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

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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.

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

61

62 **THE PREHABILITATION PROGRAM**

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

80

81 **EVALUATIONS**

82 Functional and physical capacities were assessed at the beginning and at the end of the
83 prehabilitation program (the day before commencement and the day after completion). An
84 initial CPX was performed on a cycle ergometer Ergoselect 10 (Ergoline GmbH), and flow
85 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
86 Ergocard metabograph (MGC Diagnostics). An individualized incremental ramp protocol was
87 used and the patient was encouraged to exercise until voluntary exhaustion, according to the
88 standard procedure for patients with HF.⁸ The flow rate was provided by the Aeson TAH
89 controller in real time. The TAH was in automatic mode during the CPX: variation of flow
90 rate occurred as a function of preload detected by the pressure sensors, per Starling's law. A
91 standardized 6-min walk test was administered to the patient in a corridor with distance
92 markers at 5-m intervals,⁹ with oxygen saturation and heart rate measured with an O2-EASY
93 pulse oximeter (CA-MI). A sit-to-stand test was also performed for 30 sec to assess functional
94 strength of lower limbs,¹⁰ in which the number of repetitions was recorded.

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

98 Patient characteristics and initial CPX values are summarized in Table 1 and details of the
99 cardiorespiratory cycle ergometer sessions during the 12-d prehabilitation program are
100 presented in Table 2. The main reason for termination of the exercise tests was peripheral
101 limitations (muscular fatigue of the lower limbs). Values of functional capacities and QoL
102 before and after prehabilitation are reported in Table 3. All had improved at the end of this
103 prehabilitation protocol: 6-min walk test (+27%), sit-to-stand test (+27%), SF-12 (+22% and
104 +39% for physical and mental scores, respectively).

105 After this prehabilitation program, the patient returned home and resumed a normal daily life,
106 although under a tight medical supervision and follow-up. He was then successfully
107 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	
$\dot{V}O_{2max}$, mL·kg ⁻¹ ·min ⁻¹ (% predicted)	11.0 (35%)
MAP, W	55
$\dot{V}eT$, W/% $\dot{V}O_{2max}$	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; $\dot{V}O_{2max}$, maximal oxygen uptake.

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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 ($\dot{V}O_{2max}$ = 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.

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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

128 ergometer with a load increase during the last session. The available data regarding the short-
 129 term effects of CR on functional recovery in patients with HF or HT are still scarce, as
 130 standard CR routines usually last between 12 wk and several months, and usually include
 131 various modalities. A mean 18-d rehabilitation program in various patients with HF (angina
 132 pectoris, myocardial infarction, and cardiac surgery) led to a 31% increase in the 6-min walk
 133 test.^{16,17} Similarly, a multicenter study confirmed a more modest, but very significant, +16%
 134 improvement in a large and varied cohort of patients with HF following completion of a 3to
 135 4-wk CR program.¹⁸ These data are in accordance with our observations, although the CR
 136 duration of our protocol was shorter. Apart from functional recovery, we also observed a large
 137 increase of QoL, in both physical and mental components (SF-12 scores). These increases
 138 (+22% and +39%, respectively) seem to be greater than those in the aforementioned article,¹⁹
 139 reporting maximal physical and mental score increases of 15% and 14%, respectively,
 140 whereas a previous review failed to find such short-term improvements.²⁰ The difference is
 141 notably marked for the mental component score, and further investigation will be required on
 142 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 _{rest} /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.

143
 144 Finally, the first follow-up of a patient with HF transplanted with a TAH following a
 145 standardized prehabilitation program may provide the first model of their dissociated central
 146 (heart) and peripheral (locomotor muscle) effects and limitations. The main limitations to
 147 exercise at mild and maximal intensities in patients recovering from HF are primarily of
 148 cardiac or cardiocirculatory origin.^{21,22} “Removing” the latter limitation, as the TAH is
 149 potentially able to do by mechanically sustaining a higher cardiac output, we may then
 150 hypothesize that these limitations would switch from central to more peripheral locations,
 151 such as exercising and skeletal muscle blood demand. As an example, during the initial CPX,
 152 the patient reported lower limb fatigue as the primary cause of exhaustion.

153
 154 **SUMMARY**

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

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