nervous systems, function abnormally.<sup>10</sup> RF has a wide range of causes, including interstitial lung disease, pulmonary embolism, severe pneumonia, kyphoscoliosis, diaphragmatic paralysis, Guillain-Barre syndrome, and decreased central respiratory drive from sedatives or other diseases of the central nervous system.<sup>9</sup> The combination of tonsillar herniation and syrinx results in mechanical compression of the respiratory centers of the brainstem along with ascending and descending respiratory fibers, resulting in respiratory distress.<sup>11</sup>

Progressive RF secondary to ACM1 alone is well documented in both pediatric and adult patients and has been reported both before and after posterior fossa decompression.<sup>6,11–21</sup> Although our patient did initially present with hemiparesis, symptoms that are not atypical for patients presenting with ACM1, she only began showing signs of RF after administration of diazepam. In this unique case, the RF in our estimation was primarily caused by the patient's severe

syringomyelia, particularly since it affected medullary descending fibers. It is also possible, based on a serum bicarbonate level of 34 mmol/L recorded 2 years before initial symptom presentation, that the patient may have had an underlying chronic hypercapnic respiratory disorder.<sup>22</sup> The protracted nature of the symptoms observed in this unique case was most likely due to long-standing, slowly progressive RF that quickly decompensated after use of diazepam.

The patient was also noted to have scoliosis with chest wall deformities, which may have contributed to her respiratory compromise; however, the distortion did not appear clinically severe enough to disrupt normal respiration.<sup>23</sup> Because of her chronic respiratory acidosis, it is also possible to suggest that the patient's baseline response to CO<sub>2</sub> via central chemoreceptors was blunted. After administration of a respiratory depressant, the patient's responsiveness to CO<sub>2</sub> would have been further depressed as well as any other compensatory ventilatory mechanisms involved in arousal and airway or chest wall muscle tone, thus explaining the patient's acute decline, chronic respiratory muscle weakness and nocturnal ventilatory dependency.<sup>24,25</sup>

There have been numerous reported cases of patients with syringomyelia and ACM1 developing acute RF, with a number of these patients reported to continue experiencing hypercapnic RF weeks or even years after their posterior fossa decompression.<sup>6,14,26,27</sup> Despite this, this case is still an extremely rare phenomenon in that there has been only one other reported case in which a patient with a CM developed hypercapnic RF that was incidentally induced through administered medications, although the patient in that case had a subarachnoid block of morphine and experienced RF that gradually resolved over the course of 36 hours.<sup>28</sup> To our knowledge, this is the only incidental case of sudden, chronic protracted hypercapnic RF in a patient with syringomyelia and ACM1 with no known history of respiratory distress after administration of an anxiolytic.

Control of respiration is regulated by the Kölliker-Fuse nucleus and parabrachial nuclei of the pontine respiratory group, along with the nucleus of the solitary tract, pre-Böttinger complex, postinspiratory complex, and the lateral portion of the parafascial respiratory group of the dorsal and ventral respiratory groups within the medulla of the brainstem.<sup>29</sup> These structures receive and integrate signals from multiple sources responsible for monitoring PaCO<sub>2</sub> and PaO<sub>2</sub> levels, particularly from peripheral chemoreceptors such as the carotid and aortic bodies as well as central chemoreceptors in the retrotrapezoid nucleus and the ventral surface of the medulla.<sup>30</sup> It is from these respiratory centers that the activity of motor neurons innervating the diaphragm and the internal and external intercostal muscles are modulated, allowing for centrally controlled breathing. With compression of these respiratory centers, this essential autonomic circuitry is disrupted and can lead to a state of unresponsiveness to changes in the levels of blood CO<sub>2</sub> and O<sub>2</sub>.

Isolated benzodiazepine toxicity can depress central respiratory drive and chemoreceptor responsiveness to elevated blood CO<sub>2</sub> levels, as well as decreased respiratory muscle strength through the activation of GABA-A receptors in the peripheral nervous system, thus resulting in decreased arousal and relaxed respiratory muscle tone.<sup>31,32</sup> Diazepam is a long-acting, medium-potency benzodiazepine.<sup>33,34</sup> Although primarily metabolized by the liver, the active metabolites of this hepatic breakdown can exert their own sedative and anxiolytic actions.<sup>33</sup> This in turn can prolong the

therapeutic effects of the medication and extend its typical elimination half-life of roughly 48 hours to values as high as 100 hours, requiring careful consideration before administration in patients with hepatic dysfunction.<sup>35</sup>

Despite its rarity, this case underscores the need for early identification and intervention in patients with syringomyelia and ACM1 due to the possibility of sudden hypercapnic RF developing, as in our patient. There are reports of an increased prevalence of sleep-disordered breathing in patients with ACM1 regardless of syrinx presence, particularly in pediatric patients or those already displaying neurological signs secondary to brainstem compression.<sup>36,37</sup> Because of this, a formal sleep study via polysomnography should be conducted for all patients with known ACM1 regardless of syrinx status who display neurological symptoms or who have evidence of respiratory distress such as hypercapnia. For patients with known ACM1 who need emergency surgery because of significant hind-brain herniation, a formal sleep study would also be recommended after their surgery to assess postoperative nocturnal respiratory status as well as the possible need for providing ventilatory support to such patients. However, if such patients are asymptomatic on initial presentation, only clinical monitoring and imaging would be needed, with a formal sleep study being unnecessary in these situations unless indicated by the sudden development of neurological or depressed respiratory signs. An ABG study may also be ordered in patients with a crowded foramen magnum and associated syrinx to assess for chronic compensated hypercapnia on initial presentation. The results of these studies could suggest consideration of use of ventilatory support if administration of sedatives or anxiolytics for imaging studies are needed.

During preoperative workup, sedatives and anxiolytics with known effects on respiration drive or upper airway patency, such as benzodiazepines, barbiturates, opioids, and propofol, should be limited in patients because of the potential for exacerbation of RF in a patient with a potentially compromised respiratory system.<sup>38,39</sup> Lorazepam is an alternative anxiolytic in such situations due to its lower potential for respiratory depression compared with other benzodiazepines, particularly diazepam.<sup>40</sup> In terms of sedatives, dexmedetomidine has the lowest risk of respiratory depression among sedatives and has been shown to have no direct effect on upper airway patency.<sup>38</sup> Additionally, ketamine does not cause respiratory depression and actually decreases airway resistance, aiding in preservation of baseline pulmonary function in patients.<sup>41,42</sup> Although the main adverse effects of dexmedetomidine and ketamine relate to cardiac and hemodynamic changes, in a patient such as this without a history of cardiovascular disease, these two medications serve as valid alternatives for sedation.<sup>43,44</sup>

## Lessons

Here, we present a case of decompensated RF following diazepam administration in a patient with global syringomyelia. RF is well known to be associated with ACM1 and syringomyelia in both pediatric and adult patients; however, to our knowledge, this is the first report of anxiolytic-induced refractory RF in an adult patient with these conditions. We believe that the novelty of this case lies in the severe compression of respiratory centers due primarily to the uncommon occurrence of syringomyelia extending from medullary centers involved in respiration. In these patients requiring sedation or anxiolytics, anesthesia providers should be involved, and medications such as dexmedetomidine, ketamine, or lorazepam could provide



adequate sedation or anxiety relief without the risk of producing decreased respiratory drive. Also, noninvasive ventilation for patients with chronic respiratory acidosis secondary to posterior fossa malformations should be carefully considered in case respiratory depressants such as benzodiazepines or opiates need to be administered.

## References

- Hidalgo JA, Tork CA, Varacallo M. Arnold Chiari Malformation. In: *StatPearls*. StatPearls Publishing; September 5, 2022. Accessed February 13, 2023. <https://www.ncbi.nlm.nih.gov/books/NBK431076/>.
- Shenoy VS, Sampath R. Syringomyelia. In: *StatPearls*. StatPearls Publishing; August 11, 2022. Accessed April 20, 2023. <https://www.ncbi.nlm.nih.gov/books/NBK537110/>.
- Holly LT, Batzdorf U. Chiari malformation and syringomyelia. *J Neurosurg Spine*. 2019;31(5):619–628.
- Wu J, Ji S, Niu P, et al. Knowledge mapping of syringomyelia from 2003 to 2022: a bibliometric analysis. *J Clin Neurosci*. 2023;110:63–70.
- Flint G. Syringomyelia: diagnosis and management. *Pract Neurol*. 2021;21(5):403–411.
- Kijsrichareanchai K, Limsuwat C, Mankongpaisarnrun C, Nantsupawat N, Nugent K. Chiari syndrome and respiratory failure: a literature review. *J Intensive Care Med*. 2014;29(5):260–268.
- Milhorat TH, Chou MW, Trinidad EM, et al. Chiari I malformation redefined: clinical and radiographic findings for 364 symptomatic patients. *Neurosurgery*. 1999;44(5):1005–1017.
- Lamba TS, Sharara RS, Singh AC, Balaan M. Pathophysiology and classification of respiratory failure. *Crit Care Nurs Q*. 2016;39(2):85–93.
- Shebl E, Mirabile VS, Sankari A, Burns B. Respiratory Failure. In: *StatPearls*. StatPearls Publishing; November 3, 2022. Accessed March 1, 2023. <https://www.ncbi.nlm.nih.gov/books/NBK526127/>.
- Haddad M, Sharma S. Physiology, Lung. In: *StatPearls*. StatPearls Publishing; July 18, 2022. Accessed March 1, 2023. <https://www.ncbi.nlm.nih.gov/books/NBK545177/>.
- Williams DL, Umedaly H, Martin IL, Boulton A. Chiari type I malformation and postoperative respiratory failure. *Can J Anaesth*. 2000;47(12):1220–1223.
- Tsara V, Serasli E, Kimiskidis V, et al. Acute respiratory failure and sleep-disordered breathing in Arnold-Chiari malformation. *Clin Neurol Neurosurg*. 2005;107(6):521–524.
- Fanfulla F, Eleftheriou D, Patruno V, Bruschi C, Rampulla C. Chronic respiratory failure in a patient with type I Arnold-Chiari malformation (ACM1) and syringomyelia. *Monaldi Arch Chest Dis*. 1998;53(2):138–141.
- Bullock R, Todd NV, Easton J, Hadley D. Isolated central respiratory failure due to syringomyelia and Arnold-Chiari malformation. *BMJ*. 1988;297(6661):1448–1449.
- Montserrat JM, Picado C, Agustí-Vidal A. Arnold-Chiari malformation and paralysis of the diaphragm. *Respiration*. 1988;53(2):128–131.
- Ali MM, Russell N, Awada A, McLean D. A cranio-cervical malformation presenting as acute respiratory failure. *J Emerg Med*. 1996;14(5):569–572.
- Nosedá A, Devriendt J, Hoffmann G, Schmerber J. Isolated respiratory insufficiency in Arnold-Chiari malformation. Article in French. *Rev Mal Respir*. 1996;13(4):440–442.
- Moro ER, Teive HA, de Souza SM, Lambrecht F, Werneck LC. Type I Chiari malformation: report of 2 cases with unusual clinical presentation. Article in Portuguese. *Arq Neuropsiquiatr*. 1999;57(3A):666–671.
- Vasani VM, Konar SK, Satish S. Hypercapnic respiratory failure in case of Chiari 1.5 malformation: case report and review of the literature. *Indian J Crit Care Med*. 2017;21(10):707–709.
- Omer S, al-Kawi MZ, Bohlega S, Bouchama A, Mclean D. Respiratory arrest: a complication of Arnold-Chiari malformation in adults. *Eur Neurol*. 1996;36(1):36–38.
- Fish DR, Howard RS, Wiles CM, Simon L. Respiratory arrest: a complication of cerebellar ectopia in adults. *J Neurol Neurosurg Psychiatry*. 1988;51(5):714–716.
- Centor RM. Serum total carbon dioxide. Walker HK, Hall WD, and Hurst JW, eds. *Clinical Methods: The History, Physical, and Laboratory Examinations*. 3rd ed. Butterworths; 1990:888–889.
- Tsiligiannis T, Grivas T. Pulmonary function in children with idiopathic scoliosis. *Scoliosis*. 2012;7(1):7.
- Eckert DJ, Jordan AS, Merchia P, Malhotra A. Central sleep apnea: pathophysiology and treatment. *Chest*. 2007;131(2):595–607.
- Dauvilliers Y, Stal V, Abril B, et al. Chiari malformation and sleep related breathing disorders. *J Neurol Neurosurg Psychiatry*. 2007;78(12):1344–1348.
- Al Bashapshe A, Bhatia H, Aziz S. Acute respiratory failure as a first manifestation of syringomyelia. *Lung India*. 2010;27(2):93–95.
- Alvarez D, Requena I, Arias M, Valdés L, Pereiro I, De la Torre R. Acute respiratory failure as the first sign of Arnold-Chiari malformation associated with syringomyelia. *Eur Respir J*. 1995;8(4):661–663.
- Ankichey SP, Khunein S, Venkatraghavan L. Presentation of occult Chiari I malformation following spinal anesthesia. *Indian J Anaesth*. 2012;56(6):579–581.
- Schottelkotte KM, Crone SA. Forebrain control of breathing: Anatomy and potential functions. *Front Neurol*. 2022;13:1041887.
- Brinkman JE, Toro F, Sharma S. Physiology, Respiratory Drive. In: *StatPearls*. StatPearls Publishing; June 8, 2022. Accessed May 25, 2023. <https://www.ncbi.nlm.nih.gov/books/NBK482414/>.
- Masneuf S, Buettler J, Koester C, Crestani F. Role of  $\alpha$ 1- and  $\alpha$ 2-GABA(A) receptors in mediating the respiratory changes associated with benzodiazepine sedation. *Br J Pharmacol*. 2012;166(1):339–348.
- Vozoris NT. Do benzodiazepines contribute to respiratory problems? *Expert Rev Respir Med*. 2014;8(6):661–663.
- Griffin CE 3rd, Kaye AM, Bueno FR, Kaye AD. Benzodiazepine pharmacology and central nervous system-mediated effects. *Ochsner J*. 2013;13(2):214–223.
- Fox C, Liu H, Kaye AD. Antianxiety agents. Manchikanti L, Trescott AM, Christo PJ, et al, eds. *Clinical Aspects of Pain Medicine and Interventional Pain Management: A Comprehensive Review*. ASIP Publishing; 2011;543–552.
- Dhaliwal JS, Rosani A, Saadabadi A. Diazepam. In: *StatPearls*. StatPearls Publishing; September 3, 2022. Accessed May 25, 2023. <https://www.ncbi.nlm.nih.gov/books/NBK537022/>.
- Dhamija R, Wetjen NM, Slocumb NL, Mandrekar J, Kotagal S. The role of nocturnal polysomnography in assessing children with Chiari type I malformation. *Clin Neurol Neurosurg*. 2013;115(9):1837–1841.
- Abel F, Tahir MZ. Role of sleep study in children with Chiari malformation and sleep disordered breathing. *Childs Nerv Syst*. 2019;35(10):1763–1768.
- Longrois D, Conti G, Mantz J, Faltthausen A, Aantaa R, Tonner P. Sedation in non-invasive ventilation: do we know what to do (and why)? *Multidiscip Respir Med*. 2014;9(1):56.
- Eastwood PR, Platt PR, Shepherd K, Maddison K, Hillman DR. Collapsibility of the upper airway at different concentrations of propofol anesthesia. *Anesthesiology*. 2005;103(3):470–477.
- Stewart WA, Harrison R, Dooley JM. Respiratory depression in the acute management of seizures. *Arch Dis Child*. 2002;87(3):225–226.
- Morel DR, Forster A, Gemperle M. Noninvasive evaluation of breathing pattern and thoraco-abdominal motion following the infusion of ketamine or droperidol in humans. *Anesthesiology*. 1986;65(4):392–398.
- Miller AC, Jamin CT, Elamin EM. Continuous intravenous infusion of ketamine for maintenance sedation. *Minerva Anesthesiol*. 2011;77(8):812–820.
- Reel B, Maani CV. Dexmedetomidine. In: *StatPearls*. StatPearls Publishing; May 8, 2022. Accessed July 2, 2023. <https://www.ncbi.nlm.nih.gov/books/NBK513303/>.

44. Rosenbaum SB, Gupta V, Patel P, Palacios JL. Ketamine. In: *StatPearls*. StatPearls Publishing; November 24, 2022. Accessed July 2, 2023. <https://www.ncbi.nlm.nih.gov/books/NBK470357/>.

### **Disclosures**

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

### **Author Contributions**

Conception and design: Webb, Saway, Chalela, Rowland. Acquisition of data: all authors. Analysis and interpretation of data: Bauerle,

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