Chapter

Sarcopenia in Patients with End-Stage Cardiac Failure Requiring Ventricular Assist Device or Heart Transplantation

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Abstract

Sarcopenia has been defined as the age-related reduced skeletal muscle mass, strength, and physical capacity and is frequently associated with serious complications in patients with heart failure (HF). However, when HF progressed to end-stage HF requiring advanced therapies, such as heart transplantation (HTx) and implantation of left ventricular assist device (LVAD), an even higher prevalence of sarcopenia has been reported in younger patients with end-stage HF than elderly patients with less advanced HF. Many literatures have reported that sarcopenia is greatly associated with high rates of morbidity and mortality after HTx and LVAD implantation. Therefore, therapeutic interventions to prevent and reverse sarcopenia, such as cardiac rehabilitation and nutrition supplementation, are important in patients with end-stage HF prior to HTx and LVAD implantation. Although moderate or severe sarcopenia is a contraindication for HTx, the patients who can recover from sarcopenia after LVAD implantation would be considered eligible for HTx. Then, therapeutic options to reverse sarcopenia in patients supported with LVAD are also important to improve patient prognosis after LVAD implantation. In this review, the impacts of sarcopenia on prognosis after LVAD implantation and HTx and vice versa were summarized and therapeutic interventions to reverse sarcopenia before and after LVAD implantation are discussed.

Keywords: sarcopenia, end-stage heart failure, heart transplantation, left ventricular assist device, cardiac rehabilitation, nutrition supplementation

1. Introduction

Heart failure (HF) is a general acute and chronic disease expressing the advanced stage of various types of heart disease, and its prevalence is increasing year by year [1]. As the risk of HF increases with age [2], elderly patients occupy more than four-fifth of all patients with HF. HF may reduce organ and physical functional capacity and their daily life performance in patients. HF greatly affects physical function as well as body composition of skeletal muscle, which is greatly correlated with high rates of morbidity, hospitalization, and mortality [3, 4].

Sarcopenia is a syndrome characterized by general skeletal muscle mass loss and strength, which is related to poor outcomes and high mortality in patients with a

variety of underlying diseases [5]. Although sarcopenia has been first defined as an age-related syndrome, it was also frequently associated with serious complications in even younger patients with advanced stage of HF [6, 7]. The alteration in the skeletal muscle system in patients with HF plays the main role in developing many signs and symptoms related to HF [8, 9]. Then, sarcopenia may significantly greatly attribute to the poor prognosis in patients with HF than in those of the same age without HF [8]. The rate of sarcopenia in a patient with HF is reported to be higher at 19.5% than that in healthy individuals of the same age [10]. Although sarcopenia is more frequently associated with increasing age, an even higher prevalence of 47% has been reported in patients younger than 55 years with dilated cardiomyopathy [11]. Therefore, the patient population with end-stage HF requiring ventricular assist device (VAD) or heart transplantation (HTx) may be different from those with less advanced HF.

Even in younger patients with end-stage HF, metabolic abnormalities related to sarcopenia develop and affect renal and hepatic function [11]. Skeletal muscle, which is the greatest reservoir of protein, is easily wasted in catabolic illness including end-stage HF. However, therapeutic interventions to reverse progressive local and systemic catabolism in advanced HF are limited. Growth hormone (GH) administration and aerobic exercise rehabilitation are known to increase insulin-like growth factor (IGF)-1 level in the blood and increase skeletal muscle volume in HF [12–14]. VAD implantation for bridge-to-transplantation (BTT) and destination therapy (DT) improves local and systemic metabolism probably due to corrected hemodynamics and tissue perfusion in patients with end-stage HF [15, 16]. Multiple literatures have reported that advanced strategies for HF, such as VAD implantation and HTx, provide optimal hemodynamic support and improve local and systemic metabolism, resulting in improvement of other organ function as well as physical capacity [17, 18].

Due to the great development in the field of left VAD (LVAD) in the past two decades, patients referred to this therapy are greatly increased. Although great advances in methodology and increased clinical experience in LVAD therapy had improved patient survival with end-stage HF over time, a certain amount of patients still has a high prevalence of mortality, comorbidity, and hospitalization after LVAD implantation, even in clinical trial settings [19]. As patients for DT are older and have more commodities before LVAD implantation than those for BTT, the use of LVAD for DT recently approved clinically worldwide may lead to higher mortality and morbidity in patients implanted with LVAD.

In this article, we review the impacts of both VAD and HTx on variables associated with sarcopenia as well as malnutrition in patients with end-stage HF and vice versa and discuss therapeutic interventions to reverse sarcopenia before and after LVAD implantation.

2. Diagnosis of sarcopenia

According to the consensus on definition and diagnosis by the European Working Group on Sarcopenia in Older People (EWGSOP), sarcopenia is defined by the presence of both reduced skeletal muscle mass and function as well as reduced physical performance (**Figure 1**) [20]. Skeletal muscle strength is assessed by handgrip strength (HGS), whereas physical performance is assessed by usual gait speed. In the presence of reduced skeletal muscle function, defined by a reduced gait speed (<0.8 m/s) and/or a reduced HGS (<26–30 kg for men and <16–20 kg for women), the diagnosis requires verification of reduced skeletal muscle mass. Currently, magnetic resonance imaging (MRI) and computed tomography (CT)

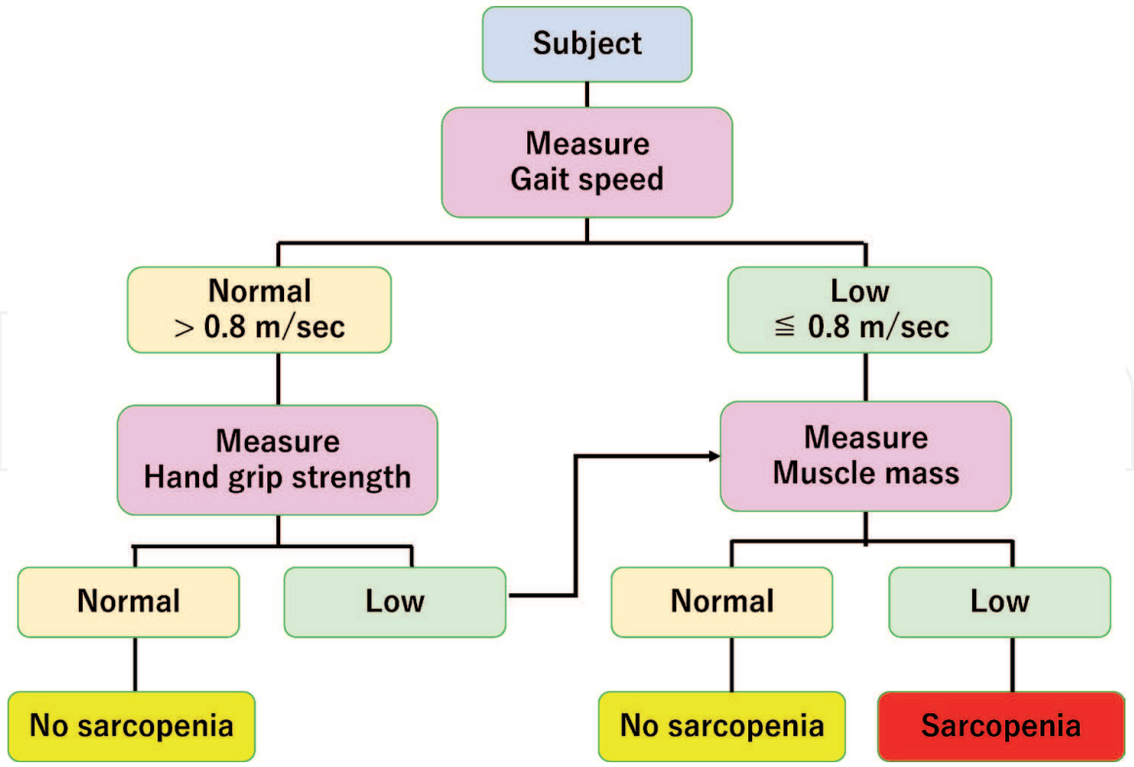

Figure 1.
Sarcopenia assessment algorithm.

have been the gold standard to accurately measure the mass of a skeletal muscle as well as its density and fatty infiltration.

The HGS is an easy and simple tool but suffers from that peripheral muscle strength and function might improve after LVAD implantation and HTx as previously described [21, 22]. To resolve these limitations, investigators in the field of mechanical circulatory support and HTx have begun to estimate the grade of sarcopenia by evaluating the mass of skeletal muscles, such as psoas and pectoralis muscles with clinical prognosis. Positive results have been reported in patients undergoing invasive thoracic and abdominal surgeries [23–26] as well as in those with advanced HF [27–29]. CT scans provide precise identification and quantification of individual skeletal muscle and fat tissue components [30–32].

Creatinine excretion rate index (CER index) in 24-hour urine collection is an easily measurable and less invasive classic marker of total-body skeletal muscle mass [33] and a reliable biomarker even in patients with advanced HF [34, 35]. Iwasaki et al. [36] reported that the CER index in patients with continuous-flow implantable LVAD (CF-LVAD) was significantly correlated with psoas and pectoralis muscles mass measured by CT scan.

3. Impact of sarcopenia at pre-LVAD on outcome after LVAD implantation

Clinical studies of sarcopenia in patients with advanced heart failure referred for left ventricular assist device implantation or heart transplantation is summarized in (**Table 1**).

3.1 Skeletal muscle function

Chung et al. [21] examined the correlation of HGS with outcomes after LVAD implantation, showing that HGS less than 25% of body weight was related to higher

Study	Population	No.	Mean age (years) Gender	Sarcopenia assessment	Main findings	Comment
Chung [21]	Pre- and post LVAD	72	59 89% male	Reduced HGS < 25% body weight	HGS < 25% at pre-LVAD associated with increased operative mortality and postoperative complications. HGS increased by 18.2 +/− 5.6% at 3 months (n 5 29) and 45.5 +/− 23.9% at 6 months post-LVAD implantation.	Reduced HGS in 22% pre-LVAD Improved HGS in survivors at 3 and 6 months post-LVAD. HGS correlated with serum albumin level. HGS was measured with Jamar dynamometer.
Khawaja [22]	Pre-BTT LVAD	25	62 88% male	HGS	Mean HGS at pre-LVAD 35.8 +/− 7.8 vs. 55.6 +/− 12.7 kg in control (no cardiac disease, nonsmokers) (P < 0.05) % increase in HGS at 6 mo on LVAD: +26.5 +/− 27.5% (P = 0.05)	LVAD implantation corrects GH/IGF-1 signaling, improves muscle structure and function, and enhances oxidative muscle metabolism in patients with advanced HF
Heberton [37]	Pre-DT LVAD	100	54 77% male	Psoas muscle area on CT scan at L3-L4 level defined as lowest tertile for gender	Significant increase in composite endpoint of prolonged hospital-stay or inpatient mortality (P = 0.043)	Retrospective study 100 of 333 patients with usable CT scans The psoas muscle area cut-off values for the lowest tertiles were 12.0 cm^2 for men and 6.5 cm^2 for women, resulting in 32 sarcopenic patients (32%).
Teigen [32]	Pre-BTT LVAD	143	60 89% male	PMI and PHUm pre-LVAD	Increased PMI and PHUm associated with a 27% reduction in the hazard of death after LVAD	For PMI, the estimated survival by tertile was the following: highest 86%, middle 84%, and lowest 59% (P = 0.002 by log-rank test).
Fernandes [38]	Pre-HTx (on Waiting list)	23	51 87% male	CSAbPm, HGS, MIP and MEP in waiting list group and after HTx	Reduced CSAbPm, HGS, MIP and MEP in waiting list group compared to healthy control Increased CSAbPm, HGS, MIP and MEP in patients surviving longer than 6 mo after HTx	

Study	Population	No.	Mean age (years) Gender	Sarcopenia assessment	Main findings	Comment
Cogswell [39]	Pre-BTT LVAD	Not defined	Not defined	Minnesota Pectoralis Risk Score (MPRS),	The calculated MPRS place each patient in the low, medium, or high-risk category and estimates survival probability at 30, 60, and 365 days after LVAD implantation.	MPRS was calculated by a set of predictors, such as a PHUm, PMI, African American race, creatinine, total bilirubin, body mass index, bridge to transplant, and the presence or absence of contrast. Receiver-operating characteristic curves for 30-, 90-, and 365-day survival were generated. The area under the curve for the model at 30, 90, and 365 days was 0.78, 0.76, and 0.76, respectively.
Tsuji [40]	Pre-BTT LVAD	78	42 71% male	Skeletal muscle index (SMI) on CT scan at L3 level	Muscle wasting was associated with post-LVAD mortality (hazard ratio: 4.32; 95% CI: 1.19–20.2)	The SMI cut-off values for the lowest tertiles were 36.7 cm^2/m^2 for men and 28.2 cm^2/m^2 for women, resulting in 26 patients (33.3%) with muscle wasting.
Iwasaki [36]	Pre-BTT LVAD	147	44 72% male	Creatinine excretion rate (CER) index	A low CER index was an independent predictor of intracranial hemorrhage in patients receiving a CF-iLVAD	CER index = [Cr]urine×24-h urine volume/body weight
Cogswell [41]	Pre-LVAD	276	61 84% male	PMI	Patients in the low PMI group associated with post-LVAD mortality irrespectively of INTERMACS profile, but INTERMACS 3 and 4 patients in the high PMI groups had the highest survival on LVAD support	Patients with the largest deterioration in renal function (highest slope) between −365 and − 60 days before LVAD were more likely to be INTERMACS 1 and 2 at the time of LVAD implantation.

Abbreviations: LVAD left ventricular assist device, HGS handgrip strength, BTT bridge to transplant,, GH: growth hormone, IGF-1; insulin-like growth factor, DT destination therapy, CT computed tomography, PMI Unilateral Pectoralis muscle mass indexed to BSA, PHUm pectoralis muscle mean Hounsfield unit, HTx heart transplantation, CSAbPm cross-sectional area of the bilateral psoas major muscle, MIP and MEP the maximum inspiratory and expiratory pressure body surface area, CI confidence interval, Cr serum creatinine.

Table 1.
Clinical studies of sarcopenia in patients with advanced heart failure referred for left ventricular assist device implantation or heart transplantation.

mortality. Khawaja et al. [22] reported that patients with advanced HF had significantly lower HGS prior to CF-LVAD implantation compared to healthy controls and that the average HGS increased greater than 25% after 6 months after CF-LVAD implantation.

3.2 Skeletal muscle mass measurement

Heberton et al. [37] first introduced the assessment of skeletal muscle mass in the field of LVAD therapy and reported that sarcopenia by measuring psoas muscle area at L3-L4 vertebrae was significantly related to longer hospital stay and higher mortality after implantation of HeartMate II LVAD. On the other hand, Teigen et al. reported that pectoralis muscle mass and tissue quality by measuring Hounsfield units (PHUm) and size-indexed to body surface area were highly associated with post-LVAD mortality and surpassed any other variables in the University of Minnesota dataset [32]. This group further added an external dataset to create a user-friendly, multivariable post-LVAD mortality-prediction score, the so-called the Minnesota Pectoralis Risk Score (MPRS) [39]. This final model included PHUm, pectoralis muscle index (PMI), African American race, serum creatinine and total bilirubin, body mass index (BMI), BTT or DT, and the presence or absence of contrast. The estimated 1-year survival for patients after LVAD implantation by MPRS risk category (tertiles) was the following—low, medium, and high risks were 95, 79, and 58%, respectively ($P < 0.0001$ by log-rank test). These skeletal muscle measures appear to add important prognostic value to pre-LVAD risk assessment [39]. A further study by them [41] described that INTERMACS 3 and four patients with the highest PMI had the best survival after CF-LVAD implantation. Tsuji et al. [40] also reported that muscle wasting defined by skeletal muscle index on CT scan at L3 level was also associated with post-LVAD mortality. From these findings, CT scan quantification of sarcopenia may help us to identify the optimal timing of LVAD implantation.

3.3 Creatinine excretion rate index

Iwasaki et al. [36] reported that reduced CER index was significantly related to a higher rate of mortality and intracranial hemorrhage after CF-LVAD implantation. Preoperative reduced CER index might be an independent predictor of intracranial hemorrhage after CF-LVAD implantation.

4. Impact of sarcopenia as well as malnutrition at pre-HTx on outcome after HTx

4.1 Sarcopenia and indication for HTx

The donor heart shortage restricts HTx to a small portion of potential recipients. Moreover, serious complications accompanied with patients with end-stage HF, such as sarcopenia, systemic infection, and irreversible renal and hepatic dysfunction, more greatly affect patient prognosis after HTx than other cardiac surgery, because HTx recipients need immunosuppressive medication to prevent allograft rejection. Therefore, HTx is a treatment option for a few carefully selected patients with end-stage HF. The number of patients above the age of 60 years being transplanted has increased over the past 10 years. And recent post-HTx survival in patients aged between 60 and 69 years has been satisfactory. However, 5-year mortality in those aged 70 years and older are significantly poorer compared with

those aged between 18 and 59 years. Therefore, recipients aged older than 70 years are less acutely ill, have fewer comorbidities, and are less likely to have durable LVAD support for BTT [42]. Therefore, usually moderate or severe sarcopenia, as well as frailty, might be a contraindication for HTx. However, LVAD implantation in patients with frailty could be applicable as a bridge to candidacy. Patients who can recover from a frail state after LVAD implantation presumably after a certain period of physical rehabilitation and nutrition supplementation would then be considered eligible for HTx. This means that a sarcopenia patient who is firstly likely to survive LVAD implantation and secondly to reverse his/her frailty or sarcopenia can be a potential candidate for HTx [43]. For these reasons, there has been no published data concerning the impacts of real sarcopenia on outcomes after HTx.

4.2 Impact of malnutrition and physical rehabilitation at before and after HTx on exercise capacity post-HTx

Although previous studies have shown that the recipients exhibit improvements in exercise capacity and physical performance after HTx, the recipients often have a lower exercise capacity than normal healthy controls of the same age and gender soon and long after HTx.

Yanase et al. [44] investigated the effects of the recipient and donor predictive risk factors on the patient's exercise capacity early after HTx. In this study, 3-month rehabilitation exercise training significantly increased peak VO2 irrespective of the main recipient or donor risk predictive factors on post-HTx survival, which included paracorporeal or implantable LVAD, and several marginal donor heart risk factors. Only younger recipient age and better several nutrition factors, such as higher choline esterase and higher blood lymphocyte count, at the entry of 3-month exercise program were significantly associated with higher peak VO2 at the entry and the end of the 3-month training program. These data suggested that nutrition management and rehabilitation at the bedside prior to starting the exercise training program play a significant role in increasing peak VO2 at the entry of the rehabilitation program.

5. Impact of LVAD implantation on sarcopenia

As mentioned earlier, many investigators have shown that sarcopenia was associated with increased comorbidity and mortality after implantation of LVAD. On the other hand, only limited studies concerning the impact of LVAD implantation on sarcopenia have been available. Several investigators reported improvement of HGS after implantation of CF-LVAD [21, 22]. Although it has been reported that frailty prior to BTT LVAD implantation is associated with an increased post-LVAD morbidity and mortality, it has also been reported that frailty is reversible in most patients who survive the perioperative period [45, 46]. Maurer et al. [47] assessed reversal of frailty in 29 elderly frail LVAD recipients with a mean age of 71 years. Although frailty improved overall, 53% of the patients remained frail 6 months after LVAD implantation. These data suggested that frailty may be less reversible in aged patients supported with LVAD.

Multiple studies have shown that implantation of LVAD not only provides adequate hemodynamic support but also improves renal and liver function and psychical capacity especially after receiving physical rehabilitation. However, there are multifactorial limitations to exercise in patients supported with LVAD [38]. Although LVAD implantation improves hemodynamics in end-stage HF patients at rest, the device is unable to provide full circulatory support during exercise,

especially in patients with CF-LVAD. Thus, significant limitations in exercise capacity persist soon and long after CF-LVAD implantation. Maximizing LV unloading and improving native myocardial function in association with an automated increase in LVAD speed could provide an increase in maximal exercise capacity in patients with the old-type pulsatile implantable LVAD. However, CF-LVAD can provide only partial improvement in maximal exercise capacity. Further studies are needed regarding the role of RV function, recovery of native cardiac function, the role of rehabilitation and nutrition intervention, changes in skeletal muscle function after CF-LVAD, and their contribution to endurance exercise [38].

6. Impact of HTx on sarcopenia

Fernandes et al. [48] investigated the impact of HTx on the recovery of peripheral and respiratory muscle mass and strength in patients with congestive HF. They showed significant decreases in a cross-sectional area of the bilateral psoas major muscle (CSAbPm), a bilateral HGS, and the maximum inspiratory and expiratory pressure (MIP and MEP) in patients on the waiting list compared with the healthy controls with normal cardiac function. They also found significant increases during waiting for HTx to 6- and 18-month post-HTx in the CSAbPm (1305.4 vs. 1458.1 vs. 1431.3 mm^2, respectively), bilateral HGS (27.3 vs. 30.2 vs. 34.7 kg/f, respectively), MIP (59.5 vs. 85.5 vs. 90.9 cmH_2O, respectively), and MEP (79.5 vs. 93.2 vs. 101.8 cmH_2O, respectively). These results revealed that patients recovered peripheral and respiratory muscle mass and strength early after HTx. However, Schaufelberger et al. [49] demonstrated that intrinsic abnormalities in skeletal muscle found before HTx remained 6–9 months after HTx and might contribute to a reduced exercise capacity and muscle strength in these patients, in contrast to the former paper's findings.

7. Management of sarcopenia after LVAD implantation

As mentioned earlier, sarcopenia is a strong negative predictor on outcome after LVAD implantation and HTx. Therefore, sarcopenia is one of the main therapeutic targets in patients with end-stage HF referred to LVAD implantation and HTx to avoid related comorbidity and to improve prognosis post-LVAD implantation and post-HTx. Although moderate or severe sarcopenia as well as frailty is a contraindication for HTx, patients who can reverse frail after LVAD implantation would be considered eligible for HTx. Therefore, to further improve outcomes after LVAD implantation or HTx, therapeutic management for sarcopenia should be established in patients supported with LVAD as well as those prior to LVAD implantation. As the management of sarcopenia in patients prior to LVAD implantation might be the same in medically treated patients with end-stage HF and has been previously well discussed in many previous literatures, those for patients supported with CF-LVAD will be discussed in this review.

According to the pathophysiological factors involved in the pathogenesis of sarcopenia, therapeutic approaches for sarcopenia are summarized in **Figure 2**. Although Khawaja et al. [22] reported that CF-LVAD implantation corrects GH/IGF-1 signaling and improves muscle structure and function, only limited data were available regarding anti-inflammation strategies and hormonal therapies, such as GF/IGF-1 and ghrelin administration for sarcopenia in patients supported with LVAD. Therefore, exercise training and nutrition supplementation in patients supported with LVAD are reviewed in this review.

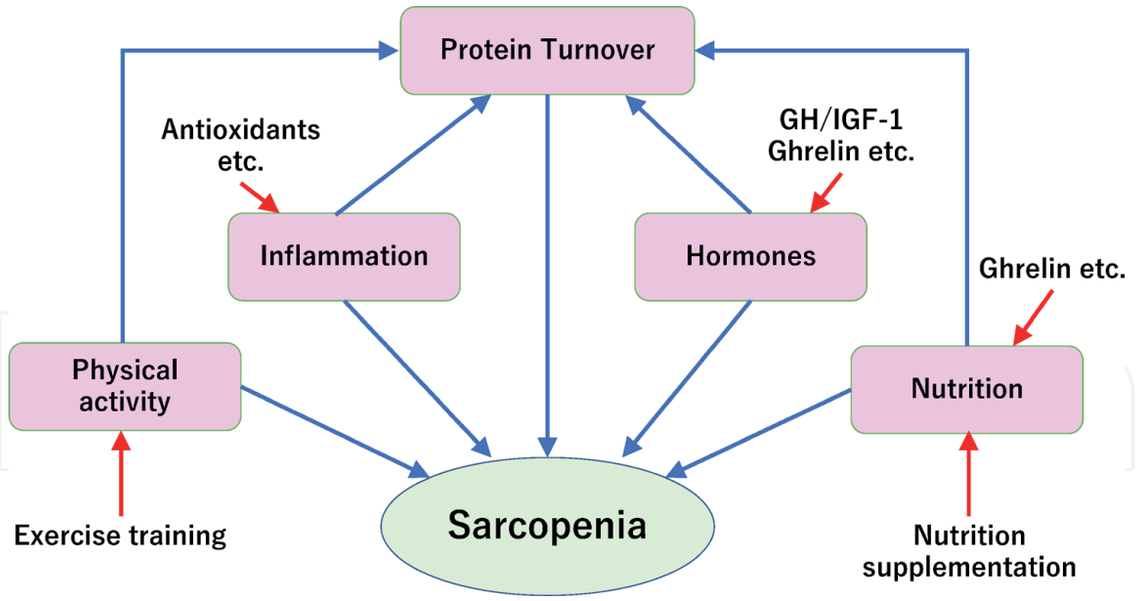

Figure 2.
Sarcopenia pathogenesis and therapeutic approaches: GH growth hormone, IGF-1 insulin-like growth factor-1.

7.1 Exercise training (rehabilitation) in LVAD patients

Generally, HTx or LVAD recipients attend a cardiac rehabilitation program to promote recovery after surgery. Such rehabilitation programs consist of standardized sessions of physical exercise training, with the same intensity and duration regardless of HTx or LVAD implantation. However, surgical indication and method, individual medical and surgical therapies, and possible adverse events after surgery might affect the efficacy of cardiac rehabilitation differently in HTx and LVAD patients. If this occurs, rehabilitation programs better tailored to LVAD patients should be designed.

Yanase et al. [44] reported that short term, such as 3-month rehabilitation program, could significantly increase post-HTx exercise capacity irrespective of age, gender, type of LVAD, and underlying disease. But, even in those patients, better several nutrition factors at exercise program admission were significantly associated with peak VO2 at the end of the exercise program. Therefore, nutrition supplementation during LVAD support might be also essential to improve exercise capacity post-HTx as well as exercise training. However, there are no guidelines regarding the best way to cardiac exercise prescription, especially for CF-LVAD patients. As a result, LVAD patients currently undergo rehabilitation protocols designed for other types of cardiovascular diseases or cardiac surgeries.

As patients receiving LVAD are deeply deconditioned due to advanced HF, it is recommended that patients with sarcopenia as well as frailty are admitted to an in-patient rehabilitation program soon after implanting LVAD. Alsara et al. [50] reviewed the literatures regarding cardiac rehabilitation in patients supported with LVAD and concluded that exercise training is safe and recommended early mobilization between 7 and 10 days post-LVAD and treadmill exercise training beginning at 21 days post-LVAD. However, there is very few information regarding the improvements derived from exercise training in LVAD patients.

Currently, pulsatile-flow LVADs (PF-LVADs) are seldom used as durable support in patients with end-stage HF, but they have a pneumatically/electrically driven ventricle operating in the complete fill/ and empty mode. Therefore, cardiac output during exercise will increase by an automatic increase in pump rate responding to an increase in left ventricular (LV) preload. PF-LVADs work independently from LV afterload and produce a maximal cardiac output of 10 liters/min with a pump rate

of 120 beats/min [51]. On the other hand, the CF-LVAD has no inflow or outflow valves, unloads the ventricle in both systole and diastole, and operates at a fixed pump speed. The two types of CF-LVADs are axial and centrifugal. Pump flow changes according to the differential pressure between the inflow and outflow cannulas. The sensitivity of axial and centrifugal pumps to changes in preload is similar, whereas centrifugal pumps are more sensitive to afterload [52]. During exercise, pump flow increases in the CF-LVAD according to changes in LV preload and afterload. For example, RV failure decreases LV preload and high systemic pressure decreases LV afterload, resulting in reduced pump flow. Therefore, CF-LVAD cannot fully increase pump flow with exercise, whereas PF-LVAD can do so.

Haft et al. [53] reported the differences in the exercise hemodynamic responses between PF-LVAD and CF-LVAD. Peak VO2 as well as resting central venous pressure, mean arterial pressure, and pulmonary capillary wedge pressure were similar and pump flow increased peak VO2 in both groups. However, the increase in pump flow was approximately 20% greater in the PF-LVAD than in the CF-LVAD. Moreover, the significance of this finding is unclear because the pump flow through for the CF-LVAD is not directly measured but only estimated. Martina et al. [54] reported that patients supported with CF-LVAD showed a mean peak VO2 of 18 mL/kg/min (55% of predicted) and a mean total maximum cardiac output of 8.5 liters/min. From these studies, patients supported with CF-LVAD may have a similar peak VO2 independently of the type of CF-LVAD. Although maximum cardiac output increases with exercise in patients supported with CF-LVAD, it does not reach levels found in healthy individuals with normal cardiac function.

Many factors, such as underlying heart disease, native heart function, especially right ventricular function, both ventricular morphology, co-existing arrhythmia, type of LVAD, rehabilitation protocol, and nutrition intervention may influence the effect of cardiac rehabilitation on improvement in exercise capacity and recovery from sarcopenia. Therefore, individualized exercise prescriptions leading to optimal improvements in exercise capacity in patients supported with CF-LVAD are not well known and should be established in the field of LVAD therapy [47].

7.2 Nutrition

There is no doubt that malnutrition is involved in the pathogenesis of sarcopenia, and that it contributes to the poor muscle function observed in patients with end-stage HF, particularly in frail elderly patients. In general, the proposition of nutritional interventions should be based on the delivery of an adequate energy supply and on the supplementation of specific nutrients as an effective treatment in preventing and/or reversing sarcopenia in patients with advanced HF. However, there are very few literatures regarding the recovery from sarcopenia by nutrition interventions particularly in patients supported by LVAD.

8. Conclusion

Sarcopenia as well as frailty is a strong negative predictor on outcome after LVAD implantation and HTx. Assessment of skeletal muscle function such as HGS and gait speed, and measurement of skeletal muscle mass and CER index prior to surgery are useful tools to predict patient's outcome after LVAD implantation and HTx. Therefore, therapeutic strategies to reverse sarcopenia prior to surgery and after LVAD implantation are important to improve their outcomes. However, many factors, such as the indication, surgical method, postoperative therapies, and possible adverse events, might affect the efficacy of cardiac rehabilitation and nutrition

supplementation on quality of life as well as survival differently in HTx and LVAD patients. Therefore, individualized exercise prescriptions and nutrition interventions leading to the reversal of sarcopenia as well as frailty in patients undergoing and supported with CF-LVAD should be established in the near future.

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