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Telemonitoring associated with synchronous video consultation in patients on home mechanical ventilation: is it an efficient and effective intervention?

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Abstract

Telemonitoring combined with synchronous video consultation is an increasingly used strategy in the management of patients on home mechanical ventilation (HMV). The aim of this study was to evaluate ventilation parameters and healthcare resource utilization in a telemonitoring program (TG) compared to usual care (UG). A retrospective comparative study was conducted, comparing HMV patients assigned to telematic follow-up with a historical cohort receiving standard in-person follow-up. Ventilation parameters included apnea-hypopnea index (AHI), average daily use (h/day), and mean leak (L/min). Efficiency was assessed by the total number of hospital visits and in-person hospital visits.

Average daily use (8.3±2.9 h/day *vs.* 8.5±3.4 h/day; p=0.714) and mean leak (6.4±11.9 L/min *vs.* 6.3±9.6 L/min; p=0.701) did not differ significantly between groups. The TG showed a lower AHI compared with the UG [4.1±5.0/hour *vs.* 7.9±12.2/hour; respectively (p=0.008)]. The TG was also associated with fewer annual total visits (3.5±2.4 *vs.* 6.9±5.0; p<0.001) and fewer annual in-person visits (2.1±1.6 *vs.* 6.9±5.0; p<0.001). Kaplan-Meier curves were used for descriptive purposes. In multivariable Cox regression adjusted for age category, diagnostic group, baseline arterial blood carbon dioxide pressure, and sex, the TG was associated with a lower hazard of death (0.51; 95% confidence interval 0.24-1.09; p=0.08). These findings indicate that telemonitoring combined with synchronous video consultation was associated with better ventilatory control (lower AHI) and lower use of in-person healthcare visits, without evidence of impaired adherence or safety.

Key words: telemonitoring, home mechanical ventilation, telemedicine, videoconsultation, effectiveness, efficiency, respiratory failure.

Introduction

Telemedicine is the use of telecommunication systems to provide healthcare services remotely [1]. Healthcare services can be diagnostic, such as indicating or monitoring treatments, and even in disease prevention [2]. Telemedicine can be divided into two modalities: the provision of healthcare (teleconsultation, tele-surgery) or the stand-alone monitoring of patients' physiological variables (telemonitoring) [3]. According to the World Health Organization (WHO), the effects of telemedicine programs should be to reduce healthcare costs, increase the efficiency of healthcare services, and improve patients' quality of life and survival [2]. In recent years, there has been significant growth in telemedicine, driven by both the development of digital technology and the SARS-CoV-2 pandemic [4,5].

In terms of respiratory pathology, there are various experiences with telemedicine programs, primarily focusing on telemonitoring strategies. In patients with chronic obstructive pulmonary disease (COPD), telemonitoring, when added to usual respiratory care, has been shown to decrease hospital readmissions and improve quality of life, although it has no impact on mortality [6]. In patients with bronchial asthma, some studies have demonstrated that telemonitoring can improve clinical control, treatment adherence, and quality of life, although there are limitations regarding its use by healthcare professionals [7-9]. In patients with obstructive sleep apnoea (OSA), telemonitoring improves adherence to continuous positive airway pressure (CPAP) therapy, although it has no effect on daytime sleepiness [10,11].

In patients with chronic hypercapnic respiratory failure requiring home mechanical ventilation (HMV), telemonitoring has begun to be utilized, mainly due to advances in ventilator technology [12]. Adapting to HMV, whether at home or via telemonitoring, for patients with stable COPD and chronic hypercapnic respiratory failure is equally effective as adaptation conducted in hospitals, but at a lower economic cost [13,14]. In patients with neuromuscular diseases, including amyotrophic lateral sclerosis (ALS), telemonitoring for HMV adaptation is also feasible [15-17]. Telemonitoring of patients on HMV reduces healthcare costs and improves efficacy [13,15,18-20], although it is not widely implemented in routine practice [21].

In patients with respiratory pathology, healthcare assistance through telecommunications primarily relies on phone calls [3]. Synchronous video consultations have been used in the management of patients with heart diseases, diabetes mellitus, neurological vascular conditions, psychiatric pathology, and for functional muscular rehabilitation programs [3]. Synchronous teleconsultations for patients with chronic respiratory pathology would allow for visual assessment of signs without the need to travel to healthcare facilities, enabling a more appropriate evaluation.

For patients with chronic respiratory pathology who use HMV, it would be interesting to understand the effect of associating synchronous video consultations with telemonitoring. Therefore, the objective of this study is to assess whether telemonitoring combined with synchronous teleconsultations (video consultations) in patients on HMV has effects on ventilation parameters, healthcare resource utilization, and survival.

Materials and Methods

Population and study design

We conducted a retrospective, descriptive observational study conducted at Hospital del Mar (Barcelona), including all patients on home mechanical ventilation (HMV), monitored in the pulmonary medicine department during two predefined time periods: the first from January 1, 2010, to December 31, 2013 (Usual Group, UG), and the second from January 1, 2018, to December 31, 2021 (Telematic Group, TG). Group allocation was determined exclusively by the period of follow-up, reflecting the availability of ventilatory technology rather than individual patient selection. Specifically, ventilators with telemonitoring capabilities were not routinely available before 2017, and therefore patients included in the UG were followed exclusively through in-person visits. From 2017 onwards, all ventilators used in our centre incorporated telemonitoring functions, allowing the implementation of a structured telematic follow-up model for all HMV patients included in the TG. Patients with amyotrophic lateral sclerosis (ALS) were excluded because ALS is a rapidly progressive neuromuscular disease with a distinct clinical course and prognosis.

Description of the intervention

The two groups differed only in the modality of follow-up. In the UG, patients were evaluated exclusively through in-person visits as indicated by the same healthcare professionals (respiratory physiotherapist and pulmonologist). Visits were scheduled routinely or prompted by telephone contact due to symptoms or alarm signs, and each in-person visit included ventilator assessment and data download. In the TG, in-person visits alternated with synchronous video consultations. In addition, ventilators were monitored through the MyVent® platform (a company for Home Respiratory Therapy, *Oxigen Salud*, Barcelona, Spain), which provides daily asynchronous uploads of ventilation efficacy variables, including usage (days and hours used), leak, minute ventilation (MV), and apnoea-hypopnoea index (AHI). Alarm thresholds for usage, leak, AHI, and minute ventilation were individually set by the respiratory physiotherapist, taking into account the patient's underlying condition, baseline ventilator parameters, and expected physiological variability. These thresholds were established at baseline and revised as needed throughout follow-up when clinically indicated. Alerts were reviewed daily by the respiratory physiotherapist, and each was classified according to its severity and need for intervention. Minor deviations were resolved remotely through ventilator data review, whereas alerts requiring direct assessment prompted a synchronous video consultation. Only when issues could not be resolved remotely was an in-person visit scheduled. This workflow minimized unnecessary face-to-face evaluations and optimized clinical responses.

Daily monitoring of ventilator parameters and first-line triage of alerts were performed by the respiratory physiotherapist. The pulmonologist intervened in cases requiring clinical reassessment, ventilator re-titration, or when the physiotherapist identified deviations suggestive of clinical deterioration.

Alarm thresholds (usage, leak, AHI, and minute ventilation) were individualized by the respiratory physiotherapist, based on each patient's underlying disease, baseline ventilator settings, and clinically expected variability. Thresholds were validated at baseline and subsequently adjusted when clinically necessary.

Data collection

Demographic data (sex, date of birth, date of death), indication for HMV, and baseline arterial carbon dioxide pressure ($PaCO_2$) were extracted from medical records. Ventilator characteristics were collected from the final month preceding the last clinical encounter in each study period (UG, December 31, 2013, and TG, December 31, 2021). Recorded ventilator parameters included mode (pressure-limited or volume-limited), inspiratory pressure (IPAP), expiratory pressure (EPAP), trigger sensitivity, cycling criteria, backup respiratory rate (BRR), tidal volume, and interface (nasal, oronasal or full face mask).

Ventilation parameters from the last in-person or telematic visit included average daily use, leak, MV, and AHI from the last month, and the most recent $PaCO_2$ value near that visit. Healthcare utilisation (number and type of visits, emergency department visits over 24 hours, and hospital admissions with their causes) was also recorded.

Furthermore, the impact of the program on direct hospital costs was estimated, measured in monetary units (euros, 2019). The source of economic data for each resource was the analytical accounting system, distributing structural expenses to the cost centers that treat patients and then allocating them to each patient. In 2019, the costs for in-person visits, telematic consultations, and hospital admissions were 57.39, 51.26, and 865.85, respectively. The average expenditure per patient per year was calculated by multiplying the unit cost of in-person visits, telematic visits, and hospital admissions by the average number of times each patient used these services [22].

The ethical committee of our institution approved this study (CEIm 2022/10498).

Statistical analysis

Descriptive statics are presented as mean±standard deviation (SD) for normally distributed quantitative variables and as median with interquartile range (IQR) for variables with a skewed distribution. Between group comparisons of quantitative variables were performed using Student´s t-test for normally distributed variables and the Mann-Whitney U or Wilcoxon tests for non-normal distribution data. Proportions between groups were compared using the chi-square test. When expected cell counts were less than 5%, Fisher's exact test was used, as appropriate.

Survival over the four-year follow-up was first assessed using Kaplan-Meier curves. To address residual confounding, we performed a multivariable Cox proportional hazards model adjusted for age category, diagnostic group, baseline $PaCO_2$, and sex, reporting hazard ratios (HR) with 95% confidence intervals (95% CI). Age was initially categorized for the Cox model due to the limited number of events and the absence of deaths in younger age categories, which prevented stable estimation when modeling age as a continuous variable or using more flexible non-linear approaches. Because the <50 years age category contained no events, a prespecified sensitivity analysis was performed using an alternative dichotomization of age (<75 vs 75 years), yielding virtually identical estimates. This approach was chosen to balance model stability and interpretability given the number of observed events.

All statistical tests were two-sided, with significance defined as $p < 0.05$. Analyses were performed using SPSS version 22 (SPSS Inc. Released 2008. SPSS Statistics for Windows, Chicago, USA).

Results

A total of 223 patients on HMV were included. In the UG, there were 93 patients with a mean age of 70.6±12.9 years (38 men - 55 women), while the TG included 130 patients with a mean age of 72.3±13.9 years (46 men - 84 women).

Patient profile

No statistically significant differences were found between the groups in terms of age or sex (Table 1). The primary diagnosis in the UG was non-ALS neuromuscular disease (38.7%), followed by obesity-related hypoventilation (36.6%), restrictive thoracic disease (18.3%), and finally COPD (6.5%). In the TG, the primary diagnosis was also non-ALS neuromuscular disease (40.6%), followed by obesity-related hypoventilation (30.7%), COPD (14.8%), and finally restrictive thoracic disease (13.9%). No statistically significant differences were observed in diagnoses between the groups, although there was an increase in patients with

COPD in the TG. There were no differences in the $PaCO_2$ levels prior to the start of ventilation between the groups (Table 1).

Ventilator characteristics

In the UG, a higher number of patients were on volume-limited mechanical ventilation compared to the TG (29% vs. 4.6% of patients, respectively, p<0.001). In patients with volume-limited ventilation in both groups, controlled assist mode was used, while those with pressure-limited ventilators used bi-level assisted control mode. There were statistically significant differences between the UG and TG in IPAP (18.2±3.0 vs. 17.0±4.2 cmH_2O, respectively, p=0.049), activation (4.9±0.1 vs. 4.6±1.1 cmH_2O, respectively, p<0.001), and cycling (25.1±1.1 vs. 25.8±5.4% maximum inspiratory flow drop, respectively, p<0.001) (Table 2). There were no differences between the patients in both groups regarding the type of masks used. In both groups, the most commonly used mask type was the oronasal mask (91% in the UG vs. 97% in the TG; p=0.07).

Efficacy of HMV

There were no differences in home ventilator use in the last month between the groups. Regarding the efficacy parameters of the ventilator, a statistically significant decrease was found in the AHI in the TG (4.1±5.0/h) compared to the UG (7.9±12.2/h) (p=0.008) (Table 3). No difference was noted in $PaCO_2$ levels at the final visit or in the reduction achieved with ventilation between the two groups (Table 2).

Survival

The UG patients had a mortality rate of 19.4%, whereas 11.5% of patients in the TG died during follow-up. Kaplan-Meier survival curves are presented in Figure 1a and suggest differences between groups during the first year of follow-up; however, as no deaths occurred in the TG after 12 months and the survival curves crossed over time, formal comparison using the log-rank test was not performed. Survival analysis was therefore based on multivariable Cox proportional hazards regression. In the multivariable Cox model adjusted for age category, diagnostic group, baseline $PaCO_2$, and sex, the TG was associated with a lower hazard of death compared with UG (HR 0.51; 95% CI 0.24-1.09; p = 0.08). Because the <50-years category had no deaths, a prespecified sensitivity analysis dichotomizing age (<75 vs 75 years) yielded virtually identical estimates (HR 0.51; 95% CI 0.24–1.09; p=0.08). These findings should be interpreted as associations, given the observational design and the use of a historical control group.

Resource use

Total visits per year were 6.9±5.0 in the UG and 3.5±2.4 in the TG, showing a statistically significant reduction ($p<0.001$). The distribution of visits per year in the TG was: in-person 2.1±1.6 and telematic 1.6±1.7 (Table 3).

No statistically significant differences were found between the groups regarding the number of admissions for respiratory pathology or other causes (Table 3). Among non-respiratory aetiologies, the most frequent cause of hospitalization in the UG was cardiac pathology (35.1% of admissions). In the TG, the most frequent non-respiratory cause of hospitalization was complications from neoplastic pathology (15.5%) (Figure 1b).

As reflected by the large standard deviations in Table 3, costs showed a highly skewed distribution. Therefore, comparisons between groups were performed using the Mann-Whitney U test. Given the substantial dispersion observed, median values were considered more appropriate for group comparison. The median total cost was 889.5 in the UG and 309.4 in the TG ($p = 0.014$), representing a 56.1% reduction in total costs in the TG.

Hospitalisation costs were not significantly different between groups ($p = 0.54$). Notably, the median hospitalisation cost in the TG was 0.0, reflecting the absences of hospitalisation in at least half of the patients. In contrast, visit-related median costs were significantly lower in the TG ($p < 0.001$).

Discussion

In patients with HMV, telematic monitoring (telemonitoring with specific alarms combined with synchronous video consultation; TG) was associated with maintained ventilation efficacy compared with historical cohort of patients who only had in-person visits (UG). However, the TG was associated with lower use of healthcare resources and lower mortality compared with the UG.

In Europe, the prevalence of patients on HMV was 6.6 per 100,000 inhabitants in 2005, with marked variability between countries [23]. In recent years, the number of patients on HMV has increased across Europe, partly due to new indications such as COPD [24,25]. Our study reflects this trend by showing an increase in the proportion of COPD patients on HMV in recent years.

The rising prevalence of patients on HMV has promoted the development of new control strategies such us telemonitoring, enabled by new ventilators capable of transmitting home-ventilation data [21,26]. Previous studies have shown that telemonitoring may be comparable to usual care while being associated with reduced healthcare costs [13-20]. However, clinical implementation remains complex due to data-protection considerations and the need for daily data review by healthcare professionals [21].

One of the strengths of the telemonitoring system used in this study was the use of individualized alarm thresholds configured by healthcare professionals, which facilitated efficient data review. In our cohort, telemonitoring with present alarms specifically tailored to each patient, combined with synchronous video consultations was associated with maintained ventilation efficacy and lower healthcare resource use, particularly regarding in-person visits. The lack of a difference in hospital admissions compared with the UG mirrors the heterogeneity seen in the literature. Comparisons with other studies are challenging due to differences in patient selections and models of care. For example, Lopes de Almeida et al. reported that costs per patient per year for outpatient visits and admissions related to HMV management in ALS patients through telemonitoring and phone consultations were reduced by 81% compared to usual care [19]. In contrast, our study involved hospital admissions for monitoring ALS patients on HMV in the UG. Another difference was the combination of telemonitoring with phone consultations rather than synchronous video consultation [24]. In our study, synchronous video consultation after detecting an alarm during telemonitoring allowed visualization of patient signs such as respiratory patterns, facial injuries, or improper mask placement, facilitating incident resolution.

Telemonitoring with synchronous video consultation in patients on HMV was associated with lower mortality. A previous study in patients with ALS and HMV, showed that telemonitoring and phone consultations were associated with an increase in survival days, although not reaching statistical significance compared with usual care [24]. Our study population excluded patients with ALS due to their poorer prognosis, which may have contributed to the observed pattern of lower mortality in the TG. Another potential source of confounding is the temporal difference between cohorts: the TG was studied later than the UG, coinciding with changes in ventilator technology and increased use of pressure-limited modes. The gradual shift form volume-limited to pressure-limited modes has beeb previously described [25]. Despite these differences, both groups showed similar improvements in $PaCO_2$, the primary marker of HMV effectiveness [25].

Limitations

This study is not a randomized trial; and therefore unmeasured confounding cannot be excluded. The control group corresponds to a historical cohort of HMV patients. In addition, the two groups are not contemporaneous, raising the possibility that improvements in ventilator technology over time may have influenced some outcomes, including survival. The TG also included a higher proportion of COPD patients, a condition historically associated with poorer survival and higher exacerbations rates, which may represent an additional source of confounding.

We did not quantify the time required for healthcare professionals to review telemonitoring platform for ventilated patients. Nevertheless, the number of professionals involved in patient care was the same between study periods, and the telematic period included a larger number of patients on HMV. Assessing professional workload and satisfaction, as well as patient satisfaction, would be valuable in future studies.

Finally, we did not consider the costs associated with patient travel to the hospital, which means that the difference in total costs could be greater, as patients in the usual-care group had more in-person visits. Improvement in HMV devices enabling telemonitoring did not involve any additional hospital cost and were therefore not included in the cost analysis.

Conclusions

In patients with HMV, telematic monitoring was associated with maintained ventilation efficacy and lower healthcare cost as well as lower mortality compared with a historical cohort of patients managed exclusively through in-person visits. Further prospective or adjusted studies are needed to confirm these signals.

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Table 1. General characteristics of patients with home mechanical ventilation according to study group.

	USUAL	TELEMATIC	p
Population, number	93	130	
Age. years (mean - standard deviation)	70.6 ±12.9	72.3 ± 13.9	0.367
Sex (M/W)	38/55	46/84	0.484
Diagnoses (number; % of global):			0.226
Neuromuscular Diseases no ALS	36 (38.7%)	53 (40.6%)	
Obesity Hypoventilation Syndrome	34 (36.6%)	40 (30.7%)	
Thoracic Cage Disease	17 (18.3%)	18 (13.9%)	
COPD	6 (6.5%)	19 (14.8%)	
$PaCO_2$ initial, mmHg	57.1 ± 10.5	56.8 ± 11.5	0.421

M, men; W, women; ALS, amyotrophic lateral sclerosis; COPD, chronic obstructive pulmonary disease: $PaCO_2$, arterial blood carbon dioxide pressure. mmHg: millimetres of mercury. Variables are expressed as mean and standard deviation (age) or as absolute values and/or percentage of the total (sex and diagnoses)

Table 2. General characteristics of home ventilators and efficacy in each patient group.

	USUAL	TELEMATIC	p
Mode:			<0.001
BiPAP spontaneous assisted, number (%)	66 (71%)	124 (95.4%)	
ACV, number (%)	27 (29%)	6 (4.6%)	
IPAP, cmH2O	18.2 ± 3.0	17.0 ± 3.7	0.049
EPAP, cmH2O	6.7 ± 4.0	6.4 ± 2.1	0.343
Backup respiratory rate, bpm	16.8 ± 3.4	15.6 ± 3.1	0.056
Tidal volume, ml	568.6 ± 133.9	558.3 ± 190.4	0.381
Trigger sensitivity, l/min	4.9 ± 0.1	4.6 ± 1.1	<0.001
Cycling, % of peak flow drop	25.1 ± 1.1	25.8 ± 5.4	<0.001
Mask (Nasal / Oro-Nasal / Full Face)	7/85/1	4/126/1	0.229
Average usage, hours/day	8.5 ± 3.4	8.3 ± 2.9	0.714
Average leakage, l/min	6.3 ± 9.6	6.4 ± 11.9	0.701
Average AHI, /hour	7.9 ± 12.2	4.1 ± 5.0	0.008
Average minute ventilation, l/min	7.9 ± 2.9	8.1 ± 2.6	0.489
Final $PaCO_2$, mmHg	44.8 ± 4.9	43.8 ± 4.8	0.152
PaCO2 drop, mmHg	12.6 ± 10.1	14.2 ± 10.4	0.147

BiPAP, bi-level positive airway pressure; ACV, assisted controlled volume; IPAP, inspiratory positive airway pressure; cmH_2O, centimetres of water; EPAP, expiratory positive airway pressure; bpm, breath per minute; ml, millilitres; l, litres; min, minute; AIH, apnoea-hypopnoea index; $PaCO_2$, arterial blood carbon dioxide pressure. mmHg, millimetres of mercury. Variables are expressed as mean and standard deviation. except for the ventilation mode and masks. which are presented as absolute values.

Table 3. Analysis of healthcare resource utilization and expenditure.

	USUAL	TELEMATIC	p
Total visits per year	6.9 ± 5.0	3.5 ± 2.4	<0.001
In-person visits per year	6.9 ± 5.0	2.1 ± 1.6	<0.001
Telematics visits per year	-	1.6 ± 1.7	<0.001
Respiratory admissions per year	1.1 ± 2.1	1.0 ± 1.9	0.684
Non-respiratory admissions per year	1.3 ± 2.8	1.0 ± 1.9	0.153
Hospital stay days per year	12.7 ± 38.5	7.1 ± 39.3	0.192
Total cost of medical visits, Euros patients-year	306.1 [200.9-502.2]	175.8 [94.5-260.0]	<0.001
Total cost of hospital admissions, Euros patients-year	170.3 [0.0-3844.4]	0.0 [0.0-3722.7]	0.540
Total cost, Euros patients-year	889.5 [315.6-3987.8]	390.4 [166.0-3869.7]	0.14

Healthcare resource data are presented as mean±SD, whereas healthcare cost values are expressed as both mean±SD and median (IQR, Q1-Q3). Between-group tests: Student's t-test for normally distributed variables; Mann-Whitney U test for skewed cost data.

Figure 1a

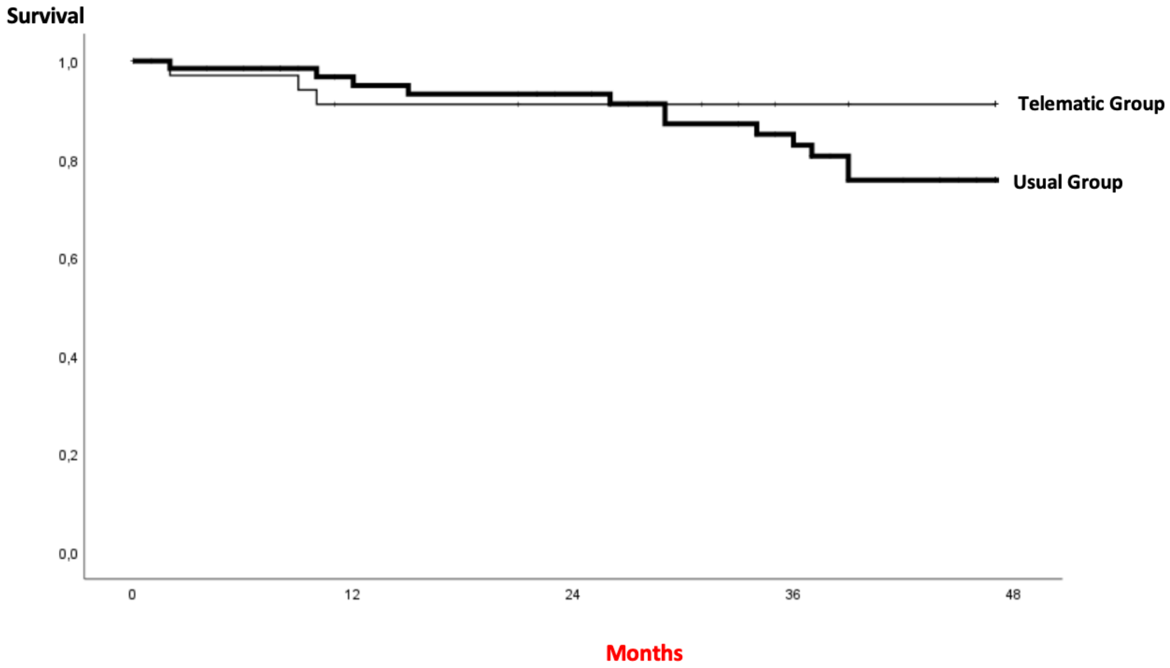

Figure 1b

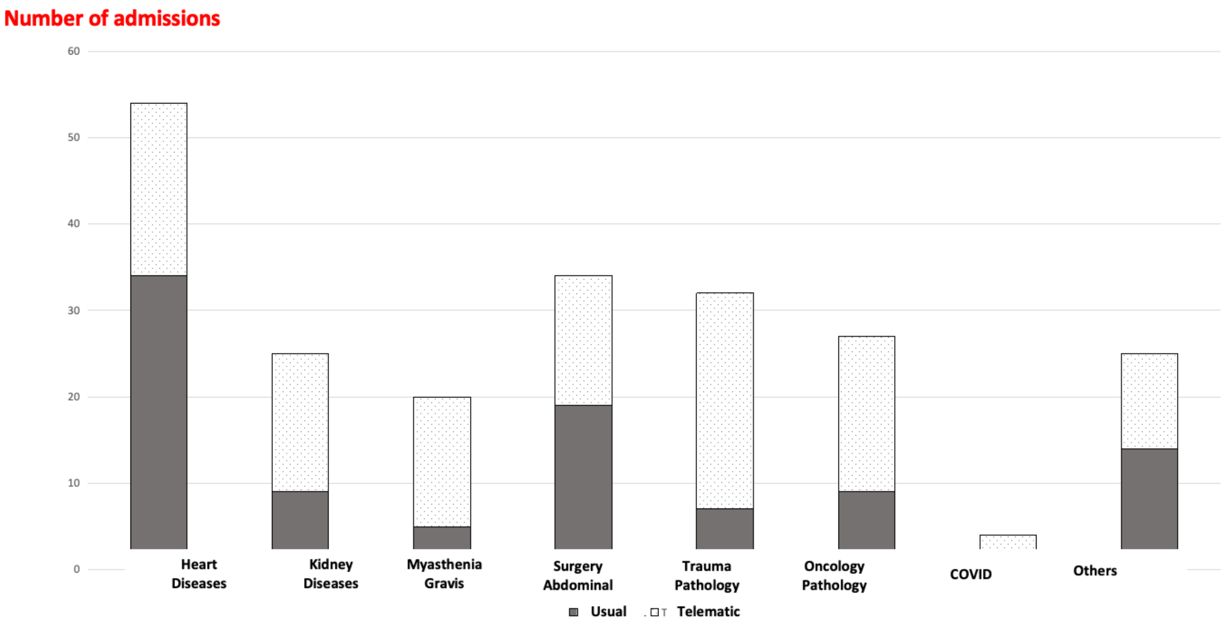

Figure 1. a) Survival of both groups of patients with VMD, usual care or telematic control; b) number of hospital admissions by cause in both groups of patients with VMD, receiving usual care or telematic control.