



Prehabilitation Using a Cardiac Rehabilitation Program for a Patient With a Total Artificial Heart Prior to Heart Transplantation

Michaël Racodon, Éric Hermand, Jean-Michel Lemahieu, Pauline Blairon, Pierre Vanhove, Amandine Secq

► To cite this version:

Michaël Racodon, Éric Hermand, Jean-Michel Lemahieu, Pauline Blairon, Pierre Vanhove, et al.. Prehabilitation Using a Cardiac Rehabilitation Program for a Patient With a Total Artificial Heart Prior to Heart Transplantation. *Journal of Cardiopulmonary Rehabilitation and Prevention*, 2024, 44 (2), pp.137-140. 10.1097/HCR.0000000000000842 . hal-04479725

HAL Id: hal-04479725

<https://sorbonne-paris-nord.hal.science/hal-04479725>

Submitted on 27 Feb 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Prehabilitation Using a Cardiac Rehabilitation Program for a Patient With a Total Artificial Heart Prior to Heart Transplantation

Michaël Racodon^{1,2}, PhD; Éric Hermand², PhD; Jean-Michel Lemahieu¹, PhD; Pauline Blairon¹, MSc; Pierre Vanhove¹, PhD; Amandine Secq¹, PhD

¹Clinique la Mitterie, Cardiac Rehabilitation, Lille, France

²Univ. Lille, Univ. Artois, Univ. Littoral Côte d'Opale, Lille, France

Introduction: The last few decades have been marked by significant advances in mechanical cardiocirculatory support. A total artificial heart (TAH) became a viable therapeutic option for numerous patients as a bridge to heart transplantation, particularly for those in end-stage heart failure. This technology aims to address the various subsequent shortfalls of organs. This report reviews the impact of a prehabilitation on a patient with an Aeson TAH (Carmat).

Discussion: We assessed improvements in functional capacity and quality of life (QoL) in a newly implanted patient following standard cardiac rehabilitation as a prehabilitation program, using 6-min walk test and the Short Form-12 (SF-12) health survey, respectively. Similar functional improvements were observed over a short period of 2 wk compared with a longer protocol for patients with a heart transplant, and superior effects on QoL. The patient was successfully transplanted 5 mo after the TAH implantation.

Summary: Prehabilitation of a patient with a TAH increased both their physical capacity and QoL.

Key Words: cardiac rehabilitation • physical abilities • prehabilitation • quality of life • total artificial heart

A growing number of studies have recently focused on the total artificial heart (TAH), a pump transplanted in the chest to replace the ventricles and valves of a damaged heart.¹ This device now represents a viable treatment option for numerous patients suffering from end-stage heart failure (HF), particularly as a bridge to heart transplantation (HT). The global prevalence of HF is increasing,² and despite significant advances over recent decades in the treatment and prevention of chronic HF, a proportion of patients with endstage HF do not respond well to available treatments.³ In most cases HT remains the most common option for these patients. However, HT relies upon the availability of potential donors, which limits the number of procedures that can be performed.⁴ Hence, mechanical circulatory support systems, such as TAH, are being developed.

An Aeson TAH (Carmat) uses an inner electrohydraulic system to preserve the pulsatile nature of the human heart.⁵ It is designed and built with biocompatible materials to fully replace the native heart.⁶ This device includes four biologic valves and as such is completely autonomous. The TAH consists of a motor pump unit that moves the fluid through the membranes, generating both systole and diastole, and two ventricular cavities. Integrated sensors are implemented inside the system to respond to the physiological needs of the patient. This case study aimed to investigate the impact of prehabilitation⁷ on functional capacity and quality of life (QoL) in a patient newly implanted with a TAH. We considered the physical capabilities and well-being of the patient over the post-surgery period.

A 52-yr-old man, monitored for hypertrophic cardiomyopathy first identified in 1990, developed dilated cardiomyopathy with several episodes of decompensation. In November 2022, the patient went into cardiogenic shock during admission for streptococcus pneumonia, without the possibility of weaning from intravenous amines. The patient was transplanted with a TAH in December 2022 and carried out a subsequent prehabilitation program following 1 mo of post-operation recovery and observation.

We followed the patient from February to March 2023 during this prehabilitation program. The patient gave his informed written consent beforehand, and the study was approved by a national ethics committee (ClinicalTrials Identifier: NCT04475393). The exclusion criteria for the prehabilitation program were similar to those of patients with HF admitted to the clinic and included: unstable HF; symptomatic severe aortic stenosis; decompensated HF; acute pulmonary embolus or pulmonary infarction; serious or uncontrolled arrhythmias; severe atrial flutter or fibrillation; and rheumatoid or osteoarthritis.

THE PREHABILITATION PROGRAM

The patient followed a standard prehabilitation program over 12 d, which comprised of physical and educational activities supervised by experienced hospital practitioners. The first week included daily breathing exercises and endurance work in the form of walking 1 km. The pace was defined by a subjective Borg index ≤ 6 , using the Borg 1-10 scale. In total, the first week consisted of four gymnastic sessions (45 min) and five walking sessions (45 min). The patient underwent a cardiopulmonary exercise test (CPX) at the beginning of the second week, which is routinely used as a standardized tool for the management of patients with HF. He then performed two endurance sessions on a cycle ergometer (30 min), before a light gymnastic session (45 min), and a 1.5-km walk. By the end of the week, the patient had completed five outdoor walks, three gymnastics sessions, and three cycling sessions. After 2 d of rest, on the first day of the final third week, the patient carried out one endurance session on a cycle ergometer, followed by gymnastics, and a 2.5-km walk. The second day was dedicated to various clinical and functional tests. Endurance sessions were performed on a cycle ergometer and by walking in a park around the clinic on a 500-m course. Duration and intensity were set according to subjective perception of effort, at a maximal level 7 on the Borg scale. The gymnastic session was composed of a muscular/segmental training composed of flexibility or resistance movements over 45 min.

EVALUATIONS

Functional and physical capacities were assessed at the beginning and at the end of the prehabilitation program (the day before commencement and the day after completion). An initial CPX was performed on a cycle ergometer Ergoselect 10 (Ergoline GmbH), and flow rate of respiratory gases ($\dot{V}O_2$, for oxygen uptake, $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) was measured using an Ergocard metabograph (MGC Diagnostics). An individualized incremental ramp protocol was used and the patient was encouraged to exercise until voluntary exhaustion, according to the standard procedure for patients with HF.⁸ The flow rate was provided by the Aeson TAH controller in real time. The TAH was in automatic mode during the CPX: variation of flow rate occurred as a function of preload detected by the pressure sensors, per Starling's law. A standardized 6-min walk test was administered to the patient in a corridor with distance markers at 5-m intervals,⁹ with oxygen saturation and heart rate measured with an O2-EASY pulse oximeter (CA-MI). A sit-to-stand test was also performed for 30 sec to assess functional strength of lower limbs,¹⁰ in which the number of repetitions was recorded.

Assessment of QoL was made using a self-administered Short Form-12 (SF-12) questionnaire, which provides a composite score of physical and mental QoL linked to health. The higher the score, the greater the ability of the patient.^{11,12}

Patient characteristics and initial CPX values are summarized in Table 1 and details of the cardiorespiratory cycle ergometer sessions during the 12-d prehabilitation program are presented in Table 2. The main reason for termination of the exercise tests was peripheral limitations (muscular fatigue of the lower limbs). Values of functional capacities and QoL before and after prehabilitation are reported in Table 3. All had improved at the end of this prehabilitation protocol: 6-min walk test (+27%), sit-to-stand test (+27%), SF-12 (+22% and +39% for physical and mental scores, respectively).

After this prehabilitation program, the patient returned home and resumed a normal daily life, although under a tight medical supervision and follow-up. He was then successfully transplanted 3 mo later.

Table 1
Patient Characteristics and Initial Cardiorespiratory Capacities

Sex	Male
Age, yr	52
Height, cm	168
Weight, kg	56
BMI, kg·m ⁻²	19.6
Cardiopulmonary exercise test results	
$\dot{V}O_{2\max}$, mL·kg ⁻¹ ·min ⁻¹ (% predicted)	11.0 (35%)
MAP, W	55
$\dot{V}eT$, W/% $\dot{V}O_{2\max}$	30 (23%)
HR _{rest} /HR _{max} , bpm	121/140
CO _{rest} /CO _{max} , L·min ⁻¹	5/6.5
$\dot{V}E/\dot{V}CO_2$	43.8
FVC, L (% predicted)	1.82 (42%)
SBP _{rest} /SBP _{max} , mm Hg	115/140
DBP _{rest} /DBP _{max} , mm Hg	80/70

Abbreviations: BMI, body mass index; CO, cardiac output; DBP, diastolic blood pressure; FVC, forced vital capacity; HR, heart rate; MAP, maximal aerobic power; SBP, systolic blood pressure; $\dot{V}eT$, power at ventilation threshold; $\dot{V}E/\dot{V}CO_2$, ventilatory equivalent for carbon dioxide; $\dot{V}O_{2\max}$, maximal oxygen uptake.

APPLICATION TO CLINICAL PRACTICE

A prehabilitation program is widely recommended for patients suffering from HF and patients who have undergone HT.¹³ In addition, cardiac rehabilitation (CR) is known to greatly decrease the risk of cardiovascular complications and subsequent readmission following myocardial infarction or HT.^{14,15} However, to our knowledge, there is no data regarding the functional effects of CR following TAH implantation.

Our findings suggest that this patient had experienced a prior decrease in cardiorespiratory fitness, secondary to muscle deconditioning and cardiac changes, due to the nature of the TAH implantation surgery and the subsequent time spent in hospital for recovery. There was a restrictive ventilatory disorder reflected in spirometry values at rest (forced vital capacity = 1.82 L, 42% of predicted value). This was linked to both the sternotomy performed during the surgery and the room occupied by the TAH in the thorax. This likely resulted in restricted thoracic expansion tremely diminished cardiorespiratory fitness ($\dot{V}O_{2\max}$ = 11 mL·kg⁻¹·min⁻¹, 35% of predicted), which was caused by mixed peripheral and respiratory limitations at maximal effort.

Table 2
Cardiorespiratory Values During Cycle Ergometer Training Over a 15-d Period

	Session			
	1	2	3	4
Duration, min	30	30	30	30
Power, W	25	25	25	30
CO _{rest} /CO _{max} , L·min ⁻¹	5/6.2	4.8/6.2	5/6.2	5.3/6.4
Borg RPE, 0-10 scale	6	5	5	6
SBP _{rest} /SBP _{max} , mm Hg	120/130	126/133	125/134	109/131
DBP _{rest} /DBP _{max} , mm Hg	87/89	86/90	99/95	88/85

Abbreviations: CO, cardiac output; DBP, diastolic blood pressure; RPE, rating of perceived exertion; SBP, systolic blood pressure.

In this case, a short prehabilitation of 12 d led to a very significant increase in functional capacity and QoL. The patient was able to complete 30-min endurance sessions on a cycle

ergometer with a load increase during the last session. The available data regarding the short-term effects of CR on functional recovery in patients with HF or HT are still scarce, as standard CR routines usually last between 12 wk and several months, and usually include various modalities. A mean 18-d rehabilitation program in various patients with HF (angina pectoris, myocardial infarction, and cardiac surgery) led to a 31% increase in the 6-min walk test.^{16,17} Similarly, a multicenter study confirmed a more modest, but very significant, +16% improvement in a large and varied cohort of patients with HF following completion of a 3to 4-wk CR program.¹⁸ These data are in accordance with our observations, although the CR duration of our protocol was shorter. Apart from functional recovery, we also observed a large increase of QoL, in both physical and mental components (SF-12 scores). These increases (+22% and +39%, respectively) seem to be greater than those in the aforementioned article,¹⁹ reporting maximal physical and mental score increases of 15% and 14%, respectively, whereas a previous review failed to find such short-term improvements.²⁰ The difference is notably marked for the mental component score, and further investigation will be required on that matter to clarify its origin.

Table 3
Outcome Variables at Baseline and After Prehabilitation

	Baseline	After Prehabilitation	Evolution, %
6MWT			
Distance, m	395	505	+27
SpO _{2rest} /SpO _{2min} , %	96/95	96/95	...
HR _{res} /HR _{max} , bpm	109/143	101/125	-13
SBP _{rest} /SBP _{max} , mmHg	120/131	118/133	...
DBP _{rest} /SBP _{max} , mmHg	80/89	81/92	...
STT	11	14	+27
SF-12			
Physical score	34.3	41.9	+22
Mental score	38.5	53.6	+39

Abbreviations: 6MWT, 6-min walk test; DBP, diastolic blood pressure; HR, heart rate; SpO₂, pulse oxygen saturation; SBP, systolic blood pressure; SF-12, Short Form 12; STT, sit-to-stand test.

Finally, the first follow-up of a patient with HF transplanted with a TAH following a standardized prehabilitation program may provide the first model of their dissociated central (heart) and peripheral (locomotor muscle) effects and limitations. The main limitations to exercise at mild and maximal intensities in patients recovering from HF are primarily of cardiac or cardiocirculatory origin.^{21,22} “Removing” the latter limitation, as the TAH is potentially able to do by mechanically sustaining a higher cardiac output, we may then hypothesize that these limitations would switch from central to more peripheral locations, such as exercising and skeletal muscle blood demand. As an example, during the initial CPX, the patient reported lower limb fatigue as the primary cause of exhaustion.

SUMMARY

The major conclusion from this case was that a standardized prehabilitation program is a viable and feasible therapeutic possibility following TAH implementation. The prehabilitation program allowed the patient to increase both his functional capacity and QoL over a very short-term period. These data provide hope that this patient may complete the ensuing full CR program of a minimum 20 sessions, 2 d/wk, as any patient with HF would. Moreover, the now reliable conception of TAH may, in the future, greatly reduce the inherent cardiac limitations of exercising patients with HF. Finally, and most importantly, the TAH prevented the patient from suffering potential and lethal cardiac complications.

164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216

REFERENCES

1. Essandoh M, Kumar N. Total artificial heart system. *Intl Anesthes Clin.* 2022;60(4):39-45.

2. Savarese G, Lund LH. Global public health burden of heart failure. *Card Fail Rev.* 2017;3(1):7-11.

3. Benjamin EJ, Muntner P, Alonso A, et al. Heart disease and stroke statistics—2019 update: a report from the American Heart Association. *Circulation.* 2019;139(10):e56-e528.

4. Stehlik J, Mehra MR. Secular changes in organ donor profiles and impact on heart and lung transplantation. *J Heart Lung Transplant.* 2020;39(10):997-1002.

5. Han JJ. Aeson—the Carmat total artificial heart is approved for enrollment in the United States. *Artif Organs.* 2021;45(5): 445-446.

6. Carpentier A, Latrémouille C, Cholley B, et al. First clinical use of a bioprosthetic total artificial heart: report of two cases. *Lancet North Am Ed.* 2015;386(10003):1556-1563.

7. Myers J, Niebauer J, Humphrey R. Prehabilitation coming of age: implications for cardiac and pulmonary rehabilitation. *J Cardiopulm Rehabil Prev.* 2021;41(3):141-146.

8. Working Group on Cardiac Rehabilitation & Exercise Physiology and Working Group on Heart Failure of the European Society of Cardiology. Recommendations for exercise training in chronic heart failure patients. *Eur Heart J.* 2001;22(2):125-135.

9. ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories. ATS statement: guidelines for the six-minute walk test. *Am J Respir Crit Care Med.* 2002;166(1):111-117.

10. Takai Y, Ohta M, Akagi R, Kanehisa H, Kawakami Y, Fukunaga T. Sit-to-stand test to evaluate knee extensor muscle size and strength in the elderly: a novel approach. *J Physiol Anthropol.* 2009;28(3):123-128.

11. Gandek B, Ware JE, Aaronson NK, et al. Cross-validation of item selection and scoring for the SF-12 Health Survey in nine countries. *J Clin Epi.* 1998;51(11):1171-1178.

12. Mchorney CA, John WJ, Anastasia R. The MOS 36-Item ShortForm Health Survey (SF-36): II. Psychometric and clinical tests of validity in measuring physical and mental health constructs. *Med Care.* 1993;31(3):247-263.

13. Bachmann JM, Shah AS, Duncan MS, et al. Cardiac rehabilitation and readmissions after heart transplantation. *J Heart Lung Transplant.* 2018;37(4):467-476.

14. Dunlay SM, Pack QR, Thomas RJ, Killian JM, Roger VL. Participation in cardiac rehabilitation, readmissions, and death after acute myocardial infarction. *Am J Med.* 2014;127(6):538-546.

15. Donovan MP, Drusin RE, Edwards NM, Lietz K. Analysis of trends in hospital readmissions and postoperative complications in heart transplant recipients: single center study. *Transplant Proc.* 2002;34(5):1853-1854.

16. Beigiene A, Petruševičienė D, Barasaite V, Kubilius R, Macijauskiene J. Cardiac rehabilitation and complementary physical training in elderly patients after acute coronary syndrome: a pilot study. *Medicina (Kaunas).* 2021;57(6):529. doi:10.3390/medicina57060529.

17. Amstad T, Taeymans J, Englberger L, et al. Cardiac rehabilitation in patients with ventricular assist device. *J Cardiopulm Rehabil Prev.* 2022;42(2):97-102.

18. Zoch-Lesniak B, Dobberke J, Schlitt A, et al. Performance measures for short-term cardiac rehabilitation in patients of working age: results of the prospective observational multicenter registry OutCaRe. *Arch Rehabil Res Clin Transl.* 2020;2(2):100043. doi:10.1016/j.arct.2020.100043.

19. Duarte Freitas P, Haida A, Bousquet M, Richard L, Mauriège P, Guiraud T. Short-term impact of a 4-week intensive cardiac rehabilitation program on quality of life and anxiety-depression. *Ann Phys Rehabil Med.* 2011;54(3):132-143.

20. Shepherd CW, While AE. Cardiac rehabilitation and quality of life: a systematic review. *Intl J Nurs Stud.* 2012;49(6):755-771.

- 217 21. Albouaini K, Egred M, Alahmar A, Wright DJ. Cardiopulmonary exercise testing and
218 its application. *Postgrad Med J*. 2007;83(985):675-682.
- 219 22. Laveneziana P, Paolo MD, Palange P. The clinical value of cardiopulmonary exercise
220 testing in the modern era. *Eur Resp Rev*. 2021;30(159):200187. doi:10.1183/16000617.0187-
221 2020.
- 222
- 223