Predictors for Invasive Home Mechanical Ventilation Duration in Chronic Lung Disease of Prematurity

Carolyn Foster MD, MS1,2,3, Paige Noreen, MD4,5, Jennifer Grage, MD4,5, Soyang Kwon, PhD2, Lindsey P. Hird-McCorry, BSN, RN, CPN5,6, Angela Janus, BSN, RN, CPN5,6, Matthew M. Davis, MD, MPP1,2,5,7, Denise Goodman, MD, MS5,6,8, Theresa Laguna, MD, MSCS5,6,9

**Affiliations:**

1Division of Advanced General Pediatrics and Primary Care, Department of Pediatrics, Northwestern University Feinberg School of Medicine, 2Mary Ann & J. Milburn Smith Child Health Outcomes, Research, and Evaluation Center, Stanley Manne Children's Research Institute, Ann & Robert H. Lurie Children’s Hospital of Chicago, 3Digital Health, Ann & Robert H. Lurie Children’s Hospital of Chicago, 4McGaw Medical Center, Northwestern University, 5Ann & Robert H. Lurie Children’s Hospital of Chicago, 6Pulmonary Habilitation Program, Ann & Robert H. Lurie Children’s Hospital of Chicago, 7Departments of Medicine and Preventive Medicine, Northwestern University Feinberg School of Medicine, 8Division of Critical Care Medicine, Department of Pediatrics, Northwestern University Feinberg School of Medicine, 9Division of Pulmonary and Sleep Medicine, Department of Pediatrics, Northwestern University Feinberg School of Medicine

**Address correspondence to**: Carolyn C. Foster, MD, MS, Division of Advanced General Pediatrics and Primary Care, Department of Pediatrics, Northwestern University Feinberg School of Medicine, Mary Ann & J. Milburn Smith Child Outcomes, Research, and Evaluation Center, Stanley Manne Children's Research Institute, Ann & Robert H. Lurie Children’s Hospital of Chicago, 225 East Chicago Avenue, Box 162, Chicago, Illinois 60611, Telephone 312-227-2665, Fax 312-227-9801, Email: [ccfoster@luriechildrens.org](mailto:ccfoster@luriechildrens.org)

**Conflict of Interest:** None

**Financial disclosures:** Dr. Foster has received compensation for medical record consultation and/or expert witness testimony.

**Funding Support:** Dr. Foster is supported under 1K23HL149829-01A1 for research on care of children with home mechanical ventilation. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

REDCap is supported at FSM by the Northwestern University Clinical and Translational Science (NUCATS) Institute, Research reported in this publication was supported, in part, by the National Institutes of Health's National Center for Advancing Translational Sciences, Grant Number UL1TR001422. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health

**Keywords:** long-term mechanical ventilation, chronic lung disease, bronchopulmonary dysplasia, children with medical complexity

**Clinical Trial Registration**: Not applicable

**Abbreviations:**  bronchopulmonary dysplasia (BPD), chronic lung disease (CLD), invasive home mechanical ventilation (iHMV)

**Abbreviated title:** Duration of Invasive Home Ventilation after Prematurity

# Abstract

**Background**

Children with chronic lung disease (CLD) of prematurity who require invasive home mechanical ventilation (iHMV) are medically vulnerable and experience high caregiving and healthcare costs. Predictors for duration of iHMV remain unclear, which can make prognostication and decision-making challenging.

**Methods**

A retrospective cohort study of children with CLD of prematurity requiring invasive iHMV was conducted from an independent children’s hospital records (2005-2021). The primary outcome was iHMV duration, defined as time from initial discharge home on iHMV until cessation of positive pressure ventilation (day and night). Two new variables were included: corrected tracheostomy age (CTA) (chronological age at discharge minus age at tracheotomy) and level of ventilator support at discharge (minute ventilation per kg per day). Univariable Cox regression was performed with variables of interest compared to iHMV duration. Significant nonlinear factors (P<0.05) were included in the multivariable analysis.

**Results**

One-hundred-and-nineteen patients used iHMV primarily for CLD of prematurity. Patient median index hospitalization lasted 12 months (IQR 8.0,14.4). Once home, half of patients were weaned off iHMV by 36.0 months and 90% by 52.2 months. Being Hispanic/Lantix ethnicity (HR 0.14 (95% CI 0.04, 0.53), p<0.01) and having a higher CTA were associated with increased iHMV duration (HR 0.66 (CI 0.43, 0.98), p<0.05).

**Conclusions**

Disparity in iHMV duration exists among patients using iHMV after prematurity. Prospective multisite studies that further investigate new analytic variables, such as CTA and level of ventilator support, and address standardization of iHMV care are needed to create more equitable iHMV management strategies.

# Introduction

Due to clinical and technological advances over the past 20-30 years, children with severe chronic lung disease (CLD) of prematurity are increasingly discharged home on long-term invasive mechanical ventilation via tracheostomy. 1-8 In one estimate, the number of children with severe CLD reliant on invasive home mechanical ventilation (iHMV) has quadrupled from 1.2 per 100,000 to 4.8 per 100,000 between 1984 and 2010. 1 While iHMV provides essential life-sustaining support to children, iHMV can limit patient development and social participation, 9 negatively impact family wellbeing, 9-13 and lead to high-cost equipment rental and home nursing service expenditures. 14,15

Understanding which factors contribute to the duration of time children with CLD spend on iHMV remains an understudied area. Previous seminal studies have described tracheostomy duration, total invasive iHMV duration, and factors associated with iHMV liberation and mortality on iHMV. 1,2,4,16-20 However, to our knowledge, the literature has not yet identified factors associated with duration of time children spend on positive pressure iHMV once home. A recent review stated that early predictors of long-term outcomes remain unclear, 21 and there exists a comparative lack of evidence-based guidelines for post-discharge management of iHMV compared to other respiratory diseases of childhood. 22 Additionally, we are unaware of studies specifically focusing on factors impacting just the ventilation period at home. Given that iHMV use is associated with high patient and family costs, more information is needed about what factors impacts how long children with CLD spend on iHMV.

Therefore, the goal of this study was to investigate the factors associated with the duration of iHMV with specific focus on the duration on positive pressure ventilation in the home environment. Specifically, our aims were to 1) describe the variation of iHMV duration among a population of children with CLD of prematurity using iHMV, and 2) identify which demographic and clinical factors are associated with the duration of their iHMV use. We hypothesized that demographic factors such as race/ethnicity and insurance, birth information such as gestational age and weight, medical status at the time of discharge such as oxygen use and higher levels of daily ventilator support, presence of cardiac and neurologic comorbidities, and who the primary pulmonologist was managing the patient’s outpatient care would be associated with iHMV duration.

**Methods**

## Study Design

We conducted a retrospective cohort study of the Lurie Children’s Hospital Pulmonary Habilitation Program registry and electronic health records data that included patients admitted to the program from November, 1, 2005 through May 31, 2021 with a study endpoint on August 31, 2021. The Pulmonary Habilitation Program registry is composed of all children cared for at our independent children’s hospital with iHMV. Available data elements such as patient demographics and utilization were extracted directly from the EHR and registry. Additional chart review was conducted using Research Electronic Data Capture tools hosted at Northwestern University to collect remaining study variables. 23 To ensure a reproducible chart review process, a manual of operations was developed and tested among the study team’s abstractors. Double chart review and comparison was conducted to ensure consistency.

## Study Population

Inclusion criteria were patients who were initiated on iHMV via tracheostomy due to CLD of prematurity during infancy following a provider-based diagnosis of bronchopulmonary dysplasia (BPD) confirmed by chart review. We excluded patients that used iHMV for the following reasons: neuromuscular weakness, central hypoventilation, isolated airway disease, primary cardiac disease, pulmonary hypoplasia from congenital conditions such as diaphragmatic hernia or omphalocele, and acquired lung disease after infancy. We also excluded patients who were initiated on iHMV but weaned prior to discharge home and those with unavailable chart information that would not allow determination of iHMV duration (**Figure 1**).

*Study Outcome*

To guide study data collection, a framework illustrating the timeline of a child born prematurely who eventually required iHMV, representing key timepoints from birth through tracheostomy tube decannulation was created (**Appendix A).** The study primary outcome was *the duration of iHMV use* defined as the period in months between the date of discharge from the first (index) hospitalization with iHMV and the date of discontinuation of positive pressure ventilation both during the day and night, including illness. If a child was transferred from an outside hospital prior to being sent home, the hospitalization where tracheostomy placement and iHMV training occurred was considered the index hospitalization. Patients in the study cohort were categorized as: 1) weaned off iHMV at study end, 2) still on the ventilator receiving iHMV at study end, 3) lost to follow-up, or 4) deceased.

*Predictor Variables of Interest*

Demographic factors examined included biological sex, race/ethnicity (Asian, non-Hispanic Black, Hispanic, non-Hispanic White, other/unknown), and insurance type (any public, private only, other/unknown). 24 While examined race/ethnicity as they have been shown to be socially construct variables that are linked to disparities in access that stem from structural barriers and bias. Gestational age in weeks and gestational weight were examined as possible indicators for severity of CLD of prematurity. To capture information reflective of pulmonary health at the start of iHMV, we included a length-for age Z score based on the U.S. Centers for Disease Control growth chart as reflection of chest size, presence of pulmonary hypertension (yes/no), oxygen use (yes/no), hours of ventilator support, and level of daily ventilatory support. A novel variable was created to capture the level of daily ventilator supportat discharge to iHMV, calculated as *minute ventilation per kg per day* by multiplying the mean tidal delivered volume at discharge (liters per kilogram) by the set breaths per minute by 60 minutes per hour by the hours per day the child was set to use the ventilator. This variable was created to account for differences in ventilator mode, intensity of support, and duration during the day in one variable that could be used consistently for all children in the cohort.

Age at discharge from initial hospitalization was included, and we considered that iHMV duration at home may be artificially foreshortened due to non-medical reasons such as a home nursing shortage. 25 To address this possibility, we created 2 additional variables: *corrected gestational age* in weeks defined as the chronological age in weeks at discharge minus birth in weeks and the *corrected* *tracheostomy age* in weeks, defined as the chronological age in weeks at discharge minus age at tracheotomy. While we considered examining time from tracheostomy placement to end of iHMV use, by creating the CTA variable, we established a new construct where continued non-medical stay could be treated as a confounder rather than adding into the outcome measure. This approached allowed us to duration of iHMV care at home more specifically.

We additionally included a variable for the primary pulmonologist who managed a child’s outpatient care to account for individual practice variation that may impact ventilator support decision-making. Two physicians (Pulmonologist A and Pulmonologist B) took care of >80% of the cohort with the remaining physicians taking care of only 5 or fewer patients. The remaining physicians were labeled together as a “Pulmonologist Group”.

Lastly, to account for non-pulmonary co-morbidities that may impact duration of iHMV, we used previously validated classifications of neurologic and cardiac co-morbidities. First, we identified if patients had a high-intensive neurologic impairment, defined as a neurological diagnosis expected to last 12 months or longer and result in significant functional impairments requiring subspecialty medical care. 26,27 We also identified the presence of a critical congenital heart condition, defined by the American Academy of Pediatrics, American Heart Association, and Centers for Disease Control as specified heart conditions requiring surgery in the first year of life (e.g., hypoplastic left heart syndrome, pulmonary atresia, tetralogy of Fallot, transposition of the great arteries). 28,29

*Analyses*

All analyses were conducted using SAS 9.4 (Cary, NC). Descriptive analyses, including distribution analyses, were performed to describe the study variables. Continuous variables that were not normally distributed were standardized (with a mean of 0 and a standard deviation [SD] of 1). As the primary endpoint iHMV duration, we used survival analysis approach to model the iHMV duration. Patients who did not stop iHMV were censored at the time of last follow-up. iHMV duration was illustrated with a Kaplan-Meier curve. Cox regression analysis was used to examine the associations between the patient-level factors of interest and iHMV duration. We conducted univariable analysis between each of the patient-level factors and iHMV duration. Significant factors from the univariable analysis (P<0.05) were selected to be considered as predictors in the subsequent multivariable analysis. We conducted correlation analysis to examine co-linearity between those selected factors; if which collinearity was >0.9, we chose one variable among those highly correlated variables to be include in the model. Hazard ratios (HR) less than one reflect “longer survival” on iHMV (i.e., longer iHMV duration) and were interpreted to be a less favorable outcome. HRs greater than one reflects “shorter survival” on iHMV (i.e., shorter iHMV duration) and were interpreted as a more favorable outcome.

**Results**

*Study Cohort*

Of 598 records screened from the registry list, an initial 408 were determined to be ineligible primarily because they used iHMV for a reason other than CLD of prematurity (**Figure 1**). In-depth chart review removed another 31 patients because data was unavailable in the electronic record, another 29 patients did not have confirmed CLD of prematurity, and another 11 patients who were never home on ventilation. A total of 119 patients were eligible for the study.

*Patient Demographics and Clinical Characteristics*

The study cohort had a slight male predominance (55%) and the most common race/ethnicity was Non-Hispanic Black (35%) (**Table 1**). Average gestation age at birth was 26.0 (SD 1.9) weeks and average corrected gestational age was 38.1 (SD 19.3) weeks.

Raw median age at index discharge was 12.0 (interquartile range (IQR) 8.9, 14.4) months (**Table 1**). The median corrected gestational age of 38.1 weeks (SD 19.3) was very similar to the mean corrected tracheostomy age of 37.9 (SD 23.1) except a slightly wider SD spread.

About three-quarters of patients (76%, n=91) were diagnosed with pulmonary hypertension of which the majority still had pulmonary hypertension at discharge (57.1% (n=68). Half of patients used oxygen at discharge (49.6%, n=59), a fifth (21.0%, n=25) had high-intensive neurologic impairment, and 12.6% (n=15) had critical congenital heart disease. Most patients (n=108, 91%) were on iHMV continuously (24/7) at index discharge. Among those who took breaks off the ventilator, they used iHMV an average of 18.0 (SD 5.4) hours/day, such that across the study cohort patients were using a ventilator for a mean 23.3 (SD 2.7) hours/day. The level of daily ventilator support ranged from 678.0 to 6,434.4 liters/kg/day. On average patients received 3,309.6 (SD 1,275.0) of liters/kg/day.

*iHMV Duration*

Among the study cohort, half (n=58, 49%) fully weaned from iHMV by the study endpoint at a mean of 29.7 (SD 19.8) months. A third of patients (n=38, 32%) were still actively using iHMV at the study end (**Table 2**). Twelve percent (n=14) were lost-to follow-up for moving out of state (n=4) and transferring care locally (n=10). Another 7% (n=9) died during the iHMV period. **Figure 2** shows the Kaplan-Meier curve illustrating the fraction of patients remaining on iHMV over time in months. Fifty percent of the sample was weaned off iHMV by 36 months and 90% was weaned off iHMV by 52 months.

*Univariable Cox Regression Analysis of iHMV Duration*

Several unadjusted patient-level variables were associated with duration on iHMV (**Table 3**). Patient with Hispanic/Latinx ethnicity were more likely to be on the ventilator longer compared to Non-Hispanic White patients with a Hazard Ratio (HR) of 0.31 (95% Confidence Interval (CI) 0.13, 0.7; p<0.01). Patients who were older at discharge, had an older corrected gestational age, and who had an older corrected tracheostomy age were more likely to be on iHMV for a shorter period. Consistent with our hypothesis, patients with higher levels of ventilator support were on the ventilator for longer periods of time (HR 0.69 (CI 0.48, 0.99), p=0.04). Children with a high intensity neurologic impairment were also more likely to be on iHMV longer with a HR of 0.38 (0.18, 0.78), p<0.01. Patients cared for by Pulmonologist B were more likely to use iHMV longer (HR 0.46 (CI 0.22, 0.98, p=0.04)) than Pulmonologist A.

*Multivariable Cox Regression Analysis of iHMV Duration*

Given that age at discharge, corrected gestational age, and corrected tracheostomy age were highly correlated (0.92-0.99), we selected corrected tracheostomy age to be included in the multivariable analysis. Together, the following predictors were analyzed in the multivariable model: corrected tracheostomy age, race/ethnicity, presence of a high-intensive neurologic impairment, level of ventilatory support at discharge, and which primary pulmonologist managed a patient’s iHMV care (**Table 4**). Among those examined, only race and ethnicity remained significantly associated with duration of iHMV. Hispanic/Lantix patients had an even lower HR of 0.14 (CI 0.04, 0.53, p<0.01) leading to higher probability of longer iHMV duration compared to the univariate analysis. In the multivariable model, patients grouped as Mix, Other or Unknown race and ethnicity were just at the cut-off of longer iHMV duration as well (HR 0.37 (CI 0.14, 1.01, p=0.05). Lastly, in the multivariable model, corrected tracheostomy age remained statistically associated with longer iHMV duration with a HR of 0.66 (CI 0.43, 0.98, p<0.05).

# Discussion

In this retrospective cohort study, we found considerable variation in the time children spent on iHMV. Only half of the population weaned off iHMV after two years and about 10 percent weaned off iHMV after 4 years, which is consistent with other institution’s findings. 1,2,20,30 We also found that children who were Hispanic/Latinx ethnicity were more likely to use iHMV longer compared to non-Hispanic White patients as did those with higher corrected tracheostomy age in both univariable and multivariable models. Among the univariable analysis, other factors such as patient age at discharge and which pulmonologist managed their outpatient iHMV care were associated with iHMV duration. Several individual-level biologic factors such as biological sex, presence of pulmonary hypertension, presence of a complex congenital heart conditions, oxygen use, and length were not associated with the duration of iHMV.

Notable among these results is the presence of a healthcare disparity for Hispanic/Latinx patients. While we recognize that ethnicity is a social construct, structural barriers including bias and racism are known to play a role in access to health outcomes. This finding is consistent with a recent paper examining outcomes in infants with CLD that found that non-Hispanic White patients liberated from the ventilator by 24 months of age and have public insurance had significantly greater odds of being decannulated by 48 months of age. 20 While ethnicity is a different social variable than socioeconomic status, these findings are also consistent with a recent paper that found children from lower socioeconomic groups use tracheostomy for 10 month longer than children from higher socioeconomic groups. 31 Together, these results suggest that even though children with CLD who use iHMV have complicated medical needs, social and health system factors still likely play an significant role in how long the children are using costly medical technologies.

To what degree variation in these outcomes are modifiable remains uncertain. But, identifying opportunities to equitably improve modifiable factors that impact duration of iHMV is increasing importance given new research demonstrating the longer iHMV duration is a likely barrier to motor and language development. 32 Concerted efforts are needed not only to safely reduce medically unnecessary iHMV use at home but also reduce the almost year long periods that children are spending awaiting hospital discharge. 33,34

Medical management prior to discharge, including standardizing the timing of the initiation of tracheostomy and ventilatory strategies are examples of modifiable opportunities to impact iHMV duration. 35 Non-medical delays such as the lack of home nursing25 and the need to standardize workflows and hospital procedures can be addressed through health service and policy interventions. 36 With this in mind, it is not so surprising that children who are discharged later will be on the ventilator at home for shorter periods of time, if what kept them hospitalized were the lack of social and health services as well medical considerations.

Lastly, we also found that slightly less than 10% of patients died while home with iHMV. Previous literature has identified ethical and logistical challenges providers and families face in discussing whether iHMV is the right medical choice for a given patient and their family. 9,37-39 Understanding how an individual child’s medical profile may impact the duration they may use iHMV and their probability of death at home, may facilitate a conversation regarding expectations for iHMV duration and acknowledgement of the realistic possibility of death after discharge home. Given the incredible constraints placed on patients and families using iHMV, the additional information provided in our study may further enrich these conversations by helping them more accurately prepare for and cope with the impact iHMV on their lives.

## Limitations and Future Work

As with any retrospective chart review, this approach had several limitations including missing data and historical bias due of removing patients who were cared for prior to electronic charting. Ventilator strategies and devices change over time which we were unable able to examine in this paper. For some of the relationships, the ability to detect differences was likely limited due to power. While we were able to examine whether the presence of a co-morbidities was associated with iHMV duration, we did not account for severity of those co-morbidities. However, our introduction of the variables *corrected tracheostomy age* and *level of ventilator use* provide new opportunities to further study of variability in iHMV care. Future multisite evaluations with higher power and more enriched medical variables may allow for exploration of more predictors with greater power.

# Conclusions

Children with CLD of prematurity who require iHMV are medically vulnerable patients who experience high family caregiving and healthcare costs. Identifying factors that impact duration of iHMV provides opportunities to mitigate iHMV’s impact on patients and families. We found disparity in iHMV duration among children using iHMV after prematurity, likely due to variability in both inpatient and outpatient management approaches. Prospective multisite studies that further elucidate which factors impact iHMV duration and that develop more standardized and equitable iHMV management strategies are needed.

# References

1. Cristea AI, Carroll AE, Davis SD, Swigonski NL, Ackerman VL. Outcomes of children with severe bronchopulmonary dysplasia who were ventilator dependent at home. *Pediatrics*. Sep 2013;132(3):e727-34. doi:10.1542/peds.2012-2990

2. Amin R, Sayal P, Syed F, Chaves A, Moraes TJ, MacLusky I. Pediatric long-term home mechanical ventilation: twenty years of follow-up from one Canadian center. *Pediatric pulmonology*. Aug 2014;49(8):816-24. doi:10.1002/ppul.22868

3. McDougall CM, Adderley RJ, Wensley DF, Seear MD. Long-term ventilation in children: longitudinal trends and outcomes. *Archives of disease in childhood*. Sep 2013;98(9):660-5. doi:10.1136/archdischild-2012-303062

4. Benneyworth BD, Gebremariam A, Clark SJ, Shanley TP, Davis MM. Inpatient health care utilization for children dependent on long-term mechanical ventilation. *Pediatrics*. Jun 2011;127(6):e1533-41. doi:10.1542/peds.2010-2026

5. Gowans M, Keenan HT, Bratton SL. The population prevalence of children receiving invasive home ventilation in Utah. *Pediatric pulmonology*. Mar 2007;42(3):231-6. doi:10.1002/ppul.20558

6. Wallis C, Paton JY, Beaton S, Jardine E. Children on long-term ventilatory support: 10 years of progress. *Archives of disease in childhood*. Nov 2011;96(11):998-1002. doi:10.1136/adc.2010.192864

7. Paulides FM, Plotz FB, Verweij-van den Oudenrijn LP, van Gestel JP, Kampelmacher MJ. Thirty years of home mechanical ventilation in children: escalating need for pediatric intensive care beds. *Intensive care medicine*. May 2012;38(5):847-52. doi:10.1007/s00134-012-2545-9

8. Hsia SH, Lin JJ, Huang IA, Wu CT. Outcome of long-term mechanical ventilation support in children. *Pediatrics and neonatology*. Oct 2012;53(5):304-8. doi:10.1016/j.pedneo.2012.07.005

9. Rahman M, Jeffreys J, Massie J. A narrative review of the experience and decision-making for children on home mechanical ventilation. *Journal of paediatrics and child health*. Jun 2021;57(6):791-796. doi:10.1111/jpc.15506

10. Meltzer LJ, Sanchez-Ortuno MJ, Edinger JD, Avis KT. Sleep patterns, sleep instability, and health related quality of life in parents of ventilator-assisted children. *Journal of clinical sleep medicine : JCSM : official publication of the American Academy of Sleep Medicine*. Mar 15 2015;11(3):251-8. doi:10.5664/jcsm.4538

11. Keilty K, Cohen E, Spalding K, Pullenayegum E, Stremler R. Sleep disturbance in family caregivers of children who depend on medical technology. *Archives of disease in childhood*. Feb 2018;103(2):137-142. doi:10.1136/archdischild-2016-312205

12. Meltzer LJ, Boroughs DS, Downes JJ. The relationship between home nursing coverage, sleep, and daytime functioning in parents of ventilator-assisted children. *Journal of pediatric nursing*. Aug 2010;25(4):250-7. doi:10.1016/j.pedn.2009.01.007

13. Feeley CA, Turner-Henson A, Christian BJ, et al. Sleep quality, stress, caregiver burden, and quality of life in maternal caregivers of young children with bronchopulmonary dysplasia. *Journal of pediatric nursing*. Jan-Feb 2014;29(1):29-38. doi:10.1016/j.pedn.2013.08.001

14. Fields AI, Rosenblatt A, Pollack MM, Kaufman J. Home care cost-effectiveness for respiratory technology-dependent children. *American journal of diseases of children (1960)*. Jul 1991;145(7):729-33.

15. Hazlett DE. A study of pediatric home ventilator management: medical, psychosocial, and financial aspects. *Journal of pediatric nursing*. Aug 1989;4(4):284-94.

16. McPherson ML, Shekerdemian L, Goldsworthy M, et al. A decade of pediatric tracheostomies: Indications, outcomes, and long-term prognosis. *Pediatric pulmonology*. Jul 2017;52(7):946-953. doi:10.1002/ppul.23657

17. Edwards JD, Kun SS, Keens TG. Outcomes and causes of death in children on home mechanical ventilation via tracheostomy: an institutional and literature review. *J Pediatr*. Dec 2010;157(6):955-959.e2. doi:10.1016/j.jpeds.2010.06.012

18. Rogerson CM, Beardsley AL, Nitu ME, Cristea AI. Health Care Resource Utilization for Children Requiring Prolonged Mechanical Ventilation via Tracheostomy. *Respiratory care*. Feb 4 2020;doi:10.4187/respcare.07342

19. Henningfeld JK, Maletta K, Ren B, Richards KL, Wegner C, D'Andrea LA. Liberation from home mechanical ventilation and decannulation in children. *Pediatric pulmonology*. Aug 2016;51(8):838-49. doi:10.1002/ppul.23396

20. Akangire G, Lachica C, Noel-MacDonnell J, et al. Outcomes of infants with severe bronchopulmonary dysplasia who received tracheostomy and home ventilation. *Pediatric pulmonology*. Nov 14 2022;doi:10.1002/ppul.26248

21. Baker CD. Mechanical Ventilation During Chronic Lung Disease. *Clin Perinatol*. Dec 2021;48(4):881-893. doi:10.1016/j.clp.2021.08.004

22. Collaco JM, Agarwal A, Austin ED, et al. Characteristics of infants or children presenting to outpatient bronchopulmonary dysplasia clinics in the United States. *Pediatric pulmonology*. Jun 2021;56(6):1617-1625. doi:10.1002/ppul.25332

23. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)--a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform*. Apr 2009;42(2):377-81. doi:10.1016/j.jbi.2008.08.010

24. Arnegard ME, Whitten LA, Hunter C, Clayton JA. Sex as a Biological Variable: A 5-Year Progress Report and Call to Action. *J Womens Health (Larchmt)*. Jun 2020;29(6):858-864. doi:10.1089/jwh.2019.8247

25. Sobotka SA FC, Lynch E, Hird-McCorry L, Goodman DM. Attributable Delay of Discharge for Children with Long-term Mechanical Ventilation. *J Pediatr*. 2019;

26. Thomson JE, Feinstein JA, Hall M, Gay JC, Butts B, Berry JG. Identification of Children With High-Intensity Neurological Impairment. *JAMA Pediatr*. Oct 1 2019;173(10):989-991. doi:10.1001/jamapediatrics.2019.2672

27. High Intensity Neurologic Impairment Codes Toolkit. Childrens Hospial Association. Updated Published March 6, 2019. https://www.childrenshospitals.org/content/analytics/toolkit/high-intensity-neurologic-impairment-codes.

28. Mahle WT, Newburger JW, Matherne GP, et al. Role of Pulse Oximetry in Examining Newborns for Congenital Heart Disease: A Scientific Statement from the AHA and AAP. *Pediatrics*. 2009;124(2):823-836. doi:10.1542/peds.2009-1397

29. National Center on Birth Defects and Developmental Disabilities CfDCaP. Centers for Disease Control, U.S. Department of Health & Human Services. Accessed Accessed May 23, 2022, https://www.cdc.gov/ncbddd/heartdefects/cchd-facts.html

30. Cristea AI, Baker CD. Ventilator weaning and tracheostomy decannulation in children: More than one way. *Pediatric pulmonology*. Aug 2016;51(8):773-4. doi:10.1002/ppul.23418

31. Smith MM, Hart CK, Benscoter DT, et al. The Impact of Socioeconomic Status on Time to Decannulation Among Children With Tracheostomies. *Otolaryngol Head Neck Surg*. Dec 2021;165(6):876-880. doi:10.1177/0194599820988501

32. Sobotka SA, Agrawal RK, Msall ME. Prolonged Hospital Discharge for Children with Technology Dependency: A Source of Health Care Disparities. *Pediatric annals*. Oct 1 2017;46(10):e365-e370. doi:10.3928/19382359-20170919-01

33. Sobotka SA, Foster C, Lynch E, Hird-McCorry L, Goodman DM. Attributable Delay of Discharge for Children with Long-Term Mechanical Ventilation. *Journal of Pediatrics*. 2019;212:166-171. doi:10.1016/j.jpeds.2019.04.034

34. Maynard R, Christensen E, Cady R, et al. Home Health Care Availability and Discharge Delays in Children With Medical Complexity. *Pediatrics*. Jan 2019;143(1)doi:10.1542/peds.2018-1951

35. McKinney RL, Napolitano N, Levin JJ, et al. Ventilatory Strategies in Infants with Established Severe Bronchopulmonary Dysplasia: A Multicenter Point Prevalence Study. *J Pediatr*. Mar 2022;242:248-252.e1. doi:10.1016/j.jpeds.2021.10.036

36. Baker CD, Martin S, Thrasher J, et al. A Standardized Discharge Process Decreases Length of Stay for Ventilator-Dependent Children. *Pediatrics*. Apr 2016;137(4)doi:10.1542/peds.2015-0637

37. Jabre NA, Raisanen JC, Shipman KJ, Henderson CM, Boss RD, Wilfond BS. Parent perspectives on facilitating decision-making around pediatric home ventilation. *Pediatric pulmonology*. Feb 2022;57(2):567-575. doi:10.1002/ppul.25749

38. Henderson CM, Raisanen JC, Shipman KJ, Jabre NA, Wilfond BS, Boss RD. Life with pediatric home ventilation: Expectations versus experience. *Pediatric pulmonology*. Oct 2021;56(10):3366-3373. doi:10.1002/ppul.25577

39. Boss RD, Henderson CM, Raisanen JC, Jabre NA, Shipman K, Wilfond BS. Family Experiences Deciding For and Against Pediatric Home Ventilation. *J Pediatr*. Feb 2021;229:223-231. doi:10.1016/j.jpeds.2020.10.014

# Appendix A. Timeline Framework for Children with Chronic Lung Disease of Prematurity Requiring Invasive Home Mechanical Ventilation

Figure shows a representative timeline of a child born prematurely requiring home mechanical ventilation from birth through decannulation. The focus of this study was area shown in shaded square, from initial discharge home with invasive mechanical ventilation until complete cessation of positive pressure ventilation during the night and day.



**Figure 1. Study Population**

Figure shows identification of eligible patients and reasons for patient exclusion.



**Figure 2. Invasive Home Mechanical Ventilation Duration**

Kaplan-Meier curve probability of the 119 patients remaining on home mechanical ventilation (iHMV) (y-axis) over time in months (x-axis). Patients censored for death or lost to follow-up. Remaining number of patients in cohort also indicated along x-axis. Solid black lines shows that 50% of the population weaned off iHMV by 36.3 months.

Chart, histogram

Description automatically generated

**Table 1. Study Population Demographics and Clinical Characteristics**

All values are n (%) unless otherwise indicated as mean with standard deviation (SD) or interquartile range (IQR) if skewed. N= 119 patients.

|  |  |
| --- | --- |
| **Characteristics** | n (%) |
| **Patient biological sex** |  |
| Male | 66 (55.5%) |
| Female | 53 (44.5%) |
| **Patient Race Ethnicity** |  |
| Non-Hispanic White | 32 (26.9%) |
| Non-Hispanic Black | 42 (35.3%) |
| Hispanic/Latinx | 22 (18.5%) |
| Asian | 7 (5.9%) |
| Mixed, other or unknown | 16 (13.5%) |
| **Insurance Type** |  |
| Any Public | 80 (67.3%) |
| Private only | 36 (30.3%) |
| Other or unknown | 3 (2.5%) |
| **Birth Information** |  |
| Gestational age, mean (SD) | 26.0 (1.9) |
| Corrected gestational age, mean (SD) | 38.1 (19.3) |
| Birthweight, mean (SD) | 765.5 (0.3) |
| **Comorbidities** |  |
| Pulmonary hypertension ever | 91 (76.4%) |
| Pulmonary hypertension at discharge | 68 (57.1%) |
| High-intensive neurologic impairment | 25 (21.0%) |
| Complex congenital heart condition | 15 (12.6%) |
| **Index Hospitalization Information** |  |
| Age at discharge (months), median (IQR) | 12.0 (8.9,14.4) |
| Corrected tracheostomy age (weeks), median (SD) | 37.9 (23.1) |
| Oxygen use at discharge | 59 (49.6%) |
| Length/Height Z score at discharge, mean (SD) | -3.18 (SD 3.17) |
| Proportion on ventilator 24/7 at discharge | 108 (91%) |
| Level of ventilatory support at discharge ((L/kg/day), mean (SD)¥ | 3,309.6 (SD 1,275.0) |
| **Outpatient Primary Pulmonologist** |  |
| Pulmonologist A | 79 (66.4%) |
| Pulmonologist B | 29 (24.4%) |
| Pulmonologists Grouped | 11 (9.2%) |
| ¥ Missing n=23. |  |

**Table 2. Unadjusted Cox Regression Analysis Invasive Home Mechanical Ventilation Duration**

The table shows 4 mutually exclusive outcomes in months: time to weaning off positive pressure of home mechanical ventilation (iHMV), ongoing use of iHMV at time of study end, death or lost to follow-up (N=119).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Patient outcomes** | n (%) | Mean | Std Dev | Minimum | 25th Pctl | Median | 75th Pctl | Maximum |
| Patients weaned off positive pressure iHMV | 58 (49%) | 29.69 | 19.82 | 0.20 | 16.67 | 25.87 | 37.38 | 113.74 |
| Patients still on iHMV | 38 (32%) | 29.06 | 21.81 | 4.14 | 14.04 | 23.64 | 32.38 | 99.15 |
| Patients lost to follow-up | 14 (12%) | 20.05 | 17.96 | 0.72 | 7.32 | 16.08 | 26.88 | 65.03 |
| Patients who died after starting iHMV | 9 (7%) | 17.16 | 19.68 | 2.83 | 7.63 | 12.2 | 15.35 | 67.52 |

**Table 3. Univariable Cox Regression Analysis of Home Mechanical Ventilation Duration**

Table shows univariable hazard ratios comparing variables association with invasive home mechanical ventilation duration. 95% confidence intervals show in parentheses. P<0.05 was considered significant.

|  |  |  |
| --- | --- | --- |
| **Patient-level factors** | **Survival HR** | **P-value** |
| **Patient biological sex** |  |  |
| Female versus male | 1.13 (0.67, 1.91) | 0.64 |
| **Patient Race Ethnicity** (compared to Non-Hispanic White) |  |  |
| Non-Hispanic Black | 0.82 (0.42, 1.57) | 0.54 |
| Hispanic/Latinx | **0.31 (0.13, 0.71)** | **<0.01** |
| Asian | 0.58 (0.17, 2.00) | 0.39 |
| Mixed, other or unknown | 0.48 (0.20, 1.11) | 0.09 |
| **Insurance Type** (compared to other/unknown) |  |  |
| Any Public | 0.53 (0.07, 3.95) | 0.54 |
| Private only | 0.88 (0.12, 6.63) | 0.9 |
| **Birth Information** |  |  |
| Gestational age (standardized) | 0.99 (0.75, 1.32) | 0.95 |
| Corrected gestational age | **0.60 (0.43, 0.84)** | **<0.01** |
| Birthweight (standardized) | 1.07 (0.79, 1.44) | 0.67 |
| **Comorbidities** (absent compared to present) |  |  |
| Pulmonary hypertension ever | 0.83 (0.45, 1.54) | 0.56 |
| Pulmonary hypertension at discharge | 1.03 (0.60, 1.76) | 0.93 |
| High-intensive neurologic impairment | **0.38 (0.18, 0.78)** | **<0.01** |
| Complex congenital heart condition | 1.10 (0.39, 3.06) | 0.86 |
| **Index Hospitalization Information** |  |  |
| Age at discharge (standardized) | **0.61 (0.44, 0.84)** | **<0.01** |
| Corrected tracheostomy age (standardized) | **0.69 (0.53, 0.91)** | **<0.01** |
| Oxygen use at discharge (non-use compared to use) | 0.65 (0.38, 1.10) | 0.11 |
| Length/Height Z score at discharge (standardized) | 0.90 (0.72, 1.13) | 0.36 |
| On ventilator 24/7 at discharge versus partial day use | 0.50 (0.22, 1.11) | 0.09 |
| Level of ventilatory support at discharge (standardized)¥ | **0.69 (0.48, 0.99)** | **0.04** |
| **Outpatient Primary Pulmonologist** (compared to Pulmonologist A) |  |  |
| Pulmonologist B | **0.46 (0.22, 0.98)** | **0.04** |
| Pulmonologist group | 1.88 (0.67, 5.27) | 0.23 |
| ¥ Missing n=23. |  |  |

**Table 4. Multivariable Cox Regression Analysis for Invasive Home Mechanical Ventilation Duration**

Table shows multivariable hazard ratios comparing variables association with invasive home mechanical ventilation duration. 95% confidence intervals show in parentheses. P<0.05 was considered significant.

|  |  |  |
| --- | --- | --- |
| **Patient-level factors** | **Survival HR** | **P-value** |
| **Patient Race Ethnicity** (compared to Non-Hispanic White) |  |  |
| Non-Hispanic Black | 0.49 (0.21, 1.13) | 0.09 |
| Hispanic/Latinx | **0.14 (0.04, 0.53)** | **<0.01** |
| Asian | 0.55 (0.12, 2.57) | 0.4443 |
| Mixed, other or unknown | 0.37 (0.14, 1.01) | 0.05 |
| **Comorbidities** (absent compared to present) |  |  |
| High-intensive neurologic impairment | 0.67 (0.26, 1.74) | 0.41 |
| **Index Hospitalization Information** |  |  |
| Corrected tracheostomy age (standardized) | **0.66 (0.43, 0.98)** | **<0.05** |
| Level of ventilatory support at discharge (standardized) | 0.72 (0.49, 1.07) | 0.11 |
| **Outpatient Primary Pulmonologist** (compared to Pulmonologist A) |  |  |
| Pulmonologist B | 1.37 (0.28, 6.80) | 0.70 |
| Pulmonologist group | 0.59 (0.26, 1.36) | 0.22 |