

Paediatric Long-Term Home Respiratory Support: Recommendations of the Swiss Society of Paediatric Pulmonology.

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Over the past 2 or 3 decades, there has been a steady increase in the number of children receiving long-term home respiratory support (HRS) [1]. This trend can be attributed to several factors, including advancements in medical technologies and novel therapies, such as treatments for spinal muscle atrophy (SMA). These advances have improved survival rates and heightened awareness of sleep-related breathing disorders (SRBDs), leading to more widespread screening in at-risk populations, such as patients with neuromuscular disorders (NMDs) or trisomy 21, and the availability of home-based ventilation systems [2 , 3]. Additionally, ventilators designed specifically for children and infants, as well as tailored interfaces like masks for non-invasive ventilation (NIV), have become more accessible. The evolution of ethical perspectives has further supported this shift. Consequently, many patients who would not have survived to adulthood only a few decades ago now transition to adult care, necessitating that specialists develop expertise in the management of these complex conditions.

When caring for children requiring long-term respiratory support, several general considerations should be kept in mind. Firstly, there is an exponential increase in the number of children being considered for such support. Secondly, the complexity of cases with HRS is steadily increasing. Thirdly, each patient requires an individualized approach, as is applied across a highly heterogeneous spectrum of diseases. Fourthly, multiple coexisting factors, such as obesity, bronchial aspiration leading to secondary pneumopathy, muscle weakness, central causes, or upper airway collapse (e.g., in cerebral palsy), must be considered, as they can influence the indication for respiratory support and can contribute to chronic respiratory failure.

Close follow-up is essential for children on long-term respiratory support to tailor the care plan to their growth and disease progression and to assess therapy adherence, a task often challenging in paediatrics. Neurocognitive impairment is common among this patient population and can significantly impact therapy feasibility and implementation. Many children who require long-term respiratory support present with comorbidities affecting multiple organs, often within the context of complex chronic disorders. This necessitates a multidisciplinary approach, with care ideally coordinated through a case manager, or preferably, an integrated care model. For families caring for a child with special needs, this situation can impose a significant financial burden and negatively affect the health of other family members, leading to issues such as sleep disturbances or psychological stress [4 , 5].

This article provides comprehensive paediatric recommendations for Switzerland, including indications and guidance on establishing an optimal care team. It outlines the necessary materials and equipment and their practical applications, and further addresses therapeutic education,

follow-up procedures, ethical considerations, and the transition to adult care [1].

All members of the “Special Interest Group in paediatric Home Mechanical Ventilation” of the Swiss Society of Paediatric Pulmonology (SSPP) were invited to participate in a task force aiming at establishing recommendations on paediatric long-term HRS in Switzerland. These recommendations are based on an extensive review of the medical literature over the past 5 years through PubMed, of other national guidelines, and of the specifics of paediatric care for long-term HRS in Switzerland.

Following the 2022 European Respiratory Society (ERS) statement on paediatric long-term non-invasive respiratory support [5] that included publications up until September 2019, we performed a MEDLINE search for the period running from October 2019 until May 2023. Search terms were those cited in the ERS publication (“Continuous Positive Airway Pressure” “CPAP,” “NCPAP,” “bi-level ventilation,” “BPAP,” “BiPAP,” “airway pressure release ventilation,” “APRV,” “noninvasive ventilation,” “NIV,” “NPPV,” “NIPPV,” “NIAV,” or Invasive Ventilation “IV” with a child and adolescent search filter). Inclusion criteria were articles published in English for humans aged <18 years. Exclusion criteria were articles not published in English, as well as those concerning neonatology or intensive care settings, acute or emergency conditions, acute infections, COVID-19, or case reports. We also took into account recent national guidelines from German- and French-speaking countries that we are familiar with. Two independent reviewers (R.C. and I.R-M.) screened a total of 592 articles, of which 260 met the inclusion criteria.

The final text was discussed in depth among the members of the SSPP's Special Interest Group in paediatric Home Mechanical Ventilation to reach a consensus. This document focuses on HRS that covers also mechanical ventilation delivered in long-term care institutions, providing indications, modalities, and follow-up recommendations for patients on HRS (e.g., continuous positive airway pressure [CPAP], NIV, IMV, etc.). This document does not cover NIV in the acute setting (emergency ward, intensive care unit [ICU], acute-care hospital wards) or the adult population.

Long-term mechanical ventilation is feasible at any age, including in newborns and infants [6 , 7]. In younger patients, invasive ventilation (IV) is often preferred to NIV due to factors such as underlying pathology, physiologically longer sleeping hours, and the unavailability of appropriately sized masks for NIV.

The medical conditions necessitating long-term mechanical ventilation are diverse and often overlap in individual patients (Table 1). Depending on the underlying pathology and the progression of the disease, it is sometimes possible to transition from IV to NIV (e.g., in cases of congenital central hypoventilation syndrome) [8] or, conversely, from NIV to IV (e.g., in NMDs) [9].

Paediatric conditions leading to the need for long-term mechanical ventilation

Central muscle tone dysregulation (e.g., trisomy 21, cerebral palsy)

Chronic lung disease from premature birth

Chest wall deformities syndromes (e.g., Jeune syndrome)

Congenital malformation of airways (e.g., Pierre Robin sequence)

Multilevel airway obstruction (e.g., trisomy 21, VACTERL association)

Brain stem lesions (e.g., tumour, syrinx, inflammatory)

Brain stem compression (e.g., Arnold-Chiari malformation, achondroplasia)

Genetic disorders (e.g., Rett syndrome, ROHHAD)

CCHS, congenital central hypoventilation syndrome; DMD, Duchenne muscular dystrophy; ENT, ear, nose and throat; NMD, neuromuscular diseases; OSA, obstructive sleep apnoea; ROHHAD, rapid-onset obesity with hypothalamic dysfunction, hyperventilation and autonomic dysregulation; SMA, spinal muscular atrophy; VACTERL, vertebral defects, anal atresia, cardiac malformations, trachea-oesophageal fistula, renal anomalies and limb abnormalities.

Initiation criterion for respiratory support in children is a subject that is still sparsely discussed in the literature in an integrated approach. Standardizing decisions on measured values is only a piece of the puzzle and depends on the underlying disease and the individual clinical and social conditions.

Medical indications: The decision to initiate ventilation is primarily guided by the medical needs of the child.

Feasibility for the child and family: An individualized approach with every decision tailored to the unique circumstances of the patient and family, ensuring that medical, practical, and ethical concerns are balanced [10].

Multifactorial assessment: The decision to introduce ventilation should not rely on a single parameter but rather on a comprehensive evaluation. Major factors to consider include the following:

Severity and duration of symptoms: Assess the severity and length of symptoms, with specific thresholds guiding initiation.

The presence of clinical indicators should inform the decision, such as increased work of breathing while awake, failure to thrive, recurrent respiratory infections, or symptoms of SRBD (e.g., snoring, choking, or gasping during sleep) [5 , 11].

Abnormal gas exchange: Identify significant deviations in gas exchange values.

Oxygen levels: Similarly, oxygen thresholds lack consensus and should be contextualized within clinical findings.

Capnia levels: While there is no consensus on acceptable levels, ERS guidelines provide general reference points. Nocturnal hypoventilation is defined by the American Academy of Sleep Medicine (AASM) as $pCO_2 > 50$ mm Hg for $> 25\%$ of total sleep time. Other sources propose a more restrictive definition, which should also be considered in clinical decision-making [5]. For example, thresholds for NMDs may be stricter [12].

The assessment of sleep integrity and the presence of sleep apnoea as contributing factors are important based on polysomnographic or polygraphic findings using paediatric index values.

Lung function measurements could also be considered (e.g., a decline in vital capacity).

Special consideration for specific illnesses, such as SMA or NMDs, must be made by medical teams in charge of the patient.

HRS for Infants and Young Children (1–23 Months Old) with Obstructive Sleep Apnoea . Obstructive sleep apnoea (OSA) severity should be determined based on polysomnographic findings. Where polysomnography (PSG) is unavailable, polygraphy (PG), or at least

oxi-capnometry, can be considered as alternative diagnostic tools. An obstructive apnoea-hypopnea index (AHI) $\geq 1/h$ is considered abnormal at this age. Whether HRS is indicated depends on numerous other factors, and expected benefits must be carefully weighed against treatment burden and expected outcome [11].

These additional factors influencing the decision include the presence of comorbidities (e.g., craniofacial malformations); risk factors, including developmental delays, growth issues, or a history of a brief resolved unexplained event; apparent upper airway obstruction during wakefulness; or the occurrence of recurrent infections.

HRS for Children with Persistent OSA (2–18 Years Old) . According to the ERS Guidelines, HRS therapy should be considered when OSA persists after a stepwise approach. Persistent OSA (6 to 9 months) is defined based on a sleep study, with a recommendation for HRS as follows: (1) AHI $>5/h$ – HRS is recommended irrespective of the presence of morbidity; (2) AHI 1–5/h – treatment may still be beneficial, especially in the presence of cardiovascular morbidity, central nervous system morbidity, enuresis, somatic growth delay or growth failure, decreased quality of life, or risk factors for persistent SRBD [13].

If diagnostic tools such as PSG or PG are unavailable for SRBD patients, treatment may be considered based on positive oxi-capnometry findings, validated SRBD questionnaires, or evidence of morbidity. For these patients, HRS can also be a first-line treatment in cases where other interventions (e.g., adenotonsillectomy) are not indicated or feasible.

The American Thoracic Society (ATS) recommendations for persistent OSA are stricter, defining persistent OSA as AHI $>1/h$. They propose to consider HRS therapy for children with persistent OSA and who are not candidates for surgery. While HRS or surgery was historically reserved for cases of AHI $\geq 5/h$, this treatment option is now increasingly considered for children with milder symptoms but persistent morbidity. A more precise definition and additional criteria relating to persistent OSA remain to be better defined in order to improve future patient care [14].

The decision to initiate IV should be made by the physician, considering all relevant clinical factors, including patient history, the severity of respiratory failure, and the expected evolution. If a patient requires NIV for more than 16 h per day, this may indicate the need for IV [15]. Some patients may even stay for 24 h under NIV, especially those capable to use mouthpiece ventilation.

In neonates and young infants, invasive long-term ventilation is often required in conditions such as severe chronic respiratory failure, including bronchopulmonary dysplasia, childhood interstitial lung diseases, congenital central hypoventilation syndrome, or NMDs. Patients may also require IV if they fail to wean from a ventilator in the ICU as following surgery or in the case of spinal cord or brainstem injuries/lesion and if weaning to NIV is not feasible.

For patients with progressive diseases who require ventilatory support, the potential need for IV should be evaluated early. The possibility of transitioning to IV should be addressed openly with the patient and family, respecting the patient's preferences in decision-making. These criteria emphasize early assessment, continuous monitoring, and involving the patient and their family in discussions around the need for IV (Table 2).

Criteria to consider before initiating home mechanical ventilation in children

AHI, apnea-hypopnea index; $p_{tc} CO_2$, transcutaneous estimation of $PaCO_2$; SRBD, sleep-related breathing disorders.

Initiating respiratory support in children, especially those with complex or chronic conditions, is a multifaceted decision that requires careful consideration and a multidisciplinary approach. The SIG group recommends taking into account the following points in the decision-making process: 1.

Indications for long-term ventilation: Long-term HRS may be justified when the child has been unable to wean from IV or CPAP/NIV after being treated in the paediatric intensive care unit (PICU). Weaning failure may indicate that the child's respiratory system requires ongoing support, either due to chronic disease or insufficient recovery.

Ventilation strategy in newborns: For newborns, both term and preterm, a gradual transition from permissive ventilation to targeted eucapnic ventilation will facilitate the optimal ventilatory support in the evolving respiratory system of the child.

Screening for SRBD: Children with conditions that increase the risk of SRBD – such as craniofacial malformations or NMDs – should undergo PSG or PG prior to elective surgery. If SRBD is confirmed, HRS should be considered to minimize perioperative risks, including failed extubating or difficulties during recovery from anaesthesia. This proactive measure may help prevent complications and reduces the risk of intraoperative complications. In addition, prior difficult airway experiences, i.e., failed extubation, or prolonged recovery period should be inquired and addressed prior to surgery.

Hospital and intensive care competence in paediatric respiratory support: The hospital in which respiratory support is initiated should be equipped with a PICU or within a hospital network with established links to a specialized paediatric centre, as initiation carries risks, including complications that may require advanced monitoring and immediate medical intervention. For complex or high-risk patients, the hospital team should be well versed in paediatric respiratory care and have access to resources for managing potential complications.

Technical progress in interfaces and machines should always be checked against individual patient needs, taking into account the patient's and family's quality of life. Anatomical barriers for ventilatory support include mid-face anomalies for NIV or a short neck for tracheostomy.

When using HRS, several factors must be taken into consideration and adapted to the specific situation, considering both the patient's age and clinical context. Prolonged use of CPAP or NIV beyond 12–16 h per day might indicate that more intensive ventilatory support (IV) is needed.

Uncontrolled or severe gastroesophageal reflux can increase the risk of aspiration, which may require invasive management.

Inadequate swallowing function or bulbar involvement that leads to aspiration risk.

If the patient cannot adequately protect his/her airway, such as in cases of neurological impairment, non-invasive options may not be sufficient and IV with a cuffed tracheal cannula would be needed.

Recent upper airway or craniofacial surgery in these areas can compromise the effectiveness or safety of CPAP or NIV.

If optimal CPAP or NIV cannot correct issues such as OSA or hypoventilation/hypercapnia, if children remain dyspnoeic, or if a proper interface (mask or nasal cannula) cannot be adequately fitted to the patient, IV may be considered.

If the patient cannot tolerate the mask or device, it may not be a sustainable option.

Lack of cooperation from patient and/or family with a non-compliance or unwillingness to use CPAP or NIV effectively.

In some situations, initiating IV may not be appropriate. These include the following: If the prognosis is poor and further medical interventions, including IV, are unlikely to provide meaningful benefit, it

may not be appropriate to proceed with IV.

Certain anatomical or medical conditions, such as a short neck, may preclude the possibility of performing a tracheostomy, making IV less feasible or safe.

IV should not be initiated if it goes against the expressed wishes of the patient or their family. If the patient or parents are unfit to decide, we could proceed as the patient's best care stands first. Shared decision-making is crucial in these circumstances [16].

There may be ethical concerns surrounding the use of IV, particularly if it contradicts principles such as autonomy, the patient's quality of life, or the potential for suffering [17 , 18].

These factors emphasize a patient-centred, ethical approach to decision-making, where both clinical guidelines and individual patient preferences are considered.

NIV in younger children is often initiated in hospital [19]; however, no data are available on the impact of initial setting location (PICU, ward, ambulatory) on long-term NIV efficacy and adherence [19]. Literature suggests that CPAP may be initiated at home [20] or in the outpatient clinic [21]. In contrast, invasive HRS must be initiated in hospital, in a well-controlled setting, usually the PICU.

When considering outpatient initiation on ventilation, certain key factors need to be met to ensure treatment safety and effectiveness. These include the following: Stability of the patient:

The patient should be in a stable clinical condition, with no acute exacerbations.

Adequate management of any underlying medical condition should be set up to prevent complications during outpatient treatment.

Children who are older than kindergarten or primary school age are considered suitable candidates for outpatient initiation. Younger children may need more intensive monitoring and care, which may require inpatient initiation.

However, age alone is not a strict determinant, and this criterion should be adjusted based on the specific needs of the child and family.

Regular follow-up and monitoring are essential to track the patient's response to treatment and adjust care as needed.

A monitoring plan must be established, and the appropriate mode of monitoring (e.g., pulse oximetry, capnography, etc.) should be discussed and agreed upon by the healthcare team.

Parents and caregivers must feel comfortable and confident in managing the ventilation equipment, including using and maintaining the devices, and responding to any emergencies or complications.

This may include training on equipment use, troubleshooting, and emergency procedures.

Healthcare team expertise to begin ventilation:

The healthcare team should have expertise in managing patients considered for outpatient ventilation, including knowledge of the specific type of ventilation used, and monitoring strategies for outpatient management.

A multidisciplinary approach involving respiratory therapists, nurses, and physicians may be necessary to ensure comprehensive care. These minimal requirements aim to ensure that the

outpatient initiation of ventilation is safe, effective, and sustainable for the healthcare team, the patient, and their family.

Initiating respiratory support at home without the full resources of a hospital setting is not recommended in children due to the associated risks, including the lack of immediate access to medical expertise, monitoring, and advanced interventions. HRS should only be considered once the child has been properly stabilized and managed in the hospital, and the family has received clear protocols for ongoing home care.

A multidisciplinary team approach is essential for delivering optimal care when considering ventilation, to ensure that children receive the appropriate respiratory support. Each team member's expertise should combine experience in both paediatric and neonatal intensive care, to ensure that children across all age ranges can be managed effectively and safely. Collaboration among paediatric medical doctors, nurses, physiotherapists, and other specialists is key to providing holistic care tailored to each child's individual needs.

When transitioning to home care, a compromise must be found between ensuring the best possible safety for the child and meeting the realistic requirements of the family and caregivers. Aspects to consider include the child's medical needs and the family's capacity to provide the necessary care. The requirements for care team support at home depend on several factors. Mode of HRS (e.g., NIV vs. tracheostomy).

Degree of ventilator dependence (whether the child can breathe spontaneously for certain periods).

Cognitive and neuromuscular capacity of the patient (degree of independence of the child has, and level of assistance needed).

Degree of caregiver comfort, which can vary widely among families.

The ATS recommends that a trained caregiver should always be present in the home when a child requires chronic IV. At least two family member caregivers should be trained to provide care to ensure constant coverage. Professional healthcare providers are not required to always be present at home but must be available for guidance and emergency situations. It is essential that 7/7 technical support is available for children on invasive HRS. This should include a hospital backup, ensuring a hospital team is available for emergencies or guidance, including trained professionals who can assist with routine outpatient care and emergency situations, a paediatrician able to provide ongoing health care and coordinate with specialists when necessary, and social workers to support the family with emotional, logistical, and financial challenges that may arise from the complex care needs [22]. Material support to ensure ventilator replacement including other devices as suctioning device needs to be available 24 h/day 7/7.

The content of training for parents and caregivers is crucial but often not clearly defined. Ideally, standardized training on routine care and emergency measures should be provided to improve the confidence and competence of caregivers. The education programmes should focus on (1) routine care (e.g., managing ventilator equipment, airway clearance, monitoring respiratory status) and (2) recognition and management of emergencies (e.g., dealing with ventilator malfunctions, respiratory distress, or aspiration events).

1. Children dependent on invasive HRS: Children who are HRS-dependent should receive care in hospitals equipped with a PICU or within hospital networks with established links to a specialized paediatric centre. These patients are at increased risk of complications and require complex, multidisciplinary care, including regular follow-up, specialized equipment management, and coordinated support for both the child and family.

Multidisciplinary approach to decision-making: Clinical, feasibility, and quality of life considerations need to be considered when considering HRS. The decision should balance clinical aspects (e.g., severity of respiratory failure), feasibility for both the child and family, and the potential impact on clinical outcomes and quality of life. Involvement of a multidisciplinary team ensures that all relevant aspects, including medical, psychological, social, and practical considerations, are considered. This team should typically include paediatric pulmonologists or intensivists, paediatricians, nurses, physiotherapists, psychologists, and social workers.

Shared decision-making: For children with complex chronic diseases, shared decision-making between the medical team and parents and family is essential. The decision should be reached based on a consensus of the interdisciplinary team, ensuring that the family's values, preferences, and goals are respected. Engaging in open and transparent communication with the family fosters trust and helps them understand the potential benefits and challenges of respiratory support, whether CPAP, NIV, or IV.

Avoiding decision-making in acute settings for long-term ventilation: Whenever possible, decisions regarding long-term ventilation should not be made during an acute crisis or exacerbation. Acute settings may lead to rushed decisions without the time to accurately assess the full picture or to involve all key stakeholders. Elective or planned decisions about long-term respiratory support are preferable to allow for proper planning, family involvement, and a clear understanding of the child's needs.

Advanced care plans: An advanced care plan should be developed before initiating HRS. This plan should be created in collaboration with the child (if age-appropriate), the parents, and the interdisciplinary team. Advanced care planning helps ensure that the family and medical team are aligned on treatment goals, particularly for long-term conditions, and addresses issues such as do-not-resuscitate orders, escalation of care decisions, and the goals of care in case of complications.

There are two distinct types of respiratory devices, each serving a unique purpose: life support devices and non-life support devices (Table 3). The performance of ventilators may not always be optimal for paediatric patients, particularly in terms of trigger sensitivity. Therefore, they must be carefully adjusted to suit each patient's specific needs. Additionally, these devices are typically approved by manufacturers with specific minimum weight requirements. It is currently recommended that a single-limb circuit with intentional leaks is safely utilized in out-of-hospital settings, including for IV [16].

Non-exhaustive list of ventilators with their specificities used in children

CPAP, continuous positive airway pressure; IV, invasive ventilation; NIV, non-invasive ventilation; Vt, tidal volume.

The selection of a ventilator or HRS device is determined by the patient's medical needs and individual characteristics. The lack of standardized nomenclature for modes and settings results in significant variability between manufacturers and devices.

Due to weight restrictions of various devices, life support devices are often utilized for very young children, even if they are not entirely dependent on them. The constant pressure (CPAP)p is the first-line treatment for paediatric SRBD.

More advanced modes, such as auto-CPAP, are reserved for selected patients. High-flow nasal cannula (HFNC) may be considered an alternative treatment for patients intolerant to CPAP.

Tracheotomized patients should always be equipped with a device approved for IV. A backup life support device will become necessary when dependence on respiratory support exceeds 16 h per

day [5].

Setting ventilatory parameters must consider each patient's unique physiological and respiratory characteristics. For a purely obstructive respiratory pattern, such as persistent OSA, titration with CPAP alone may suffice [23 – 27]. In contrast, patients with a mixed central and obstructive pattern, as seen in neuromuscular conditions, require a tailored approach. This includes determining the optimal mean airway pressure for oxygenation, achieving the best minute ventilation (MV), and incorporating a backup respiratory rate (BURR) to effectively regulate PCO₂ levels.

The AASM recommends using titration in ventilation initiation with a PSG to determine optimal inspiratory positive airway pressure (IPAP) and expiratory positive airway pressure (EPAP) levels [28]. However, adequate titration may also be achieved without a full PSG or with a PG only [29 , 30]. In addition, other objective assessment tools exist to help titrate settings and to achieve clinical efficacy [28 , 29 , 31].

The choice of ventilation is also a matter of debate. Indeed, even if initiating CPAP in children with OSA is considered safe, it does not show superiority over bi-level pressure ventilation in terms of comfort and adherence [32]. In contrast, HFNC may serve as a more tolerable alternative treatment for paediatric OSA, though current evidence supporting its efficacy remains limited [33].

The different ventilatory modes available are dependent on treatment goals and the patient's needs, including bi-level, pressure control, volume control, trigger types, and variations in inspiratory time. The starting pressures could be EPAP: 4 centimetres of water (cm H₂O), or IPAP: 8 cm H₂O [34 – 36]. To address alveolar hypoventilation, a tidal volume of 6–10 mL·kg⁻¹ is recommended. Sometimes, higher pressure levels may be necessary for children with advanced disease or requiring IV [37]. The suggested NIV parameters after titration include IPAP: 10–14 cm H₂O and EPAP: 4–6 cm H₂O.

For CPAP, the mean level required to resolve respiratory events is generally 8 ± 3 cm H₂O following titration [5 , 23 , 24]. In morbidly obese patients, very high CPAP may be required and switching to bi-level positive airway pressure may then improve comfort.

It is important to highlight that for children with an NMD, pressure levels are largely age-independent [34] and a BURR is commonly applied, as in children with an impaired central drive. Typically, the respiratory rate should be set to 2–3 breaths around the patient's breathing rate [35 , 37 , 38].

An essential aspect of HRS is selecting the appropriate interface. Comparing performance, adherence, and complication risks among mask interfaces in paediatric patients is challenging as shown in Figure 1 . Most available data are derived from adult studies. Close monitoring and a proactive approach are crucial to minimize complications and optimize the use of HRS in home settings. Interfaces can be categorized into five types: nasal mask, oronasal mask, full-face mask, nasal prongs, and mouthpiece [39]. 1. Nasal masks/nasal prongs are well tolerated, pose minimal risk of aspiration, and allow for effective communication with the patient. Nasal masks are safer because they allow unimpaired spontaneous breathing in case of equipment failure. An optimal fit of the nasal mask with no leak despite minimal tension of the straps improves comfort and compliance and reduces the risk of mid-face hypoplasia.

Oronasal or full-face masks help reduce mouth leaks but may limit communication capabilities. They are associated with a higher risk of aspiration, potential skin injuries, and lower tolerance [40 – 42].

Mouthpieces are suitable only for awake and cooperative patients who can create a seal around the mouthpiece with their lips. These devices enable communication and pose no risk of aspiration or

skin injury.

Types of masks with age-related specificities. Adapted from Khirani and Ducrot [43].

The choice of interface depends on several factors, including the provider's experience, the availability of interfaces that suit the patient's morphology, the patient's tolerance, and the ability to meet initial respiratory support goals [30 , 44]. The selection of the correct size for a tracheal cannula is also critical. Indeed, to enable vocalization or speech, the cannula must provide enough space around the trachea for adequate airflow flux. For this reason, the type of tracheal cannula should be tailored to the patient's needs, and testing distinct types may help identify the most suitable option.

HFNC has shown promise in various settings; however, its use in home paediatric ventilation should always be guided by professional clinical judgement and tailored to individual patient needs. HFNC is a safe and effective method for improving oxygenation and reducing the work of breathing through the delivery of continuous humidified air/oxygen, and it also tends to be better tolerated and accepted by children. The enhanced comfort provided by this respiratory support device often leads to greater satisfaction among patients and their parents. However, HFNC has no internal battery and needs sector electricity. Additionally, its cost-effectiveness in reducing hospital admissions is currently under evaluation. Current HFNC indications are as follows: Obstructive sleep apnoea syndrome (OSAS) [45 , 46].

Severe forms of childhood interstitial lung disease and end-stage cystic fibrosis [42].

In case of intolerance to the NIV or CPAP mask, the RAM cannula or the Optiflow™ interface can be considered [41 , 42].

Double-limb systems provide precise measurements of tidal volume and MV. They offer a better trigger performance, leading to improved control of MV [21]. However, HRS is typically delivered via single-tube systems with a standardized intentional leak. The decision between these systems should be made by experienced paediatric medical professionals based on the child's clinical needs, particularly if IV is necessary. If the ability to speak is a priority , double-limb systems are not suitable.

Non-humidified NIV is often less comfortable and can lead to problems associated with thick secretions. An adult study showed that humidified CPAP resulted in fewer adverse upper airway symptoms and better therapy adherence in patients with OSA. However, other studies failed to demonstrate improved adherence with humidified therapy [48 , 49].

For children, an active humidification on NIV at home is optional [21 , 48 – 51]. Nevertheless, children with mucociliary clearance problems and/or cough insufficiency should be equipped with active humidification while on NIV. In addition, patients with a significant mouth leak or ventilated by face mask due to an increased nasal resistance will also benefit from active humidification.

Heat and moisture exchanger (HME) filters are less efficient than active humidification but can improve tolerance for spontaneous breathing in tracheotomized children. However, it is important to consider the additional resistance and dead space they add to the ventilatory circuit. For these reasons, the use of HME is limited for some children. In invasively ventilated children, HME may be used for specific periods, such as during transport or outdoor activities [52]. It is important to highlight that insufficient humidification can lead to thicker secretions, increasing the risk of cannula occlusion. In the literature, only one adult study found higher rates of endotracheal tube occlusion with HME compared to active humidification [53].

Heating of the tubing helps reduce condensation [54], leading to turbulent airflow, which may participate in patient-ventilator asynchrony (e.g., auto-triggering) or result in the spillage of

condensate into the patient's mask/airway. Smaller children are particularly vulnerable to these issues.

To avoid heating trouble, it is proposed to heat the tubing to enhance treatment adherence. The need for heating depends on the initial pathology, the patient's age, and the type of ventilation used. Adjustments should be tailored to individual patient needs. The heating temperature varies between 34° for NIV and 37° for IV. To avoid mould developing, the water present in the humidifier needs to be changed every day. Heated humidification and HME are the two most used methods of artificial humidification in ventilated patients. However, HME should be carefully evaluated in patients with limited respiratory reserve due to the resistance it may induce.

Each centre should define a limited set of devices for each type of respiratory support (life support, life sustaining, CPAP). This allows a better knowledge of the material by all team taking care of these patients.

The selection of a device should be based on the child's characteristics, medical needs, and the preferences of the paediatric care team.

Off-label use of some devices may need to be considered for selected patients (e.g., life support device in infants with need of CPAP, toddlers' CPAP device although approved at >30 kg).

Bi-level positive pressure support ventilation in spontaneous/timed mode (S/T) is commonly used in clinical practice.

Starting inspiratory and expiratory pressures are set at 8 cm H₂O and 4 cm H₂O, respectively, with a final IPAP of 10–14 cm H₂O and EPAP of 4–6 cm H₂O. Pressures, however, must be tailored to patient's needs, and pressures outside the recommended range might be required both for EPAP and for IPAP for selected patients, especially for children with NMDs who often are more efficiently ventilated with lower EPAP. See Table 4 .

A backup rate is commonly used in children with NMD and/or with impaired central drive.

Ventilator settings should be regularly re-evaluated based on the patient's age and development (BURR, inspiratory time), disease progression or improvement (IPAP, EPAP), and adherence.

Patients with high ventilator dependency (>16 h per day) must have a backup device.

Prepubertal children may be better treated with humidified systems rather than non-humidified ones, in particular infants.

Ventilators used outside the home should not be equipped with active humidification. The use of HME should be limited to a defined period, based on the patient's age and clinical condition.

Humidification and heated tubing are not always mandatory for children older than kindergarten or primary school age (>4–6 years) on NIV, while this is all the time recommended for younger children on NIV and for all children on invasive HRS.

Family-centred care refers to the family's experience and expertise in perceiving and responding to emerging needs during a patient's health problem [55]. Aspects to consider include the family's perception of the health problem and the resources available within the family system in order to develop a specific, coherent, and tailored care plan, which may include nurses, social workers, ergotherapists, and psychological support [5 , 22 , 56 – 59].

Preparing patients on respiratory support for discharge involves a multidisciplinary care team, either in an inpatient unit or on an outpatient basis. This team should include lung specialists, intensivists, paediatric ear, nose and throat specialist, and a group of specialized nurses and physiotherapists experienced in home ventilation. The indication for NIV, along with its objectives and expected effects, should be clearly explained to the child and their family, to promote adherence and prevent doubts regarding therapeutic decisions. The patient's condition should be stable for several days before discharge, with controlled gas exchange and respiratory effort. The child should be comfortable. There should be no active infections, and vaccinations should be up to date. Installation of the equipment can be performed on a hospital outpatient basis over several days, or in a hospital inpatient basis.

At this stage, the autonomy of parents and caregivers should be ensured. Therapeutic patient education occurs in multiple phases: an initial teaching phase, followed by observation of the family's actions to ensure their ability to manage care independently. In this perspective, the parents should have 24 to 48 h to practice autonomy in caring for their child, in either an ICU or hospital unit, before discharge. A well-organized return home is crucial for long-term adherence to treatment [60 , 61]. Involving siblings in the process can be beneficial [18 , 62].

It is important to assess the family's resources, including immediate family and extended family, school, nursery, institutions, homecare, and other relevant support systems. Encouraging the family to express their emotions, anxieties, and uncertainties provides valuable information to address their most pressing concerns.

Criteria for discharge in NIV and IV are detailed in Tables 5 and 6 . IV using a tracheostomy tube increases the level of therapeutic education required for the child, their family, and caregivers. Learning objectives must be clearly defined to ensure the child's safety and the effectiveness of the treatment. In this case, the autonomy of parents and/or caregivers in managing the upkeep of the cannula and ventilator will be a key criterion in determining whether the child can safely return home. Ideally, the child should be managed by at least two persons (parents, family members, or caregivers).

CPAP, continuous positive airway pressure; NIV, non-invasive ventilation; ptcCO₂ , transcutaneous estimation of PaCO₂ .

BLS, basic life support; IV, invasive ventilation; Vt, tidal volume; ENT, ear, nose and throat.

In the weeks leading up to discharge, parents are required to spend around 24 to 48 h in the hospital, practising caring for their child independently. The medical and nursing team should be available for support and follow-up with the family the day after the child returns home. All the child's follow-up should be organized in advance through multidisciplinary collaboration, including specialists involved in respiratory, nutritional, psychological, mobility, social, and cognitive support.

Various adverse effects associated with respiratory support devices have been documented in the literature, affecting approximately one-third of the paediatric population, despite medical staff's awareness of these risks. Monitoring and addressing these complications are essential to ensure good adherence to therapy by both patients and their families. The most frequent side effects are as follows: 1. Skin injuries that must be systematically monitored at each consultation [63 – 65].

Air leaks around the mask, leading to xerophthalmia or conjunctival irritation, typically due to poor fitting (shape, size) or improper positioning, must be consistently monitored during consultations [1 , 63 , 64].

Nasal symptoms, such as dryness, nasal congestion, or bleeding, that affect 5–38% of patients and can be improved with humidification and/or heated circuits [64 , 66].

Mid-face anomalies, which may develop with long-term NIV/CPAP, especially if initiated early in life, and depend on the type of mask and the patient's genetic susceptibility. A maxillofacial and orthodontic evaluation is recommended if needed. A mid-face hypoplasia occurs in 3–37% of patients, with a higher incidence in younger children. Changing the interface can modify pressure points on the patient's face [63 , 64].

Risk of broncho-aspiration, particularly with oronasal masks in patients with NMD. Other interfaces should be considered for these individuals [5].

Pneumothorax, although its occurrence is infrequent [64 , 67].

Initiation of HRS should be accompanied by a clear follow-up plan for the patient, their family, and the medical staff. A well-structured follow-up enhances the ability to adapt HRS to the patient's evolving needs, including pressure adjustments or device modifications, as well as adjustments in response to changes in the family's daily life over the years.

The frequency of follow-up after the initiation of HRS depends on multiple factors, such as the patient's age, underlying diagnosis, ventilation mode, available support services, and monitoring capabilities. Typically, the first visit should be scheduled 1–3 months after starting, followed by regular visits every 3–6 months [5 , 68]. For patients who are clinically stable and less dependent on respiratory support, annual visits (every 12 months) may be appropriate [69]. After each intervention, such as changes in ventilator settings or surgical procedures, a sleep study should be conducted to verify effectiveness of the HRS settings [5].

In general, younger, and/or clinically unstable children require shorter intervals between hospital visits and data collection to facilitate timely treatment adjustments. Most HRS devices have a built-in software that allows the download of respiratory parameters. These data may help improve HRS settings during follow-up visits, but they must be used with caution in children, as AHI scoring by the device may be over- or underestimated [70 – 72]. Analysis of built-in software data is therefore complementary and useful but cannot replace sleep studies.

Follow-ups on HRS should include at least overnight monitoring of gas exchange by oximetry (oxygen saturation [SpO₂] measurement) and capnometry (transcutaneous estimation of PaCO₂ measurement) [73]. Oximetry alone is insufficient for the evaluation of respiratory support as SpO₂ is not necessarily indicative of effective ventilation [74]. These measurements may be performed at home [75]. In Switzerland, several providers, such as the Lung Leagues and various device companies, deliver a home service to collect measurements and transmit data to physicians. PSG or PG can provide essential information to improve control of SRBD [76 , 77]. In several international guidelines, regular PSG/PG is recommended for the evaluation of child on HRS [51 , 78 , 79].

Poor adherence to treatment is a major challenge in long-term HRS for children [60 , 80 – 86]. The aim is consistent use of CPAP/NIV throughout the entire sleep period. Although no validated definition of optimal adherence exists for children, it should be maximized through individually tailored strategies [87 – 90]. For children who rely on NIV as life support, optimizing adherence is critical and requires continuous reassessment. Adherence should be evaluated at every visit using objective data from the HRS device's built-in software, as children and caregivers often overestimate actual use [91].

Telemedicine represents one of the most promising advancements in the management of NIV. Recent innovations aim to identify potential issues more quickly, enabling timely interventions before the next scheduled in-person visit.

Telemonitoring with remote data analysis from HRS devices' built-in software and home-recorded sleep studies is feasible. This approach offers a convenient way for both patients and physicians to

verify and adjust HRS settings, as well as manage respiratory exacerbations [92 – 95].

Videoconferencing has also been shown to be beneficial in the management of children, fostering high levels of family confidence in clinical decisions and offering value to clinicians in their decision-making process [92 , 95]. However, it remains unclear whether these approaches are cost-effective, or if they improve outcomes or adherence to treatment in children [69 , 96].

The first visit after initiation of HRS should be scheduled at 1–3 months, followed by regular visits every 3–12 months, which should include monitoring as described below.

Monitoring HRS efficiency should at least include analysis of device data and measurement of gas exchange (oximetry and capnometry). An adequate ventilation ($p\text{CO}_2 < 6.5\text{Pa}$ or significant decrease from the initial value) and oxygenation, a normal work of breathing while awake, and an absence of symptoms of SRBD are essential to evaluate the efficiency of the HRS adjustment.

Adherence to HRS should be assessed at every visit.

Lack of adherence should trigger investigation on patient-ventilator asynchrony and mask leaks, and other reasons of discomfort, closer follow-ups, and additional home support should be offered.

It is important to recognize when the entire system or family is struggling with adherence and provide extra help and support.

While telemonitoring and telemedicine show promise, they should complement, not replace, regular face-to-face visits.

Telemonitoring needs to be well documented and define clear responsibility for follow-up and adjustment of settings.

Unlike invasive mechanical ventilation, weaning, or failure thereof, has not been clearly defined for patients on non-invasive respiratory support. This lack of standardization is critically important, as maintaining unnecessary ventilatory support can be intrusive, while premature discontinuation may lead to increased morbidity and prolonged ventilation duration.

Unfortunately, there are only a few studies in the literature that provide detailed weaning criteria [97 , 98]. It is important to highlight that not all children on HRS can be weaned; this depends largely on the underlying disorder. For children with severe lung disease, weaning from respiratory support could be due to natural improvement over time and enhanced respiratory muscle strength, with weaning potentially occurring through spontaneous recovery, physiological growth, or sometimes following specific interventions (e.g., orthodontic treatment, surgical procedure), nutritional support, or weight loss, particularly in cases of OSAS [99].

Weaning is first initiated during daytime while the child is awake, with the duration off the ventilator gradually increased. Weaning from nocturnal use occurs only once the child can remain off the ventilator while awake. Regular clinical assessments should include measuring SpO_2 and PCO_2 to monitor tolerance. Signs of weaning failure include rising transcutaneous estimation of PaCO_2 , recurrent pneumonias, growth failure (due to increased caloric expenditure from the work of breathing), with reduced energy available for activities which enhance quality of life. In addition, parents should be taught to observe the child for signs of respiratory distress and report any concerns to healthcare providers.

A washout period may be necessary during weaning, during which HRS is temporarily discontinued prior to performing a sleep study. This period varies depending on the patient's condition and can last several days to several weeks [5] as shown in Figure 2 .

Possible ventilation weaning schemes. Dark blue dots represent periods with ventilation, white dots represent periods without ventilation, orange line represents nap period, and blue line represents lunch period. a Daytime period with gradual increase in ventilatory weaning. b Nighttime period with gradual increase in ventilatory weaning.

Several factors can contribute to the failure to initiate or maintain non-invasive respiratory support. A thorough understanding of the psychosocial context of the child and family, as well as the treatment goals, is essential, as these aspects can significantly impact the success of ventilation and must be carefully evaluated by the medical team.

There is a lack of precise definition for non-invasive HRS failure in the paediatric population. Distinct factors such as mask discomfort, asynchrony, and major leaks likely have a negative impact on adherence. The cognitive status, psychosocial context, domestic environment, and the cooperation of both the child and their family are thought to play a determining role in success or failure. Based on factors identified as contributing to non-invasive HRS failure, targeted interventions can be proposed to address the specific challenges [100].

The following recommendations are proposed regarding HRS weaning or failure: Initiate daytime weaning while the child is awake, progressively increasing the extent of time without the respiratory support. Only proceed with nighttime weaning once the child can tolerate extended periods off the ventilator during the day.

Monitor for rising PCO₂ levels, development of pneumonia, and signs of growth failure, which may result from increased caloric expenditure due to the effort of breathing and can lead to less energy available for activities that enhance quality of life.

Mask discomfort, asynchrony, and major air leaks have a negative impact on NIV adherence, while cognitive status, psychosocial context, domestic environment, and the cooperation of both the child and their family are suspected to play a determinant role in NIV success or failure. All these aspects need to be considered to allow successful use of HRS.

Travel has become a common part of life for most ventilated children today. Enabling families to maintain a sense of normality should be a shared goal for each patient and their medical team. Supporting this helps both the patient and their family to experience a more typical and fulfilling lifestyle.

Traveling with HRS is possible but requires careful anticipation and planning. For patients with nocturnal HRS, daytime travel may be preferred to align with their respiratory needs. Key considerations include the following: Journey conditions (e.g., accessibility to electricity during travel).

Conditions at the destination (e.g., proximity to a hospital capable of handling respiratory exacerbations).

The altitude at which the patient will be flying must be taken into consideration beforehand in case device settings require adjustment for operation at higher altitudes. The flight duration should also be considered. Patients will need to check whether they need to apply for airline (operator) approval for carrying and using the respiratory device, including the battery. Patients should carry the device as hand luggage and have a hospital letter explaining the need for HRS. In serious cases like patients needing oxygen or with severe conditions, a hypoxic challenge test may be considered before travel to assess altitude tolerance. For children ventilated invasively with a cuffed canula, the cuff pressure must be adjusted when flying at high altitudes due to the risk of cuff expansion leading to tracheal injury.

Devices for mechanical insufflation/exsufflation (MIE) assist children with impaired coughing ability by applying positive airway pressure (insufflation) followed by a rapid shift to negative pressure (exsufflation) to simulate a natural cough [101 , 102]. The indications for MIE are the presence of secretions that the patient cannot effectively cough up on his own. In adults, cough peak flow (CPF) values <270 L/min are a relative indication, while values <160 L/min are an absolute indication. Such thresholds described in the literature do not apply to children, particularly younger ones [103]. In children, reference values and thresholds of CPF are age and, from the onset of puberty, sex dependent [104]. CPF values <50% of median reference values correspond to a CPF <270 L/min in adults.

MIE is most effective in children who can cooperate, typically from 3 to 5 years of age. Early use is encouraged for all patients with airway clearance difficulties to prevent and treat pulmonary complications [105 – 109].

The interfaces for MIE devices can be used with a facial mask, mouthpiece, or tracheostomy cannula. Initiation typically begins with lower insufflation and exsufflation pressures, gradually increasing as tolerated. Reported pressure ranges are between 10 and 50 cm H₂O for insufflation and between –10 and –60 cm H₂O for exsufflation. All settings are adjusted with growth, using longer times and higher pressures as children grow. Asymmetric pressures (e.g., higher insufflation or lower exsufflation pressures) can address issues like abdominal distention, reflux, or emesis.

There are no clear guidelines regarding optimal MIE settings in children. Existing guidelines are derived from algorithms and can only serve as a guide for initiation [105 , 106]. Families can use MIE devices at home after receiving training by physiotherapists, nurses, or device-specific staff. Combining MIE with manually assisted cough techniques improves outcomes [106 , 110 , 111]. Adherence can be a challenge, and barriers to regular use must be identified and addressed [112 , 113]. While pneumothorax is a theoretical risk, no direct cases have been reported in children.

The following recommendations are proposed regarding the use of MIE: Early use in infants: MIE may be beneficial even in infants, potentially from the first year of life, depending on the disease and the child's level of cooperation.

When to initiate: MIE should be introduced to reduce the risk of recurrent respiratory infections and in children with a stable respiratory condition. NMD patients requiring ventilatory support should, with few exceptions, be started on MIE; it may serve also for lung-volume recruitment.

Pressure and adaptation: MIE pressures must be tailored to the child's age, clinical needs, and tolerance. Regular reassessment of settings and techniques is essential to ensure ongoing effectiveness and safety.

Implementation: Initial MIE sessions should be conducted by a physiotherapist, ideally in a hospital ambulatory setting. Transition to home use requires proper training and monitoring by experienced professionals. Caregivers should also receive training to handle respiratory tract infections and aspiration events.

HRS in paediatrics represents a highly specific context of care, frequently raising ethical challenges due to the lack of scientific data and literature to guide decision-making, particularly in cases where patients refuse HRS. The extreme heterogeneity of situations (including pathology, age, prognosis, and family context) together with the need for tripartite decision-making involving the medical team, the patient, and the parents further complicates both medical and ethical considerations.

Creating a context in which the patient is able to take decisions freely may improve adherence care and facilitate transparent discussions among the patient, physicians, and family [114]. The patient should have the final decision provided they have the capacity to do so. The decision-making process should promote a factual risk-benefit analysis and consider not only the child's physical

benefit, but also impact on quality of life and consequences on others [115]. This is a dynamic and evolving process, and the decision whether to apply HRS should be re-evaluated regularly. The medical team should ensure that patients and family are aware that no decision is definitive. A decision to not apply HRS should be accompanied by alternative support and palliative care [116]. Finally, the decision must be documented in the medical file.

The following recommendations are proposed regarding ethical considerations: 1. Promote discussions based on a factual description of treatment risks and benefits.

Consider the principles of beneficence and non-maleficence in each decision, in close discussion with the patient and their family. The decision to apply or not HRS results from a joint decision-making process that should include all the medical teams taking care of the patient, the patient, and his/her family.

Ensure equity between patients by avoiding subjective projections, balancing the financial burden between society and the patient, and considering the broader consequences of each decision for both the patient and their family. The medical team should anticipate the child's loss of communication or comprehension skills [117].

Consider cultural background, individual beliefs, and the family environment at each stage of discussion and decision.

Reassess all decisions regularly and depending on the patient's evolution.

HRS has been proposed in several palliative situations, including severe neuro-disability, but very few data are available. Consequently, clear indications and prescription criteria are limited by the lack of scientific arguments for and against HRS.

The efficacy of HRS has been reported in specific contexts and considered in specific palliative situations, including severe neuro-disability. It is important to highlight that it can increase survival, reduce time spent in hospital, and improve children's quality of life.

HRS can contribute to the improvement of sleep, sleep apnoea, and quality of life in children with severe neuro-disability. Each decision must be documented in the medical file, including, as with any ethical discussion, the objective and expected benefits of care. The care plan should define the modalities best suited to the objectives: type of HRS, location and method of implementation, trial duration, success criteria, failure criteria. The decisions should include anticipated directives in case of acute decompensation. Ultimately, the efficacy of HRS in palliative situations is defined by improvement of comfort, reductions in hospital stay duration, and alleviation of dyspnoea.

The transition period to adult care represents a critical time for young adults requiring long-term HRS, often marked by a conflict between their desire for independence and the increasing healthcare needs associated with the progression of their underlying disease. To date, most paediatric pulmonary services responsible for these patients lack standardized transition programmes, which may leave them without structured guidance during this crucial phase. However, there is growing evidence that implementing a standardized transition process can significantly improve outcomes, as patients demonstrate better compliance with treatment and enhanced self-management skills.

A well-designed transition program should consider the unique medical and psychosocial needs of everyone, offering personalized plans that emphasize education and training to foster self-management. Collaboration between paediatric and adult care teams is essential to ensure continuity of care, while also addressing the emotional and psychological challenges that often accompany this transition. Standardizing the process not only eases the burden on patients and families but also promotes independence and long-term adherence to care, underscoring the

importance of investing in structured transition pathways for this vulnerable population [118].

The transition is a maturation process and must start early to provide the time needed for preparation. It involves the patient, parents, therapists, and doctors [119]. During this period, a care coordinator is crucial, especially for patients with cognitive impairments who may not be fully capable of self-care. Many of these patients may outlive their main caregivers (typically their parents), making the role of a care coordinator even more essential. Rare diseases or conditions with unexpected outcomes (e.g., SMA type 1) further highlight the importance of a structured transition process.

Finally, adult care teams may lack experience in rare respiratory conditions, emphasizing the need for a well-organized transition plan. A coordinated effort between paediatric and adult care is essential to bridge knowledge gaps and ensure continuity. A structured transition also helps prevent interruptions in care that could compromise the patient's future well-being.

The number of patients requiring long-term mechanical ventilation is rapidly increasing. Clinicians must adapt their practices not only by regularly updating available technologies but also by evolving their approaches to the care of patients transitioning into adulthood. Drawing from limited paediatric literature and expert consensus, we propose follow-up strategies designed to support the development of standardized care. Ultimately, multicentre studies and the establishment of national and international guidelines will be essential to improve and harmonize follow-up and weaning practices for children on home mechanical respiratory support.

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