HHS Public Access
Author manuscript
J Card Fail. Author manuscript; available in PMC 2015 December 01.

Published in final edited form as:
J Card Fail. 2014 December ; 20(12): 973–983. doi:10.1016/j.cardfail.2014.08.011.

Functional Status in Left Ventricular Assist Device-Supported Patients: A Literature Review

Martha Abshire, RN, MS[1], **Cheryl R. Dennison Himmelfarb, RN, PhD**[1,2], and **Stuart D. Russell, MD**[2]

[1]Johns Hopkins University School of Nursing

[2]Johns Hopkins University School of Medicine

Abstract

The prevalence of advanced heart failure (HF) is increasing due to the aging population and improvements in HF management strategies. Left Ventricular Assist Device (LVAD) technology and management continue to advance rapidly and it is anticipated that the number of LVAD implants will increase. LVADs have been demonstrated to extend life and improve outcomes in patients with advanced HF. The purpose of this article is to review and synthesize the evidence on impact of LVAD therapy on functional status. Significant functional gains were demonstrated in patients supported by LVAD throughout the first year with most improvement in distance walked and peak oxygen consumption demonstrated in the first 6 months. Interventions to enhance exercise performance have had inconsistent effects on functional status. Poor exercise performance was associated with increased risk of adverse events. Functional status improved with LVAD therapy, though performance remained substantially reduced compared to age adjusted norms. There is tremendous need to enhance our understanding of factors influencing functional outcomes in this high-risk population.

Keywords

Heart-Assist Device; Functional Status; Quality of Life; Outcomes; Left Ventricular Assist Device

Left Ventricular Assist Devices Improve Functional Status

According to the American Heart Association in 2014 there were 5.1 million Americans adults diagnosed with heart failure (HF).(1) This growing number is attributable to the aging of the population as well as overall improvements in HF management. Of patients with advanced HF, less than 4,000 are on the waiting list for heart transplant.(2,3) Though 2,506 Left Ventricular Assist Devices (LVAD) were implanted in 2013 in the US, it is estimated that between 40,000 – 200,000 HF patients may benefit from the support of an LVAD.(4,5) The number of patients receiving LVAD is anticipated to increase because of the limited

Corresponding Author: Martha Abshire, RN, MS, 525 N. Wolfe Street, Baltimore, MD 21205, Mabshir1@jhu.edu, 443.340.6201.

availability of hearts for transplantation and the growing body of evidence supporting the use of LVAD as destination in addition to bridge to transplant therapy.(6)

Left Ventricular Assist Devices have been demonstrated to improve functional status and quality of life (QOL) over medical management through the REMATCH trial and other LVAD clinical trials.(7–14) A systematic review of the literature regarding QOL has been reported, but the current state of the science with regard to functional status in patients supported by LVAD has not been published.(15) The purpose of this article is to provide a current review of functional status in patients supported by LVAD.

Search Methods

A systematic literature search of the PUBMED and CINAHL databases was conducted. Search terms included the MESH term "heart-assist device" as well as "left ventricular". For functional status, the terms "functional capacity", "functional status", "exercise capacity", "exercise tolerance" and "exercise performance" were used. "Quality of life" was added to the search list because in HF QOL is often measured with a parallel functional measure. In addition, the references of the articles were reviewed to identify supplementary articles of interest.

The search was limited to studies published from 2007 through February 2014. This limitation was in consideration of the vast technological improvements to LVADs, in particular the transition from pulsatile LVADs to continuous-flow devices. Continuous flow LVADs, used in current practice, are more reliable and patients with these LVADs have less thrombotic events than those with pulsatile devices.(16) Articles were limited to English language and international studies were included. Studies were included if they reported original research with a sample including at least 1/3 LVAD patients. Also for inclusion, functional measures were measured or functional outcomes were reported (in qualitative studies). Studies were excluded if the emphasis was on molecular or surgical function, right-sided HF or if a case study was reported. Titles and abstracts (n=331) were reviewed and 241 were excluded. Sixty additional articles were excluded after article review. Thirty studies met criteria for inclusion in this review. Several large cohort studies had overlapping samples with smaller studies. Of the 30 articles selected for review, three categories emerged. Articles focused on describing functional progress, interventions to improve functional status and alternative approaches to understanding functional status. The results are categorized according to these themes.

Describing Functional Progress

Functional Gains Measured by a Six Minute Walk Test

Prior to LVAD insertion most HF patients were classified New York Heart Association (NYHA) class IV with many dependent on inotrope therapy, therefore unable to perform exercise testing.(14) Studies mapping the recovery and functional gains of LVAD recipients found an increase of cardiac output within 2 days of insertion.(17) Functional gains were demonstrated as early as one month.(14,18–20) NYHA class improved to I-II in nearly half of the sample at one month post-implantation in a study by Adamson et al.(19) However, overall surgical recovery and gains were more apparent 3 to 6 months after insertion.(13,14,20) Patients demonstrated marked increase of distance walked during the 6MWT. Distance walked at 1 month ranged from 225 to 367 meters.(14,18,20) By 6 months distance walked increased to 327 to 430 meters.(14,20,21) Between men and women there was a significant difference in distances at each time point, but overall improvement was similar (men improved from 247m to 356m and women from 219m to 327m).(14,20) At later time periods, 6MWT distance further improved at 12 months and remained stable at 24 months for those who could perform the test.(14) At 1 year, Allen et al reported mean 6MWT distance of 393±290m and at 24 months Rogers et al reported stable 6MWT for destination therapy patients.(13,14) These and other findings are summarized in Tables 1 and 2.

Functional Gains Measured by a Cardiopulmonary Exercise Testing

In addition to distance walked, cardiopulmonary exercise (CPX) testing demonstrated that over time patients supported by LVAD increased peak VO_2. Only one study reported CPX testing at 1 month; mean peak VO_2 was 10.5 ± 2.3 in a group assigned for a physical training intervention and 12.4 ± 1.7 in the control group.(18) Mean peak VO_2 at 3 months increased to a range from 12.66 to 18.3 mL/kg/min across several studies.(18,22–24) By 6 months, peak VO_2 ranged from 12.7 to 18.7 mL/kg/min.(21,24–26) Percentage of predicted norms reflected these increases with percentages increasing from 48–61% at 1 month to 42–66% at 12 months.(24–28) These large improvements illustrated that patients function better after LVAD, however function remained significantly below age-adjusted norms.

The studies reviewed had a variety of comparison groups. Pulsatile devices were compared to continuous-flow devices, though this comparison has limited relevance as pulsatile devices have limited use at this time. Patients with LVADs were also compared to heart transplant patients, and heart transplant patients consistently demonstrated greater improvements in functional measures. In Germany, a study comparing CPX testing in LVAD and heart transplant recipients found similar increases in workload between groups, but higher peak VO2 and self-rated QOL in the heart transplant group.(27) This is similar to findings reported in the US.(10)

Prediction of whom among LVAD recipients will have the best overall outcomes remains difficult. Outcomes do not appear to be associated consistently with disease severity, age, gender or race.(10,14,29) Hasin et al used 6MWT performance to group patients into performance groups (< 300m or > 300m).(30) This study used the first 6MWT (mean 4.1 months) after LVAD surgery to predict adverse outcomes, showing a 21% increase in mortality for every 10m less than 300m walked during the test.

Peak exercise capacity has been favored as an objective measure with multiple diagnostic and prognostic applications. The increase of exercise capacity over time in LVAD patients is impressive, but further research is needed to understand how best to help low-scoring patients improve. No published prospective studies have reported serial CPX testing with the same sample and no studies have focused on interventions to support low-functional status LVAD patients. The peak VO_2 improvements, supported by reported gains in quality of life and other functional measure data in the articles reviewed, contribute to the growing body of literature demonstrating the long-term benefit of LVAD therapy.

Functional status was measured using CPX and/or 6MWT in the studies reviewed, but the timing of the exercise testing after surgery was often not standardized. The 2013 International Society for Heart and Lung Transplantation Guidelines suggest CPX or 6MWT at regular intervals: an initial assessment post-op to guide rehab, 3 months, and every 6 months until 2 years after LVAD placement with yearly assessments after that.(31) Future collaborative research will need to further assess the appropriateness and utility of these intervals for functional capacity testing in larger populations of patients.

Interventions to Improve Functional Status

Physical Training Shows Modest Benefit in Small Studies

Interventional studies were conducted in various countries to examine the effect of physical training and other lifestyle-related interventions on functional status. Intervention studies are summarized in Table 3. Physical training studies utilized multi-faceted intervention strategies to enhance functional status, although no two studies used the same combination of strategies.(18,21,28) Intervention strategies included: dietary coaching, psychosocial counseling, aerobic training, strength training and inspiratory muscle training. These studies based their selection of intervention strategies on other cardiac surgery rehabilitation interventions. The multiple modality approach addresses physical recovery multi-dimensionally, however it does not provide evidence of the strength of any individual component of the multi-faceted intervention among LVAD patients..

All physical training interventional studies demonstrated within group improvements in functional status measures for both control and intervention groups.(18,21,27) Intervention groups realized greater improvements in exercise tolerance and 6MWT distance and less weight gain than control groups.(21,28) With an intervention for inspiratory muscle training, Laoutaris et al saw significant within-group improvements in peak VO2, 6MWT and pulmonary function testing in the intervention group while no significant gains were made in the control group.(21) Between group comparisons of change in each functional measure were not statistically significant.(18,21,27) Some of the improvements seen over time were attributable to recovery from the operative procedure and the LVAD benefit of improved cardiac output, however in spite of non-significant findings in these small studies trends towards significance demonstrate an area for continued intervention and investigation. Despite functional improvements made in these studies of physical training interventions, functional status remained far below predicted norms for age groups.

The interventional studies were each conducted at single-sites with small samples; with small studies limited in power to detect differences between groups. Although there may be some methodological benefits to having a comparison group or in some cases, randomizing, the lack of differences between control and intervention groups may be attributed to dividing an already small sample into smaller groups. Another limitation in these studies was that patients entered the intervention programs at different points in their recovery. For instance, in the Hayes et al intervention study patients were included in the intervention after they were able to walk one complete lap on the surgical unit (mean days since implant was 32).(18) Functional status improvements may represent not only the intervention but also time since surgery or complications.

This body of evidence is insufficient to support specific interventions that can produce higher functional outcomes in LVAD patients. Modest benefits were seen in all exercise intervention studies reviewed. The 2013 Guidelines suggest that all capable LVAD patients should be involved in programs for cardiac rehabilitation.(31) Although the guidelines are not specific about intervention methods, articles reviewed here suggest a multi-modal approach of dietary guidance, inspiratory muscle, strength and endurance training may be of benefit.

Pump Speed Alterations

Exercise testing also was used to measure peak exercise performance with LVAD pump speed alterations. Exercise performance was evaluated before and after an LVAD pump speed decrease of 30% in two studies.(32,33) Cardiac output drop commensurate with the pump speed alteration as well as other similar effects were observed in both studies. However, Noor et al further compared change in pump speed by dividing the sample based on an ejection fraction of 40%.(33) Those in the higher ejection fraction group did not significantly drop cardiac output with a pump speed decrease, demonstrating native heart function.

Two studies examined increasing pump speed with exercise (400 rpm per exercise stage) and compared results with the same group of patients performing an exercise test at usual fixed pump speed.(34,35) Brassard et al showed cardiac output increased at submaximal exercise with increased pump speed (at rest cardiac output was 6 ± 2.1 L/min; submaximal exercise 60W cardiac output was 8.7 ± 1.1 L/min).(34) But, this study did not demonstrate significant differences at maximal exercise between the increased pump speed and constant pump speed groups. However, in a follow-up study, Jung et al demonstrated the benefit of increasing pump speed to support maximal exercise.(35) A significant increase of speed of pump (control group 9,357 ± 238 rpm to pump increase group 10,843 ± 835 rpm) resulted in peak VO2 that was significantly higher in the group with increased pump speed (control group 14.1 ± 6.3 ml/kg/min; pump increase group 15.4 ± 5.9 ml/kg/min). The earlier study used a Swan Ganz catheter to capture cardiac output, but this approach may have limited the participants from reaching maximum exhaustion.(34) Jung et al did not use invasive catheterization to measure cardiac output.(35) They did, however, have an older sample with longer mean days of support.

This important area of research merits further investigation as it may produce a means to support higher activity level in LVAD patients. The possibility of developing pump algorithms to support increased demand could be realized with confirmatory studies in larger samples. Here it is also important to highlight the debated relevance of peak versus submaximal exercise. Peak VO_2, even after 6–12 months of recovery, is still poor enough in most LVAD patients to suggest the need for transplant. In a recent study, 6MWT was approximately 80m further in patients with LVAD compared to heart failure patients medically managed with the same peak VO_2.(36) Submaximal exercise testing during CPX and 6MWT may more clearly reflect the functional gains that patients experience and require for improved ability to execute activities of daily living, participate in active hobbies and recreation and even return to work.

Functional Status Improves During Inpatient Rehabilitation

Three retrospective studies examined the effect of inpatient rehabilitation, a common discharge setting for patients following LVAD surgery, by comparing functional status, using the Functional Independence Measure (FIM), at admission and discharge.(37–39) The FIM is a reliable tool that quantifies several domains of function including: self-care, motor control, ambulation, etc.(40) All three of these studies demonstrated gains in FIM and FIM efficiency (FIM/length of stay) (depicted in Table 3).(37–39) These studies were limited by quasi-experimental design and measurement of few outcomes. However, more research efforts focusing on this discharge setting may help address concerns of a group of LVAD users at increased risk, i.e., those who cannot safely go home with a single caregiver or have increased supervision and physical activity and/or nursing care needs.

The value of early mobilization and increased physical activity post LVAD has been well supported.(41) However, acute complications can limit functional recovery and ability to engage in rehabilitation, leading to poor outcomes. Acute complications were addressed in several of the articles reviewed and particularly in the studies evaluating inpatient rehabilitation. Complications during inpatient rehabilitation were varied but included: acute, symptomatic anemia, epistaxis, depression, and stroke.(37–39) These complications demonstrated the necessity for patient and provider education regarding signs and symptoms of complications, evaluating discharge practices and understanding the burden of the medical complexity of these patients.

Alternative Approaches to Understanding Functional Status

Most studies used approaches to measure functional status that focused on physiologic measures (as the 6MWT, CPX), but several qualitative studies sought to broaden the understanding of what ‘function’ meant to LVAD patients and examined functional disruptions. Individuals living with LVAD struggled after discharge with bathing independently, interrupted sleep and returning to pleasurable and meaningful activities including sexual intercourse and driving, which negatively affected both functional status and QOL.(42–47) These findings suggest a need to further explore the specific stressors that cause functional limitations and trouble LVAD patients.

Casida et al explored the relationship between sleepiness, daytime function and QOL. QOL was negatively correlated with sleepiness and positively correlated with daytime function.(42) Sleepiness was found to improve from baseline (1 month post-implantation) to time 2 (6 months), though LVAD patients were still more sleepy at 6 months post-implantation than the age-adjusted norms. Sleep disturbance has been directly related to symptoms of cardiopulmonary congestion and pain in heart failure patients. These have been demonstrated to impact depression which can have additional effects on functional and QOL outcomes.(48) The importance of sleep for LVAD patients is not well understood and should be further investigated in future research.

Functional status has been measured under the assumption that physical exercise (maximal or submaximal) represents the effort of performing ADLs and other functional requirements. The work of Casida and others draws attention that measuring functional status and QOL likely does not capture the ways that life with an LVAD is functionally difficult. There have been few studies with an emphasis on nutrition, BMI, sleep, frailty and other topics that are likely to be important influences on functional status. Continued research is necessary to create a comprehensive understanding of barriers and facilitators of good functional outcomes in patients supported by LVAD.

Recommendations for Future Research

While functional gains are dramatic for those measured, a large number of LVAD patients die in the early peri-operative period and within the first year.(13,23,25) In addition, only the LVAD patients that are assessed to be physically capable are included in exercise testing. Thus, the patients with greatest illness severity likely are not represented and therefore the findings have limited generalizability. Research methodologies and reporting should continue to provide clarity about how many patients are unable to participate in measurement of functional outcomes. As the use of LVAD increases, understanding who is most at risk to have poor outcomes will influence studies that examine patient selection for LVAD placement, LVAD care coordination and interventions to maximize functional and QOL outcomes.

Addressing health disparities is a priority for both the American Heart Association and the National Institutes of Health. However, due to the predominantly white, male LVAD population, the diversity of LVAD research samples has been limited. According to Interagency Registry for Mechanically Assisted Circulatory Support women receive about 21% of LVADs.(49) This inequality may be attributable to the greater age at which women develop late stage HF. LVAD research participation reflects this gender gap. In addition to gender disparities, there is little LVAD research done comparing racial groups, although some work has been done comparing African-Americans and Caucasians.(29) Also, it was noted that mean age of participants, particularly in the intervention studies, was lower than the mean age of the LVAD program population from which they were selected, suggesting a potential selection bias related to age. Although there may be many reasons these disparities in research participation exist, future LVAD research will need to broaden samples to enhance generalizability, particularly as it is anticipated that LVAD programs will move out of academic centers and into the community.(50)

In accordance with the 2013 guidelines, LVAD programs will begin to gather functional status and quality of life data at regular intervals.(31) As programs grow, future research will need to continue to assess these intervals and functional gains to determine the appropriateness of the intervals and the measures. More comparisons will need to consider implant strategy, bridge to transplant versus destination therapy. Functional gains up to 6 months are clearly and consistently demonstrated, but interventions should be developed and tested to help enhance these gains throughout LVAD therapy. This review also demonstrates opportunities for improved understanding of how changes in pump settings can improve functional outcomes.

Finally, years of single-center studies have been published reporting LVAD outcomes. Multi-center collaborations are necessary to advance the science of caring for this advanced heart failure population with high healthcare utilization to improve prediction models, functional outcomes and the lives of the patients and families receiving LVAD therapy.

Acknowledgments

Funding Source: NIH, NINR, T32 NR 012704, Heart Failure Society of America Nurse Research Grant (2014–2016) and the Predoctoral Training in Research Program (NIH 5TL1TR001078-02 (2014–2015)

Disclosures

Dr. Russell is a consultant for and has received research support from Thoratec.

References

1. Go AS, Mozaffarian D, Roger VL, Benjamin EJ, Berry JD, Blaha MJ, et al. Heart disease and stroke statistics--2014 update: a report from the American Heart Association. Circulation [Internet]. 2014 Jan 21; 129(3):e28–e292. Available from: http://circ.ahajournals.org/content/129/3/e28.
2. Colvin-Adams M, Smithy JM, Heubner BM, Skeans MA, Edwards LB, Waller C, et al. OPTN/SRTR 2012 Annual Data Report: heart. Am J Transplant [Internet]. 2014 Jan; 14(Suppl 1):113–138. Available from: http://www.ncbi.nlm.nih.gov/pubmed/24373170.
3. Introduction. Am J Transplant [Internet]. 2014 Jan; 14(Suppl 1):8–10. Available from: http://www.ncbi.nlm.nih.gov/pubmed/24373165.
4. Kirklin, J.; Naftel, D.; Myers, S.; Clark, M.; Collum, S.; Hollifield, K., et al. Quarterly Statistical Report 2013 4th Quarter. Birmingham, Alabama: 2014.
5. Miller LW. Left ventricular assist devices are underutilized. Circulation [Internet]. 2011 Apr 12; 123(14):1552–1558. discussion 1558. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21482973.
6. Lietz K, Long JW, Kfoury AG, Slaughter MS, Silver Ma, Milano Ca, et al. Outcomes of left ventricular assist device implantation as destination therapy in the post-REMATCH era: implications for patient selection. Circulation [Internet]. 2007 Jul 31; 116(5):497–505. Available from: http://www.ncbi.nlm.nih.gov/pubmed/17638928.
7. Rose, Ea; Gelijns, AC.; Moskowitz, AJ.; Heitjan, D.; Stevenson, LW.; Dembitsky, W., et al. LONG-TERM USE OF A LEFT VENTRICULAR ASSIST DEVICE. N Engl J Med. 2001; 345(20):1435–1443. [PubMed: 11794191]
8. Grady KL, Meyer P, Mattea A, White-Williams C, Ormaza S, Kaan A, et al. Improvement in quality of life outcomes 2 weeks after left ventricular assist device implantation. J Heart Lung Transplant [Internet]. 2001 Jun; 20(6):657–669. Available from: http://www.ncbi.nlm.nih.gov/pubmed/11404172.
9. Grady KL, Meyer P, Mattea A, Dressler D, Ormaza S, White-Williams C, et al. Change in physical and psychosocial domains of quality of life from before to after discharge post left ventricular assist device implantation. J Heart Lung Transplant [Internet]. 2001 Mar.20(2):203. Available from: http://www.ncbi.nlm.nih.gov/pubmed/11250362.
10. Grady KL, Meyer PM, Dressler D, White-Williams C, Kaan A, Mattea A, et al. Change in quality of life from after left ventricular assist device implantation to after heart transplantation. J Hear Lung Transplant [Internet]. 2003 Nov; 22(11):1254–1267. Available from: http://linkinghub.elsevier.com/retrieve/pii/S1053249802012263.
11. Grady KL, Meyer P, Mattea A, Dressler D, Ormaza S, White-Williams C, et al. Predictors of quality of life at 1 month after implantation of a left ventricular assist device. Am J Crit Care [Internet]. 2002 Jul; 11(4):345–352. Available from: http://www.ncbi.nlm.nih.gov/pubmed/12102435.
12. Grady KL, Meyer PM, Dressler D, Mattea A, Chillcott S, Loo A, et al. Longitudinal change in quality of life and impact on survival after left ventricular assist device implantation. Ann Thorac Surg [Internet]. 2004 Apr; 77(4):1321–1327. Available from: http://www.ncbi.nlm.nih.gov/pubmed/15063260.

13. Allen, JG.; Weiss, ES.; Schaffer, JM.; Patel, ND.; Ullrich, SL.; Russell, SD., et al. J Heart Lung Transplant [Internet]. Vol. 29. Elsevier Inc; 2010 Mar. Quality of life and functional status in patients surviving 12 months after left ventricular assist device implantation; p. 278-285.Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2887481&tool=pmcentrez&rendertype=abstract [cited 2014 Feb 10]
14. Rogers, JG.; Aaronson, KD.; Boyle, AJ.; Russell, SD.; Milano, Ca; Pagani, FD., et al. J Am Coll Cardiol [Internet]. Vol. 55. Elsevier Inc; 2010 Apr 27. Continuous flow left ventricular assist device improves functional capacity and quality of life of advanced heart failure patients; p. 1826-1834.Available from: http://www.ncbi.nlm.nih.gov/pubmed/20413033 [cited 2014 Feb 10]
15. Maciver J, Rao V, Ross HJ. Quality of life for patients supported on a left ventricular assist device. Expert Rev Med Devices [Internet]. 2011 May; 8(3):325–337. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21542706.
16. Slaughter, MS.; Pagani, FD.; Rogers, JG.; Miller, LW.; Sun, B.; Russell, SD., et al. J Heart Lung Transplant [Internet]. Vol. 29. Elsevier Inc; 2010 Apr. Clinical management of continuous-flow left ventricular assist devices in advanced heart failure; p. S1-S39.Available from: http://www.ncbi.nlm.nih.gov/pubmed/20181499 [cited 2014 Feb 10]
17. Loforte A, Montalto A, Ranocchi F, Casali G, Luzi G, Monica PL Della, et al. Heartmate II axial-flow left ventricular assist system: management, clinical review and personal experience. J Cardiovasc Med (Hagerstown) [Internet]. 2009 Oct; 10(10):765–771. Available from: http://www.ncbi.nlm.nih.gov/pubmed/19465866.
18. Hayes, K.; Leet, AS.; Bradley, SJ.; Holland, AE. J Heart Lung Transplant [Internet]. Vol. 31. Elsevier Inc; 2012 Jul. Effects of exercise training on exercise capacity and quality of life in patients with a left ventricular assist device: a preliminary randomized controlled trial; p. 729-734.Available from: http://www.ncbi.nlm.nih.gov/pubmed/22425235 [cited 2014 Jan 29]
19. Adamson, RM.; Stahovich, M.; Chillcott, S.; Baradarian, S.; Chammas, J.; Jaski, B., et al. J Am Coll Cardiol [Internet]. Vol. 57. Elsevier Inc; 2011 Jun 21. Clinical strategies and outcomes in advanced heart failure patients older than 70 years of age receiving the HeartMate II left ventricular assist device: a community hospital experience; p. 2487-2495.Available from: http://www.ncbi.nlm.nih.gov/pubmed/21679851 [cited 2014 Mar 20]
20. Bogaev RC, Pamboukian SV, Moore SA, Chen L, John R, Boyle AJ, et al. Comparison of outcomes in women versus men using a continuous-flow left ventricular assist device as a bridge to transplantation. J Heart Lung Transplant [Internet]. 2011 May; 30(5):515–522. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21257321.
21. Laoutaris ID, Dritsas A, Adamopoulos S, Manginas A, Gouziouta A, Kallistratos MS, et al. Benefits of physical training on exercise capacity, inspiratory muscle function, and quality of life in patients with ventricular assist devices long-term postimplantation. Eur J Cardiovasc Prev Rehabil [Internet]. 2011 Feb; 18(1):33–40. Available from: http://www.ncbi.nlm.nih.gov/pubmed/20571404.
22. Haft J, Armstrong W, Dyke DB, Aaronson KD, Koelling TM, Farrar DJ, et al. Hemodynamic and exercise performance with pulsatile and continuous-flow left ventricular assist devices. Circulation [Internet]. 2007 Sep 11; 116(11 Suppl):I8–I15. Available from: http://www.ncbi.nlm.nih.gov/pubmed/17846330.
23. Pruijsten RV, Lok SI, Kirkels HH, Klöpping C, Lahpor JR, de Jonge N. Functional and haemodynamic recovery after implantation of continuous-flow left ventricular assist devices in comparison with pulsatile left ventricular assist devices in patients with end-stage heart failure. Eur J Heart Fail [Internet]. 2012 Mar; 14(3):319–325. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22294758.
24. Leibner ES, Cysyk J, Eleuteri K, El-Banayosy A, Boehmer JP, Pae WE. Changes in the functional status measures of heart failure patients with mechanical assist devices. ASAIO J [Internet]. 2013; 59(2):117–122. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23438772.
25. McDiarmid A, Gordon B, Wrightson N, Robinson-Smith N, Pillay T, Parry G, et al. Hemodynamic, echocardiographic, and exercise-related effects of the HeartWare left ventricular assist device in advanced heart failure. Congest Heart Fail [Internet]. 19(1):11–15. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22804927.

26. Martina J, de Jonge N, Rutten M, Kirkels JH, Klöpping C, Rodermans B, et al. Exercise hemodynamics during extended continuous flow left ventricular assist device support: the response of systemic cardiovascular parameters and pump performance. Artif Organs [Internet]. 2013 Sep; 37(9):754–762. Available from: http://www.ncbi.nlm.nih.gov/pubmed/24074245.
27. Kugler C, Malehsa D, Tegtbur U, Guetzlaff E, Meyer AL, Bara C, et al. Health-related quality of life and exercise tolerance in recipients of heart transplants and left ventricular assist devices: a prospective, comparative study. J Heart Lung Transplant [Internet]. 2011 Feb; 30(2):204–210. Available from: http://www.ncbi.nlm.nih.gov/pubmed/20980169.
28. Kugler C, Malehsa D, Schrader E, Tegtbur U, Guetzlaff E, Haverich A, et al. A multimodal intervention in management of left ventricular assist device outpatients: dietary counselling, controlled exercise and psychosocial support. Eur J Cardiothorac Surg [Internet]. 2012 Dec; 42(6): 1026–1032. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22723614.
29. Aggarwal A, Gupta A, Pappas PS, Tatooles A, Bhat G. Racial differences in patients with left ventricular assist devices. ASAIO J [Internet]. 58(5):499–502. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22929898.
30. Hasin, T.; Topilsky, Y.; Kremers, WK.; Boilson, Ba; Schirger, Ja; Edwards, BS., et al. Am J Cardiol [Internet]. Vol. 110. Elsevier Inc; 2012 Nov 1. Usefulness of the six-minute walk test after continuous axial flow left ventricular device implantation to predict survival; p. 1322-1328.Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3501384&tool=pmcentrez&rendertype=abstract [cited 2014 Feb 10]
31. Feldman D, Pamboukian SV, Teuteberg JJ, Birks E, Lietz K, Moore SA, et al. The 2013 International Society for Heart and Lung Transplantation Guidelines for mechanical circulatory support: executive summary. J Heart Lung Transplant [Internet]. 2013 Mar; 32(2):157–187. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23352391.
32. Jakovljevic DG, George RS, Nunan D, Donovan G, Bougard RS, Yacoub MH, et al. The impact of acute reduction of continuous-flow left ventricular assist device support on cardiac and exercise performance. Heart [Internet]. 2010 Sep; 96(17):1390–1395. Available from: http://www.ncbi.nlm.nih.gov/pubmed/20643664.
33. Noor MR, Bowles C, Banner NR. Relationship between pump speed and exercise capacity during HeartMate II left ventricular assist device support: influence of residual left ventricular function. Eur J Heart Fail [Internet]. 2012 Jun; 14(6):613–620. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22505397.
34. Brassard P, Jensen AS, Nordsborg N, Gustafsson F, Møller JE, Hassager C, et al. Central and peripheral blood flow during exercise with a continuous-flow left ventricular assist device: constant versus increasing pump speed: a pilot study. Circ Heart Fail [Internet]. 2011 Sep; 4(5): 554–560. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21765126.
35. Jung MH, Hansen PB, Sander K, Olsen PS, Rossing K, Boesgaard S, et al. Effect of increasing pump speed during exercise on peak oxygen uptake in heart failure patients supported with a continuous-flow left ventricular assist device. A double-blind randomized study. Eur J Heart Fail [Internet]. 2014 Jan.8:1–6. Available from: http://www.ncbi.nlm.nih.gov/pubmed/24464845.
36. Nahumi, N.; Morrison, Ka; Garan, AR.; Uriel, N.; Jorde, UP. J Heart Lung Transplant [Internet]. Vol. 33. Elsevier; 2014 Mar. Peak exercise capacity is a poor indicator of functional capacity for patients supported by a continuous-flow left ventricular assist device; p. 213-215.Available from: http://www.ncbi.nlm.nih.gov/pubmed/24365765 [cited 2014 Apr 29]
37. Kohli, HS.; Canada, J.; Arena, R.; Tang, DG.; Peberdy, MA.; Harton, S., et al. J Heart Lung Transplant [Internet]. Vol. 30. Elsevier Inc; 2011 Nov. Exercise blood pressure response during assisted circulatory support: comparison of the total artificial [corrected] heart with a left ventricular assist device during rehabilitation; p. 1207-1213.Available from: http://www.ncbi.nlm.nih.gov/pubmed/21862351 [cited 2014 Feb 10]
38. Nguyen, E.; Stein, J. PM R [Internet]. Vol. 5. Elsevier Inc; 2013 Feb. Functional outcomes of adults with left ventricular assist devices receiving inpatient rehabilitation; p. 99-103.Available from: http://www.ncbi.nlm.nih.gov/pubmed/23332348 [cited 2014 Feb 10]
39. English ML, Speed J. Effectiveness of acute inpatient rehabilitation after left ventricular assist device placement. Am J Phys Med Rehabil [Internet]. 2013 Jul; 92(7):621–626. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23117269.

40. Ottenbacher KJ, Hsu Y, Granger CV, Fiedler RC. The reliability of the functional independence measure: a quantitative review. Arch Phys Med Rehabil [Internet]. 1996 Dec; 77(12):1226–1232. Available from: http://www.ncbi.nlm.nih.gov/pubmed/8976303.
41. Ueno A, Tomizawa Y. Cardiac rehabilitation and artificial heart devices. J Artif Organs [Internet]. 2009 Jan; 12(2):90–97. Available from: http://www.ncbi.nlm.nih.gov/pubmed/19536625.
42. Casida JM, Parker J. A preliminary investigation of symptom pattern and prevalence before and up to 6 months after implantation of a left ventricular assist device. J Artif Organs [Internet]. 2012 Jun; 15(2):211–214. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22120165.
43. Marcuccilli L, Casida JJ, Peters RM, Wright S. Sex and intimacy among patients with implantable left-ventricular assist devices. J Cardiovasc Nurs [Internet]. 2011; 26(6):504–511. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21372729.
44. Casida JM, Marcuccilli L, Peters RM, Wright S. Lifestyle adjustments of adults with longterm implantable left ventricular assist devices: a phenomenologic inquiry. Heart Lung [Internet]. 2011; 40(6):511–520. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21722957.
45. Overgaard D, Grufstedt Kjeldgaard H, Egerod I. Life in transition: a qualitative study of the illness experience and vocational adjustment of patients with left ventricular assist device. J Cardiovasc Nurs [Internet]. 2012; 27(5):394–402. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21912269.
46. Chapman E, Parameshwar J, Jenkins D, Large S, Tsui S. PSYCHOSOCIAL ISSUES FOR PATIENTS WITH VENTRICULAR. 2007; (800):72–81.
47. Hallas C, Banner NR, Wray J. A qualitative study of the psychological experience of patients during and after mechanical cardiac support. J Cardiovasc Nurs [Internet]. 2009; 24(1):31–39. Available from: http://www.ncbi.nlm.nih.gov/pubmed/19114799.
48. Johansson P, Dahlström U, Broström A. Consequences and predictors of depression in patients with chronic heart failure: implications for nursing care and future research. Prog Cardiovasc Nurs [Internet]. 2006 Jan; 21(4):202–211. Available from: http://www.ncbi.nlm.nih.gov/pubmed/17170596.
49. Kirklin, JK.; Naftel, DC.; Kormos, RL.; Stevenson, LW.; Pagani, FD.; Miller, Ma, et al. J Heart Lung Transplant [Internet]. Vol. 32. Elsevier; 2013 Feb. Fifth INTERMACS annual report: risk factor analysis from more than 6,000 mechanical circulatory support patients; p. 141-156.Available from: http://www.ncbi.nlm.nih.gov/pubmed/23352390 [cited 2014 Jan 22]
50. Peura JL, Colvin-Adams M, Francis GS, Grady KL, Hoffman TM, Jessup M, et al. Recommendations for the use of mechanical circulatory support: device strategies and patient selection: a scientific statement from the American Heart Association. Circulation [Internet]. 2012 Nov 27; 126(22):2648–2667. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23109468.

Highlights

- LVAD patients demonstrate improvement to NYHA class I-II throughout first year of therapy with largest functional gains made during the first six months of therapy.
- Physical training intervention studies have demonstrated prevention of weight gain, increased 6-minute walk test distances and improved pulmonary function but further intervention studies are needed.
- Pump speed alterations have produced varied results, but further studies should consider the value of submaximal exercise testing which may more clearly reflect the functional gains that patients experience

Table 1

Functional Gains Over Time

	Pre-op	1 month	3 months	6 months	12 months	18 months	24 months
NYHA class (I–IV)							
Rogers*	~III–IV	~II–III	~I–III	~I–III	~I–III		
McDiarmid (mean)	3.6 ± 0.5			2.3 ± 0.7	1.7 ± 0.8		
Bogaev	0% of sample class I			83–85% of sample class I			
Allen					1.4±0.6		
Adamson < 70 years > 70 years	I–II – 0% I–II – 0%	I–II – 48% I–II – 42%	I–II – 86% I–II – 90%	I–II – 100% I–II – 89%			
Peak VO_2 (ml/kg/min)							
McDiarmid	9.9 ± 2.1			14.3 ± 5.1	14.6 ± 4.6		
Leibner	11.16 ± 3.1			12.66 ±3.52	10.74 ± 2.7	11.18 ± 1.7	
Pruijsten			18.3 ± 4.8				
Haft			15.6 ± 4.7				
Hayes+ IGr CGr		10.5 ± 2.3 12.4 ± 1.7	14.8 ± 4.9 15.3 ± 4.4				
Martina				18.7± 5.8	18.8 ± 5.7		
Laoutaris+ IGr CGr				16.8 ± 3.7 14.9 ± 4	19.3 ± 4.5 14.8 ± 4.2		
Percentage of Predicted peak VO_2 (%)							
McDiarmid	32.3 ± 7.4			41.4 ±12.7	42 ± 15		
Leibner	40.4 ± 9.3			46.94 ± 10.2	46.81 ± 11.5	50.09 ± 6.1	
Pruijsten			49 ± 11				
Martina				51 ± 13	52 ± 13		
Haft			49.1 ± 13.6				
Kugler		~48		~56			

	Pre-op	1 month	3 months	6 months	12 months	18 months	24 months
Kugler+ IGr CGr		59–61		58–62	61–66	62–69	
6MWT (meters)							
Rogers DT BTT	204 ± 150 214 ± 125	~225 ~250	~280 ~350	350 ± 198 372 ± 199	~325	360±210	~350
Bogaev Female Male	219 ± 173 247 ± 112	238 ± 108 275 ± 162	306 ± 147 351 ± 163	327 ± 114 356 ± 179			
Adamson < 70 years >70 years	256 ± 96 233 ± 100	188 ± 113 162 ± 114	354 ± 162 256 ± 100	275 ± 135 295 ± 97			
Allen					393 ± 290		
Laoutaris+ IGr CGr				462 ± 88 430 ± 41	527 ± 76 448 ± 55		
Hayes+ IGr CGr		351 ± 77 367 ± 129	531 ± 131 489 ± 95				
SF-36 (patient-rated Physical Health only)							
Kugler (Physical Function)		50 ± 3.8		55 ± 5.5			
Kugler+ IGr CGr		34.7 ± 1.5 30.4 ± 1.4		~37 ~37	~39 ~36	~40 ~35	
Hayes+ IGr CGr		23.4 ± 8.9 33 ± 104	53.7 ± 23.8 47.7 ± 9.4				

~ data is obtained from graphs and is approximate

+ exercise intervention study

IGr Intervention Group
CGr Control Group

Table 2

LVAD Functional Outcomes

Study (country)	**Sample**	**Design**	**Findings**
Functional Gains Measured by Six Minute Walk Test			
Adamson et al, (2011) (US)	LVAD type: HMII N LVADs: 55 Female: not reported Mean age in years: < 70: 56.7 ± 14.3 > 70: 76.3 ± 3.9	Retrospective HMII trial participants compared outcomes for patients > 70 years and < 70 years old.	- Within group improvements were similar across time and there was no statistical difference between groups for QOL, 6MWT and METs - No difference in the incidence of adverse events for this small sample. - Survival was comparable across time regardless of age - Demonstrated value of LVAD therapy for patients > 70 years
Bogaev et al, (2011) (US)	LVAD type(s): HMII N LVADs: 465 Female: 22% Mean age in years: Men 52.4±12.8 Women 49.6±14.2	Retrospective Compared outcomes by gender	- Men and women had similar improvements in 6MWT and NYHA class at 6 months. - 6MWT at 6 months compared to baseline pre-op (most patients could not perform pre-op 6MWT): Women improved from 219 to 327m and men improved from 247 to 356m. - NYHA I or II at 6 months - 83% women and 85% men (0% NYHA I or II at baseline for men or women) - Distance walked at all times was greater for men (p=0.037).
Rogers et al, (2010) (US)	LVAD type(s): HMII N LVADs: 655 Female: BTT – 24% DT – 27% Mean age in years: BTT - 50±13 DT - 63±12	Prospective 2 years Compared BTT vs DT	- Dramatic improvement in distance walked up to 6 months, leveling from 6–24 months - Only 14% BTT and 34% DT were able to do 6MWT pre-op - DT improved 6MWT +146m at 24 months from baseline pre-op - 80–82% in NYHA class I-II from 6–24 months - 60% of DT rated exercise ability moderate-very high
Allen et al, (2010) (US)	LVAD type(s): HMII and others (not specified) N LVADs: 103 Female: survivors – 27% died in 1st year – 21% Mean age in years: survivors – 48.2±12.4 died in 1st year – 49.8±13.7	Retrospective Compared 1-year survivors with those who died in the 1st year	- Survivors were more likely to have had HMII, planned DT (not BTT), and did not have intra-aortic balloon pump pre-op. - Mean days of support for those who died in the 1st year was 148±153. - Among survivors at 1 year, mean 6MWT 393±290m and mean NYHA 1.4±0.6. - Survivors spent 87.3% ± 14% of time out of hospital, but 23/30 survivors required re-operation.
Loforte et al, (2009) (Italy)	LVAD type: HMII N LVADs: 18 Female: 28% Mean age in years: 52± 8	Retrospective Reported Progress Over Time	- 30-day mortality 27.7% - 12/18 discharged NYHA class I - Mean Cardiac Index improved from 1.8 to 3.5 by 48 hours post-op (no p-value reported) - Greater proportion able to complete 6MWT and go further distance at 30 days (no number reported)

Study (country)	Sample	Design	Findings
Hasin et al, (2012) (US)	LVAD type: HMII N LVADs: 65 Female: 17% Mean age in years: 65.92	Retrospective Examined risk for mortality based on 6MWT results	- 21% increased mortality for every 10m less than 300m - Poor performers were older, had diabetes and hypertension comorbidity, decreased glomerular filtration rates, required prolonged inotropy, had increased ventilator time, increased length of stay, and increased Right Atrial Pressures at 1 month. - Created 3 risk predictor categories: pre-op issues, peri-op issues and 1 month echo result indicators
Functional Gains Measured by CardioPulmonary Exercise Testing			
McDiarmid et al, (2013) (UK)	LVAD type: Heartware N LVADs: 30 Female: 27% Mean age in years: 47±12	Retrospective Compared 2 timepoints – approximately 6 (mean 201 ± 86 days) and 12 months (mean 351 ± 86 days)	- By 12 months, improved NYHA from 3.6 to 1.7 - Improved VO_2 from 9.9 ± 2.1 to 14.6 ± 4.6 - Improved from 32.3% predicted norm for peak VO_2 to 42% of predicted norm
Leibner et al, (2013) (US)	LVAD type: Heartware and HMII N LVADs: 31 Female: 24% Mean age in years: 63.9 ±11.3	Retrospective multiple timepoints: pre-LVAD, 3–6 and 12 months and >1 year	- No significant change in peak VO_2 across timepoints - % predicted norm did improve, but still severe functional limitation - Only 10 living at > 1 year time
Martina et al, (2013) (Netherlands)	LVAD type: HMII N LVADs: 30 Female: 23% Mean age in years: 43 ± 14	Prospective Compared 2 timepoints -6 and 12 months	- Peak VO2 was stable at 6 and 12 months (18.7±5.8 and 18.8±5.7 mL/min, respectively). - Main focus of study was on changes in hemodynamics: from rest to max exercise HR, BP, TCO increased and SVR decreased. - Older age and gender affected exercise capacity (BP increased significantly in men compared to women).
Pruijsten et al, (2012) (Netherlands)	LVAD type: HMI (prior to 2005) and HMII (2006-present) N HMI: 42 HMI Female: 10% HMI Mean age in years: 39 ± 12 N HMII: 33 HMII Female: 21% HMII Mean age in years: 44 ± 12	Retrospective Compared pulsatile (HMI) vs continuous-flow (HMII) LVADs	- No difference in peak VO_2 after adjusting for BMI - Labs: Significant improvement in all lab values esp BNP and Creatinine, Hemoglobin improved in both groups by 3months - Echo: greater decrease in dimensions of LV in pulsatile group (80±10mm vs 72 ±12mm; p=0.005)
Kugler et al, (2011) (Germany)	LVAD type: HMII N LVADs: 27 N HTx: 54 Female: 3% Mean age in years: 47±13	Prospective Compared LVAD and HTx recipient outcomes	- Peak VO_2 increased 7% LVAD, 10% HTx (p=0.01) - 7% increase in BMI-adjusted workload LVADs vs 8% HTx at 6 months (P=0.01)
Jakovljevic et al, (2010) (UK)	LVAD type: HMII N LVADs: 27 N Explanted: 54 N HF: 20 Female: 0% Mean age in years: 39±14 (LVAD group)	Retrospective Compared 3 groups: Heart Failure, Implanted LVAD and Explanted LVAD patients	- Peak CPO and exercise performance are best in explanted patients - No difference at rest between groups in CPO or VO_2 - No precision of timing of exercise test Cardiac Power Output: peak: Explant & LVAD > HF Cardiac Output at rest: LVAD>HF (by 1.4 L/min or 25%) - Peak VO_2: Explant> LVAD>HF

Study (country)	Sample	Design	Findings
			- % Max predicted O2 Consumption: Explant 83% > LVAD 57% > HF 46% Exercise Duration: LVAD>HF – stopped due to fatigue or dyspnea
Pruijsten et al, (2008) (Netherlands)	LVAD type: HMII N LVADs: 44 N HTx: 29 of the 44 Female: not reported Mean age in years: Not reported	Retrospective Compared outcomes 3 months after LVAD to 3 months after HTx in same patients	- Mean peak VO_2 3 months post-LVAD insertion is compatible with ADLs - 50% mean predicted VO_2 for age and gender in both groups - Post transplant VO_2> post-LVAD - Normalized BNP and renal function 3 months after LVAD
Haft et al, (2007) (US)	LVAD type: HMXVE and HMII N LVADs: 34 Female: 6% HMXVE and 17% HMII Mean age in years: 52 ± 14 years	Retrospective Compared HMXVE and HMII outcomes	- Peak VO_2 15.4±4 HMXVE and 15.6±4.7 HMII at 3 months - Peak % predicted 46.8 HMXVE and 49.1 HMII - Exercise time 10:25±3 minutes HMXVE and 9:31±3 minutes HMII - No difference between devices in hemodynamic support and exercise capacity - HMXVE had improved left ventricular unloading

HMII, Heartmate II Continuous Flow LVAD; HMXVE, Heartmate XVE Pulsatile LVAD; TAH, Total Artificial Heart; HTx, Heart Transplant; BTT, Bridge to Transplant; DT, Destination Therapy; 6MWT, 6 Minute Walk Test; NYHA, New York Heart Association Heart Failure Functional Classification; FS, Functional Status; QOL, Quality of Life; METS, Metabolic Equivalent Test Score; CPX, Cardiopulmonary Exercise Testing; CPO, Cardiac Power Output

Table 3

Interventions to Improve Functional Outcomes

Study(country)	Sample	Design	Findings
Physical Training Interventions			
Kugler et al, (2012) (Germany)	LVAD type(s): Continuous Flow N LVADs: 70 Female: 14% Mean age in years: 52±2	Randomized control trial Intervention included dietary counseling, home ergometry and psycho-social counseling for 8 weeks	- Intervention prevented weight gain in IGr, CGr BMI increased by mean of 5.9 kg/m^2 (p<0.02) - Exercise Tolerance was higher in IGr - Both exercise capacity and QOL remained below predicted norms in both groups despite improvement over time
Laoutaris et al, (2011) (Greece)	LVAD type(s): LVAD and BiVAD N LVADs: 15 Female: 7% Mean age in years: 37.2 ± 17.7 (IGr)	Randomized control trial Intervention included mod-intensity aerobic & inspiratory muscle training for 10 weeks	- Peak VO_2 increased in IGr only (+15%) (p<0.008) - 6MWT increased in IGr only (+14%, p<0.005) - Pulmonary Function increased significantly in IGr only (p<0.008)
Hayes et al, (2012) (Australia)	LVAD type(s): VentrAssist N LVADs: 14 Female: 14% Mean age in years: 48.7 ± 14.5 (IGr)	Randomized control trial Intervention included gym-based aerobic and strength training for 8 weeks	- Both groups had significant improvement of peak VO_2, workload and 6MWT, but no difference between groups - Early mobilization without any acute complications
Altering Pump Speed			
Jung et al, (2014) (Denmark)	LVAD type(s): HMII N LVADs: 16 Female: 14% Mean age in years: 55 ± 13 Mean support days: 465 ± 483	Intervention – paired randomization Compared fixed pump speed with incremental increases in pump speed in the same group of LVAD patients	- Mean peak VO_2 was significantly greater in the test with incremental increases in pump speed versus fixed speed (15.4±5.9 mL/kg/min vs. 14.1±6.3 mL/kg/min; P=0.012) - Mean Baseline fixed pump speed was 9,357±238 rpm. Mean Increased pump speed to 10,843 ± 835rpm, increase of 9.2% in increments of 400rpm/2min. - No differences between tests for exercise time work-load or post-exercise blood lactate
Noor et al, (2012) (UK)	LVAD type(s): HMII N LVADs: 30 Female: 7% Mean age in years: 35 ± 13	Intervention Compared Clinical pump speed (9000rpm) with lowest speed (6000rpm) and EF <40% to EF >40%	- Peak VO2 was lower in the low EF group at both clinical and reduced speeds (21.4 ±4.8 mL/kg/min and 14.7 ± 5.9 mL/kg/min, respectively). - At low speed, peak VO2 dropped by 2.5mL/kg/min in the low EF group - No significant change in peak VO2 in >40% EF group with change in pump speed.

Study(country)	Sample	Design	Findings
Brassard et al, (2011) (Denmark)	LVAD type(s): HMII N LVADs: 8 Female: 12.5% Mean age in years: 39 ± 18 Mean support days: 329 ± 190	Intervention – paired randomization Compared fixed pump speed with incremental increases in pump speed of 400 rpm in the same group of LVAD patients	- During light exercise, increased pump speed was associated with increased cardiac output and cerebral perfusion. - No difference noted at max exertion between group with increased LVAD speed compared to fixed speed - Transcranial Doppler showed 80% of normal cerebral blood flow at rest and an increase with light exertion - High patient burden – only 3 patients with Swan Ganz catheter and femoral sheath
Jakovljevic et al, (2010) (UK)	LVAD type(s): HMII N LVADs: 12 Female: 0% Mean age in years: 33 ± 13	Intervention Compared Normal LVAD speed (9000–9600 revs/min) vs. reduced speed (6000 revs/min)	- With reduction in LVAD speed: CPO decreased by 39% at peak exercise ($p<0.001$) CO decreased by 30% at peak exercise ($p<0.001$) - Additional significant changes in VO2, SVR, BP, VE slope, SV, HR and exercise time - CPO is sensitive to changes in LVAD speed
Inpatient Rehabilitation			
Kohli et al, (2011) (US)	LVAD type(s): HMII N LVADs: 12 N TAH: 30 Female: 17% Mean age in years: 51.2 ± 13.6 (HMII)	Retrospective Compared LVAD and TAH	- Greater BP response in LVADs vs TAH - Mean arterial pressure positively correlated with Metabolic equivalents in LVADs ($p=0.04$) - LVAD was comparison group – not all results for LVAD disclosed
Nguyen (2013) (US)	LVAD type(s): HMII N LVADs: 11 Female: 27% Mean age in years: 61.8 ± 11.9	Retrospective	- Mean FIM increase from Admission to Discharge: 22.1 - Mean Length of Stay: 11.6 days - FIM efficiency = FIM/LOS = 2.4 - Discharge setting: 7/11 home and 4/11 hospital - LVAD patients safely completed 3 hours of rehab for 5 days of the week.
English (2012) (US)	LVAD type(s): HMII N LVADs: 20 Female: not reported Mean age in years: 60.6 ± 10.4	Retrospective	- Mean FIM increase from Admission to Discharge: 27 - Mean Length of Stay: 11.3 days - FIM efficiency = FIM/LOS = 2.8 - Discharge setting: 16/20 home and 4/20 hospital

HMII, Heartmate II Continuous Flow LVAD; HMXVE, Heartmate XVE Pulsatile LVAD; TAH, Total Artificial Heart; HTx, Heart Transplant; BTT, 6MWT, 6 Minute Walk Test; NYHA, New York Heart Association Heart Failure Functional Classification; IGr, Intervention Group; CGr, Control Group; BMI, Body Mass Index; BP, Blood Pressure; FIM, Functional Independence Measure