Identifying Changes in Functional Capacity of Cardiorespiratory Patients Undergoing Exercise Rehabilitation

Ganesh Raam Kumarasamy[1,2,3,4], Hélène De Cannière[4,5], Julie Deckers[1,2,4], Julie Vranken[1,2,4], David Ruttens[2,4,7], Peter Karsmakers[3,6], Pieter Vandervoort[1,2,4,8]

[1]UHasselt, Limburg Clinical Research Center, 3590 Diepenbeek, Belgium
[2]Future Health, Ziekenhuis Oost-Limburg, 3600 Genk, Belgium
[3] KU Leuven, Faculty of Engineering Technology, 2440 Geel, Belgium
[4]UHasselt, Faculty of Medicine and Life Sciences, 3590 Diepenbeek, Belgium
[5]UHasselt, THINK[3] Innovation and Simulation Lab, 3590 Diepenbeek, Belgium
[6]Flanders Make, 3001 Heverlee, Belgium
[7]Department of Pulmonology, Ziekenhuis Oost-Limburg, 3600 Genk, Belgium
[8]Department of Cardiology, Ziekenhuis Oost-Limburg, 3600 Genk, Belgium

Abstract

Heart failure (HF) and chronic obstructive pulmonary disease (COPD) are two common complex multimorbid cardiorespiratory diseases. Due to their complex nature, it is challenging to identify changes in health status of affected patients. In this study, we analyse the progression of functional capacity as a first step in identifying changes in disease status of HF and COPD patients.

60 patients (N_{HF}=35, N_{COPD}=25) undergoing cardiopulmonary rehabilitation were included in this study. A six-minute walk test (6MWT) assessing the six-minute walking distance (6MWD) was used to monitor the functional capacity of these patients. Patients performed five 6MWTs in total (1 baseline, 4 follow-up) with spot-check HR and SpO2 values also being measured before and after each 6MWT. The progression of the 6MWDs was analysed using a two-way mixed ANOVA. To predict changes in functional capacity, patients were divided into two groups (“improved” vs “not improved”) based on a minimal clinically significant distance change. A decision tree classifier was trained on 6MWD, HR and SpO2 data features and evaluated using balanced accuracy.

The mixed ANOVA showed a significant interaction effect as well as significant between-subjects and within-subject effects. The classifier showed good performance in predicting improvement of functional capacity.

1. Introduction

Cardiorespiratory diseases have been increasing in prevalence over the past two decades owing to lifestyle changes, population aging and environmental changes. HF and COPD are complex multimorbid cardiorespiratory diseases affecting hundreds of millions of people globally.

HF is a chronic & progressive disease characterized by the inability of the heart to pump enough oxygen- and nutrient-rich blood to the rest of the body. It can occur due to several conditions such as coronary heart disease, hypertension, arrhythmias, etc.[1]. HF is characterised by a one-year mortality rate ranging between 17-45% and a five-year mortality rate of 41-75% [2,3].

COPD is a heterogenous lung condition that causes progressive airway obstructions due to abnormalities in the airways and/or alveoli. COPD is characterized by dyspnoea, frequent infections, sputum production and persistent coughing and wheezing. Like HF, COPD is chronic, progressive and complex, affecting an estimated 300 million people worldwide [4,5].

Cardiopulmonary exercise rehabilitation is recommended for HF and COPD patients to improve their functional capacity, quality of life and reduce hospital readmissions [6,7]. Due to disease complexity, it is challenging to objectively track progression of health status in affected patients. Insight into changes in health status can be obtained by assessing changes in functional capacity [8]. Earlier prediction of changes in functional capacity can help understand patients’ response to rehabilitation and allow for changes in the rehabilitation program. In this study we analysed the progression in functional capacity (via a 6MWT) of a HF and COPD patient cohort undergoing exercise rehabilitation and evaluated the performance of a decision tree classifier in

 ISSN: 2325-887X DOI: 10.22489/CinC.2024.166

predicting changes in functional capacity at later stages of rehabilitation.

2. Materials and methods

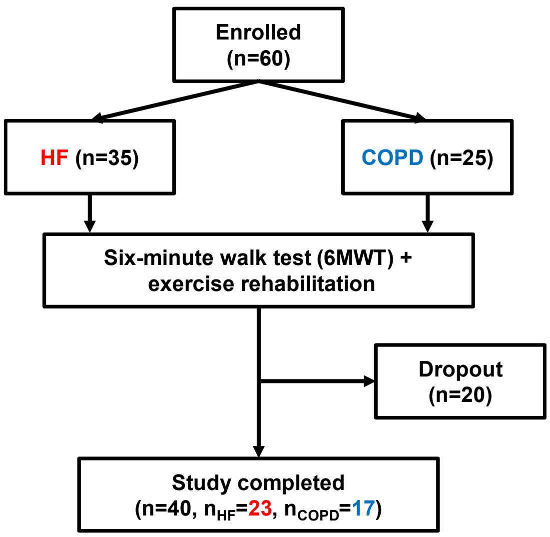

Figure 1 Overview of study enrolment

2.1. Data collection

60 cardiorespiratory patients (N_{HF}=35, N_{COPD}=25) were included in this monocentric, prospective, interventional cohort study (Figure 1) (B3712020000014). The patients were following a cardiorespiratory rehabilitation program at Ziekenhuis Oost-Limburg for a maximum of two weeks prior to the start of the study. This program consisted of 45 sessions of one hour and combined aerobic and strength training (Figure 2).

Patients performed a baseline 6MWT at the beginning of the study and subsequently once every three weeks for a total of five 6WMTs. The submaximal functional capacity was measured using the 6MWD measured by the researcher administering the test. Spot-check heart rate (HR) and oxygen saturation (SpO_2) levels were measured before and after 6MWT using a fingertip pulse oximeter (PC-60F Fingertip Oximeter, Hamburg, Germany). Demographic data collected from patients included age, gender, height and weight.

2.2. Statistical Analysis

Demographic data was analysed using an independent samples t-test for continuous variables and a chi-squared test for categorical variables. The presence of a within-subjects factor (6MWTs) and a between-subjects factor (disease) necessitated the use of a two-way mixed ANOVA test to compare the differences in 6MWD between the HF and COPD patient groups (Figure 3). Post-hoc analysis was performed using paired t-tests to determine the 6MWT pairs that differed significantly.

2.3. Identifying changes in functional capacity

To identify clinically relevant changes in functional capacity of cardiorespiratory patients, literature suggests a 6MWD ranging between 25-55 metres [9,10]. Based on this, a distance of 40 metres as the minimum clinically significant distance between two 6MWTs was chosen. Improvement in functional capacity was defined as an increase of ≥ 40 metres, which led to allocating all patients in two groups (i.e., not/reaching an increase of 40m). A

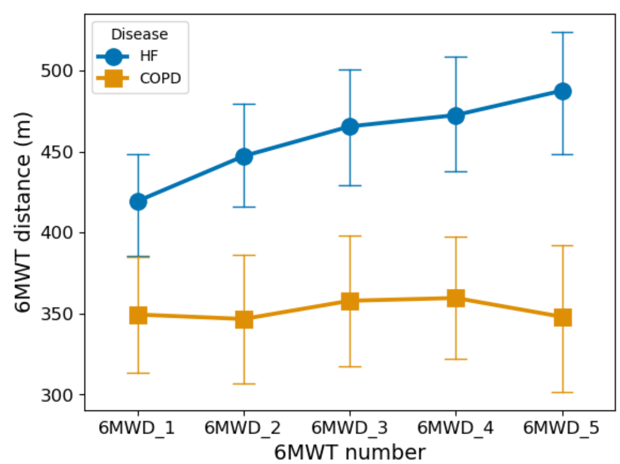

Figure 3 Changes in six-minute walking distance over the duration of the study

decision tree classifier was trained using Gini Impurity as the splitting criterion.

The features used for training the decision tree

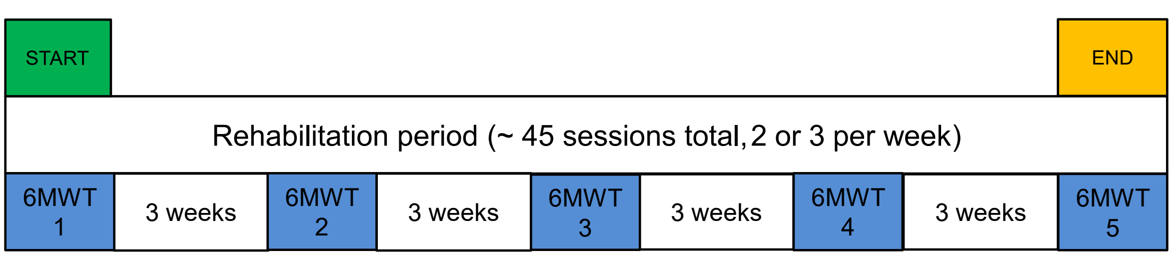

Figure 2 Longitudinal overview of study

comprised a combination of distance-based and physiological features. A concise list of features is shown in Table 1. The classifier was designed to be disease-agnostic by withholding the disease information in the list of features. A leave-one-out CV strategy was used due to the limited number of patients in the study. Tree depths of n=1,2,3 and 4 were chosen as hyperparameters. The performance of the different trees was evaluated using balanced accuracy due to unequal number of HF and COPD patients.

Table 1 List of decision tree features

	Feature	Example Formula
Distance -based	Pairwise differences in 6MWD	$6MWD_3 - 6MWD_2$
	Pairwise differences in 6MWD relative to baseline	$\frac{6MWD_3 - 6MWD_2}{6MWD_1}$
Physio-logical	Difference in HR before and after 6MWT	$HRafter_{T1} - HRbefore_{T1}$
	Difference in SpO2 before and after 6MWT	$SpO2after_{T1} - SpO2before_{T1}$

3. Results

3.1. Statistical Analysis

No significant differences were found between age, gender and BMI (p>0.05) using the independent samples t-test and the chi-squared test (Table 2).

Table 2 Summary of demographic parameters

Parameter	HF	COPD	p-value
BMI (kg/m^2)	28.3 ± 4.9	26.1 ± 6.0	0.15
Age	63.2 ± 10.2	64.9 ± 6.1	0.48
Sex male, n (%)	21 (91)	10 (59)	0.07

Table 3 Summary of mixed ANOVA results

	F	p	η_p^2
Disease (between-subjects factor)	17.42	< 0.01	0.314
Test number (within-subjects factor)	13.78	< 0.01	0.266
Interaction	4.04	0.004	0.096

The between-subjects factor was significantly different between the HF and COPD groups with p<0.01. The mixed ANOVA results also showed a significant effect of the within-subjects factor (p<0.01) indicating that there were differences across the 6MWTs. The interaction between the two factors was also significant with p=0.004. The results of the mixed ANOVA are summarised in Table 3. Post-hoc analysis using pairwise t-tests showed that the distance for all pairs of 6MWTs except (6MWT_4, 6MWT_5) and (6MWT_3, 6MWT_4) was significantly different with p<0.05.

3.2. Predicting improvement in functional capacity

Overall, the distance-based features outperformed the physiological features in both 6MWT_4 and 6MWT_5 in balanced accuracy. The highest balanced accuracy obtained was 0.932 for 6MWT_4 with distance features and a tree depth of 2. The lowest value for accuracy was 0.676 for 6MWT_4 using physiological features with tree depth=1. Physiological features did not improve the classification accuracy when combined with distance-based features as seen in Table 4 and Table 5.

The most discriminative feature overall was the relative difference between 6MWD_3 and 6MWD_1 as a fraction of 6MWD_1 i.e. $\frac{6MWD_3 - 6MWD_1}{6MWD_1}$. The relative difference in SpO_2 values after 6MWT_3 and 6MWT_1 was the most discriminative physiological feature with the lowest Gini impurity.

Table 4 Accuracy values for 6MWT_4

Maximum tree depth	Distance features	Physiological features	Combined
1	0.873	0.676	0.873
2	0.932	0.769	0.932
3	0.932	0.912	0.932
4	0.932	0.923	0.932

Table 5 Accuracy values for 6MWT_5

Maximum tree depth	Distance features	Physiological features	Combined
1	0.875	0.597	0.875
2	0.917	0.722	0.917
3	0.917	0.722	0.917
4	0.917	0.722	0.917

4. Discussion

4.1. General discussion

The results of the mixed ANOVA showed a difference in 6MWD between both patient groups. HF patients had a higher baseline distance and a positive slope in 6MWD throughout rehabilitation. The trend was less discernible in COPD patients with a lower mean difference between 6MWD_5 and 6MWD_1. This could be explained by the fact that several COPD patients took pauses during their 6MWT to consume oxygen before resuming walking. For some patients, the stoppages occurred multiple times during a single 6MWT. The significant effect of the within-subjects factor can be explained by the greater contribution of HF patients to the variance. The significant interaction factor indicated that the progression in distance over the various 6MWTs differed between HF and COPD patients.

The distance-based features outperformed the physiological features in balanced classification accuracy in both 6MWT_4 and 6MWT_5. This can be explained by the highly correlative nature of the 6MWD in this cohort. Due to limited temporal resolution, spot-check data may not always capture physiological variability. It is therefore possible that better performance for physiological features could be obtained using continuously measured HR and SpO2 values that provide greater granularity. In both 6MWT_4 and 6MWT_5, tree depths of 3 and 4 provided marginal or no improvement in accuracy over a depth of 2 suggesting that improvement can be predicted using a maximum of 3 features.

To the best of our knowledge, this is one of the first studies to use a decision tree-based approach to predict patient improvement in functional capacity in a HF and COPD cohort. Using this approach, we were able to good performances on balanced accuracy. Other studies have used the 6MWT to predict mortality using survival analysis and have measured the data at a lower frequency over longer durations [11]. A limitation of these studies is the need for a more frequent monitoring protocol since COPD and HF patients are susceptible to sudden changes in health status.

4.2. Limitations

Since the data was collected in a single tertiary care center, the clinically significant difference in 6MWD may not be suited to other cohorts. The heterogeneity in COPD and HF patients warrants the need for a larger patient cohort before adopting a common distance threshold into clinical practice. Moreover, using the same changes in distance for HF and COPD does not take into account patient-specific disease severity which can affect baseline functional capacity. Disease-specific decision thresholds in combination with relative changes in distance (as a percentage) could account for baseline differences. Most patients who participated in the study either had an increase in their 6MWD or did not have a significant decrease (greater than 40m) as they were participating in an exercise rehabilitation program. Therefore, it was not possible to analyse patients whose 6MWD decreased significantly – however, we believe that the versatility of the methods used in this study can be extended to these patients as well.

Acknowledgments

The authors would like to thank Daimy Roebroek, Frauke Somers and Julie Deckers for their help in collecting data from patients for this study.

References

[1] Kemp CD, Conte JV. The Pathophysiology of Heart Failure. Cardiovascular Pathology. 2019 Sep;21(5):365–71.
[2] Groenewegen A, Rutten FH, Mosterd A, Hoes AW. Epidemiology of Heart Failure. European Journal of Heart Failure. 2020;22(8):1342–56.
[3] Ponikowski P, Anker SD, AlHabib KF, Cowie MR, Force TL, Hu S, et al. Heart Failure: Preventing Disease and Death Worldwide. ESC Heart Failure. 2014 Sep;1(1):4–25.
[4] Ruvuna L, Sood A. Epidemiology of Chronic Obstructive Pulmonary Disease. Clinics in Chest Medicine. 2020;41(3):315–27.
[5] André S, Conde B, Fragoso E, Boléo-Tomé JP, Areias V, Cardoso J. COPD and Cardiovascular Disease. Pulmonology. 2019 May;25(3):168–76.
[6] Piepoli MF, Conraads V, Corrà U, Dickstein K, Francis DP, Jaarsma T, et al. Exercise Training in Heart Failure: From Theory to Practice. A Consensus Document of the Heart Failure Association and the European Association for Cardiovascular Prevention and Rehabilitation. European Journal of Heart Failure. 2011 Apr;13(4):347–57.
[7] Borghi-Silva A, Garcia-Araújo AS, Winkermann E, Caruso FR, Bassi-Dibai D, Goulart C da L, et al. Exercise-Based Rehabilitation Delivery Models in Comorbid Chronic Pulmonary Disease and Chronic Heart Failure. Frontiers in Cardiovascular Medicine. 2021 Oct 13;8.
[8] Goulart C da L, Dos Santos PB, Caruso FR, Arêas GPT, Marinho RS, Camargo P de F, et al. The Value of Cardiopulmonary Exercise Testing in Determining Severity in Patients with Both Systolic Heart Failure and COPD. Scientific Reports. 2020 Mar 9;10(1):4309.
[9] Wise RA, Brown CD. Minimal Clinically Important Differences in the Six-Minute Walk Test and the Incremental Shuttle Walking Test. COPD: Journal of Chronic Obstructive Pulmonary Disease. 2005 Jan;2(1):125–9.
[10] Holland AE, Nici L. The Return of the Minimum Clinically Important Difference for 6-Minute-Walk Distance in Chronic Obstructive Pulmonary Disease. American Journal of Respiratory and Critical Care Medicine. 2013 Feb 15;187(4):335–6.
[11] Dajczman E, Wardini R, Kasymjanova G, Préfontaine D, Baltzan MA, Wolkove N. Six Minute Walk Distance is a Predictor of Survival in Patients with Chronic Obstructive Pulmonary Disease Undergoing Pulmonary Rehabilitation. Canadian Respiratory Journal : Journal of the Canadian Thoracic Society. 2015;22(4):225–9.

Address for correspondence:

Ganesh Raam Kumarasamy
Ziekenhuis Oost-Limburg
Synaps Park 1, Genk
3600 Belgium
ganesh.kumarasamy@uhasselt.be