

# Cost-effectiveness of home mechanical ventilation in children living in a developing country

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## Abstract

**Background:** Home mechanical ventilation is a promising option for children requiring long-term mechanically assisted ventilation, despite data on the cost-effectiveness of this approach being limited. The aim of the study was to investigate the cost-effectiveness of home mechanical ventilation in children requiring long-term mechanically assisted ventilation.

**Methods:** A retrospective cohort study was conducted on 67 children (32 girls, 47.7%) requiring mechanically assisted ventilation. The underlying diseases of the children concerned were as follows: congenital airway malformations in 24; cystic fibrosis in 4; severe laryngomalacia in 16; polyneuropathy syndrome in 6; mitochondrial myopathy in 5; hypoxic ischaemic encephalopathy in 6; and cerebral palsy in 2. The children were admitted to paediatric intensive care units (ICU) for 2 weeks. After discharge, they were placed on home mechanical ventilation and were followed-up for 1 year. Data on the daily costs of hospital stay at the ICU, re-hospitalisations, weaning, educational performance and muscle strength were gathered.

**Results:** The mean age of children at time of initiation of mechanically assisted ventilation was  $5.2 \pm 4.9$  years (ranging from 2 months to 15 years). The mean number of re-hospitalisations was  $3.6 \pm 4.9$  times with a mean duration of  $53.2 \pm 44.9$  days. Of the children on mechanical ventilation, 1 was attending school, 2 had been weaned, and 21 had experienced improvement in muscle strength. No fatal or serious complications were observed while the children were on home mechanical ventilation. The median (IQR) cost of daily ICU stay admission was USD 3,625.0 (USD 7,075.0), while the median daily cost of home mechanical ventilation was USD 1,402.0 (USD 1,044.2) ( $P < 0.001$ ).

**Conclusions:** Home mechanical ventilation is more cost-effective compared with ICU stay for only mechanically assisted ventilation.

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**Key words:** mechanical ventilation, home; costs; children

Home mechanical ventilation (HMV) is a new therapeutic approach which provides mechanical respiratory support for children with various chronic respiratory disorders outside the hospital or in a paediatric intensive care unit [1, 2]. HMV provides a better lifestyle and life-expectancy for children and infants older than one month who require prolonged mechanical ventilation [3–5]. According to the American Association of Respiratory Care Guidelines, the long-term goals of mechanical ventilation at home include attaining sustainable life and development, increased quality of life, reduced morbidity, better growth and development, as well as convenient and affordable treatment [6].

Patients who require mechanical ventilation aged more than three months are candidates for HMV [6, 7]. The rising cost of health care provided at hospitals and improvements in home mechanical ventilation with positive pressure ventilation constitute incentives for transferring patients home for extra support [8]. It was estimated that the cost of HMV for children is almost 50% of the total medical expenses at hospital. Nowadays, the number of patients requiring mechanical ventilation at home is increasing [9–11]. In one study, the number of patients requiring long-term mechanical support had increased three-fold compared with previous years [8].

Due to the increasing number of patients on HMV and the growing cost of health care, there is more motivation to transfer these patients home more than ever before. Moreover, the freeing up of paediatric ICU beds, the avoidance of acquired hospital infections, the ICU personnel's focus on other admitted patients and better development and progress in cognitive (mental) health are other benefits of this method. Patients that are managed at home live as a member of their families and may even go to school and participate in social activities. These patients have a near-normal life while their parents also return to routine life and daily activities. The long-term expected consequence of this method ranges from prolonged remission (no need for mechanical ventilation support) to survive but conditions dependence on technology.

As there has been no study evaluating HMV in the Iranian paediatric age group, a comprehensive study in the assessment of these patients is crucial in order to accomplish monitoring and supporting services for these patients in the Iranian health system. This study evaluates the characteristics of paediatric patients requiring prolonged mechanical ventilation in hospital and the characteristics and complications of HMV in these patients. Moreover, this study compares hospitalisation expenses with the cost of HMV in Iran.

## **METHODS**

### **PATIENTS**

This cross-sectional study was performed on all admitted paediatric patients to the Children's Medical Centre, affiliated to Tehran University of Medical Sciences, Iran, during the period from 2013 to 2015. All patients requiring prolonged mechanical ventilation need it to support their respiratory system in order to prevent hypoxic respiratory failure or hypercapnic respiratory failure. In this study, patients were included who had required more than 3 months of ventilation support and had not responded just to oxygen administration, regardless of the cause of respiratory failure. These patients needed fixed oxygen therapy for a period of two weeks without any change of treatment programmes and nutrition. Patients were enrolled in the study for a period of 2 weeks requiring their oxygen content to be stable without any changes to the patient's treatment and nutrition plans. During this period, the patient looked at and opened and the metabolic conditions were stable so that no life-threatening events could occur to the patients. Patient selection for this study was performed under the supervision of a paediatric pulmonologist. The study was approved by the ethics committee of Tehran University of Medical Sciences on 30 October 2017 (Ethics Code: IR.TUMS.VCR.REC.1396.3587). Informed consent was obtained from the patients or their parents.

### **METHODS**

An attempt to use the HMV method was started after separating the patients from their ventilator in the PICU. The entire process from the beginning to the end is performed by a team including a paediatric pulmonologist, an assistant paediatric pulmonologist, a trained nurse, a respiratory care, physical therapist, a speech therapist, an occupational therapist, a psychologist, a nutritionist and an HMV sales representative. The patient's discharge was provided for step by step, along with adequate quality assurance.

The equipment used included the following: a ventilator that includes a non-invasive, maskable or aggressive non-invasive ventilation device for use by tracheostomy; a source of oxygen; a pulse oximeter; an Ambu bag; moisturisers; a ventilator in case of a tracheostomy, manual suction if needed; tools for feeding the patient with non-oral methods; and first aid kits containing equipment for resuscitation.

Parents and caregivers of patients at home are trained in the necessary skills in order to work with equipment. including the following: a home ventilator; suctioning and tracheostomy tube care (if there is a tracheostomy); working with a nebuliser machine; and feeding the patient with non-oral methods. The practical skills of the service providers are evaluated by the research team. The basic measures of life

support and resuscitations at home and risky conditions were pointed out to them. In addition, strategies based on suitable physical and mental health, mortality and morbidity reduction, better quality of life, nutritional support and help to minimise the patient's disabilities were provided to the patients' caregivers.

During the transition of patients home, this medical team supported and settled them into their home environment. Permanent access to a nurse, an assistant paediatric pulmonologist or a paediatric pulmonologist were provided via mobile or home phone.

After establishing proper setting for home ventilation during hospitalisation, the patient ventilator settings were locked for home use with at least four alarms (low tidal volume, high pressure, mask separation and defect in engine). Medical care for these patients was provided according to a monthly report during the first three months of follow up and every 3-6 months after the first three months by a skilled nurse in respiratory care and non-invasive ventilation. In the respiratory clinic of Tehran Children's Medical Centre, every two days a morning session was held in order to determine the frequency of visits required to the paediatric respiratory room or necessary support from the HMV team based on patient's need. The frequency of visits and care was higher in the early stages of the programme and decreased with the passage of time due to the proper functioning of caregivers at home and the greater reliance of patients on them. Early in the programme, this sequence was 2-3 times a month, or up to 6 times a month as needed, but taking place at least once a month. All data collected through observations and inspections were registered in prepared data forms.

The evaluation of patients was performed with the following: a pulmonary function test (if age > 6 years and with patient cooperation); arterial blood gas every three months or a change in the status of the patient (with parental consent); recording of pulse oximetry; respiratory rate (report by parents and nurse visits); hours required for the device; and

an HMV report that was submitted by a technician written between 1 and 160 days previously.

### STATISTICAL ANALYSIS

In this study, although the mean, standard deviation, median and inter quartile ranges were used for the analysis of quantitative variables, frequency and ratio were used for qualitative variables. The normality of data related to the cost was evaluated by the Shapiro-Wilk test. The Wilcoxon test was used to compare the monthly cost of care at home and during the hospitalisation stage. Statistical tests were performed as two-tailed tests with a significance level of  $P < 0.05$ . Data were analysed with SPSS software version 22 (IBM Corporation, Armonk, USA).

### RESULTS

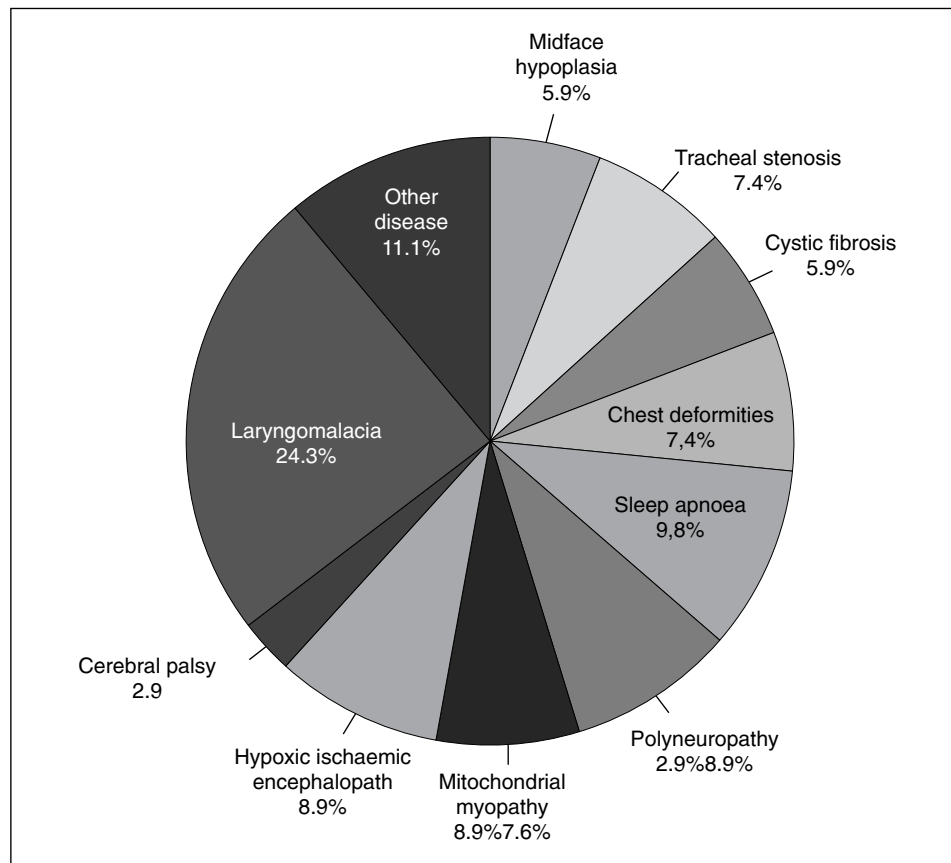
In this study, 67 patients were enrolled. The average age of the patients was  $5.2 \pm 4.9$  years old ranging from 2 months to 15 years old (Table 1). In these patients, 35 children (52.2%) were male and 32 children (47.7%) were female. Twenty-five children (37.3%) had been born by vaginal delivery while 42 children (62.6%) had been by caesarean section. The mean birth weight of these patients was 3,092.8 grams (ranging from 1,500 to 5,000 grams). During the previous year, patients had been admitted to hospital an average number of 6.3 times and for an average period of 45 days (Table 1). From the aspect of the feeding method used, 39 patients (58.2%) were fed orally, twenty-two patients (32.8%) by orogastric tube (OGT) and 6 patients (8.9%) by percutaneous endoscopic gastrostomy (PEG).

The known or probable diseases that had led to prolonged mechanical ventilation in these patients included the following: four cases of midfacial hypoplasia; five cases of tracheal stenosis; four cases of cystic fibrosis; five cases of chest deformity; seven cases of obstructive sleep apnoea; six cases of polyneuropathy syndrome; five cases of mitochondrial myopathy; six cases of hypotoxic-ischaemic

**Table 1.** Characteristics of hospitalised children requiring prolonged mechanical ventilation and the cost of using home mechanical ventilation (HMV) and hospitalisation in paediatric patients, in Iran, Tehran, 2013-2015

	min.-max.	median (IQR*)	mean (SD*)
Age (year)	0.17-15	4 (8.75-0.60)	5.2 (4.9)
Birth mass (kg)	1.50-5.00	3.0 (3.20-2.78)	3.10 (0.580)
Frequency of hospitalisation	1-30	2.5 (3.0-2.0)	3.6 (4.9)
Days of hospitalisation	7-180	45 (60-20)	53.2 (44.9)
Use of home ventilator (hour)	day	7.5 (12.0-2.0)	6.6 (4.3)
	night	6-12	11.5 (12.0-10.0)
Cost of hospitalisation (USD)	350.0-30,000.0	3,625.0 (8,125.0-1,050.0)	5,700.7 (6,430.5)
Cost of HMV purchase and maintenance (USD)	630.0-4,650.0	1,402.0 (1,734.0-689.7)	1,509.9 (1,038.2)

\* IQR: interquartile range (75<sup>th</sup>-25<sup>th</sup> percentiles); SD: standard deviation



**Figure 1.** Distribution of the causes of prolonged mechanical ventilation use in paediatric patients, in Iran, Tehran, 2013–2015

encephalopathy; two cases of cerebral palsy; sixteen cases of laryngomalacia; and six cases of other diseases (Fig. 1). The overall results showed that 30 children (44.7%) had respiratory conflict, 21 children (31.3%) had neuromuscular disease, 9 children (13.4%) had a metabolic disorder (Niemann-Pick disease and other glycogen storage diseases), while 7 children (10.4%) had other disorders.

The mean duration of training for parents or caregivers with HMV was 4.2 days (SD = 2.5) ranging from 1–10 days. The reason for using HMV was airway obstruction in 32 patients (47.7%), alveolar hypoventilation in 28 cases (41.7%) and combined obstructive pulmonary disease and hypoventilation in 13 children (19.4%).

The device used noninvasive ventilation — NIV (CPAP) in 31 patients (46.2%), NIV (VPAPS) in 19 patients (27.8%), NIV (VPAPST) in 10 patients (4.19%), IMV in 5 patients (8.3%) and NIV (Auto-CPAP) in 2 patients (2.8%). The mean time of HMV use was 6.6 hours during the day and 6.1 hours during the night (Table 1).

No complications were observed during the use of HMV in 8 patients (22.2%). However, the following complications of HMV were detected in 28 patients including: 4 patients (11.1%) with nasal dryness; 8 patients (22.2%) with mask intolerance; 9 patients (25%) had a lack of a fixed and suit-

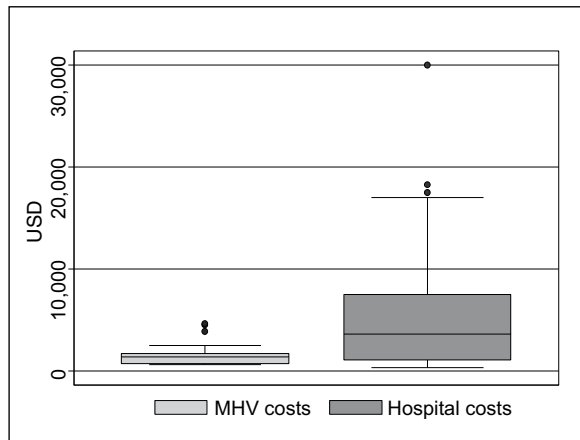
able mask; 6 patients (16.7%) had red skin with no scars; 2 patients (5.6%) had wounds on the bridge of the nose; one case (2.8%) had abdominal distension; while other individual case (2.8%) also had nasal bleeding.

The mean (SD) and median (IQR) monthly cost of hospitalisation was USD 5,700.70 (USD 6,430.50) and USD 3,625.00 USD 7,075.00, respectively. The mean (SD) and median (IQR) costs of the ventilator in both purchasing and maintenance costs were USD 1,509.90 (USD 1,038.20) and USD 1,402.00 (USD 1,044.30), respectively. There was a statistically significant difference between the average cost of hospitalisation and the purchase of the device ( $P < 0.001$ ) (Fig. 2).

## DISCUSSION

The findings of the present study indicate that home mechanical ventilation is a cost-effective method for paediatric patients dependent on mechanical ventilation. This method is an attractive treatment modality compared with prolonged hospitalisations and offers a better quality of life and lower costs in this patient population.

Currently, there are around 3,500 ICU and PICU beds in Iran, with an occupancy rate of approximately 100 percent. The occupancy rate has led to there being not enough space to admit patients at some times of the day. Monitoring



**Figure 2.** Comparing the costs (USD) of using home mechanical ventilation (HMV) and hospitalisation in paediatric patients, in Iran, Tehran, 2013–2014

devices are also inadequate in our country. In addition, the establishment of ICU and PICU beds involves high costs, with an ICU bed requiring expenses of approximately over USD 300 to be provided which is quite remarkable, and which would be difficult to afford. Currently, the best solution is to manage the existing beds. In some circumstances, PICU beds are occupied by patients who require the use of mechanical ventilation, even though they can be managed at home. For this purpose, we must improve the appropriate strategies. The duration of patient's hospital stay will be reduced by the standard promotion of care in the PICU.

The Children's Medical Centre has two PICUs with a total of 20 beds. The average bed occupancy rate in the PICUs was 97.76% in 2014. During this period of time, 1,024 children from other wards, 184 patients directly from the emergency department and 36 patients from other centres were admitted to the PICU. Therefore, most PICU beds were occupied by patients from other wards in our hospital. Due to a lack of sufficient beds in the PICU, it is impossible to provide care for patients of other centres who need special care in a PICU.

In a study by Fleur *et al.* in 1979–2009 (30 years) the numbers of patients increased from 8 patients (between years 1979 to 1989) to 122 patients (between years 1999 to 2008). This was a clear sign of the increasing need of HMV for children [8].

Given the high prevalence of respiratory failure with a neurologic origin which had led to prolonged hospitalisation in our study and other studies, Graham has emphasised the need for extensive planning in order to organise these patients to free up beds [12].

In this study, 19.4% of children had respiratory compromise; 55.6% had neuromuscular disease; 13.9% had a metabolic disorder, while 11.1% of patients were suffering from other diseases. In a survey conducted in 2003 in France [13] on 102 patients requiring prolonged mechanical ventilation,

34% of patients had neuromuscular disease while 30% were suffering from sleep apnoea. In Italy, a study by Ottonella *et al.* [14], evaluated 20 children requiring prolonged mechanical ventilation. In this study, the most chronic diseases requiring prolonged mechanical ventilation was myopathy and chest wall deformity. In the study by Graham *et al.* [12], however, the main causes of prolonged mechanical ventilation were neurologic diseases (36.8%), respiratory disease (22.6%), along with cardiovascular (19.6%), genetic (19.6%) and metabolic diseases (4.8%). Other conditions included blood disease, as well as kidney and gastrointestinal malignancies [12].

In an Australian study [15], the most common indications were obstructive hypoventilation syndrome (31%) and neuromuscular diseases (30%). The most common feeding method in children was the oral method (66.7%). The reasons for using mechanical ventilation at home were airway obstruction (44.4%), alveolar hypoventilation (38.9%) and combined obstructive pulmonary disease and hypoventilation (16.7%). In a study by Fauroux, the causes of prolonged mechanical ventilation were listed as: nocturnal hypoventilation (67%); lack of weight gain (21%); and acute injuries resulted from underlying diseases (28%) [13].

In our study, the average required time for a home ventilator was 6.6 hours during the day, ranging from 0–12 hours a day and 6.10 hours during the night. In the study by Ottonella *et al.* [14], only 10% of patients were dependent on HMV through the day, 20% needing 8–12 hours a day, and 70% of patients only needing HMV nightly.

No complications of using HMV were observed in 6 patients. Complications associated with HMV were detected in 28 patients including the following: nasal dryness in 11.1%; mask intolerance in 22.2%; a lack of proper fixation of the mask in 25%; non-ulcer skin redness in 16.7%; wounds on the nasal bridge in 5.6%; abdominal distension in 2.8%; and nasal bleeding in 2.8%. These complications can be caused by a mismatch in the size and shape of the mask and the inadequate size of the mask for patients.

The monthly cost of hospitalisation was very much higher than the cost of HMV. Regarding the Iranian health care system, around 94% of hospitalisation costs are paid by the national insurance system and government. Therefore, it is right to reduce the bed occupancy rate concerning patients who only need HMV in a PICU. This measure will result in a significant reduction in hospitalisation costs.

#### STUDY LIMITATION

Given that this was the first study of its kind to be carried out, our medical insurance did not accept the cost involved in purchasing HMV and its services. Only patients were enrolled in this study who could afford to pay for these expenses themselves. Therefore, it would be possible to

arrange health insurance co-operation by organising this group according to growing health care conditions.

## CONCLUSION

As the average cost of hospitalisation was much higher when compared with the cost of buying and maintaining HMV, it would be more reasonable for families to be able purchase this medical equipment once covered by the Iranian health insurance system. The application of HMV resulted in mild complications in no more than three or four children who were under investigation. Complications occurred as a result of parental carelessness in the application of mask, as well as how to clean the face mask and the patient's nose. Therefore, it seems that these complications can be avoided by training parents by providing detailed instructions about the occurrence of these complications.

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