Physiotherapy and Rehabilitation Management in Adult LVAD Patients

L. Compostella, M. Polastri, M. Lamotte, Fabio Bellotto, and M. Antoine

40.1 Introduction – 404

40.2 Before Implantation – 404

40.3 Intensive Care Unit Stay and Related Patient Goals: Early Postoperative Physiotherapy in a High Intensity Level of Care (The First Ten Days) – 404

40.4 Sub-intensive Setting Stay and Related Patient Goals: Postoperative Physiotherapy in a Medium Intensity Level of Care (From Tenth to Thirtieth/ Fortieth Day) – 406

40.5 Outcome Measures, Evaluation Tools, and Treatment Progression in LVAD Recipients – 409

40.6 Discharge Facility: Advanced Rehabilitation in a Low Intensity Level of Care Setting (Over the Thirtieth Day) – 411

40.7 LVAD Equipment Wear and Body Posture – 415

References – 416

A. Montalto et al. (eds.), *Mechanical Circulatory Support in End-Stage Heart Failure*,
DOI 10.1007/978-3-319-43383-7_40

40.1 Introduction

Increasing numbers of patients require implantation of permanent ventricular assist devices (VADs) for treatment of refractory end-stage heart failure [1, 2], as confirmed by surveys conducted in several European hospitals [3, 4]. VADs have been initially employed either as a bridge to recovery or bridge to transplantation [5]. It has been reported that 78% of VAD implants (between 2002 and 2004) have been used as bridge to transplantation, 11.9% as destination therapy, and 5.3% as bridge to recovery [6]: rehabilitation management, if we consider these data, would be centered on maintaining motor abilities in order to prepare patient for a future transplantation when VADs are used as bridge treatment. Such a trend is nowadays differing since, due to the donor crisis, VADs are increasingly used as destination therapy. Although this practice is widely experienced in end-stage heart failure populations, mortality remains high: appropriateness of enrollment criteria is determinant in order to avoid inappropriate patient selection. In this regard, it has been found that patient's frailty reduce the left ventricular assist devices (LVADs) outcomes; mortality at 1 year after implantation is higher in frail patients when compared with not frails [7]. Earlier reviews examined indications for LVAD use, LVAD suitability, cost-effectiveness, and the utility of the devices when used to treat refractory end-stage heart disease [8–16]. VAD implantation is indicated in order to augment or replace left ventricle (LVAD), right ventricle (RVAD), or both ventricle (BiVAD) function [6]. Postoperative complications of physiotherapic interest are mainly represented by infections, bleeding, thromboembolic events, device malfunction, and depression [17]. Indeed, postoperative rehabilitation in VAD recipients does not substantially differ from common cardiac surgery patients, as the main goals are related to the treatment/prevention of postoperative pulmonary complications, in the early phase. One of the major differences between common surgery patients and LVAD recipients consists in the complexity of the preoperative general conditions, being LVAD patients more prone to physical deconditioning often determined by forced bed rest and physical inactivity. Another substantial difference concerns the safety issues related to the device management, either by patients or by those providing care, including caregivers.

Herein, we aim to discuss emerging aspects of the physiotherapeutic intervention in LVAD patients, dividing the rehabilitation pathway in several steps from the acute phase to discharge home.

40.2 Before Implantation

Some of the patients sent for an LVAD implantation are chronic patients suffering from heart failure and who are slowly deteriorating. A program of revalidation is frequently proposed: it is now evident that there are clinical benefits in this type of population. Recommendations for physical exercises are established: they propose mixed training to obtain central and peripheral effects – dynamic training, resistive training, and work on the respiratory muscles [18, 19]. Another aspect of this rehabilitation is that all these cardiac patients (heart failure, LVAD, heart transplantation) are following their training in the same sports hall: they are progressively familiarized with the post-LVAD implantation or even the post-transplantation program.

40.3 Intensive Care Unit Stay and Related Patient Goals: Early Postoperative Physiotherapy in a High Intensity Level of Care (The First Ten Days)

Physiotherapeutic intervention takes place at every phase during the postoperative recovery, starting in the intensive care unit (ICU), as early as the subject is awake. Physiotherapists are actively involved in the pathway of care, and they are recognized as a key figure within the multidisciplinary team in order to achieve patient recovery and manage postoperative complications in those subjected to cardiac surgical procedures [20]. Rehabilitation pathway in LVAD patients can be divided into some phases according to the patient's clinical status, and intensity of care characteristics (Fig. 40.1). The early recovery phase, after implantation, consists of the treatment and/or prevention of pulmonary complications and

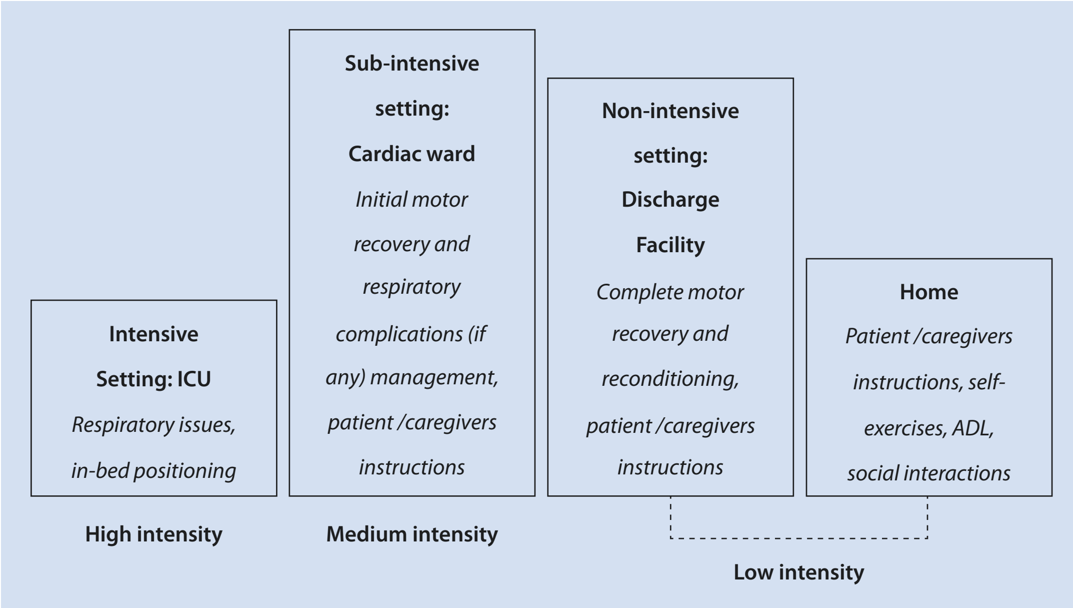

Fig. 40.1 Rehabilitation phases and intensity of care. *ICU* intensive care unit, *ADL* activities of daily living

improvement of respiratory function if compromised by surgery (i.e., pulmonary atelectasis, oxygenation impairment, pleural effusion). To this end, in the first 24/48 h or after extubation, and/or when sedation is reduced and then stopped, an early physiotherapeutic evaluation process should start. The bedside evaluation will consist in observing the respiratory pattern: Is chest dynamic altered? Is the patient breathing spontaneously? How much oxygen support is needed and, if yes, which kind of support is provided? Is pain preventing appropriate breathing? Are pulmonary secretions present, and, if yes, is patient able to eliminate them by means of effective cough?

All of these issues should be checked in order to obtain a global view of the pulmonary condition and function, postoperatively. Indeed, ICU is the safer place in a hospital since intensive monitoring and staff allocation usually guarantee the highest degree of assistance to the patient. The physiotherapeutic approach must be oriented to share clinical information with the multidisciplinary team: multidisciplinarity in ICU is not an option rather a true need. Physiotherapy intervention must take place both according to the patient's clinical status and team shared decisions: a certain degree of personal attitude and the willingness to cooperate must identify a physiotherapist in such a setting. Physiotherapeutic evaluation must be oriented to identify red flags and appropriateness of care, considering the patient mental status, the patient's cooperation, and stability of the vital signs. It should not be forgotten that physiotherapeutic duties can be different around the world: in example, respiratory treatment is usually carried out by respiratory therapist, and physical rehabilitation is instead provided by physical therapist in the USA. Within the Eurozone countries, physiotherapists are normally entitled to provide both respiratory and physical rehabilitation. Returning back to the matter, ICU timeframe is an exciting phase since the planning of an appropriate treatment can pave the way for further improvements along the whole postoperative recovery.

LVAD recipients, while in ICU, are initially confined to bedrest: in the first postoperative days, the patient configuration will be characterized by the presence of the Swan-Ganz catheter, infusion lines, heavy monitoring, urinary catheter, oxygen support systems (goggles or facial mask), and the VAD equipment – batteries and controller. Early mobilization and wound care play a key role in the initial management of VAD patients already in the ICU. Early physiotherapy is initiated to prevent complications of bedrest and minimize loss of mobility [21] by means of range of motion (ROM) exercises, and in-bed positioning: once hemodynamically stable, patient is assisted out of the bed to a chair [22]. In such a configuration – in uncomplicated patients – ROM exercises can be done in order to evaluate if any deficit is present and to stimulate further active movements. Indeed, enhancing patient in-bed positioning can play an important role with the aim to stimulate the first patient's movements. Mobilization in ICU of patients on mechanical circulatory support is considered a standard of care and it can begin with simple activities such as turning in bed [23]. The ICU phase is generally protective against pulmonary complications; they are more frequently seen in the sub-intensive setting as they become more evident at 48–72 h, because a certain amount of time is necessary to develop and, consequently, observe imaging alterations and related clinical findings. As previously observed, an important ICU physiotherapeutic goal is to prevent the onset of pulmonary complications and enhance the respiratory pattern, if altered. On the other hand, pleural effusion and dysventilation phenomena, requiring physiotherapeutic intervention, are common after cardiac surgical procedures [24, 25]. To this end, respiratory therapy should be proposed including deep breathing exercises and secretions clearance techniques. Deep breathing exercises and resistive breathing are commonly carried out in ICU patients, postoperatively [26]. The major objective to be pursued by means of respiratory exercises is to encourage patients to perform deep breathings in order to treat atelectasis, improve hypoxemia, and prevent worsening of the pulmonary function more in general [24]. To this end, in uncomplicated patients, the blow-bottle device can be used as soon as the subject is awake and sedation stopped. Blow bottle is a respiratory device used to allow lung expansion in postsurgical setting. It consists of a set that can be built up using material commonly available in hospital wards, such as a saline bottle and a chest drain tubing (length 20–30 cm, >30 cm) [25, 26] (Fig. 40.2). The patient is asked to make an inspiration and then blow into the tube: during the expiration, the water contained in the bottle provides an expiratory resistance. The blow-bottle respiratory exercises, a simple and feasible technique, can be used in the first postoperative days, when needed. This exercise can be repeated – several daily sessions by a defined set of repetitions according to the patient's status – and it can be performed either in a sitting or in a supine position. Patient must be awake and cooperative. Effective coughing can also play an important role in the secretions clearance: the subject is instructed to effective coughing in order to facilitate the secretions clearance. A pillow embraced with the arms while coughing is usually well accepted in order to reduce chest pain during cough.

40.4 Sub-intensive Setting Stay and Related Patient Goals: Postoperative Physiotherapy in a Medium Intensity Level of Care (From Tenth to Thirtieth/Fortieth Day)

At the ICU discharge, VAD recipients are usually transferred to a sub-intensive setting where the principal objectives of the physiotherapeutic intervention are improving safe movements and postural passages and improving autonomy of daily activities. Monitoring of the pulmonary function still remains an important aspect. To this end, continuing evaluation of the chest imaging, together with the clinical observation, should be adopted to avoid worsening of the respiratory function if it has been already jeopardized during the ICU stay. Pleural effusion, atelectasis, and lung dysventilation must be also prevented/treated by means of a respiratory program focused on respiratory exercises (Fig. 40.3). Particularly in those showing pulmonary alterations, and that do not require a more intense treatment, respiratory therapy can be continued by means of incentive spirometry exercises, in order to encourage deep breathings and enhance diaphragmatic excursion and chest wall expansion. This practice, during the initial postoperative timeframe, also contributes to obtain the active patient involvement. Respiratory exercises can be scheduled during the day in more than one session; once the patient is trained on the use of the incentive spirometry device, the exercise can be performed autonomously. Furthermore, since the degree of patient's mobility normally increases during this phase, there is also the need to plan a specific device training activity in order to preserve and guarantee the patient's safety. Thus, the main goals of the initial rehabilitation treatment are centered on patient's autonomy and device management: exercise sessions are a

Fig. 40.2 Exercises with blow-bottle device. **a**–**c** The blow-bottle device can be made using common material available in hospital wards. A saline bottle (500 ml) is opened and drained to the desired level of water **b**, and then the bottle is closed and a tube is inserted into the water through a slot **b**, **c** formed on the container. **d** A patient is performing the respiratory exercise while in a supine position. The device shown in this figure can be closed preventing exit of water even while patient is resting. The set should be replaced frequently in order to guarantee adequate sanitation

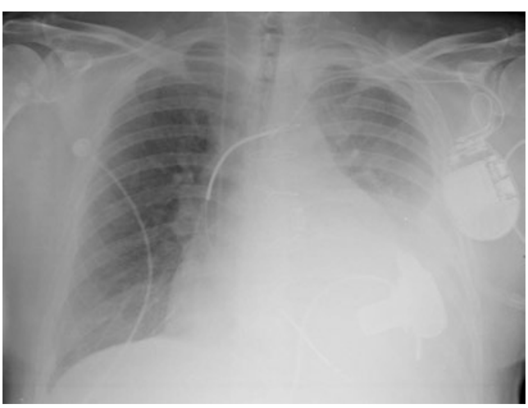

Fig. 40.3 Pulmonary complications after surgery. A left pleural effusion in a patient after LVAD implantation

good way also to teach the patient how to handle an alarm and a change of batteries. At this stage, active ROM exercises, ambulation, and stair climbing are implemented [27], and flexibility exercises are also encouraged and tailored on patient characteristics. Upper body exercises are delayed until 6–8 weeks to ensure sternal healing. Exercise is stopped in case of subjective intolerance or drop in systolic pressure. Physiotherapist must be trained in emergency procedures in case of device malfunctioning and must be also aware of patient hemodynamic instability and device dislodgement during mobilization [22].

Initial postural passages should be performed and the subject instructed how to change the position safely. These activities, for those patients who have not yet started, should be encouraged beginning with the maintenance of a sitting position at the edge of the bed, progressing toward the sitting position in a chair. Then, the patient can start a more intensive muscular program oriented to develop the ability to gain autonomously an upright position. When postural passages, upright position, and in-bed movements are carried out autonomously, patient is ready to walk with or without a walking frame. Walking, lifting on toes, bending knees, cycling, climbing stairs, and other exercises should be supervised (Figs. 40.4 and 40.5). At this stage, the patient

Fig. 40.4 Supervised lower limb exercises. **a** Stretching of the left leg posterior muscles. **b** Strengthening of the gluteus. **c** Strengthening of calves. **d** Bending on the knees and quadriceps strengthening

Fig. 40.5 Supervised cycling and walking. **a** A patient is cycling. **b** Walking onward

must be confident with the device and must be able to dress it, safely. Pre-LVAD conditions can play a major role during the postoperative rehabilitation. Patients who were already confident with the exercise may be facilitated; hemodynamic stability is needed in order to proceed with the exercise's intensity [28]. Physical activity can be made also in small groups and the duration can range between 5 and 30 min. Group activities are important as patients need to gain confidence in the equipment and become comfortable with the reactions of those who look at the device. Indeed, facilitation of LVAD acceptance is an important component of rehabilitation. At discharge, it is advisable to set up a follow-up period which comprises sessions of supervised exercise [29]. At the end of the hospitalization, the patient must be able to walk alone and to climb the stairs.

40.5 Outcome Measures, Evaluation Tools, and Treatment Progression in LVAD Recipients

No official guidelines or even recommendations exist to determine the training modality for the patients with a LVAD. It seemed appropriate to build the program on the established recommendations for heart failure since many problems are common to both populations. Therefore, we decided to take care of two aspects of the rehabilitation:

1. The aerobic metabolism: we know that there is an interaction between the pulmonary, cardiovascular, and skeletal systems during exercise. There is an improvement of the aerobic metabolism, of the autonomic regulation, and on the peripheral perfusion. This will lead to an improvement of the respiratory control and an improvement in the quality of life. A very demonstrative benefit is the decreasing of hospital readmissions.
2. The reinforcement of the resistance training: due to the usual previous physical inactivity, this part of the rehabilitation is mandatory in order to increase muscle strength and muscle endurance. Due to increased blood flow, there are an increased mitochondrial ATP production rate, a better oxidative capacity, and a relative increase of flow distribution in the area of type I fibers. Again with those physiological benefits, we will obtain an increased quality of life and probably an increased VO_2 peak but certainly no adverse events and no deterioration of the ventricular function. Based on the physiological understanding of the Fick equation, O_2 consumption per minute = pulmonary blood flow × (pulmonary artery O_2 blood concentration − pulmonary vein O_2 blood concentration) [$VO_2 = Q\,(CaO_2 - CvO_2)$], we know that we have to work on the flow (LVAD) and the muscular extraction of O_2.

Following the Fick principle, the VO_2 depends from the flow and the peripheral extraction. After LVAD implantation the improvement of VO_2 values is not concomitant with an improvement of the hemodynamic parameters given by the device: this confirms the need of a training oriented to the peripheral muscles [30, 31]. There is a common conclusion in literature to agree on the benefit of revalidation after implantation. With a well-oriented training program and combined exercises, the patients will have a better quality of life; those patients who may still develop an aortic flow during exercise could most probably be able to generate greater efforts.

Physiotherapeutic intervention is planned considering a certain degree of progression along the recovery pathway. Activities should progress from passive ROM to ambulation and resistive ROM exercises [32]. Safety during mobilization is implemented by means of the physiotherapeutic intervention as patient can be instructed how to realize postural passages and how to achieve a safe mobility program considering the safety issues related to the driveline and device management [33]. In the ICU, implanted patient is not able to manage autonomously the device, and safety is completely delegated to the staff.

The LVAD used today has a continuous flow, which does look to be an improvement [34]. The absence of pulse and the measurement of a mean arterial pressure (not always easy) have created the necessity to design the training on the maximal charge obtained during cardiopulmonary exercise testing (CPET). The rehabilitation program must propose a combined training.

The *dynamic training* is based on a CPET practiced on bicycle, treadmill, or other similar ergometers. The feasibility of a maximal test is well demonstrated in the literature, proved by the respiratory quotients (RQ) reached [35–41]. It is mandatory to obtain this maximal test in order to optimize the structure of the training and also to obtain a unique scale to compare results (intra- and inter-studies).

When this CPET is maximal with a RQ >1.15 and without anomaly, the workload will be fixed to 70–80% of the Watts max. The dynamic training must be completed by muscular reinforcement: the principal muscular groups (arms, legs, back, abdominal) must be trained with specific tools [40, 42–44]. Those specific exercises address qualitative and quantitative muscular changes which are met in the heart failure patients and increased by a prolonged bedrest [45, 46]. Based on the one repetition maximum (RM, charge that the patient can lift one time), exercises are planned at 75% of RM, and performed as two sets of ten repetitions.

Some authors define the limited zone of exercise around 60–70% of the VO2max [47] or 50% of the VO2reserve [45], but they do not explain how the training is adapted afterward.

The *interval training* has not shown this benefit, in any study, for these types of patients. Anyway, the improvements obtained in patients suffering from cardiac failure, via the peripheral pathway, and the higher workload developed with this type of training, give us the impression that this interval training should be proposed as a complementary modality. For the same reason, a training with work period above the respiratory level 1 seems to be pertinent and feasible [42–48]: cycling, walking, rowing, etc., session of 45–60 min, frequency 3–5 per week, duration 8–10 weeks.

We did not find in the literature any publication and of course no recommendation for the use of neuromuscular electrical stimulation for these patients; this technology is very limited and is more about addressing noncompliant patients. It is the same for stretching and relaxation.

40

A single study proposes a training of the respiratory muscles [39].

On the contrary, in multiple studies, as for heart failure patients, there is a major interest of a multidisciplinary team in close collaboration with the VAD team [34, 42, 43, 48, 49].

Patient's progress and rehabilitation outcomes of LVAD recipients admitted to a sub-intensive care setting after ICU discharge should be evaluated. To this end, the Functional Independence Measure (FIM) scale has been described as a suitable tool during in-patient rehabilitation [50–53]. The FIM scale consists of the evaluation of 18 functional and cognitive items: eating, grooming, bathing, upper body dressing, lower body dressing, toileting, bladder, bowel, toilet transfer, bed/chair/wheelchair transfer, tub/shower transfer, walking or wheelchair mobility, stair climbing, comprehension, expression, social interaction, problem solving, and memory. FIM, more than other evaluation tools (i.e., Barthel Index), better intercept the treatment progress thanks to the presence of a number of items that explore various functional areas: the cognitive items also contribute to the evaluation of the social and personal interactions. During in-patient rehabilitation, treatment intensity should be also established in order to guarantee appropriateness and safety of care (Fig. 40.6). In LVAD patients, the use of the Borg scale has been proven effective to check patient's status while exercising [29, 32, 40]. An exertion of somewhat hard intensity on the Borg scale should be used as a limit to interrupt the exercise [39, 40, 43].

A further evaluation tool consists in the measurement of the daily walking distance which should improve over the rehabilitation treatment: this is a simple, immediate measure which can be obtained in order to verify patient's progressions [54]. Ambulation distance can be fixed on meters or time and must take into account adverse symptoms [55].

6-min walk test has been shown, at 3.6 months postoperatively, to be a predictor of LVAD

Fig. 40.6 The work intensity is being evaluated in an LVAD patient (Jarvick). Ergometric stress test and pressure measurement (by means of Doppler technique)

mortality, since poor performance (<300 m) on the test is associated with increased mortality [56].

To our best knowledge, there is not yet any specific study in LVAD-supported patients that investigated how to best afford gait and balance problems during cardiac rehabilitation (CR). Some useful suggestions could be derived by a study on aged individuals submitted to CR after coronary bypass heart surgery [57]. In that study, besides other physical and functional evaluations, patients were assessed by a Timed-Up-and-Go (TUG) test, aimed at documenting the time taken to rise from a 43 cm high chair, walk as fast as possible to a mark on the floor 3 m away from the chair, and turn, walk back, and sit down again; [58] a TUG test taking longer than 16 s is considered a predictor of falls in older individuals. In order to improve patients' balance, in the cited study, the usual aerobic and callisthenic exercises and resistance training aimed at reinforcing legs strength have been complemented by exercises on unstable devices, such as balls and loose platforms, under progressively increasing difficulties. The intervention group showed a highly significant improvement in the TUG test, without any complication linked to the exercises. Similar positive results have been reported also by a study on rehabilitation of chronic pulmonary disease patients, [59] in which balance assessment was performed by the cited TUG test and integrated with four more evaluations: the Berg balance scale (a 14-item scale evaluating activities such as transfers, reaching, turning around, and single-leg stance, graded on a scale ranging from 0 = unable/unsafe to 4 = independent/efficient/safe) [60], the unipedal stance test (patient's ability to stand on one leg for 45 s) [61], the Tinetti test (a 16-item test divided into two sections: balance (9 items) and gait (7 items), for a total score of 28, where scores <26 indicate high risk of falling) [62], and the activities-specific balance confidence scale (it describes patient's confidence in performing 16 activities without losing their balance or becoming unsteady, on an 11-point scale) [63]. Although no study evaluating such tests and specific interventions has yet been conducted in LVAD-supported patients, the cited tests and the balance training interventions seem to be possibly useful in the particularly new group of chronic patients represented by LVAD patients. Device education and self-care management must be achieved prior to discharge and are basic conditions for admission to an outpatient rehabilitation program. A multidisciplinary approach including cardiac rehabilitation and prevention staff, contributing staff, and consultant staff is strongly recommended in order to guarantee effectiveness and appropriateness of care in VAD patients [64].

40.6 Discharge Facility: Advanced Rehabilitation in a Low Intensity Level of Care Setting (Over the Thirtieth Day)

After device implantation, a progressive reduction of left ventricular pressure and volume and a decrease of mean pulmonary artery and wedge pressures are usually observed [37]. Such modifications result in reduction and disappearance of dyspnea. The increased output obtained with the support of the LVAD leads to better perfusion of muscle masses, gradual anatomical and functional muscle fibers reverse modifications, and smoothening of neurohormonal mechanisms, which result in progressive reduction of fatigue. Thus, the majority of patients gradually improve their clinical status, from preimplantation NYHA class IV to class I or II; this improvement is most often noticed after 1 month from implantation, as reported by the HeartMate II Investigators [34]. As soon as the LVAD-supported patient is hemodynamically stable, comprehensive (mainly exercise-based) rehabilitation may begin, aimed at restoring an adequate level of mobility independence [21, 22, 65, 66]. The optimal time to start exercise training is yet to be defined. Some recent studies report beginning of exercise training after 27 ± 15 days [52], after 38 ± 18 days [67], and after 48 ± 38 days [40] when patients are considered clinically stable; this kind of rehabilitation is usually conducted as in-patient rehabilitation. Exercise-based rehabilitation is also advocated in the following period, as long-term ambulatory rehabilitation, with the aim of adequately addressing the challenges that influence patients' independence and quality of life [68]. What is known nowadays is that exercise training, as part of a multimodal intervention, is safe and effective in LVAD-supported patients, both in those ones waiting for heart transplantation (in which exercise training favorably impacts clinical course and improves post-transplant recovery) and in patients implanted with an LVAD as destination therapy [39, 42, 43, 49, 50, 69, 70]. In LVAD-supported patients, it is well known that regular physical exercise has the potential to progressively reverse – at least partially – the pre-existing negative physical and functional modifications [71]. At the beginning of more intensive rehabilitative activities, some care must be given to the fact that the device could create an obstacle to physical, mainly exercise-based, rehabilitation in a still debilitated patient. Patients supported by LVAD come usually from a long and troublesome history of low cardiac output; one of the main features they often present for weeks or months after beginning of LVAD support is sarcopenia. The reduced muscle masses cause a direct limitation on individual's capacity to stand and walk with correct balance; the effects are worsened by concomitant presence of autonomic dysfunction that may contribute to orthostatic hypotension and to reduced efficiency of receptor-integrator-effector system with consequent reduced balance/stability control.

During the most common rehabilitative activities practiced in the initial phases of CR, such as walking, treadmill, cyclette, and stepping, there is the risk of accidental falls of the patient or the device. Little is reported in literature about complications linked to such falls. It must be remembered that, in the majority of continuous-flow LVAD (cf-LVAD) models in use, the driveline (from skin to controller) is rather short, and a fall of the device (or a fall of the patient with the driveline caught in the handlebars of the ergometer or treadmill) could lead to disconnection of the LVAD's external power supply, with awful consequences [72]. In some models of cf-LVADs, spring wire extensions are used between the body cable and the external controller, which could be rather long (up to 2 m or more); patients should be instructed to avoid cable swing while cycling, a situation that could lead to trapping or stretching of the cable by the cycle treadle. In a similar way, patients should be instructed to avoid carrying by hand the bag containing batteries and controller, as the long extension cables could swing near their feet and be accidentally stump. In patients with heart failure, all training intensities have been shown to be effective in improving exercise capacity, while moderate to high intensity aerobic training seems to be more effective to induce reverse left ventricular remodeling [73]. In LVAD-supported patients, we would suggest that exercise training could be conducted at individual anaerobic threshold. A cardiopulmonary exercise test should thus be performed as soon as the patient is able to cycle and repeated by time to time; the effort could be limited to the amount necessary to identify the anaerobic threshold (or slightly more), with greatest attention paid to patient's symptoms (dyspnea, fatigue, sense of fainting) or clinical signs possibly indicating low peripheral perfusion (paleness, cold sweating, reduction – even small – of mean blood pressure). Performing exercise training at individual's anaerobic threshold has demonstrated to be safe and effective even in patients rehabilitated rather early, within 2 months from continuous-flow device implantation [74]. It is not yet known if patients could present different levels of effort tolerance as a consequence of different models of implanted cf-LVADs that could present different adaptation of their output to modifications of preload (different ability to accept the contribution given by the systole of the native heart) and afterload (peripheral resistances) linked to physical effort. In the past, in patients supported by pulsatile LVADs, different exercise performances have been reported for pneumatic versus electrically driven devices [75]. As regards cf-LVADs, only one study performed on a mock circulatory system tested and compared performances of an axial-flow and a centrifugal-flow device: in this experimental model, the axial-flow LVAD reached greater maximal output that – if confirmed on clinical ground – could in theory allow better physical performance; it showed anyway also a greater risk of left-ventricle suck-down, which could be counterproductive [76]. Unfortunately, on the clinical ground, no data are yet available about possible different exercise performances allowed by different models of cf-LVADs; in fact, a single study reported the main clinical differences (survival rate, incidence of perioperative bleeding, gastrointestinal bleeding, stroke, renal dysfunction, liver dysfunction, and infection) between two models of cf-LVADs (an axial-flow and a centrifugal-flow device), but did not collect informations about exercise tolerance [77]. During the initial phases of a physical effort, in patients supported by cf-LVADs, mean arterial blood pressure shows an increase whose amount is correlated to the level of METs achieved [55]. Due to the combination of limited maximum output given by the LVAD, poor function of the native heart, and inadequate autonomic regulation of peripheral vascular resistances, blood pressure could progressively reduce at higher intensities of exercise and eventually drop in case of intense effort. However, a substantial problem exists in cf-LVAD-supported patients that blood pressure is not usually measurable by traditional means in clinical practice. A method combining arm-cuff plus Doppler ultrasound identification of humeral artery opening pressure allows to identify "mean" pressure values. It is obvious that during exercise in gymnasium, it is usually difficult to check blood pressure with such method; it is in any case recommended during a cardiopulmonary exercise test, to properly identify the optimal amount of physical activity sustainable by the individual patient. According to treatment protocols for chronic heart failure patients [78], and in an attempt to maximize the unloading of the left ventricle, improve pulmonary resistances, and eventually obtain reversal remodeling of the failing heart [79], LVAD patients are most often treated with a combination of drugs that include angiotensin-converting enzyme inhibitors or angiotensin II receptor blockers associated with selective beta-blockers and aldosterone receptor antagonists drugs. The target for blood pressure control is often put at levels of mean pressure around or below 80 mmHg [80, 81]. By consequence, hypotension with related symptoms is a frequent finding during CR, as well as during normal life activities. Maintenance of an optimal circulating volume is critical to avoid symptomatic hypotension during physical activities, as well as to avoid suction effects induced by the device on interventricular septum, which modify the geometry of the right ventricle and impair its function. Activation of device alarms during physical activity or during changes of patient's decubitus is most often an indicator of poor "circulating volume," as it may happen, e.g., due to excessive sweating or important vasodilation after strenuous effort. Thus, patients should be stimulated to regularly introduce small amounts of fluids during and after exercise, in order to compensate for perspiration and avoid relative hypovolemia and consequent hypotension. We would suggest that periodical echocardiographic control of dimensions of left ventricle, position and appearance of interventricular septum, and – if possible – calculation of estimated pulmonary systolic pressure should be performed (all controls that are obviously not possible during performance of rehabilitative physical activities) [82]. Besides being linked to volemia and drugs effects, orthostatic hypotension may be present also as a consequence of the already cited profound cardiac dysautonomia. Autonomic imbalance is present during the first months from the beginning of circulatory support [83] and could progressively improve in the following months [84], reaching an almost normal cardiovascular autonomic homeostasis (and baroreflex activity) after 7–32 months [85]. While in chronic heart failure patients, it is known that exercise training reduces sympathetic outflow and leads to an improvement of baroreflex sensitivity and heart rate variability [86], in cf-LVAD-supported patients, it is not yet known if recovery of a normal autonomic activity could be accelerated by endurance exercise. It is usually not recommended to modify LVAD settings during physical exercise. Even though it should seem logical to try and increase rotational speed in order to parallel the device output with the augmented metabolic demand linked to physical activity, it must be remembered that LVAD output seems to be partially adaptive to changes in activities of daily living, allowing at least low levels of physical engagement [87] and supporting near-normal increments in cardiac output and legs perfusion (with constant cerebral perfusion) during even maximal exercise [88]. While it is true that some experiences report positive functional results with an increase of rotational speed of various models of devices (and, conversely, reduced performance with reduction of their operational speed), especially in cases with lower residual left ventricular function [88–91], the results obtained in these small dimension studies need to be evaluated face to the possible negative effects that the increased rotational pump speed may induce on right ventricle function during sustained submaximal exercise. A possible complication during physical exercise in cf-LVAD-supported patients is the appearance or worsening of atrial and ventricular arrhythmias. During the initial phases of an exercise-based rehabilitation, LVAD patients should ideally be controlled by telemetry ECG monitoring, to check for presence or appearance of major atrial or ventricular arrhythmias; it must be remembered, anyway, that ECG monitoring implies application of chest leads and carrying a transmitter that may be disturbing in a patient who is already carrying the device controller and batteries, connected to an abdominal or retroauricular driveline. Ventricular arrhythmias are rather frequent in LVAD-supported patients; it has been reported that ventricular arrhythmias account for 4.66 events per 100 patients/month in the first 12 months after implant of a cf-LVAD [92]. They are a consequence of the underlying heart disease; they may also be linked to hemodynamic modifications induced by the device and to scars around the outflow cannula. During physical exercise in orthostatic position, an even mild dehydration may reduce the diastolic dimensions of the left ventricle and lead to suction events that may cause ventricular irritation and trigger arrhythmic events [93]. This is another reason to stimulate LVAD patients to introduce repeatedly moderate amounts of fluids during and after exercise. If major or life-threatening arrhythmias occur during rehabilitation activities, they usually do not constitute, anyway, an emergency problem:

1. The circulating flow provided by the device is generally sufficient at least for the basic needs of the patient.
2. The majority of patients (at least those assisted by an LVAD as destination therapy) are already implanted with an ICD.
3. It has been reported that even episodes of sustained ventricular tachycardia and ventricular fibrillation are rather well tolerated, with modest hemodynamic deterioration [94–97].

In any case, ventricular arrhythmias, especially if sustained, should be controlled by appropriate pharmacological therapy, as they impact negatively on the function of the right ventricle and lead to reduced effort tolerance during CR [98, 99]. We would like to remember that ventricular fibrillation may be treated as usual by direct current shock, while cardiac massage must be avoided, to avoid detaching or displacing the outflow cannula of the device. Atrial fibrillation may condition some compromise of right ventricular function, due to loss of atrial contribution to ventricular filling and irregular length of diastole; symptoms of right ventricular failure may appear more often in these patients than in patients in sinus rhythm, with consequent reduction of effort tolerance [100, 101]. Patients in atrial fibrillation usually require a level of anticoagulation higher than that of LVAD cases in sinus rhythm [102]; the topic of coagulation monitoring and possible worrisome complications is treated in another chapter of this book. It is not known if the hemorrhagic risk could increase in association with performance of physical exercise. After an intensive period of in-hospital rehabilitation, continuation of a structured outpatient rehabilitative program is advocated [64]. As it is known to happen in chronic heart failure patients that benefit from CR periods as long as 12–52 weeks [103], it is reasonable to suppose that a long-lasting rehabilitative intervention followed by self-maintenance of regular physical activity could help maintaining and improving physical fitness and quality of life also in LVAD-supported patients. Some studies performed on patients supported by pneumatic LVADs reported an increase of exercise capacity over time [36–104], and occasional cases have been reported that patients supported by pulsatile or continuous-flow LVADs continue improving their functional class [105, 106]. By the contrary, a few other observational studies on small groups of patients with continuous-flow devices reported that the improvement in exercise time observed after implant was not accompanied by improvement in peak oxygen uptake, and in evaluations of exercise capacity made after the first 3–6 months, no further significant gain of physical performance was achieved [107–109]. The strategies of prolonging rehabilitative interventions with out-patient rehabilitation, targeting low levels of physical activity in LVAD-supported patients, are, anyway, guided by the aim of giving the best possible improvement of patients' quality of life; they are also supported by the observation that patients who achieve a minimally satisfactory level of physical fitness after CR seem to present better long-term survival, as demonstrated by a study in which patients that walked >300 m at a 6-min walk test conducted >2 months after device implantation presented a significantly lower risk for late all-cause mortality [56]. In general cardiac patients and specifically in chronic heart failure patients, it has recently been demonstrated that home-based long-term maintenance of rehabilitation effects is achievable by adoption of telemedicine applications that may be individually tailored [110–113]; they may also contribute to the achievement of other goals, such as enhanced care for frail patients, home hospitalization and early discharge, and support for remote diagnosis [114]. Although similar experiences applied to patients supported by cf-LVADs are at present ongoing in some centers, to our best knowledge, no results of their efficacy, effectiveness, and sustainability in the specific LVAD population have yet been published.

40.7 LVAD Equipment Wear and Body Posture

Although the models of LVAD that are currently most often implanted in adult patients are regulated by highly portable external controller and fed by rechargeable lightweight batteries, the total weight that must be carried by the patients in a wrist or shoulder bag is usually around 2–2.5 kg. This implies posture changes and a new body balance; often, patients need to change their gait, and this – besides generating earlier fatigue – could lead to easier falls. A practical suggestion for still debilitated patients could be to carry the controller and the batteries in a shoulder bag, instead of in a wrist bag (patients often pull back) or in a bag hanging from a single shoulder (patients lean sideways). Recently it has been argued that body posture may be affected by continuing device wear in LVAD recipients [115]. Further devices' miniaturizing are predictable and very welcome in order to avoid any postural issues in such a class of patient which is, today, strictly dependent on equipment technology size. In LVAD patients, body stability is influenced by the position, size, and weight of the equipment. As the load is always present, and is rather asymmetric, it is possible that a certain degree of postural alteration may develop over time. Comfort issues are important in LVAD patients who must complete daily activities and maintain a correct posture, while wearing a control unit and a power source 24 hours a day. LVAD recipients must wear bags in order to carry the equipment: to this end, a tailored body support can prevent postural alteration and body misalignment. Various LVAD vests are commercially available and may be customized to improve comfort.

Key Points

1. At an early stage, respiratory therapy should be considered in order to prevent postoperative pulmonary complications: device-assisted (i.e., incentive spirometer) and manual (i.e., deep breathings) techniques are suitable as soon as patient is cooperative.
2. Postural passages (in-bed movements, transfer from bed to a chair, and reaching an upright position) should be facilitated as soon as possible during the early postoperative timeframe.
3. Patient should be instructed on making safe movements already during the initial postoperative days and/or when mobility is increasing.
4. Begin exercise-based cardiac rehabilitation as soon as the patient is hemodynamically stable.
5. Evaluate gait and balance of the patient; teach him/her how to correct abnormal gait.
6. Avoid the driveline to be trapped in the handlebars of the cyclette or treadmill; do not leave the connecting cables too long and avoid they swing while the patient is cycling or walking.
7. Choose intensity of exercise activities according to measurable patient's parameters (ideally conduct activities at an effort approximately corresponding to aerobic threshold).
8. Stimulate patients to introduce fluids during and after exercise, in order to avoid relative hypovolemia and hypotension, and possible triggering of ventricular arrhythmias.
9. Telemetry monitoring during the first phases of exercise-based rehabilitation is indicated, to check for atrial and ventricular arrhythmias and possibly guide antiarrhythmic therapy.
10. Aim at reaching a goal of at least 300 m walked at the 6MWT, as it seems linked to better long-term survival.

References

1. Yamakawa M, Kyo S, Yamakawa S, Ono M, Kinugawa K, Nishimura T (2013) Destination therapy: the new gold standard treatment for heart failure patients with left ventricular assist devices. Gen Thorac Cardiovasc Surg 61(3):111–117
2. Potapov EV, Loforte A, Weng Y, Jurmann M, Pasic M, Drews T et al (2008) Experience with over 1000 implanted ventricular assist devices. J Card Surg 23(3):185–194
3. Strüber M, Sander K, Lahpor J, Ahn H, Litzler PY, Drakos SG et al (2008) HeartMate II left ventricular assist device; early European experience. Eur J Cardiothorac Surg 34(2):289–294
4. Lahpor J, Khaghani A, Hetzer R, Pavie A, Friedrich I, Sander K et al (2010) European results with a continuous-flow assist device for advanced heart-failure patients. Eur J Cardiothorac Surg 37(2):357–361
5. Givertz MM (2011) Cardiology patients pages: ventricular assist devices: important information for patients and families. Circulation 124(12):e305–e311
6. Sorensen E (2007) Ventricular-assist devices and total artificial hearts. Biomed Instrum Technol 41(5):385–389
7. Dunlay SM, Park SJ, Joyce LD, Daly RC, Stulak JM, McNallan SM et al (2014) Frailty and outcomes after implantation of left ventricular assist device as destination therapy. J Heart Lung Transplant 33(4):359–365
8. Emin A, Rogers CA, Parameshwar J, Macgowan G, Taylor R, Yonan N et al (2013) Trends in long-term mechanical circulatory support for advanced heart failure in the UK. Eur J Heart Fail 15(10):1185–1193
9. Neyt M, Van den Bruel A, Smit Y, De Jonge N, Erasmus M, Van Dijk D et al (2013) Cost-effectiveness of continuous-flow ventricular assist devices. Int J Technol Assess Health Care 29(3):254–260
10. Moreno SG, Novielli N, Cooper NJ (2012) Cost-effectiveness of the implantable HeartMate II left ventricular assist device for patients awaiting heart transplantation. J Heart Lung Transplant 31(5):450–458
11. Rogers JG, Bostic RR, Tong KB, Adamson R, Russo M, Slaughter MS (2012) Cost-effectiveness analysis of continuous-flow left ventricular assist devices as destination therapy. Circ Heart Fail 5(1):10–16
12. Maltais S, Jaik NP, Feurer ID, Wigger MA, Disalvo TG, Schlendorf KH et al (2013) Mechanical circulatory support and heart transplantation: donor and recipient factors influencing graft survival. Ann Thorac Surg 96(4):1252–1258
13. Atluri P, Goldstone AB, Fairman AS, Macarthur JW, Shudo Y, Cohen JE et al (2013) Predicting right ventricular failure in the modern, continuous flow left ventricular assist device era. Ann Thorac Surg 96(3):857–863
14. Ammirati E, Oliva F, Colombo T, Botta L, Cipriani M, Cannata A et al (2013) Proposal for updated listing criteria for heart transplantation and indications to implant of left ventricular assist devices. G Ital Cardiol (Rome) 14(2):110–119
15. Carrel T, Englberger L, Martinelli MV, Takala J, Boesch C, Sigurdadottir V et al (2012) Continuous flow left ventricular assist devices: a valid option for heart failure patients. Swiss Med Wkly 142:w13701
16. McDiarmid A, Gordon B, Wrightson N, Robinson-Smith N, Pillay T, Parry G et al (2013) Hemodynamic, echocardiographic, and exercise-related effects of the HeartWare left ventricular assist device in advanced heart failure. Congest Heart Fail 19(1):11–15
17. Nissinoff J, Tian F, Therattil M, Salvarrey RM, Lee SW (2011) Acute inpatient rehabilitation after left ventricular assist device implantation for congestive heart failure. PM R 3(6):586–589
18. Piepoli MF (2013) Exercise training in chronic heart failure: mechanisms and therapies. Neth Heart J 21(2):85–90
19. Taylor RS, Sagar VA, Davies FJ, Briscoe S, Coats AJ, Dalal H et al (2014) Exercise-based rehabilitation for heart failure. Cochrane Database Syst Rev 4:CD003331
20. Arcêncio L, Souza MD, Bortolin BS, Fernandes AC, Rodrigues AJ, Evora PR (2008) Pre-and postoperative care in cardiothoracic surgery: a physiotherapeutic approach. Rev Bras Cir Cardiovasc 23(3):400–410
21. Perme CS, Southard RE, Joyce DL, Noon GP, Loebe M (2006) Early mobilization of LVAD recipients who require prolonged mechanical ventilation. Tex Heart Inst J 33(2):130–133
22. Morrone TM, Buck LA, Catanese KA, Goldsmith RL, Cahalin LP, Oz MC et al (1996) Early progressive mobilization of patients with left ventricular assist devices is safe and optimizes recovery before heart transplantation. J Heart Lung Transplant 15(4):423–429
23. Freeman R, Maley K (2013) Mobilization of intensive care cardiac surgery patients on mechanical circulatory support. Crit Care Nurs Q 36(1):73–88
24. Westerdahl E, Lindmark B, Eriksson T, Friberg O, Hedenstierna G, Tenling A (2005) Deep-breathing exercises reduce atelectasis and improve pulmonary function after coronary artery bypass surgery. Chest 128(5):3482–3488
25. Johnston CL, James R, Mackney JH (2013) The current use of positive expiratory pressure (PEP) therapy by public hospital physiotherapists in New South Wales. New Zealand J Physiother 41(3):88–93
26. Westerdahl E, Lindmark B, Almgren SO, Tenling A (2001) Chest physiotherapy after coronary artery bypass graft surgery: comparison of three different techniques. J Rehabil Med 33(2):79–84
27. D'agrosa-Boiteux MC, Geoffroy E, Dauphin N, Camilleri L, Eschalier R, Cuenin C et al (2014) Left ventricle assist device: rehabilitation and management programmes. Ann Cardiol Angeiol (Paris) 63(4):245–252
28. Corrà U, Pistono M, Mezzani A, Gnemmi M, Tarro Genta F, Caruso R et al (2011) Cardiovascular Prevention and rehabilitation for patients with ventricular assist device. From exercise therapy to long-term therapy. Part I: exercise therapy. Monaldi Arch Chest Dis 76(1):27–32
29. Fattirolli F, Bonacchi M, Burgisser C, Cellai T, Francini S, Valente S et al (2009) Cardiac rehabilitation of patients with left ventricular assist device as "destination therapy". Monaldi Arch Chest Dis 72(4):190–199
30. Hambrecht R, Niebauer J, Fiehn E, Kälberer B, Offner B, Hauer K et al (1995) Physical training in patients with

stable chronic heart failure: effects on cardiorespiratory fitness and ultrastructural abnormalities of leg muscles. J Am Coll Cardiol 25(6):1239–1249
31. Maybaum S, Mancini D, Xydas S, Starling RC, Aaronson K, Pagani FD et al (2007) Cardiac improvement during mechanical circulatory support: a prospective multicenter study of the LVAD Working Group. Circulation 115(19):2497–2505
32. Reedy JE, Swartz MT, Lohmann DP, Moroney DA, Vaca KJ, McBride LR et al (1992) The importance of patient mobility with ventricular assist device support. ASAIO J 38(3):M151–M153
33. Wells CL (2013) Physical therapist management of patients with ventricular assist devices: key considerations for the acute care physical therapist. Phys Ther 93(2):266–278
34. Rogers JG, Aaronson KD, Boyle AJ, Russell SD, Milano CA, Pagani FD et al (2010) Continuous flow left ventricular assist device improves functional capacity and quality of life of advanced heart failure patients. J Am Coll Cardiol 55(17):1826–1834
35. Anagnostakou V, Chatzimichail K, Dimopoulos S, Karatzanos E, Papazachou O, Tasoulis A et al (2011) Effects of interval cycle training with or without strength training on vascular reactivity in heart failure patients. J Card Fail 17(7):585–591
36. de Jonge N, Kirkels H, Lahpor JR, Klöpping C, Hulzebos EJ, de la Rivière AB et al (2001) Exercise performance in patients with end-stage heart failure after implantation of a left ventricular assist device and after heart transplantation: an outlook for permanent assisting? J Am Coll Cardiol 37(7):1794–1799
37. Haft J, Armstrong W, Dyke DB, Aaronson KD, Koelling TM, Farrar DJ et al (2007) Hemodynamic and exercise performance with pulsatile and continuous-flow left ventricular assist devices. Circulation 116(11 Suppl):I8–15
38. Jakovljevic DG, Birks EJ, George RS, Trenell MI, Seferovic PM, Yacoub MH et al (2011) Relationship between peak cardiac pumping capability and selected exercise-derived prognostic indicators in patients treated with left ventricular assist devices. Eur J Heart Fail 13(9):992
39. Laoutaris ID, Dritsas A, Adamopoulos S, Manginas A, Gouziouta A, Kallistratos MS et al (2011) 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 18(1):33–40
40. Marko C, Danzinger G, Käferbäck M, Lackner T, Müller R, Zimpfer D et al (2014) Safety and efficacy of cardiac rehabilitation for patients with continuous flow left ventricular assist devices. Eur J Prev Cardiol 22(11):1378–1384
41. Pruijsten RV, Lok SI, Kirkels HH, Klöpping C, Lahpor JR, de Jonge N (2012) Functional and haemodynamic recovery after implantation of continuous-flow left ventricular assist devices in comparison with pulsatile left ventricular assist devices in patiens with end-stage heart failure. Eur J Heart Fail 14(3):319–325
42. Hayes K, Leet A, Bradley S, Holland A (2012) Effects of exercise training on exercise capacity and quality of life in patients with a left ventricular assist device: a preliminary randomized controlled trial. J Heart Lung Transplant 31(7):729–734
43. Karapolat H, Engin C, Eroglu M, Yagdi T, Zoghi M, Nalbantgil S et al (2013) Efficacy of the cardiac rehabilitation program in patients with end-stage heart failure, heart transplant patients, and left ventricular assist device recipients. Transplant Proc 45(9):3381–3385
44. Kerrigan DJ, Williams CT, Ehrman JK, Bronsteen K, Saval MA, Schairer JR et al (2013) Muscular strength and cardio respiratory fitness are associated with health status in patients with recently implanted continuous-flow LVADs. J Cardiopulm Rehabil Prev 33(6):396–400
45. Harrington D, Anker SD, Chua TP, Webb-Peploe KM, Ponikowski PP, Poole-Wilson PA et al (1997) Skeletal muscle function and its relation to exercise tolerance in chronic heart failure. J Am Coll Cardiol 30(7):1758–1764
46. Clark AL (2006) Origin and symptoms in chronic heart failure. Heart 92(1):12–16
47. Jaski BE, Lingle RJ, Kim J, Branch KR, Goldsmith R, Johnson MR et al (1999) Comparison of functional capacity in patients with end-stage heart failure following implantation of a left ventricular assist device versus heart transplantation: results of the experience with left ventricular assist device with exercise trial. J Heart Lung Transplant 18(11):1031–1040
48. Compostella L, Russo N, Setzu T, Bottio T, Compostella C, Tarzia V et al (2015) A practical review for cardiac rehabilitation professionals of continuous-flow left ventricular assist devices: historical and current perspectives. J Cardiopulm Rehabil Prev 35(5):301–311
49. Kugler C, Malehsa D, Schrader E, Tegtbur U, Guetzlaff E, Haverich A et al (2012) A multi-modal intervention in management of left ventricular assist device outpatients: dietary counselling, controlled exercise and psychosocial support. Eur J Cardiothorac Surg 42(6):1026–1032
50. Nguyen E, Stein J (2013) Functional outcomes of adults with left ventricular assist devices receiving inpatient rehabilitation. PM R 5(2):99–103
51. Alsara O, Reeves RK, Pyfferoen MD, Trenary TL, Engen DJ, Vitse ML et al (2014) Inpatient rehabilitation outcomes for patients receiving left ventricular assist device. Am J Phys Med Rehabil 93(10):860–868
52. Chu SK, McCormick Z, Hwang S, Sliwa JA, Rydberg L (2014) Outcomes of acute inpatient rehabilitation of patients with left ventricular assist devices. PM R 6(11):1008–1012
53. English ML, Speed J (2013) Effectiveness of acute inpatient rehabilitation after left ventricular assist device placement. Am J Phys Med Rehabil 92(7):621–626
54. Polastri M, Bacchi Reggiani ML, Cefarelli M, Jafrancesco G, Martin-Suarez S (2013) The distance walked daily as a post-operative measure after pulmonary endarterectomy. Int J Ther Rehabil 20(4):195–199
55. Kohli HS, Canada J, Arena R, Tang DG, Peberdy MA, Harton S et al (2011) Exercise blood pressure response during assisted circulatory support: comparison of the total artificial [corrected] heart with a left ventricular assist device during rehabilitation. J Heart Lung Transplant 30(11):1207–1213

56. Hasin T, Topilsky Y, Kremers WK, Boilson BA, Schirger JA, Edwards BS et al (2012) Usefulness of the six-minute walk test after continuous axial flow left ventricular device implantation to predict survival. Am J Cardiol 110(9):1322–1328
57. Busch JC, Lillou D, Wittig G, Bartsch P, Willemsen D, Oldridge N et al (2012) Resistance and balance training improves functional capacity in very old participants attending cardiac rehabilitation after coronary bypass surgery. J Am Geriatr Soc 60(12):2270–2276
58. Podsiadlo D, Richardson S (1991) The timed "Up & Go": a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc 39(2):142–148
59. Mkacher W, Mekki M, Tabka Z, Trabelsi Y (2015) Effect of 6 months of balance training during pulmonary rehabilitation in patients with COPD. J Cardiopulm Rehabil Prev 35(3):207–213
60. Berg KO, Wood-Dauphinee SL, Williams JI, Maki B (1992) Measuring balance in the elderly: validation of an instrument. Can J Public Health 83(suppl 2):S7–11
61. Hurvitz EA, Richardson JK, Werner RA, Ruhl AM, Dixon MR (2000) Unipedal stance testing as an indicator of fall risk among older outpatients. Arch Phys Med Rehabil 81(5):587–591
62. Tinetti M (1986) Performance-oriented assessment of mobility problems in elderly patients. J Am Geriatr Soc 34(2):119–126
63. Myers AM, Fletcher PC, Myers AH, Sherk W (1998) Discriminative and evaluative properties of the Activities-Specific Balance Confidence (ABC) scale. J Gerontol A Biol Sci Med Sci 53(4):M287–M294
64. Pistono M, Corrà U, Gnemmi M, Imparato A, Caruso R, Balestroni G et al (2011) Cardiovascular prevention and rehabilitation for patients with ventricular assist device from exercise therapy to long-term therapy. Part II: long-term therapy. Monaldi Arch Chest Dis 76(3):136–145
65. Ueno A, Tomizawa Y (2009) Cardiac rehabilitation and artificial heart devices. J Artif Organs 12(2):90–97
66. Scheiderer R, Belden C, Schwab D, Haney C, Paz J (2013) Exercise guidelines for inpatients following ventricular assist device placement: a systematic review of the literature. Cardiopulm Phys Ther J 24(2):35–42
67. Compostella L, Russo N, Setzu T, Compostella C, Bellotto F (2014) Exercise performance of chronic heart failure patients in the early period of support by an axial-flow left ventricular assist device as destination therapy. Artif Organs 38(5):366–373
68. Wilson SR, Givertz MM, Stewart GC, Mudge GH (2009) Ventricular assist devices. The challenges of outpatient management. J Am Coll Cardiol 54(18):1647–1659
69. Corrà U, Pistono M, Piepoli MF, Giannuzzi P (2012) Ventricular assist device patients on the horizon of cardiovascular prevention and rehabilitation. Can we convert challenges into opportunities? Eur J Prev Cardiol 19(3):490–493
70. Alsara O, Perez-Terzic C, Squires RW, Dandamudi S, Miranda WR, Park SJ et al (2014) Is exercise training safe and beneficial in patients receiving left ventricular assist device therapy? J Cardiopulm Rehabil Prev 34(4):233–240
71. Wienbergen H, Hambrecht R (2012) Trainingstherapie bei kardiologischen Patienten (Sportkardiologie). Herz 37(5):486–492
72. Matlock DD (2012) Destination unknown: the ventricular assist device and the advance of technology. J Am Geriatr Soc 60(1):154–155
73. Mezzani A, Hamm LF, Jones AM, McBride PE, Moholdt T, Stone JA et al (2012) Aerobic exercise intensity assessment and prescription in cardiac rehabilitation: a joint position statement of the European Association for Cardiovascular Prevention and Rehabilitation, the American Association of Cardiovascular and Pulmonary Rehabilitation, and the Canadian Association of Cardiac Rehabilitation. J Cardiopulm Rehabil Prev 32(6):327–350
74. Compostella L, Russo N, Setzu T, Covolo E, Vettore E, Iliceto S et al (2013) Effects of short-term exercise training at anaerobic threshold in patients with axial-flow left ventricular assist device. Eur J Prev Cardiol 20(Suppl 1):S30
75. Simon MA, Kormos RL, Gorcsan J 3rd, Dohi K, Winowich S, Stanford E et al (2005) Differential exercise performance on ventricular assist device support. J Heart Lung Transplant 24(10):1506–1512
76. Sénage T, Fèvrier D, Michel M, Pichot E, Duveau D, Tsui S et al (2014) A mock circulatory system to assess the performance of continuous-flow left ventricular assist devices (LVADs): does axial flow unload better than centrifugal LVAD? ASAIO J 60(2):140–147
77. Lalonde SD, Alba AC, Rigobon A, Ross HJ, Delgado DH, Billia F et al (2013) Clinical differences between continuous flow ventricular assist devices: a comparison between HeartMate II and HeartWare HVAD. J Card Surg 28(5):604–610
78. Yancy CW, Jessup M, Bozkurt B, Butler J, Casey DE Jr, Drazner MH et al (2013) 2013 ACCF/AHA guideline for the management of heart failure: a report of the American College of Cardiology Foundation/American Heart Association Task Force on practice guidelines. Circulation 128(16):e240–e327
79. Birks EJ, George RS, Hedger M, Bahrami T, Wilton P, Bowles CT et al (2011) Reversal of severe heart failure with a continuous-flow left ventricular assist device and pharmacological therapy: a prospective study. Circulation 123(4):381–390
80. Slaughter MS, Pagani FD, Rogers JG, Miller LW, Sun B, Russell SD et al (2010) Clinical management of continuous-flow left ventricular assist devices in advanced heart failure. J Heart Lung Transplant 29(4 Suppl):S1–39
81. Lampert BC, Eckert C, Weaver S, Scanion A, Lockard K, Allen C et al (2014) Blood pressure control in continuous flow left ventricular assist devices: efficacy and impact on adverse events. Ann Thorac Surg 97(1):139–146
82. Topilsky Y, Oh JK, Shah DK, Boilson BA, Schirger JA, Kushwaha SS et al (2011) Echocardiographic predictors of adverse outcomes after continuous left ventricular assist device implantation. JACC Cardiovasc Imaging 4(3):211–222
83. Compostella L, Russo N, Setzu T, Tursi V, Bottio T, Tarzia V et al (2013) Cardiac autonomic dysfunction in the early phase after left ventricular assist device implant: implications for surgery and follow-up. Int J Artif Organs 36(6):410–418
84. Gardiwal A, Roentgen P, Luesebrink U, Koenig T, Klein G, Oswald H (2010) Left ventricular assist improves

autonomic imbalance in patients with persistent myocardial dysfunction. Int J Artif Organs 33(12): 851–855
85. Tank J, Heusser K, Malehsa D, Hegemann K, Haufe S, Brinkmann J et al (2012) Patients with continuous-flow left ventricular assist devices provide insight in human baroreflex physiology. Hypertension 60(3):849–855
86. Gademan MG, Swenne CA, Verwey HF, van der Laarse A, Maan AC, van de Vooren H et al (2007) Effect of exercise training on autonomic derangement and neurohumoral activation in chronic heart failure. J Card Fail 13(4):294–303
87. Hu SX, Keogh AM, Macdonald PS, Kotlyar E, Robson D, Harkess M et al (2013) Interaction between physical activity and continuous-flow left ventricular assist device function in outpatients. J Card Fail 19(3):169–175
88. Brassard P, Jensen AS, Nordsborg N, Gustafsson F, Møller JE, Hassager C et al (2011) 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 4(5):554–560
89. Jakovljevic DG, George RS, Nunan D, Donovan G, Bougard RS, Yacoub MH et al (2010) The impact of acute reduction of continuous-flow left ventricular assist device support on cardiac and exercise performance. Heart 96(17):1390–1395
90. Noor MR, Bowles C, Banner NR (2012) 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 14(6):613–620
91. Jung MH, Hansen PB, Sander K, Olsen PS, Rossing K, Boesgaard S et al (2014) 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 16(4):403–408
92. Kirklin JK, Naftel DC, Kormos RL, Stevenson LW, Pagani FD, Miller MA et al (2013) Fifth INTERMACS annual report: risk factor analysis from more than 6,000 mechanical circulatory support patients. J Heart Lung Transplant 32(2):141–156
93. Vollkron M, Voitl P, Ta J, Wieselthaler G, Schima H (2007) Suction events during left ventricular support and ventricular arrhythmias. J Heart Lung Transplant 26(8):819–825
94. Boilson BA, Durham LA, Park SJ (2012) Ventricular fibrillation in an ambulatory patient supported by a left ventricular assist device: highlighting the ICD controversy. ASAIO J 58(2):170–173
95. Sims DB, Rosner G, Uriel N, González-Costello J, Ehlert FA, Jorde UP (2012) Twelve hours of sustained ventricular fibrillation supported by a continuous-flow left ventricular assist device. Pacing Clin Electrophysiol 35(5):e144–e148
96. Enriquez AD, Calenda B, Miller MA, Anyanwu AC, Pinney SP (2013) The role of implantable cardioverter-defibrillators in patients with continuous flow left ventricular assist devices. Circ Arrhythm Electrophysiol 6(4):668–674
97. Garan AR, Yuzefpolskaya M, Colombo PC, Morrow JP, Te-Frey R, Dano D et al (2013) Ventricular arrhythmias and implantable cardioverter-defibrillator therapy in patients with continuous-flow left ventricular assist devices: need for primary prevention? J Am Coll Cardiol 61(25):2542–2550
98. Raasch H, Jensen BC, Chang PP, Mounsey JP, Gehi AK, Chung EH et al (2012) Epidemiology, management, and outcomes of sustained ventricular arrhythmias after continuous-flow left ventricular assist device implantation. Am Heart J 164(3):373–378
99. Felix SE, Martina JR, Kirkels JH, Klöpping C, Nathoe H, Sukkel E et al (2012) Continuous-flow left ventricular assist device support in patients with advanced heart failure: points of interest for the daily management. Eur J Heart Fail 14(4):351–356
100. Boyle A (2012) Arrhythmias in patients with ventricular assist devices. Curr Opin Cardiol 27(1):13–18
101. Hottigoudar RU, Deam AG, Birks EJ, McCants KC, Slaughter MS, Gopinathannair R (2013) Catheter ablation of atrial flutter in patients with left ventricular assist device improves symptoms of right heart failure. Congest Heart Fail 19(4):165–171
102. Stulak JM, Deo S, Schirger J, Aaronson KD, Park SJ, Joyce LD et al (2013) Preoperative atrial fibrillation increases risk of thromboembolic events after left ventricular assist device implantation. Ann Thorac Surg 96(6):2161–2167
103. Ades PA, Keteyian SJ, Balady GJ, Houston-Miller N, Kitzman DW, Mancini DM et al (2013) Cardiac rehabilitation exercise and self-care for chronic heart failure. JACC Heart Fail 1(6):540–547
104. Nishimura M, Radovancevic B, Odegaard P, Myers T, Springer W, Frazier OH (1996) Exercise capacity recovers slowly but fully in patients with a left ventricular assist device. ASAIO J 42(5):M568–M570
105. Grapow MT, Todorov A, Bernet F, Zerkowski HR (2003) Ambulatory long-term management of a left ventricular assist device. Current modality in terminal heart failure. Swiss Surg 9(1):27–30
106. Park WH, Seo YG, Sung JD (2014) Exercise therapy for an older patient with left ventricular assist device. Ann Rehabil Med 38(3):396–400
107. Leibner ES, Cysyk J, Eleuteri K, El-Banayosy A, Boehmer JP, Pae WE (2013) Changes in the functional status measures of heart failure patients with mechanical assist devices. ASAIO J 59(2):117–122
108. Dunlay SM, Allison TG, Pereira NL (2014) Changes in cardiopulmonary exercise testing parameters following continuous flow left ventricular assist device implantation and heart transplantation. J Card Fail 20(8):548–554
109. Jakovljevic DG, McDiarmid A, Hallsworth K, Seferovic PM, Ninkovic VM, Parry G et al (2014) Effect of left ventricular assist device implantation and heart transplantation on habitual physical activity and quality of life. Am J Cardiol 114(1):88–93
110. Munro J, Angus N, Leslie SJ (2013) Patient focused Internet-based approaches to cardiovascular rehabilitation–a systematic review. J Telemed Telecare 19(6):347–353

111. Antypas K, Wangberg SC (2014) An Internet- and mobile-based tailored intervention to enhance maintenance of physical activity after cardiac rehabilitation: short-term results of a randomized controlled trial. J Med Internet Res 16(3):e77
112. Kraal JJ, Peek N, Van den Akker-Van Marle ME, Kemps HM (2014) Effects of home-based training with telemonitoring guidance in low to moderate risk patients entering cardiac rehabilitation: short-term results of the FIT@Home study. Eur J Prev Cardiol 21(2 Suppl):26–31
113. Corazza I, Bianchini D, Urbinati S, Zannoli R (2014) REHAL©, a telemedicine platform for home cardiac rehabilitation. Minerva Cardioangiol 62(5):399–405
114. Hernández C, Alonso A, Garcia-Aymerich J, Grimsmo A, Vontetsianos T, Garcia Cuyàs F et al (2015) Integrated care services: lessons learned from the deployment of the NEXES project. Int J Integr Care 15:e006
115. Polastri M, Loforte A (2015) Influence of ventricular assist devices equipment wear on body posture. Artif Organs 39(7):640–641