Exercise Prescription in Cardiac Rehabilitation

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A Practical Approach to Early Mobilization and Exercise Training

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Foreword

Cardiac rehabilitation is a rapidly evolving branch of rehabilitation medicine that seeks to optimize physical function in patients with cardiac diseases or recent cardiac surgeries. It has a robust impact on improving quality of life, reducing admissions, and enhancing favorable cardiovascular outcomes; it has therefore gained recognition as an important recommendation in all cardiovascular guidelines.

This book aims to fill the void that exists regarding the cognitive and technical knowledge of cardiac rehabilitation, with only relatively few books examining the technical and practical scope and scale of this evolving field. The target readership encompasses rehabilitation physicians, technicians, and nurses, in addition to all cardiologists and cardiac fellows, and aims to meet, at least partially, the growing demands of such practitioners to establish rehabilitation laboratories and initiate cardiac rehabilitation programs.

The book is the product of a collaborative effort by a dedicated team of cardiologists whose specialties span the entire field of cardiology, offering a practical approach to exercise prescription in cardiac rehabilitation in line with American and European guidelines and inspired by local experience. It details the technical aspects of different modalities of exercise for a broad spectrum of cardiovascular conditions and patient groups and provides strategies to overcome existing barriers to physical activity in the local population. The book consists of eight chapters that are arranged to take the reader from the basic aspects to the more complex ones, spanning the broad range of technical intricacies required to fulfill the practical requirements of cardiac rehabilitation. It describes the basics of rehabilitation, functional assessment, early mobilization, supervised and long-term exercise protocols, cardiac rehabilitation in specific groups, program management, and, finally, special considerations for Middle Eastern and Saudi Arabian populations.

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Adam Staron

Abbreviations

AACVPR	American Association of Cardiovascular and Pulmonary Rehabilitation
ABI	ankle–brachial index
ACLS	advanced cardiac life support
ACSM	American College of Sports Medicine
ADL	activities of daily living
AHA	American Heart Association
AT	anaerobic threshold
BLS	basic life support
BMI	body mass index
BP	blood pressure
CABG	coronary artery bypass grafting
CAD	coronary artery disease
CHF	congestive heart failure
CPET	cardiopulmonary exercise testing
CRT	cardiac resynchronization therapy
DBP	diastolic blood pressure
DM	diabetes mellitus
EACPR	European Association of Cardiovascular Prevention and Rehabilitation
ECG	Electrocardiogram
EE	energy expenditure
ESC	European Society of Cardiology
ET	exercise test
ExT	exercise test
FITT-VP	frequency, intensity, time, type, volume, and progression
GFR	glomerular filtration rate
GXT	graded exercise test
HF	heart failure
HIIT	high-intensity interval training
HR	heart rate
HRR	heart rate reserve
HT	heart transplantation
ICD	implantable cardioverter-defibrillator
IRI	ischemia-reperfusion injury
ISWT	incremental shuttle walking test
IT	interval training
Kg	Kilogram
Km/h	kilometers per hour
LIIT	low-intensity interval training
L/min/m^2	liters per minute per square meter
LVEF	left ventricular ejection fraction
MET	metabolic equivalent

METS	multiples of resting metabolic equivalent
MGA	multidimensional geriatric evaluation
MI	myocardial infarction
MIIT	moderate-intensity interval training
MIITC	moderate-intensity interval-to-continuous
ML/kg/min	milliliters per kilogram per minute
MPH	miles per hour
MVC	maximum voluntary contraction
NSTEMI	non-ST elevation myocardial infarction
NYHA	New York Heart Association
PCI	percutaneous coronary intervention
RHR	resting heart rate
RIC	remote ischemic conditioning
RM	repetition maximum
ROM	range of motion
RPE	rating of perceived exertion
RPP	rate pressure product
RT	resistance training
SBP	systolic blood pressure
STEMI	ST elevation myocardial infarction
THR	target heart rate
VO2	oxygen uptake
W	Watts
1-RM	one-repetition maximum
2 MST	two-minute step test
6 MWT	six-minute walk test

Preface

With this book, the author's intention is to offer readers a practical guide to implementing exercise prescription for patients undergoing cardiac rehabilitation. The latest American and European guidelines have been incorporated into the text to provide an up-to-date resource for cardiac practitioners and students with reference to research developed by the Polish School of Cardiac Rehabilitation, noted for its innovative studies in the field of cardiac rehabilitation and the development of safe and effective protocols which have been universally adopted in cardiac practice for decades. This book gives an overview of the current guidelines for cardiac rehabilitation; we hope that it will serve as an enduring resource for this area of medicine. Novel strategies and trends in exercise training, such as high-intensity interval training and telerehabilitation are discussed, with practical guidance given on how to implement them in practice. Moreover, the authors introduce and discuss several emerging topics, such as exercise prescription for COVID-19 patients and the concept of training based on exercise preconditioning.

A quick look-up format is frequently employed throughout this text, allowing readers to quickly find advice on technical aspects of exercise prescription written in a short summary format without extraneous information. This book represents a collective endeavor from medical staff at the Saudi Arabian Cardiac Center from inter-disciplinary fields, working together to provide a holistic approach to patient aftercare. Therefore, a dedicated chapter focusing on the Middle East has been included, wherein the authors have created a unique resource covering appropriate strategies for overcoming barriers to physical activity in this region, considering local conditions and the particular needs of its patients. We dedicate this book to our families.

Adam Staron, Jadwiga Wolszakiewicz, and Meteb AlSulaimi
Editors

1. Basics of Cardiac Rehabilitation

Meteb AlSulaimi, Adam Staron, Jadwiga Wolszakiewicz, Mohanned AlMarzook, Jana AlQahtani, Badri AlOtaiby and Abeer Hamza Abdulghani

1.1 Definition

According to the World Health Organization definition, cardiac rehabilitation is "the sum of activities required to influence, favorably, the underlying cause of the disease, as well as to provide the best possible physical, mental, and social conditions, so that patients may, by their own efforts, preserve or resume optimal functioning in their community and through improved health behavior, slow or reverse the progression of a disease" [1,2]. The objectives of exercise-based cardiac rehabilitation are to increase functional capacity level, reduce anginal symptoms and disability, improve quality of life, modify coronary risk factors, and reduce morbidity and mortality rates [3].

Key elements of the comprehensive cardiac rehabilitation program include [3,4]:

- Clinical assessment;
- Optimal pharmacotherapy;
- Optimal function of implanted electrical cardiac devices;
- Individually tailored exercise prescription;
- Nutritional counseling;
- Weight control management;
- Lipid management;
- Blood pressure monitoring;
- Smoking cessation;
- Psychosocial support;
- Education of the patients and their relatives;
- Monitoring of the effects of cardiac rehabilitation.

Exercise prescription remains a core component of cardiac rehabilitation.

A significant reduction in cardiovascular mortality and hospitalization has recently been validated by Cochrane analysis. The beneficial effects of cardiac rehabilitation reported in a group of patients after myocardial infarction include reductions in [5–7]:

- All-cause mortality by 11–26%;
- Cardiac mortality by 26–36%;
- Unplanned admissions to a hospital by 28–56%.

More recent Cochrane review demonstrated a significant reduction in cardiovascular mortality in exercising group compared with controls (10.4% and 7.6% respectively) [8].

The specific mechanisms responsible for these beneficial effects remain disputable, especially considering the insignificant reduction in the recurrence of myocardial infarction after cardiac rehabilitation. It has been postulated that mortality reduction is a result of a reduction in ventricular fibrillation (decreased sympathetic tone and enhanced parasympathetic tone) or due to the mechanism of ischemic preconditioning [9]. As cardiorespiratory fitness improvement is associated with reductions in mortality after a structured, comprehensive cardiac rehabilitation program, the exact mean change in fitness that occurs has been extensively studied. Sandercock's review of 31 studies demonstrated an increase in fitness of 1.55 metabolic equivalents after phase II. Converting this value to peak oxygen uptake, a gain in cardiorespiratory fitness of 5.4 mL/kg/min can be expected. The reported extent of gain was strictly related to the number of sessions completed, with >36 exercise sessions resulting in a greater gain in fitness [10]. As expected, programs with a significantly lower number of sessions resulted in a smaller increase in cardiorespiratory fitness [11].

The effectiveness of cardiac rehabilitation in reducing either cardiovascular mortality or the rate of myocardial re-infarction largely depends on the exercise volume. Data from meta-analyses have demonstrated specific requirements for the best cardiac rehabilitation outcomes as presented in Table 1 [12].

Table 1. Optimal conditions for efficacious cardiac rehabilitation.

Intervention	Multicomponent program
Start	Commenced within 3 months after discharge.
Settings	Inpatient/outpatient/community or home-based/hybrid telerehabilitation).
Exercise components	Frequency: at least two supervised sessions/week Duration: at least 36 sessions.
Other components	Management of: smoking cessation, physical exercise training, counseling for exercise/activity, diet, blood pressure, cholesterol, glucose levels, checking medication, stress management.

Source: Authors compilation based on data from [12].

1.2. Development

In the 18th century, Heberden reported that exertion reduced the frequency of anginal pain. He described a patient's health improvement after sawing wood for 30 min every day [13]. The practice of imposing limited mobility on patients with acute coronary events, however, continued over the next 150 years, leading to prolonged hospital stays and declines in functional capacity [14]. In the 1930s, patients remained bedridden for 6 weeks following myocardial infarction due to the pathologic finding that the infarction evolution process from initial ischemic necrosis to the formation of a stable scar lasts over 6 weeks. Chair therapy was introduced in the 1940s, and, from the early 1950s, a strategy of very short daily walks lasting five minutes was advocated, but only after a coronary event and four subsequent weeks of rest [15]. In 1968, a study by Saltin demonstrated the importance of exercise and the detrimental effect of prolonged bed rest [16]. Further studies by Braunwald, Hutter, Askanas, Rudnicki, Boyle, Sonnenblick, Hellerstein, Naughton, and many others established a strong case for the benefits of exercise and supported the use of early mobilization in hospital settings [17]. As a result, a phasic, multi-profile model of cardiac rehabilitation has gradually been implemented, including a return to work and social activities [18]. Early ambulation has become standard and evolved into phase 1 or inpatient cardiac rehabilitation. Activities performed in the coronary intensive care unit are typically limited to 2 METs and include self-care (such as bed bathing, sitting in a chair) and passive and active ranges of motion. The further rapid development of the use of interventional techniques in cardiology, however, has significantly shortened the duration of hospitalization following an acute coronary event to 3–5 days, thus allowing for more intense mobilization processes to be used.

Contemporary cardiac rehabilitation has gradually evolved into a comprehensive secondary prevention, multi-factorial program consisting of exercise training; the management of cardiovascular risk factors; and nutritional, psychological, behavioral, and social support to improve patient outcomes. The target population for cardiac rehabilitation has expanded significantly over the years, but post-myocardial infarction survivors remain a key population. In the guidelines of the European Society of Cardiology and the American Heart Association, cardiac rehabilitation is mandatory—i.e., it has class I recommendations for therapeutic intervention in many cardiac conditions (e.g., acute coronary syndromes, percutaneous coronary interventions and/or myocardial revascularization surgery, stable coronary artery disease, heart failure, cardiac transplant, left ventricular assistance devices or other implanted devices (cardiac pacemakers, cardioverter-defibrillators, cardiac resynchronization devices), cardiac surgery, and high cardiovascular risk-factor profiles) [19]. The different classes of recommendations, with the corresponding level of evidence-based indications needed for the most frequently referred groups of patients, are listed in Table 2.

Table 2. Evidence-based indications for cardiac rehabilitation.

Target Group	Class of Recommendations	Level of Evidence
Acute coronary syndromes	I	A
Surgical revascularization	I	B
Chronic coronary syndromes	I	B
Heart failure with reduced or preserved ejection fraction	I	A

Source: Table by authors.

Cardiac rehabilitation is constantly evolving, with new ideas and strategies being implemented all the time. Examples of new strategies are, hybrid telerehabilitation and high-intensity interval training. Recent COVID 19 pandemic highlighted the role of cardiac telerehabilitation as an efficacious, safe, and essential part of cardiac rehabilitation. There is still, however, a need to enhance cardiac rehabilitation enrollment due to the lower cardiac rehabilitation referral and participation rates of women, the elderly, and minorities [20–22]. Furthermore, cardiac rehabilitation is offered in just 55% of countries, as exhibited in Figure 1 [23].

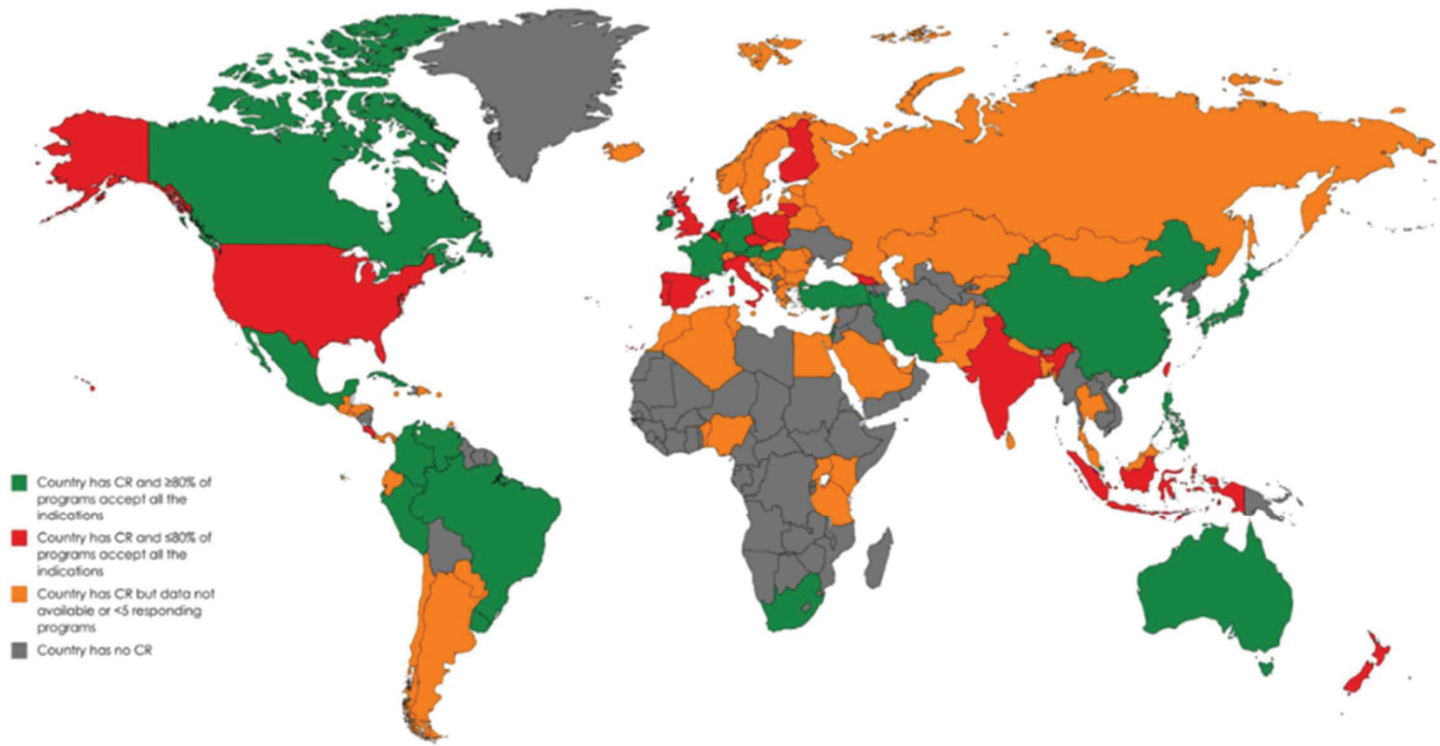

Figure 1. Global cardiac rehabilitation availability. Source: Reprinted from [23].

Thus, the distribution of cardiac rehabilitation services to the highest possible number of eligible patients should be prioritized, as should overcoming many existing barriers—e.g., the insufficient education of patients, poor adherence, lack of availability of structured programs, etc.

1.3 Phases

Cardiac rehabilitation typically comprises three phases [4]:

- Early cardiac rehabilitation:
    - Phase I: in-patient (typically 4–14 days).
    - Phase II: multidisciplinary supervised structured program (4–12 weeks).
- Late cardiac rehabilitation:
    - Phase III: home- or community-based maintenance phase (lifelong).

Phase I:

Phase I, or the inpatient phase, typically begins at the coronary care unit, intensive care unit, postoperative ward, or cardiac rehabilitation ward. It should begin as soon as the patient stabilizes after an acute cardiac event and should be continued until their discharge from hospital. Phase I comprises:

- Early patient mobilization by a physiotherapist in cooperation with a supervising physician (usually an intensive care unit physician). Mobilization rate is based mainly on the patient's clinical status and adaptation to mobilization and should aim to help them to achieve the level of activity required to leave hospital.
- Prevention of complications secondary to immobilization.
- Identification of personal cardiovascular risk factors.
- Individual plan to support lifestyle changes.
- Short-term education in the form of individual talks and the delivery of dedicated leaflets with information regarding cardiac events, psychological responses to these events, and the management of cardiac symptoms.
- Psychological screening assessment in the form of questionnaires.
- Discharge home activities plan, including walking, lifting weights, returning to work, and resumption of sexual activity.
- Referral for phase II.

Phase I B (provided in some countries):

The transitional phase encompasses the period from hospital discharge until the start of the structured program and includes:

- Education in the form of home visits or phone calls by a cardiac rehabilitation team member, usually a nurse.

- Control of gradual low-level home activity program progression.

Phase II:

Phase II should start as soon as possible, preferably within two weeks of discharge.

Phase II can take the form of a structured, multidisciplinary, supervised outpatient, residential, or hybrid program and usually lasts up to 12 weeks. Prior to the commencement of a medically supervised exercise training program, an initial assessment and risk stratification will be performed by a cardiologist. Risk stratification is based on the severity of symptoms, left ventricular function, functional capacity level, and the presence of residual ischemia or arrhythmia [24]. Phase II also includes comprehensive education and counseling regarding modifiable cardiovascular risk factors, the optimization of medical therapy, smoking cessation programs (if necessary), vocational counseling, and stress management. Residential phase II programs, typically lasting 3–4 weeks, should be limited to:

- High-risk patients;
- Patients with clinical instability;
- Patients with complications related to acute events or procedures;
- Patients with serious comorbidities;
- Frail patients;
- Patients with advanced heart failure (NYHA classes III and IV);
- Patients who underwent heart transplantation or the implantation of a left ventricular assistance device;
- Those who cannot attend outpatient programs for reasons such as them being a very long distance from the patient's home.

At the end of phase II, a re-assessment should be performed (focusing on clinical status, functional capacity, quality of life, psychological and nutritional status), and the patient's progress should be documented [12].

Phase III:

Phase III rehabilitation should be offered as a long-term (lifelong) maintenance phase to patients after they have completed phase II. It can take place in a cardiac rehabilitation or community-based center or be implemented as a home exercise program. Hybrid cardiac rehabilitation with remote monitoring is available in some countries [25]. A follow-up assessment of patients who have completed the phase II program by a cardiac specialist is essential.

1.4 Indications

Cardiac rehabilitation has evolved over the decades from simple monitoring after myocardial infarction into a comprehensive, multidisciplinary approach.

Similarly, its indications have been expanded and now encompass patients with many cardiovascular diseases. As the organization and delivery of cardiac rehabilitation programs in different countries depend on local policies, traditions, and resources, the indications for cardiac rehabilitation can vary between countries [24].

Indications for cardiac rehabilitation include [2,4]:

- Ischemic heart disease:
  - Acute coronary syndromes;
  - PCI and/or myocardial revascularization surgery;
  - Stable coronary artery disease with multiple risk factors.
- Stable heart failure.
- Cardiac surgery:
  - Coronary artery bypass graft surgery;
  - Valvular surgery;
  - Heart transplant.
- Percutaneous valvular prosthesis or MitraClip.
- Implantation of electrical cardiac devices: pacemaker, cardioverter-defibrillator, or cardiac resynchronization therapy.
- Implantation of a left ventricular assistance device.
- Peripheral arterial disease.
- Pulmonary hypertension.
- Following aorta surgery procedures

Other indications include:

- Patients with ischemic heart disease awaiting surgery;
- Patients with cardiomyopathies;
- Patients with congenital and acquired heart diseases;
- Patients who had major vascular surgery;
- Patients after myocarditis (post-acute phase);
- Patients with dysrhythmias;
- Individuals with cardiovascular risk factors—i.e., with diagnoses of diabetes, dyslipidemia, arterial hypertension [26].

1.5 Contraindications

Most patients referred for cardiac rehabilitation are eligible to participate in the program. The early assessment of these patients, including physical evaluation and risk stratification, before they commence exercise sessions should be carried out to ensure safety [24]. Contraindications for exercise training are generally accepted to include [2,4]:

Absolute contraindications:

- Recent acute coronary syndromes (within a few days);

- Resting ECG changes suggesting significant ischemia;
- Presence of ischemia < 3 METS or <50 watts;
- Uncontrolled dysrhythmias;
- Decompensated heart failure;
- Severe aortic stenosis or severe grade of another valve disease;
- Acute myocarditis or/and pericarditis;
- Aortic dissection;
- Acute pulmonary embolism;
- Acute non-cardiac disorders that may affect exercise performance or may be aggravated by exercise—e.g., infection or thyrotoxicosis;
- Acute thrombophlebitis;
- Hypertrophic cardiomyopathy with left ventricular outflow tract stenosis;
- Physical disability that would affect safe and adequate exercise performance.

Relative contraindications:

- Electrolyte abnormalities;
- Tachyarrhythmia or bradyarrhythmia;
- A high-degree atrioventricular block without a pacemaker;
- Atrial fibrillation with uncontrolled ventricular rate;
- Hypertrophic cardiomyopathy without left ventricular outflow tract stenosis;
- Resting systolic blood pressure > 180 mmHg;
- Resting diastolic blood pressure > 110 mmHg;
- Mental impairment leading to an inability to cooperate during exercise training;
- Orthostatic hypotension > 20 mmHg, with symptoms;
- Uncontrolled diabetes mellitus, with a glucose level >300 mg/dL.

1.6 Cardiovascular System and Exercise

The interplay between the cardiovascular system and exercise basically depends on the type of exercise (aerobic, resistance) performed, the exercise intensity and duration, and muscle mass involvement [27]. The most striking neurohormonal response to regular physical activity is improved cardiac parasympathetic regulation. It has been demonstrated that the heart rate values of very well-trained individuals can reach as low as 30–35 beats per minute [28].

Regular high-intensity exercise training may result in cardiac morphological adaptation, called athlete's heart—i.e., myocardial hypertrophy, which is more eccentric in patients who perform endurance training and more concentric in patients who perform resistance training [29]. It has been demonstrated that the mean left ventricular end-diastolic diameter in athletes increases compared with that in normal subjects, with typical values equal to 53.7 mm and 49.6 mm, respectively [30]. Morphological changes in the left ventricle after regular exercise have also been validated in patients with chronic heart failure. Hambrecht demonstrated reverse left ventricular remodeling with the slight improvement of the left ventricular ejection fraction from 30% to 35% after aerobic training in patients with ischemic and dilated cardiomyopathy. It has been postulated that reverse remodeling is evoked by the peripheral effects of aerobic training—i.e., improved antioxidative protection in the skeletal muscle, enhanced parasympathetic tone, and improved vasodilation [31]. To date, aerobic training has also been found to improve left ventricular diastolic filling at rest and during exercise [32]. Increases in the cross-sectional area of the coronary arteries and in coronary collateral formation have been demonstrated in animal models due to the use of a regular training program [33]. A growing body of evidence indicates that regular endurance exercise reduces the risk of death during clinical ischemia-reperfusion injury due to it offering enhanced antioxidative protection [34]. Another postulated cardioprotective effect of regular exercise is the improved electrical stability of the heart, which has been demonstrated in animal models [35,36].

Hemodynamic adaptations to exercise include increases in stroke volume. The resting stroke volume of individuals who exercise regularly may reach 100 mL due to prolonged diastolic filling period. During submaximal exercises, stroke volume increases by 20–40 mL and may reach as high as 160 mL during maximal exertion [37]. The impacts of aerobic and resistance exercise on blood pressure have been the subject of debate in the past due to safety concerns. Exercise has been shown to reduce blood pressure in both normotensive and hypertensive individuals [38]. The beneficial effect of regular exercise on plasma glucose and triglycerides has been well established [39–45]. Table 3 shows the main effects of regular exercise on the cardiovascular, neurohumoral, and other systems.

Table 3. Effects of regular exercise.

Type of System	Type of Effect
Cardiac	Ischemia-reperfusion protection; Physiologic hypertrophy; Reverse left ventricular remodeling; Electrical stability; Improved left ventricular relaxation.
Vascular	Reduced stiffness of aorta; Increased vasodilation.
Others	Neurohumoral: increased parasympathetic tone and reduced sympathetic response; Respiratory: increased vital capacity; Rheological: reduced coagulability.

Source: Table by authors.

1.7. Exercise-Induced Preconditioning

1.7.1. Ischemia-Reperfusion Injury (IRI)

Definition

Acute myocardial infarction (AMI) is the leading cause of morbidity and mortality worldwide [46]. Reperfusion procedures that involve restoring the blood flow to the ischemic region as quickly as possible are the chief therapeutic goal of AMI [47]. The primary pathological cause of AMI is paradoxical cardiomyocyte dysfunction, known as ischemia-reperfusion injury (IRI) [48]. Ischemia-reperfusion injury (IRI) is defined as the paradoxical exacerbation of cellular dysfunction and death following the restoration of blood flow to previously ischemic tissues [49].

Severity Levels of IR-Induced Cardiac Injury

The three different severity levels of IR-induced cardiac injury are proportional to the duration of ischemia. The lowest level of injury is cardiac arrhythmias followed by rapid reperfusion after one to five minutes of ischemia without impaired myocardial contractile performance or cardiac cell death. The second level of injury is five to 20 min of ischemia-reperfusion, termed as myocardial stunning, characterized by ventricular contraction deficits that last 24–72 h following the insult without cardiac cell death. The third and most severe IR injury level is myocardial cell death, which occurs when the duration of ischemia exceeds 20 min. During this IR injury level, cardiac myocytes are irreversibly damaged, and death occurs due to apoptosis and necrosis processes that take place within ventricular myocytes [48].

1.7.2. Ischemic Preconditioning

Definition

Ischemic preconditioning refers to the protection of the ischemic myocardium by short periods of sublethal ischemia separated by short bursts of reperfusion delivered before the ischemic insult [50]. It provides the myocardium with a powerful means of protection against acute myocardial ischemia and makes it more resistant to a subsequent ischemic insult. In addition, reconditioning protects against postischemic contractile dysfunction and ischemia- and reperfusion-induced ventricular arrhythmias. Ischemic preconditioning has two phases of protection. The early phase develops within minutes of the initial ischemic insult and lasts 2 to 3 h. The late phase becomes apparent 12 to 24 h later and lasts 3 to 4 days [51].

Experimental Models

Ischemic preconditioning has been demonstrated in several animal species, as well as in isolated human cardiomyocytes [50]. This term was introduced in 1986 by Murry et al., who investigated this phenomenon on an open-chest canine. An experimental dog group was exposed to four consecutive periods of ischemic episodes (5 min coronary occlusions interspersed with 5 min reperfusion periods) then subjected to a prolonged, more severe ischemic insult (a 40 min coronary occlusion followed by four days of reperfusion). The control dogs group underwent the 40 min occlusion with no prior exposure to ischemia. Surprisingly, the experimental dogs showed markedly reduced infarct size (75%) compared to the controls, and this effect was independent of differences in coronary collateral blood flow [52].

Remote Ischemic Conditioning (RIC)

It has been well established that preconditioning protection does not require brief ischemia to be applied directly to the myocardium itself. Remote ischemic conditioning was originally observed as a laboratory curiosity in non-invasive cardioprotective therapy, wherein brief bouts of ischemia-reperfusion in one coronary vascular region reduced the infarct size resulting from the sustained occlusion and reperfusion of an adjacent coronary artery. Moreover, studies have shown that RIC is a systemic phenomenon and can be evoked from longer distances [53]. For example, local insult induced by ischemia-reperfusion in the extremities or other parenchymal organs can elicit protection in the heart (in which the infarct size is reduced).

RIC can be achieved by inflating a standard sphygmomanometer cuff placed on the upper arm above systolic pressure to restrict blood flow temporarily by utilizing four cycles of five minutes of cuff inflation interspersed by five minutes of complete cuff deflation. More recently, an automated RIC device was created with the intention of providing RIC to adult patients undergoing cardiothoracic surgery or procedures [54]. In addition, RIC is an essential mechanical intervention to induce cardio protection accompanying reperfusion in patients with AMI because this method is non-invasive and can be applied during coronary occlusion before primary PCI.

1.7.3. Exercise Promotes Preconditioning

It has been well established that exercise and elevated physical activity have beneficial effects in reducing CVD risk and providing protection from cardiovascular events. Exercise displays a strong correlation with decreased risk of myocardial infarction (MI) and limits the damage caused by ischemia and reperfusion if such an MI event occurs [48]. Like the ischemic preconditioning phenomenon, the protection provided by exercise appears to occur in a biphasic manner, with two separate phases of protection, beginning immediately after a single episode of exertion and continuing for multiple days. The first phase begins immediately following the acute exercise bout and quickly subsides within three hours of preconditioning. Then, after approximately 24 h, the second phase of protection begins, persisting for at least nine days and potentially extending to several weeks. This phase has been reported to be more robust than the first phase [55]. The mechanisms contributing to exercise-induced preconditioning include the activation of mitochondrial antioxidant enzyme superoxide dismutase (SOD2) in ventricular myocytes and the increased expression of mitochondrial potassium channels [48]. The mechanisms and underlying causes of the warm-up phenomenon were investigated by Tomal et al. in 1996 [50]. In this study, patients with coronary artery disease underwent two consecutive exercise tests (ET), followed by a third test two hours later. The rate–pressure product before the onset of ischemia decreased during the third ET ($p < 0.005$) by more than during the first and second ET. In addition, the time to both 1–5 mm ST-segment depression and anginal pain onset was higher during the second and third ET ($p < 0.001$, respectively). Thus, this study suggested that the warm-up angina phenomenon observed within minutes of a first ET results from adaptation to ischemia through improvements to myocardial perfusion or preconditioning, increasing both the time to ischemia and the ischemic threshold. In contrast, the warm-up angina phenomenon observed two hours after repeated ET results from a slower increase in cardiac workload, causing an increase in time to ischemia but not in the ischemic threshold.

Training below the level of the ischemia threshold will not place sufficient ischemic stress on the myocardium to induce exercise IPC. One study compared the effects of an 8-week interval training program carried out in two groups of patients with stable angina by assessing the influence of warm-up ischemia prior to training conducted either at or below the ischemic threshold. One group underwent pre-training exercise IPC and the other group did not. The exercise IPC group showed a statistically significant improvement in all post-training variables except for maximum ST depression (STD). The improved variables included maximal workload (28%), walking distance (24%), exercise duration (20%), and time to 1 mm STD (28%). Moreover, the beneficial effect of training in the exercise IPC group on both exercise-induced ischemia and physical capacity was sustained for up to 10 days and 1 month, respectively [56]. Thus, based on the results of Korzeniowska-Kubacka et al., the warm-up effect of exercise IPC may have a major beneficial effect and appears to be necessary for exercise training in cardiac rehabilitation. Thus, cardioprotective strategies that have been used in clinical studies for acute myocardial infarction entail early and late ischemic preconditioning evoked by brief episodes of coronary occlusion–reperfusion, postconditioning (cycles of re-occlusion–reperfusion are delivered after an ischemic index event), the remote ischemic conditioning of a limb (using arm cuff inflation–deflation cycles), and pharmacological cardio protection (achieved by the intracoronary delivery of adenosine or nitrates and the intravenous delivery of beta-blocker or cyclosporine A just before or at early reperfusion).

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2. Functional Capacity Assessment

Adam Staron, Ibrahim AlMalki and Mohammed AlSubaie

2.1. Exercise Tests in Cardiac Rehabilitation

2.1.1. Introduction

Exercise stress tests determine cardiovascular system response during exertion. Historically, exercise testing has been performed to provoke myocardial ischemia; however, indications have evolved over time [1]. Exercise capacity assessment delivers crucial information for exercise prescription guidance in cardiac rehabilitation programs, and cardiopulmonary exercise testing should ideally be executed. Exercise tests are typically performed on a treadmill or stationary bike; incremental exercise tests are the gold standard.

2.1.2. Indications

General indications for exercise tests include [2]:

- The detection of coronary artery disease (CAD) in patients with chest pain or potential symptom equivalents;
- Evaluation of the functional severity of coronary artery disease;
- Evaluation of physical capacity;
- Evaluation of exercise-related symptoms;
- Assessment of chronotropic competence, arrhythmias, and response to implanted cardiac electrical device therapy;
- Assessment of the response to medical interventions.

Stress tests in cardiac rehabilitation specifically allow for:

- Risk stratification for cardiac events during exercise based on functional capacity, coronary reserve, hemodynamic response (BP, HR), and the presence of exertional arrhythmia.
- Functional capacity assessment and exercise prescription upon admission to phases II or III, including:
    - determination of an adequate training model;
    - assessment of training progression during or at the end of the exercise program.
- Vocational and recreational activity planning after discharge from the program.

2.1.3. Contraindications

Absolute contraindications to exercise testing include [3]:

- Acute myocardial infarction (within two days);
- High-risk unstable angina;
- Uncontrolled symptomatic cardiac arrhythmias;
- Symptomatic severe aortic stenosis;
- Symptomatic heart failure;
- Acute pulmonary embolism;
- Active endocarditis;
- Acute myocarditis or pericarditis;
- Aortic dissection;
- Acute non-cardiac condition, which may affect exercise performance—e.g., infection, renal failure, and thyrotoxicosis;
- Lack of patient consent.

Relative contraindications for exercise testing include:

- Left main coronary artery stenosis or its equivalent;
- Moderate aortic stenosis;
- Electrolyte abnormalities;
- Systolic blood pressure > 180/110 mmHg;
- Tachyarrhythmia or bradyarrhythmia;
- Atrial fibrillation with an uncontrolled ventricular rate;
- Hypertrophic cardiomyopathy;
- Mental impairment;
- Physical inability to exercise adequately;
- High-degree atrioventricular block without a pacemaker.

In practice, the physician in charge decides whether relative contraindications to the exercise test balance the risk with the potential benefit of the information derived from the test.

2.1.4. Exercise Test Modalities

Depending on the method of exercise, exercise tests are usually performed on a treadmill or cycle ergometer [4]. Treadmills reflect a more physiological form of exercise but require more space and are more expensive than cycle ergometers. For test adequacy, it is important to use the treadmill handrails for balance only and to avoid gripping the handrails while exercising, in order to prevent peak oxygen uptake values being overestimated. Electrically braked cycles are calibrated in watts (W) and allow for a better ECG signal compared with treadmills; however, their biggest limitation is the termination of the test due to the fatigue of the quadriceps muscles. This affects test duration, and the maximal oxygen uptake attained is lower by 10–15% compared with that obtained on a treadmill [3]. From a technical point of view, bicycle tests should be executed in a proper way—i.e., with adequate seat adjustment and a knee flexion around 25 degrees of full extension.

2.1.5. Predicted Functional Capacity

Exercise capacity is reported in metabolic equivalents of tasks (METS). The MET unit reflects the resting volume oxygen consumption per minute (VO_2) for a 70 kg, 40-year-old man, with one MET equivalent to 3.5 mL/min/kg of body weight [5]. The appropriate assessment of predicted functional capacity determines the appropriate test protocol.

Functional capacity depends on [6]:

- Age;
- Sex;
- Habitual activity;
- Clinical status;
- Genetic conditions.

There are many formulas for predicted MET calculation [7,8]:

1. Morris formula for men:
   Predicted MET = 18.0 − 0.15 × age (years)
2. Gulati formula for women:
   Predicted MET = 14.7 − 0.13 × age (years)

Predicted functional capacities for men and women in relation to age according to the Morris and Gulati formulas:

Twenty years old: women 12.1 MET, men 15.0 MET.
Thirty years old: women 10.8 MET, men 13.5 MET.
Forty years old: women 9.5 MET, men 12.0 MET.
Fifty years old: women 8.2 MET, men 10.5 MET.
Sixty years old: women 6.9 MET, men 9.0 MET.
Seventy years old: women 5.6 MET, men 7.5 MET.

The Duke Activity Status Index and the Veterans Specific Activity Questionnaire have been developed to assess the intensities of activities of daily living [9,10].

Duke Activity Status Index (DASI) comprises 12 questions assessing daily activities, with each item equaling a specific metabolic cost in MET. Patients are asked to identify each activity they can perform (Table 4).

Oxygen uptake = (0.43 × sum of points from positive answers) + 9.6.

Table 4. Duke Activity Status Index.

Is the Patient Able to?	Points
Eat, dress, bath, use the toilet	2.75
Walk indoors	1.75
Walk 1–2 blocks on level ground	2.75
Climb a flight of stairs or walk up a hill	5.5
Run a short distance	8.0
Do dusting, washing dishes	2.7
Do vacuuming, swipe floors, carry groceries	3.5
Do heavy work around the house, e.g., scrubbing floors, lifting or moving heavy furniture	8.0
Do yardwork, e.g., raking leaves, weeding, pushing a power mower	4.5
Have sexual relations	5.25
Participate in moderate recreational activities, e.g., golf, bowling, dancing, doubles tennis, throwing a baseball or football	6.0
Participate in strenuous sports, e.g., swimming, singles tennis, football, basketball, skiing	7.5

Source: Adapted from [9].

Similarly, the Veterans Specific Activity Questionnaire (VSAQ) consists of 13 items estimating aerobic fitness in cardiac patients and measures the maximal level of physical activity that patients can achieve (Table 5). Predicted MET = 4.7 + 0.97 $\times$ the highest tolerable MET from questionnaire $-$ 0.06 $\times$ age.

2.1.6. Choice of the Individual Protocol

The choice of an appropriate protocol is essential. Depending on their intensity, exercise tests can be maximal (symptom-limited) or submaximal (predefined).

In cardiac rehabilitation settings, maximal tests are typically preferred. Indicators of maximal stress test include [11]:

- A rate–pressure product (maximal heart rate $\times$ systolic blood pressure) that is >20,000;
- Perceived exertion of 18 or more on the Borg scale;
- Exhaustion of the patient.

Table 5. Veterans Specific Activity Questionnaire.

MET	The Activity, Which Performed for a Period, Would Typically Cause Fatigue, Shortness of Breath, Chest Discomfort, or a Patients' Will to Stop
1	Eating, getting dressed, working at a desk
2	Taking a shower, shopping, cooking
3	Walking slowly on a flat surface for 1 or 2 blocks, a moderate amount of work around the house, such as vacuuming, sweeping the floors, or carrying groceries
4	Light yard work (i.e., raking leaves, weeding, pushing a power mower), painting
5	Walking briskly, social dancing
6	Heavy carpentry, mowing a lawn with a push mower
7	Carrying 60 pounds, performing heavy outdoor work (i.e., digging, spading soil, etc.), walking uphill
8	Carrying groceries upstairs, moving heavy furniture, jogging slowly on a flat surface, climbing stairs quickly
9	Bicycling at a moderate pace, sawing wood
10	Swimming briskly, bicycling up a hill, jogging 6 miles per hour
11	Carrying a heavy load (i.e., a child or firewood) up 2 flights of stairs
12	Running briskly, continuously (level ground, 8 min per mile)
13	Intermittent sprinting, running competitively, rowing competitively, or riding a bicycle

Source: Adapted from [11].

The submaximal test is terminated after achieving a goal, e.g., in patients < 40 years after myocardial infarction, the test may be terminated after achieving a heart rate of 140 bpm or tolerance equal to 7 METS. In patients > 40 years, the test can be terminated at 130 bpm or at a tolerance of 5 METS. Submaximal tests are traditionally conducted in the early phase after myocardial infarction following cardiac surgery and in patients with impaired left ventricular systolic function. Optimally, the test should be terminated after between 8 and 12 min.

The stress test can be graded (GXT) or ramped (with a constant load increase). Ramp tests demonstrate a good linear correlation between the load and the maximal oxygen consumption [12,13]. Ramp protocols provide a uniform hemodynamic response and therefore can be individualized. Considering recent studies, however, a delay of the initial oxygen uptake response upon the start of the incremental exercise test compared with constant work has been demonstrated. Thus, the first and the second ventilatory thresholds are attained at lower work rates during the constant work test for a given oxygen uptake value than they are during the incremental test [14].

Treadmill Stress Test Protocols

The most common treadmill protocol used is the Bruce (Table 6) protocol; however, due to its large and uneven load increments, it is preferred for individuals with a good predicted functional capacity [15].

Table 6. Bruce protocol.

Stage	Minutes	% Incline	Km/h	METS
1	3	10	2.7	5
2	3	12	4.0	7
3	3	14	5.4	10
4	3	16	6.7	13
5	3	18	8	15
6	3	20	8.8	18

Abbreviations: Km/h—kilometers per hour; METS—multiples of resting metabolic equivalent; Source: Adapted from [15].

The modified Bruce protocol was designed for individuals who cannot exercise vigorously (Table 7). It includes two lower workload stages at the beginning of the standard Bruce protocol.

Table 7. Modified Bruce protocol.

Stage	Minutes	% Incline	Km/h	METS
1	3	0	2.7	2.3
2	3	5	2.7	3.5
3	3	10	2.7	4.6
4	3	12	4.0	7.1
5	3	14	5.5	10.2
6	3	16	6.8	13.5

Abbreviations: Km/h—kilometers per hour; METS—multiples of resting metabolic equivalent; Source: Adapted from [2].

The Naughton protocol increases the load by approximately 1 MET in 2 min stages and is recommended for use in patients who have a low predicted functional capacity (Table 8).

Table 8. Naughton protocol [2].

Stage	Minutes	% Incline	Km/h	METS
1	2	0	1.6	1.8
2	2	0	3.2	2.5
3	2	3.5	3.2	3.5
4	2	7	3.2	4.5
5	2	10.5	3.2	5.4
6	2	14.	3.2	6.4
7	2	17.5	3.2	7.4
8	2	17.5	4	8.9
9	2	17.5	4.8	10.5
10	2	17.5	5.6	12.1

Abbreviations: Km/h—kilometers per hour; METS—multiples of resting metabolic equivalent; Source: Adapted from [2].

There are many available ramp treadmill protocols—e.g., the Bruce protocol (Table 9).

Table 9. Bruce Ramp Stress Test protocol [2].

Stage	Minutes	% Incline	Km/h	METS
1	1	0	1.6	1.8
2	1	5	2.1	2.9
3	1	10	2.7	4.6
4	1	10	3.4	5.5
5	1	11	3.7	6.3
6	1	12	4	7.1
7	1	12	4.5	7.8
8	1	13	5	8.9
9	1	14	5.5	10.2
10	1	14	6.1	11.2
11	1	15	6.6	12.6
12	1	16	6.8	13.5
13	1	16	7.2	14.4
14	1	17	7.7	15.9
15	1	18	8	17.2
16	1	18	8.5	18.2
17	1	19	9	20
18	1	20	9.3	21.4

Abbreviations: Km/h—kilometers per hour; METS—multiples of resting metabolic equivalent; Source: Adapted from [2].

Underutilized individualized ramp test protocols allow for precise test termination after 8 to 12 min but are still underexploited [16].

Leg Cycle Ergometer Stress Test Protocols

Leg cycle ergometer exercise test protocols depend on body mass and predict functional capacity [2]. Typically, a graded test consists of a 1–2 min warm-up (with a 10–20 Watt load or without a load); an initial load of 25 Watts (for inactive persons or individuals with a weight < 70 kg) or 50 Watts (for active persons or individuals with a weight > 70 kg), which is typically increased by 25 Watts every 3 min; then a cool-down without a load. A formula providing an approximate METs calculation following the bicycle stress test is provided in Table 10.

Table 10. Functional capacity calculation after cycle ergometer stress test [2].

Body Mass (kg)	METS	METS	METS	METS	METS	METS	METS
	50 W	**75 W**	**100 W**	**125 W**	**150 W**	**175 W**	**200 W**
60	4.3	5.7	7.1	8.6	10	11.4	12.9
70	3.7	4.9	6.1	7.3	8.6	9.8	11
80	3.3	4.3	5.4	6.4	7.5	8.6	9.6
90	2.9	3.8	4.8	5.7	6.7	7.6	8.6
100	2.6	3.4	4.3	5.1	6	6.9	7.7

Abbreviations: kg—kilogram; METS—multiples of resting metabolic equivalent; W—watts. Source: Adapted from [2].

The steep ramp protocol created by Meyer allows for the calculation of the so-called maximal short-term exercise capacity (MSEC) and has been used for high-intensity interval training prescription. After a 3 min warm-up on a cycle without a load, the intensity is increased to 25 watt every 10 s (i.e., 150 watts is attained after 1 min). The patient continues the test until he/she can cycle at a pace of 60 revolutions/min [17].

2.1.7. The Patient's Preparation

The preparation for the stress test includes:

- Review of medical history;
- Physical examination;
- Explanation of the RPE Borg scale/angina scale;
- Correct connection of ECG electrodes;
- Convenient clothing.

On the test day, patients should not eat, drink caffeine, or smoke for 3 h before the test. Neither should they perform vigorous exercise within the 12 h prior to the testing. Patients should dress appropriately for exercise.

For a functional capacity assessment, patients should take their usual medications. For diagnostic stress tests, however, the withdrawal of some medications might be applied and should be discussed with a cardiologist, as, for example, beta-blockers attenuate exercise response [3]. In the case of patients with an implanted cardiac electrical device, testing personnel should know the reason for implantation and the current device parameters.

2.1.8. Measurements

Measurements taken during exercise testing, according to ACSM [2], are presented in Table 11.

Table 11. Monitoring intervals associated with exercise testing.

	Before Test	**During Test**	**After Test**
ECG	Monitored continuously, recorded in supine position	Monitored continuously, recorded during the last 15 s of each stage or the last 15 s of each 2 min period (in case of ramp protocols)	Monitored continuously, recorded immediately after exercise, during the last 15 s of the first min of recovery, then every 2 min
HR	Monitored continuously	Monitored continuously, recorded during the last 5 s of each minute	Monitored continuously, recorded during the last 5 s of each minute
BP	Measured and recorded in supine position and posture during exercise	Measured and recorded during the last 15 s of each stage or the last 45 s of each 2 min period (ramp protocols)	Measured and recorded immediately after exercise and then every 2 min
RPE	RPE scale should be explained	Recorded during the last 15 s of each stage or every 2 min (ramp protocols)	Peak exercise value to be obtained, not measured in recovery

Abbreviations: BP—blood pressure; ECG—electrocardiogram; HR—heart rate; RPE—rating of perceived exertion. Source: Adapted from [2].

2.1.9. Indications for Test Termination

Absolute indications for stress test termination include [18]:

- Chest pain;

- Drop in systolic blood pressure of >10 mm Hg from baseline with an increase in workload, if accompanied by other evidence of ischemia;
- Nervous system symptoms—e.g., ataxia, dizziness, or near syncope;
- Signs of poor perfusion (cyanosis or pallor);
- Sustained ventricular tachycardia;
- ST-segment elevation (≥1.0 mm in leads without diagnostic Q-waves (other than V1 or aVR));
- Inadequate ICD intervention in the case of sinus tachycardia or atrial fibrillation with a rapid ventricular rate above the ICD detection threshold;
- Difficulties in monitoring ECG or blood pressure;
- Patient's request to stop.

Relative indications for the termination of the test include:

- A drop in systolic blood pressure of ≥10 mm Hg from baseline with an increase in workload in the absence of other evidence of ischemia;
- ST-segment horizontal- or down-sloping depression > 2 mm or marked axis shift;
- Arrhythmias other than sustained ventricular tachycardia (premature ventricular contractions, supraventricular tachycardia);
- Heart block or bradyarrhythmia;
- Fatigue, shortness of breath, wheezing, leg cramps, or claudication;
- New bundle-branch block or intraventricular conduction delay that cannot be distinguished from ventricular tachycardia;
- Hypertensive response (systolic blood pressure of >250 mmHg and/or diastolic blood pressure of >/115 mmHg).

2.1.10. Stress Test Interpretation

The interpretation of exercise tests comprises ECG analysis, the assessment of chronotropic and blood pressure response, the evaluation of the level of functional capacity, and the presence of symptoms limiting exertion.

Exercise test report for cardiac rehabilitation should include the following information [3,18]:

- Test modality and protocol;
- Test duration;
- Heart rate and blood pressure values (resting on peak exercise, following exercise cessation);
- Functional capacity assessment in METS or watts (and as % of predicted);
- Reason for test termination;
- Rate of perceived exertion (Borg);
- Angina scale;
- Presence of arrhythmias;

- ECG analysis;
- Clinical interpretation.

The test result should also include the age-estimated functional capacity level as demonstrated inn Table 12 [19].

Table 12. Functional capacity classification.

Functional Capacity	**Percentage of the Age-Related Functional Capacity**
Excellent	143 and more
Good	120–142
Above average	108–119
Average	96–107
Below average	85–95
Poor	75–84
Very poor	39–74

Source: Adapted from [19].

2.1.11. Arm Ergometry

A mechanically or electrically braked arm ergometer can be applied for selected patients with lower extremity impairment caused by vascular, orthopedic, or neurological conditions—e.g., spinal injury, stroke, or leg amputation [20,21].

Moreover, it can be used for occupational evaluation in patients whose work primarily involves the arms and upper body. For testing purposes, work rate increments of 5–10 watts every 2–3 min at a pace of 60–70 revolutions per minute are suggested [22].

2.2. Cardiopulmonary Exercise Test

2.2.1. Rationale

Exercise tolerance is driven by three factors: pulmonary gas exchange, cardiovascular performance, and skeletal muscle metabolism [23]. For functional exercise testing, the Fick equation is fundamental, stating that oxygen uptake is a product of cardiac output and the arteriovenous oxygen difference at peak exercise [24].

The cardiopulmonary exercise test (CPET) utilizes a symptom-limited exercise test on a treadmill or cycle ergometer combined with respiratory gas exchange analysis—i.e., it incorporates measurements of respiratory oxygen uptake (VO_2), carbon dioxide production (VCO_2), and ventilatory measures. Hence, CPET is of great value for an assessment of cardiovascular, respiratory, and metabolic changes in response to exercise.

2.2.2. Indications

Indications for CPET include [25]:

- Differentiation between cardiac and pulmonary cause of dyspnea;
- Functional capacity assessment;
- Qualification to heart transplant or cardiac resynchronization therapy;
- Qualification for lung and heart–lung transplant;
- Prescription of exercise training intensity and evaluation of response to exercise training;
- Evaluation of response to therapeutic interventions;
- Preoperative evaluation.

Table 13 exhibits the American Thoracic Society (ATS) and American College of Chest Physicians (ACCP) indications for CPET [26].

Table 13. Indications for cardiopulmonary exercise testing.

Class	Indication
I (indicated)	1. Evaluation of exercise capacity and response to treatment in patients with heart failure, who are being considered for heart transplantation 2. Differentiation of cardiac versus pulmonary limitations as a cause of exercise-induced dyspnea or impaired exercise capacity when the cause in uncertain
IIa (good supportive evidence)	Evaluation of exercise capacity when indicated for medical reasons in patients for whom the estimates of exercise capacity from exercise test time or work rate are unreliable
IIb (weak supportive evidence)	1. Evaluation of the patient's exercise tolerance response to specific therapeutic interventions Determination of the intensity for exercise training as part of comprehensive cardiac rehabilitation
III (not indicated)	Routine use to evaluate exercise capacity

Abbreviations: AHA—American Heart Association. Source: Adapted from [26].

CPET is widely applied in the functional assessment of patients with heart failure to determine the severity of the disease (American College of Cardiology/American Heart Association recommendation Class IIa, Level of Evidence C), to identify candidates for cardiac transplantation (American College of Cardiology/American Heart Association Recommendation Class IIa, Level of Evidence B), and to facilitate the exercise prescription (American College of Cardiology/American Heart Association Recommendation Class I, Level of Evidence C) [27].

2.2.3. Technical Aspects

Patients should be instructed appropriately to attain the best possible effort. Prior to each cardiopulmonary exercise test, all CPET systems should be calibrated. This should include the calibration of airflow, volumes, and both the oxygen and carbon dioxide analyzers. It should be followed by spirometry to assess resting pulmonary function: forced expiratory volume in 1 s, forced vital capacity, and peak expiratory flow. CPET starts with 1–2 min registration, followed by warm-up (2–3 min). CPET should be performed as symptom-limited, and the optimal test duration is between 8 and 12 min. Thereby, patient–staff communication techniques during the test are essential for test safety and should be discussed before, including hand signs regarding symptom scoring—e.g., the Borg scale [26]. Both cycle ergometer and treadmill protocols can be used. The initial workload on a cycle ergometer for patients with heart failure is usually 20–25 W, which is increased by 15–25 W every 2 min until maximal exertion is attained. Optionally, ramp protocol (e.g., 10 W/min) can be executed. The modified Naughton protocol is recommended for treadmill exercise testing in patients with heart failure in order to increase the workload by approximately 1 MET for each 2 min stage [24,26]. Treadmill exercise testing has advantages over cycle ergometry, as patients, particularly those who are untrained, usually terminate cycle exercise because of quadriceps fatigue at an oxygen uptake that is on average 10% to 15% lower than oxygen uptake from a treadmill [28]. Furthermore, walking is a more familiar activity than cycling and involves a larger muscle mass. Electrocardiogram and blood pressure is monitored during the test, and BP should be recorded at rest and every 2 min or during the final 2 min of each stage (in the case of non-ramp protocol). Contraindications to cardiopulmonary exercise testing and criteria for terminating the exercise test are the same as those described earlier.

2.2.4. Parameters

CPET allows for cardiac and ventilatory parameter assessment. The main parameters assessed in CPET include [29]:

Peak Oxygen Uptake

Peak oxygen uptake is the volume of oxygen extracted from the air and inhaled over time, calculated in mL/min, and often normalized for body weight (mL/kg/min). One metabolic equivalent (MET) is the resting oxygen uptake in a sitting position and is equal to 3.5 mL/kg/min [5]. As oxygen uptake increases linearly with work, achieving a clear plateau in oxygen uptake has traditionally been used as the best evidence of maximal oxygen uptake [26]. Hence, maximal oxygen uptake is the best index of aerobic capacity and the gold standard for cardiorespiratory fitness assessment. In practice, this plateau may not be achieved before symptoms, with the termination of exercise. Consequently, peak oxygen uptake is often used as an estimate for maximal oxygen uptake (maximal and peak oxygen uptake are used interchangeably). Maximal oxygen uptake depends on age, sex, weight, height, fitness level, and ethnic origin. It can also be affected by training and patient motivation. A normal value for oxygen consumption is considered to be >20 mL/kg/min, and <10 mL/kg/min value is linked to poor prognosis [30,31]. Peak oxygen uptake has been demonstrated to predict prognosis in patients with heart failure in many studies. In a prospective study of 114 ambulatory patients with heart failure referred for cardiac transplantation, an oxygen consumption of <14 mL/kg/min has been used as a cutoff for the acceptance for cardiac transplantation [32].

Respiratory Exchange Ratio (RER)

RER is the ratio of carbon dioxide output/oxygen uptake (VCO_2/VO_2) and is the best non-invasive indicator of exercise intensity. RER increases during exercise due to either buffered lactic acid or hyperventilation. Resting RER is about 0.8, and RER > 1.0 indicates maximal exercise effort [33].

Anaerobic Threshold (AT) or Lactate Threshold

During light- to moderate-intensity incremental exercise, aerobic metabolism dominates and the blood lactates level remains stable (or is only marginally elevated). This initial, aerobic phase of CPET, lasts until 50–60% of peak oxygen uptake is attained, with expired ventilation (VE) showing a linear increase with oxygen uptake. As mentioned, at this phase the blood lactate level is relatively stable, as muscle lactic acid production is insignificant. The following period of exercise, however, with increasing effort intensity, is characterized by anaerobic metabolism, since oxygen supply is insufficient with the increasing metabolic requirements of the exercising muscles. Significant increases in lactic acid production in the muscles and in its concentration in blood are observed during this phase, and greater reliance on anaerobic metabolism is needed for continued energy production [25,26]. The oxygen uptake at the onset of blood lactate accumulation is called the first ventilatory threshold or the anaerobic threshold, above which blood lactate and pH start to increase and decrease, respectively, and ventilation accelerates to eliminate the excess carbon dioxide produced during the conversion of lactic acid to lactate [34]. The first ventilatory threshold is typically attained at 60–70% of maximal oxygen uptake [35,36]. Hence, AT estimates the onset of metabolic acidosis, is related to the oxygen uptake at which it occurs and should be expressed as a percentage of the predicted value of maximal oxygen uptake.

Several methods allow for the identification of the anaerobic threshold. AT can be determined both invasively (lactic acid) and noninvasively (ventilatory equivalent for oxygen and carbon dioxide methods: VE/VO_2, VE/VCO_2, V-slope, and the modified V-slope method).

In practice, the main non-invasive executed methods for estimating the anaerobic threshold are [24]:

The V-slope method: The anaerobic threshold is defined as the oxygen uptake at which the rate of increase in VCO_2 relative to VO_2 increases in the absence of hyperventilation. The AT determined by this method is a more reproducible estimate.

The ventilatory equivalents method: The AT is the VO_2 at which the ventilatory equivalent for O_2 (VE/VO_2 ratio) and end-tidal oxygen tension (PET O_2) begin to increase systematically without an immediate increase in the ventilatory equivalent for CO_2 (VE/VCO_2) and end-tidal CO_2 tension (PET CO_2).

AT usually occurs at 47% to 64% of the measured maximal oxygen uptake in a healthy individual. The value of AT is important for exercise prescription, as the heart rate value at AT is crucial [25]. Optimally, the exercise training heart rate should be 5% lower than the heart rate at anaerobic threshold (10% lower in heart failure individuals).

Exercise Oscillatory Breathing or Exercise Oscillatory Ventilation (EOV)

EOV is present in heart failure and has been described as the regular alteration of tidal volume with a crescendo–decrescendo pattern. The presence of EOV is a marker of significant hemodynamic impairment and is associated with worse clinical prognosis. If present, EOV should persist for 60% of the exercise test, with an amplitude of >15% [37].

A summary of the CPET variables is presented in Table 14.

Table 14. Cardiopulmonary exercise test variables [38].

CPET Variables	Definition	Values
VO_2	Describes functional capacity Indicates prognosis	Normal >20 mL/kg/min Severely reduced <10 mL/kg/min
VO_2%	Functional capacity in relation to predicted normal values	Normal >100% of predicted Moderately reduced 75–50% of predicted Severely reduced <50% of predicted
VE/VCO_2 slope	Reflects pulmonary ventilation and perfusion Indicates prognosis Increased in heart failure and in pulmonary hypertension	Normal <30 Moderately elevated: 36.0–44.9 Severely elevated: >45
Exercise oscillatory ventilation	Present in heart failure Predictor of poor prognosis	If present: must persist for 60% of the exercise test, with amplitude 15% or more
End-tidal carbon dioxide partial pressure (PET CO_2)	Reflects ventilation–perfusion mismatch within the pulmonary system	Normal values: Resting PET CO_2 >33 mmHg or 3–8 mmHg increases during an exercise test Abnormal: resting PET CO_2 < 33 mmHg and/or <3 mmHg increases during an exercise test
RER	Expresses the ratio of carbon dioxide production to oxygen consumption	Values >1.10 determines maximal exercise

Abbreviations: BP—blood pressure; CPET—cardiopulmonary exercise test; HR—heart rate; PET CO_2—end-tidal carbon dioxide partial pressure; RER—respiratory exchange ratio; VCO_2—carbon dioxide output; VE—minute ventilation; VE/VCO_2—ventilatory equivalent of carbon dioxide; VE/VO_2—ventilatory equivalent of oxygen; VO_2—oxygen uptake. Source: Adapted from [38].

2.2.5. Interpretation

Maximal effort is assumed in the presence of one or more of the criteria listed below [31,35]:

- Oxygen uptake and/or heart rate fail to increase with further increase in work rate;

- Peak respiratory exchange ratio (VCO_2/VO_2) > 1.10–1.15;
- Post exercise lactates level in blood > 8 mmol/L;
- Rating of perceived exertion > 8 on a 0–10 scale.

Among these, a plateau in the relationship of oxygen uptake versus work rate during incremental exercise is the gold standard for the determination of maximal effort.

A CPET report should include [23]:

- Reason for test;
- Diagnoses, medications, resting ECG, and BP;
- Basic data: age, height, weight;
- Exercise modality and protocol used;
- Modality of gas sampling;
- Reasons for test terminations;
- Symptoms;
- Subjective assessment of effort;
- Gas exchange and ventilatory data at peak and at the ventilatory threshold (if has been determined) in absolute values and as a percentage relative to reference;
- HR, BP, and ECG changes.

Norms for peak oxygen uptake for women and men at different ages:

For 20–29 years: women 36 $\pm$ 6.9 VO_2, men 43 $\pm$ 7.2 VO_2.
For 30–39 years: women 34 $\pm$ 6.2 VO_2, men 42 $\pm$ 7.0 VO_2.
For 40–49 years: women 32 $\pm$ 6.2 VO_2, men 40 $\pm$ 7.2 VO_2.
For 50–59 years: women 29 $\pm$ 5.4 VO_2, men 36 $\pm$ 7.1 VO_2.
For 60–69 years: women 27 $\pm$ 4.7 VO_2, men 33 $\pm$ 7.3 VO_2.
For 70–79 years: women 27 $\pm$ 5.8 VO_2, men 29 $\pm$ 7.3 VO_2.

The severity of the functional capacity impairment during incremental treadmill testing in heart failure (Weber–Janicki classification) is shown in Table 15 [39].

Table 15. Functional classification of patients with congestive heart failure.

Severity	Class	Peak VO_2, mL/kg per minute	AT	Maximal Cardiac Index, L/min/m^2
None to mild	A	>20	>14	>8
Mild to moderate	B	16–20	11–14	6–8
Moderate to severe	C	10–16	8–11	4–6
Severe	D	6–10	5–8	2–4

Abbreviations: AT—anaerobic threshold; mL/kg/min—milliliters per kilogram per minute; L/min/m^2—liters per minute per square meter; VO_2—oxygen uptake. Source: Adapted from [39].

2.3. Walking Tests

2.3.1. Six-Minute Walk Test

The six-minute walk test (6 MWT) measures the distance that a patient can walk quickly on a flat, firm surface within six minutes (Figure 2). The test should be performed in a minimally trafficked area, optimally in an enclosed corridor, but can be also performed outdoors [40]. A six-minute walk test on a treadmill is not recommended, as patients will be unfamiliar with the machinery and attain a significantly lower walk distance [41]. The six-minute walk test is a simple and safe method of approximate functional capacity assessment. As most patients do not achieve their maximal exercise capacity when walking at their own pace, the results of the 6 MWT should be considered complementary to conventional exercise testing [42,43]. The 6 MWT is not suitable for use in exercise risk stratification, as even brisk walking at a speed of 6 km/h (i.e., at an intensity of 4 METs) will not elicit an adequate intensity threshold—i.e., 5 MET—to guide exercise risk assessment [44]. In practice, 6 MWT has been used for exercise training qualification in patients following incomplete revascularization or early after cardiac surgery. On the other hand, as walking is a natural activity, the walking test is well tolerated and easy to administer. The 6 MWT has clear advantages over treadmill walking, reflecting the real situation, and can be more suitable for the elderly and patients with musculoskeletal disorders—e.g., with knee arthrosis. Furthermore, middle-aged patients and the elderly can consider the 6 MWT as a moderate- to high-intensity test. In numerous studies, a strong correlation has been found between the metabolic equivalent estimated from the 6 MWT and conventional treadmill exercise tolerance tests [45,46]. A strong correlation between peak oxygen uptake and distance covered during the 6 MWT was achieved by adding the terminal rating of perceived exertion [47].

Figure 2. The six-minute walk test. Source: Photo by authors.

Test requirements [2]:

- A walking course of 30 m in length;
- The starting point should be marked with brightly colored tape;
- The length should be marked every three meters;
- The turnaround point should be marked with a cone;
- Easy access to defibrillator, oxygen, and medications.

Appropriate patient preparation [48]:

- Patients should wear comfortable clothes and are allowed to use a stick or walking frame if necessary;
- The usual medications should be taken before the test;
- Patients are not allowed to exercise vigorously for up to two hours before the test;
- Patients should sit at the starting point ten minutes prior to the testing;
- Blood pressure, heart rate, and oxygen saturation should be documented before and after the test;
- Patients should be informed that they are allowed to slow down or stop and take a rest if necessary;

- Staff should inform the patient during the test about their time left after each minute;
- Staff should regularly encourage the patient to continue the test;
- Patient should be observed for at least 10 min following the test;
- Walk distance should be measured by counting the number of full laps and rounding to the nearest meter for the partial final lap.

Optimally, two tests should be performed due to the patient improving during the second one (learning curve effect). An increase in 6 MWT distance by 27 min on the second walk has been documented in a study including over 1500 patients with chronic pulmonary obstructive disease [49]. The six-minute walk test is considered safe; however, testing personnel should be certified in basic life support, and immediate access to emergency equipment should be provided. Absolute contraindications for 6 MWT include <7–10 days from primary angioplasty due to myocardial infarction and <24 h from elective coronary angioplasty. Relative contraindications include resting heart rate of >120 bpm, systolic blood pressure of >180 mmHg, and diastolic blood pressure of >100 mmHg [50].

Reasons for test termination include:

- Chest pain;
- Increasing dyspnea;
- Dizziness;
- Pallor;
- Diaphoresis;
- Leg cramps;
- Claudication;
- The patient's request to stop.

The test report should include:

- The patient's data;
- Current medications;
- Heart rate and blood pressure values (before and after the test);
- Borg scale at the end of test;
- Test distance;
- Data about stopping test;
- Symptoms;
- Conclusions.

The 6 MWT distance can be affected by many factors—e.g., BMI 25 kg/m^2 and age $\geq$75 years were found to be independent predictors of poor performance (i.e., <300 m) in a study by Pepera that included patients with heart failure. Furthermore, patients with heart failure have been found to have a shorter step length and to walk more slowly than controls during the 6 MWT [51].

Gibbons et al. attempted to determine the best 6-min walk distance from several repetitions in healthy volunteers. The reference value they found for 6 MWT was 698 ± 96 m [52].

Enright and Sherill developed reference equations for women and men to utilize the percentage of predicted 6 MWT distances [53]:

- For women: (2.11 × height in cm) − (2.29 × body mass in kg) − (5.78 × age) + 667 m.
- For men: (7.57 × height in cm) − (5.02 × age) − (1.76 v body mass in kg) + 309 m.

For patients after coronary artery bypass surgery and valve surgery, two formulas have been proposed; these include sex, the presence of diabetes, and atrial fibrillation [54]. The translation of the 6 MWT results into exercise prescription has been suggested, with 80% of the average 6 MWT speed corresponding to a high but tolerable exercise intensity and resulting in training benefits [55].

2.3.2. The Two-Minute Step Test

The two-minute step test (2 MST) was introduced in 1999 by Rikli and Jones as part of the Senior Fitness Test. The test requires that tested individuals march in place as fast as possible for 2 min while lifting their knees to a height midway between their patella and iliac crest when standing [56]. Similarly, like in the 6 MWT, the patients can slow down or stop the test if necessary. The norm for the 2 MST is 65 steps or more [57]. Rikli and Jones have demonstrated good inter-test reliability [58].

2.3.3. The Incremental Shuttle Walking Test

The incremental shuttle walk test (ISWT) is a symptom-limited, externally paced test performed along a 10 m course and involving walking back and forth between two cones set 0.5 m from either end of a 10 m course. The initial walking speed, indicated by an audible signal, is increased each minute until the patient is too fatigued to continue or cannot maintain the required speed. The number of completed shuttles—i.e., the ISWT total distance covered—is the test outcome. Unlike in the 6 MWT, there seems to be no learning effect in the ISWT [59]. In addition, the turning maneuver has no impact on the test result in stable patients with cardiovascular disease unless reduced mobility due to orthopedic limitations is present [60].

A relationship between the number of shuttles completed and the maximum oxygen uptake has been demonstrated, supporting the potential role of ISWT as a valuable tool for assessing changes in patients' functional capacity during cardiac rehabilitation. Numerous studies have addressed variables affecting test performance, with the ISWT distance correlating most strongly with step length and height [61]. As expected, the ISWT distance covered by men was further than that by women, with mean values of 395 and 269 m, respectively [62]. The ISWT results have been translated into exercise training intensity by the prescription of the walking exercise at an intensity equal to 70% of the peak ISWT speed [63].

2.4. Safety of Exercise Testing

Cardiovascular events during treadmill- or leg cycle ergometer-based exercise testing are rare. In 1971, a study by Rochmis and Blackburn on 170,000 exercise stress tests performed in over 70 medical centers demonstrated an overall mortality rate of one death per 10,000 tests and a serious cardiac complications rate of 4 per 1000 tests [64]. A further study by Gibbon demonstrated a total cardiac complication rate in men and women of 0.8 (0.3–1.9) complications per 10,000 tests; however, the biggest limitation was the fact that most of the study population was without known coronary disease [65]. A recent study by Pavy including 25,000 patients (34% after coronary artery bypass surgery, 18% after valve surgery, 21% after recent percutaneous coronary intervention) revealed a rate of 1 event per 8484 exercise stress tests [66]. Traditional laboratory-based exercise protocols are often replaced in daily clinical practice with the incremental shuttle walking test (ISWT). In a pilot study by Pepera, the safety of the submaximal ISWT, as well as exercise training, was assessed in 33 patients during a community-based cardiac rehabilitation program of at least 10 weeks duration [67]. Termination criteria for ISWT included: the patient feeling too breathless or fatigued to continue at the required speed, failure to complete the test within the allowed time, reaching 85% of the predicted heart rate (calculated as $210 - (0.65 \times \text{age})$), or completing all test levels. As expected, no major event was recorded for either the ISWT or training. The most clinically important event was silent ischemia (27% of ISWT), followed by atrial and ventricular ectopic beats (18% and 15%, respectively). Further studies are required, however, due to the small study population used.

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3. Phase I—Early Mobilization

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3.1. Idea of Early Mobilization

Bed rest and immobility have been the recommended standard of care following acute cardiac events for many decades [1]. The implementation of early mobilization was gradual, from chair therapy in the 1940s, to several minutes of walks after four weeks of rest in the 1950s and mobilizing patients after 12 days of rest in the 1960s [2]. A study conducted by Saltin in 1968 revealed the problem of the vicious cycle of prolonged hospital bed rest [3]. Prolonged hospital bed rest contributes to decreased cardiac output; secondary complications such as deep venous thrombosis, pneumonia, pressure sores, a rapid loss of skeletal muscle mass, reduced strength, and a decline in aerobic capacity [4,5]. Early mobilization means the initiation of mobilization activities as soon as clinical stability is achieved, typically with 1–2 days of admission, and has significant effects on the length of hospital stay and the readmission rate [6,7].

Goals of early mobilization include [8,9]:

- Limiting physical inactivity and preventing bed rest complications.
- Maintaining physical activity at the required level.
- Preparing patients for performing activities of daily living.
- Reducing disease-related stress and anxiety.
- Preparing patients for a return to work.

3.2. Early Mobilization after Myocardial Infarction

Cardiac rehabilitation should start immediately after clinical stabilization, usually at a coronary care unit, after 12–48 h [8]. The progression of the mobilization depends on the clinical course and the potential complications. All patients with myocardial infarction should be monitored for at least 24 h after an acute event and longer in cases wherein there is a high risk of arrhythmia, hemodynamic instability, severe impairment of left ventricular systolic function, unsuccessful reperfusion, or multivessel coronary disease [10].

The patient is considered appropriate for daily ambulation and mobilization if [11]:

- There has been no recurrent chest pain during the previous 8 h;
- Neither troponin nor CK-MB levels are rising;

- No new, significant abnormal rhythm or ECG ischemic changes have occurred during the previous 8 h period.

Absolute contraindications for mobilization are:

- Decompensated heart failure;
- Systolic blood pressure > 200 mmHg and diastolic > 100 mmHg;
- Complete atrioventricular block without a pacemaker;
- Endocarditis and pericarditis;
- Thrombophlebitis.

Mobilization should be stopped in the case of:

- Angina;
- Dyspnea;
- Heart rate increase > 20/min;
- Heart rate drop > 10/min;
- Complex, exercise-induced arrhythmia;
- Decrease in systolic blood pressure > 10–15 mmHg;
- Increase in systolic blood pressure of >40 mmHg and/or diastolic blood pressure of >20 mmHg compared with resting values.

Exercises are recommended to be performed twice a day, optimally on every day of the week. Blood pressure and heart rate should be checked before, during, and after exercises [10]. The key elements of the early mobilization period remain supervision during training, the regular evaluation of training response and progress, the management of clinical symptoms of hypotension, the assessment of fluid status, heart rate control, and pharmacological treatment modification. The importance of early mobilization following myocardial infarction has been well established, and a growing body of evidence suggests the improvement of the inflammatory response and impact on the ventricular remodeling process [12,13]. However, some discrepancy between the recommendations and clinical practice exists with regard to bed rest time following myocardial infarction. According to the study conducted by Cortez, mobilization in the coronary care unit takes place late, nearly 50 h after the onset of myocardial infarct, and patients spend up to 70% of their time on bed rest [14,15].

The authors of this book want to present an adapted model of early mobilization utilized widely in Poland described in Tables 16–18 (A1, A2, and B pathways):

Table 16. Suggested first stage of early mobilization after myocardial infarction.

Mobilization duration	A1: days 0–1; A2: days 0–2; B: days 0–3
Exercise duration	5–10 min, twice a day
Position of exercises	Supine position, semi-sitting, sitting
Type of exercises	Respiratory exercises Isometric exercises of small muscle groups Dynamic exercises, initially of small muscle groups, then major muscle groups Relaxation exercises
Activities	Semi-sitting position in bed Sitting in an armchair Turning to the side in bed Personal care in bed

Source: Table by authors.

Table 17. Suggested second stage of early mobilization after myocardial infarction.

Mobilization duration	A1: day 2; A2: days 2–3; B: days 4–8
Exercise duration	10–15 min twice a day
Position of exercises	Sitting
Type of exercises	As in stage 1, with an intensity increase—i.e., increased number of repetitions, or at increased pace, or the number of sets Dynamic exercises of extremities Coordination exercises Short walks
Activities	Active sitting in an armchair Eating in a sitting position in bed Transport to toilet in a wheelchair Standing up and taking a short walk around the room

Source: Table by authors.

Table 18. Suggested third stage of early mobilization after myocardial infarction.

Mobilization duration	A1: days 3–5; A2: days 4–8; B: from day 8
Exercise duration	20 min twice a day
Position of exercises	Sitting, standing, walking
Type of exercises	As in stage II with gradual intensity increase Gradual increase in walking distance up to 300 m Climbing upstairs
Activities	Complete mobilization

Source: Table by authors.

A model

The A1 model applies to the following groups of patients:

- Those with unstable angina;
- Those with uncomplicated myocardial infarction (NSTEMI, STEMI without significant impairment of the left ventricular systolic function).

The A2 model is dedicated to patients:

- With a myocardial infarction and significantly impaired left ventricular systolic function;
- Who have undergone uncomplicated cardiac surgery.

The B model applies to:

- Patients with a complicated myocardial infarction;
- Patients after cardiac surgery with a complicated early postoperative course;
- Patients who have undergone transcatheter aortic valve implantation;
- Patients who have undergone the implantation of a ventricular assistance device;
- Patients who have undergone orthotopic heart transplantation;
- Patients with heart failure.

In all presented models, mobilization comprises three stages (Tables 16–18).

3.3. Early Mobilization after Cardiac Surgery

3.3.1. Prehabilitation

The detrimental effects of prolonged bed rest in an intensive care unit have been extensively investigated. Prolonged immobilization contributes to decreased cardiac output; the development of complications such as deep venous thrombosis, pneumonia, pressure sores, and muscle atrophy; and a decline in aerobic capacity, which occurs as early as within the first few postoperative days [16]. Muscle weakness has been observed in nearly 50% of intensive care patients and is strongly associated with increased short- and long-term morbidity, the deterioration of physical capacity, and an increase in mortality [17,18]. Furthermore, patients undergoing cardiac surgery are at a risk of postoperative pulmonary complications leading to increased postoperative morbidity and mortality. These include cardiogenic pulmonary edema, acute respiratory distress syndrome, pneumothorax, pleural effusion, atelectasis, pneumonia, prolonged mechanical ventilation, and phrenic nerve injury [19]. Contributing factors include age over 70 years, diabetes mellitus, body mass index > 28, and preoperative arrhythmias [20]. Thus, preoperative assessment should entail the testing of functional capacity and frailty for an appropriate postoperative risk estimation. The inability to climb two flights of stairs or the presence of frailty is associated with a high risk of postoperative cardiac events [21,22]. Cardiac prehabilitation implements specific interventions before cardiac surgery to facilitate better postoperative outcomes [23].

Detailed goals of prehabilitation include:

- Reduction in the risk of thrombo-embolic events;
- Reduction in the risk of respiratory complications;
- Maintaining the function of the peripheral muscles;
- Minimizing postoperative stress.

Prehabilitation comprises:

- Education about the procedure and postoperative course, including potential complications;
- Inspiratory muscle training;
- Coughing exercises;
- Appropriate methods of changing position in bed;
- Low-intensity exercises, adapted individually to a patient's clinical status;
- Psychotherapeutic support.

Respiratory physiotherapy is of paramount importance and includes such practices as secretion aspiration, oxygen therapy, change in body positions, postural drainage, deep breathing/coughing exercises, inspiratory muscle training, and the use of incentive spirometers [24–26].

3.3.2. Early Mobilization

Early mobilization shortens the out-of-bed period, the length of stay in the ICU, and the total hospitalization time [7]. Typically, phase I of cardiac rehabilitation following cardiac surgery is commenced in the intensive care unit (usually 2–3 days), then is continued in the cardiac surgery department (typically days 2–7). The mobilization of patients after cardiac surgery is complex, due to clinical instability and multi-organ dysfunction. Contributing factors include respiratory insufficiency; impaired cardiovascular system; skeletal muscle weakness; and the effects of medications, especially sedatives. Postoperative recovery and thus, early exercise prescription in patients after cardiac surgery is affected by the presence of many complications: persistent chest pain, shoulder discomfort, anemia, arrhythmias (typically atrial fibrillation), post-thoracotomy syndrome, phrenic nerve injury, sternum instability, delayed wound healing, cognitive dysfunction, sleeplessness, depression, and anxiety [27].

Early mobility in the intensive care unit is contraindicated in the case of [28]:

Absolute contraindications:

- Heart rate < 40 or >120 beats per minute;
- Mean arterial pressure < 60 or >110 mmHg;
- Oxygen saturation < 90%;
- Respiratory rate > 40/min;
- Temperature < 36 or >38.5 degrees Celsius.

Relative contraindications:

- Decreased consciousness;
- Hemoglobin < 7 g/dL;
- Presence of lines if they make mobilization unsafe.

Despite the existence of supporting data for the safety of early mobilization in intensive care units, clinical practice differs, and the amount of rehabilitation offered is often insufficient. This might be because the assessments of health deficiencies are inaccurate. Utilizing existing tools—e.g., the International Classification of Functioning, Disability, and Health—has been strongly recommended for the precise evaluation of the level of cooperation, muscle strength, joint mobility, and functional status (using the Functional Independence Measure, Berg balance scale, Functional Ambulation Categories) prior to the commencement of early mobilization [29]. In the case of uncooperative, critically ill patients, body positioning (every 2 h), passive cycling (Figure 3), joint mobility, passive muscle stretching, and neuromuscular electrical stimulation can be applied [30]. Continuous passive motion prevents contractures and has been used in patients with critical illness and prolonged inactivity [31]. For those who cannot be actively mobilized and with a high risk of soft-tissue contracture—e.g., with some neurological conditions or after trauma—splinting may be recommended. A recent study demonstrated that the early application of daily bedside (initially passive) leg cycling in critically ill patients resulted in improved functional status and improved muscle function at hospital discharge compared to patients who did not receive leg cycling [32].

Neuromuscular electrical stimulation is applied in patients who cannot voluntarily perform muscle contractions to prevent muscle atrophy [33].

In the case of cooperative patients, the mobilization strategy includes transferring in bed, sitting over the edge of the bed, moving from the bed to a chair, standing, marching on the spot, and walking with or without support [34–37].

The Leuven protocol—i.e., the meticulous step-up approach for progressive early mobilization—has been recommended [35]. It includes six levels of mobilization based on cooperation status, assessed by responses to five standardized questions (“open and close eyes”, “look at me”, “open your mouth and stick out your tongue”, “shake yes or no”, “I will count to 5, frown your eyebrows afterwards”), cardiorespiratory status, the Berg balance scale, and the Medical Research Council muscle strength scale (Figure 4).

Figure 3. Passive bedside cycling. Source: Reprinted from [35], used with permission.

LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
NO COOPERATION S5Q[1] = 0	NO□LOW COOPERATION S5Q[1] < 3	MODERATE COOPERATION S5Q[1] □ 3	CLOSE TO FULL COOPERATION S5Q[1] □ 4/5	FULL COOPERATION S5Q[1] = 5	FULL COOPERATION S5Q[1] = 5
FAILS BASIC ASSESSMENT[2]	PASSES BASIC ASSESSMENT[3] +	PASSES BASIC ASSESSMENT[3] +	PASSES BASIC ASSESSMENT[3] +	PASSES BASIC ASSESSMENT[3] +	PASSES BASIC ASSESSMENT[3] +
BASIC ASSESSMENT = □Cardiorespiratory unstable: MAP < 60mmHg or FiO_2 > 60% or PaO_2/FiO_2 < 200 or RR > 30 bpm □Neurologically unstable □Acute surgery □Temp > 40°C	Neurological or surgical or trauma condition does not allow transfer to chair	Obesity or neurological or surgical or trauma condition does not allow active transfer to chair (even if MRCsum □ 36)	MRCsum □ 36 + BBS Sit to stand = 0 + BBS Standing = 0 + BBS Sitting □ 1	MRCsum □ 48 + BBS Sit to stand □ 0 + BBS Standing □ 0 + BBS Sitting □ 2	MRCsum □ 48 + BBS Sit to stand □ 1 + BBS Standing □ 2 + BBS Sitting □ 3
BODY POSITIONING[4] 2hr turning	BODY POSITIONING[4] 2hr turning Fowler's position Splinting	BODY POSITIONING[4] 2hr turning Splinting Upright sitting position in bed Passive transfer bed to chair	BODY POSITIONING[4] 2hr turning Passive transfer bed to chair Sitting out of bed Standing with assist (2 □ pers)	BODY POSITIONING[4] Active transfer bed to chair Sitting out of bed Standing with assist (□1 pers)	BODY POSITIONING[4] Active transfer bed to chair Sitting out of bed Standing
PHYSIOTHERAPY: No treatment	PHYSIOTHERAPY[4] Passive range of motion Passive bed cycling NMES	PHYSIOTHERAPY[4] Passive/Active range of motion Resistance training arms and legs Passive/Active leg and/or cycling in bed or chair NMES	PHYSIOTHERAPY[4] Passive/Active range of motion Resistance training arms and legs Active leg and/or arm cycling in bed or chair NMES ADL	PHYSIOTHERAPY[4] Passive/Active range of motion Resistance training arms and legs Active leg and/or arm cycling in chair or bed Walking (with assistance/frame) NMES ADL	PHYSIOTHERAPY[4] Passive/Active range of motion Resistance training arms and legs Active leg and arm cycling in chair Walking (with assistance) NMES ADL

Figure 4. The Leuven protocol. Abbreviations: BBS—Berg balance scale; MRC—Medical Research Council muscle strength sum scale; S5Q—response to 5 standardized questions for cooperation. Source: Reprinted from [35], used with permission.

S5Q—responses to five standardized questions for cooperation:

- “open and close eyes”;
- “look at me”;
- “open your mouth and stick out your tongue”;
- “shake yes or no”;
- “I will count to 5, frown your eyebrows afterwards”.

BBS—Berg balance scale:

- Sitting to standing:

  4—able to stand without using hands and stabilize independently;
  3—able to stand independently using hands;
  2—able to stand using hands after several tries;
  1—needs minimal aid to stand or stabilize;
  0—needs moderate or maximal assistance to stand.

- Standing unsupported:

  4—able to stand safely for 2 min;
  3—able to stand for 2 min with supervision;
  2—able to stand for 30 s unsupported;
  1—needs several trials to stand for 30 sec unsupported;
  0—unable to stand for 30 s unsupported.

- Sitting with back unsupported but feet supported on the floor or on a stool:

  4—able to sit safely and securely for 2 min;
  3—able to sit for 2 min under supervision;
  2—able to sit for 30 s;
  1—able to sit for 10 s;
  0—unable to sit without support for 10 s.

MRC (Medical Research Council muscle strength sum scale (0–60):

0—no visible contractions
1—visible contractions/no limb movement;
2—active movement but not against gravity;
3—active movement against gravity;
4—active movement against gravity and resistance;
5—active movement against full resistance,

Max score: 60 (4 limbs, 3 movements per extremity, with a maximum score of 15 points per limb)

Upper extremities: shoulder abduction/elbow flexion/wrist extension.

Lower extremities: hip flexion/knee extension/ankle dorsiflexion.

The authors recommend, as mentioned earlier, the use of the three-staged mobilization model described in Tables 19–21 (A2 and B models).

Table 19. Suggested first stage of early mobilization after cardiac surgery.

Mobilization duration	A2: days 0–2; B: days 0–3
Exercise duration	5–10 min, twice a day
Position of exercises	Supine position, semi-sitting, sitting
Type of exercises	Day 0—after weaning from mechanical ventilator: Respiratory exercises; Effective cough exercises; Percussion. Days 1–2: Exercise applied earlier; Isometric exercises of small muscle groups; Dynamic exercises, initially of small and then of major muscle groups; Inspiratory muscle training; Relaxation exercises.
Activities	Semi-sitting position in bed. Personal care in bed. Transfer to toilet in wheelchair.

Source: Table by authors.

Table 20. Suggested second stage of early mobilization after cardiac surgery.

Mobilization duration	A2: days 2–3; B: days 4–8
Exercise duration	10–15 min twice a day
Position of exercises	Supine position, sitting
Type of exercises	As in stage 1, with an intensity increase—i.e., increased number of repetitions, or at an increased pace, or an increase in the number of sets Dynamic exercises of extremities Coordination exercises Short walks within the room with assistance
Activities	Active sitting over the edge of the bed, standing Personal care in bed

Source: Table by authors.

Table 21. Suggested third stage of early mobilization after cardiac surgery.

Mobilization duration	A2: days 4–8; B: from day 8
Exercise duration	15–20 min twice a day
Position of exercises	Sitting, standing, walking
Type of exercises	As in stage II, but with a gradual intensity increase Inspiratory muscle training Dynamic exercises of major muscle groups Gradual increase in walking distance (continuous or intermittent) Climbing stairs
Activities	Complete mobilization Exercises in sitting and standing position, as well as while walking

Source: Table by authors.

3.4. Home Activity after Hospital Discharge

All eligible cardiac patients should be referred to cardiac rehabilitation after recovery from an acute cardiac event [8]. Notwithstanding that, the referral rate remains insufficient, and motivational strategies to enhance participation in cardiac rehabilitation programs and the provision of comprehensive information about the purposes and formats of cardiac rehabilitation are essential [38,39]. Many patients do not receive sufficient information about the exercise intensities allowed during their post-discharge period at home. Basically, prior to discharge, patients should attain a mobility level of approximately 3 METS, and they should be given a safe and progressive home exercise plan [40]. In some countries—e.g., in England—patients discharged from hospital are contacted by members of a cardiac rehabilitation team in the form of home visits, telephone calls, or outpatient appointments for education/health promotion classes; this period is described as the immediate post-discharge phase [41,42]. Post-discharge activities at home should aim to achieve a gradual increase in functional capacity. Patients are encouraged to walk in and around their homes and then to walk outdoors. Rates of perceived exertion or pulse should be assessed to monitor patients' exercise response. Prior to commencing a supervised exercise program, patients should be able to walk for about 30 min daily. Some specific limitations are imposed temporarily on patients after cardiac surgery. Efforts contraindicated for 12 weeks following cardiac surgery are those against high resistance or with a marked isometric aspect—e.g., lifting or moving heavy items; raising both arms for a long time above the head; and running, swimming, and skiing due to sternum stability concerns [43,44]. Sexual activities can be resumed 1–2 weeks after uncomplicated myocardial infarction without cardiac symptoms during mild to moderate physical activity, and optimally 6-8 weeks after cardiac surgery (if patients can comfortably walk about 300 m on a flat surface or climb two flights of stairs briskly without chest pain or becoming breathless). Sexual activity is contraindicated in the presence of a low angina threshold and complex ventricular dysrhythmias [45].

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4. Phase II—Supervised Exercise Training

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4.1. Initial Assessment and Risk Stratification

4.1.1. General Remarks

Early assessment allows for the identification of the individual needs of patients referred to cardiac rehabilitation. Establishing personalized goals and a plan of care before the initiation of appropriate cardiac rehabilitation service is essential [1]. Cardiac risk stratification aims to identify patients at risk for a cardiac event recurrence. It includes the methodical assessment of the clinical and functional status of the patient to classify him/her as low, moderate, or high risk [2].

4.1.2. Initial Assessment

Entry assessment comprises a clinical evaluation (medical history and interview) and tests. The clinical evaluation includes the assessment of event diagnosis, the symptoms declared by the patient, the presence of cardiovascular risk factors, comorbidities, and the medical treatment regimen [3,4]. Furthermore, in patients with implanted cardiac electrical devices, the device characteristics, intervention modes, and thresholds should be recorded [2]. Psychological screening should be performed using a questionnaire or a scale [5]. Personalized physical examination should be performed according to the main diagnoses of the patient. Entry tests include resting 12-lead electrocardiograms, routine laboratory testing, resting transthoracic echocardiography, 24 h ECG monitoring, and functional capacity testing [2].

Resting electrocardiogram enables the determination of leading rhythm, heart rate, ischemia, or conduction abnormalities. Twenty-four-hour ECG monitoring should be performed in patients during phase I and II of cardiac rehabilitation if cardiac arrhythmias are suspected, and longer electrocardiographic monitoring should be considered if they occur rarely. If followed by pharmacotherapy modification, 24 h ECG recording should be repeated. The use of a resting transthoracic echocardiogram is recommended at the end of phase II of cardiac rehabilitation in patients after an episode of acute coronary syndrome or cardiac surgery with concomitant significant impairment of the left ventricular systolic function. Resting transthoracic echocardiography is recommended for assessment of indications for implantation of cardioverter defibrillator. In addition, an echocardiogram is recommended in case of clinical deterioration during the exercise program. Echocardiogram is crucial for the assessment of the left ventricular systolic and diastolic performance, valvular abnormalities, the presence of pericardial effusion, or intracardiac thrombus. Recent routine biochemical tests, including complete blood count, hemoglobin, blood lipids panel, fasting blood glucose, renal and liver function, electrolytes, international normalized ratio (INR), and thyroid-stimulating hormone (TSH), should be reviewed upon entry to a cardiac rehabilitation program. Cardiac rehabilitation centers should have 24 h access to the rapid determination of cardiac troponins [2].

Exercise stress testing protocols (cardiopulmonary exercise testing preferable for patients with heart failure, with heart transplant, or with congenital heart disease) should be adapted to the patient's condition. A six-minute walk test is recommended when exercise stress testing is not feasible [6]. The evaluation of physical fitness should incorporate muscular strength testing [7,8]. Abreu et al. suggested the following practical cardiac rehabilitation entry checklist described in Table 22 [2].

Table 22. Cardiac rehabilitation entry checklist.

Evaluation	Core Components	Tools	Other Components
Demographics	Age, gender, race		
Index event	Acute event date	Hospital discharge report Interview	
Medical treatment	Control of tolerance and compliance	Drug prescription	
Residual symptoms	Angina, palpitations, dyspnea	NYHA class, CCS class	
Cardiovascular risk factors	History, assessment	Interview, blood testing	Brain natriuretic peptide, C-reactive protein
Clinical Examination	Cardiovascular Examination	Vital signs, waist circumference, BMI	
Comorbidities	History, clinical evaluation	Interview, reports, physical examination	

Table 22. *Cont.*

Evaluation	Core Components	Tools	Other Components
Cardiovascular Function	Non-invasive testing	Resting ECG, echocardiogram, Holter ECG, exercise test	Stress echo, magnetic resonance imaging, ankle–brachial index
Exercise capacity	Exercise testing	Symptom-limited ECG exercise test/CPET	6-min walk test
Psychological	Stress, anxiety, depression, quality of life	Stress and depression scales	
Social	Workplace	Interview	

Abbreviations: BMI—body mass index; CCS—Canadian Cardiovascular Society; CPET—cardiopulmonary exercise test; ECG—electrocardiogram; NYHA—New York Heart Association. Source: Adapted from [2].

4.1.3. Risk Stratification

Risk stratification should be applied to establish the risk of future cardiac events and the patient's chances of survival. Most centers follow the risk stratification formula developed by the American Association of Cardiovascular and Pulmonary Rehabilitation exhibited in Table 23 [1].

Table 23. Risk stratification formula developed by the AACVPR.

Parameter	Low Risk	Moderate Risk	High Risk
Left ventricular ejection fraction	LVEF 50% or more	LVEF 40%–49%	LVEF < 40%
Complex ventricular dysrhythmia	Absent at rest or during exercise testing and recovery		Present at rest or during exercise testing and recovery
Angina or other symptoms (unusual shortness of breath, lightheadedness, or dizziness)	Absent during exercise testing and recovery	Present only at high level of exertion (7 METS or more)	Present at low levels of exertion (<5 METS) or during recovery

Table 23. *Cont.*

Parameter	Low Risk	Moderate Risk	High Risk
Hemodynamics during exercise testing and recovery	Normal hemodynamics		Abnormal hemodynamics during exercise testing (i.e., chronotropic incompetence or flat or decreasing systolic blood pressure with increasing workload) or during recovery (severe post-exercise hypotension)
Ischemic ECG changes	None	ST-segment depression < 2 mm	ST-segment depression more than 2 mm
Functional capacity	7 METS or more 100 watts or more	5–6.9 METS 75–100 watts	<5 METS <75 watts
Clinical data	Uncomplicated myocardial infarction or a revascularization procedure Absence of congestive heart failure Absence of signs or symptoms of post-event/post-procedure ischemia		History of cardiac arrest Complicated myocardial infarction or revascularization procedure Presence of signs and symptoms of post-event/post – procedure ischemia Presence of congestive heart failure
Clinical depression	Absent		Present
	All characteristics listed must be present for patients to remain low-risk.	**One or more** of these findings places the patient at moderate risk.	**One or more** of these findings places the patient at high risk.

Abbreviations: AACVPR—American Association of Cardiovascular and Pulmonary Rehabilitation; LVEF—left ventricular ejection fraction; METS—multiples of resting metabolic equivalent. Source: Adapted from [1].

An alternative risk stratification approach has been recommended [9].

High risk:

- Patients with severe in-hospital complications;
- Patients with persistent clinical instability, ischemia, or arrhythmias after the acute event;
- Serious concomitant diseases, with a high risk of a cardiovascular event;
- Patients with advanced congestive heart failure (NYHA class III and IV), and/or severe ventricular dysfunction, and/or needing mechanical support;
- Patients after a recent heart transplant;
- Patients discharged very early after the acute event (<1–2 weeks depending on the index event), even if uncomplicated, and particularly if they are older, female, frail, or at higher risk for the progression of cardiovascular disease;
- Exercise performance < 4 METs;
- Cardiac arrest survivors;
- Social deprivation, low income;
- Depression.

Low risk:

- Long delay (>1–2 months) after uncomplicated acute event;
- Stable (asymptomatic, e.g., CCS = 0, NYHA = 1), uncomplicated patient;
- Exercise capacity >6 METs or >50% of predicted value;
- No residual ischemia;
- No ventricular dysfunction;
- No severe arrhythmias;
- No uncontrolled hypertension;
- Absence of comorbidities;
- No implanted cardiac electronic devices;
- Autonomy without psychosocial risk.

All other patients should be considered at intermediate risk.

4.2. Supervised Exercise Training

4.2.1. General Remarks

Phase II of cardiac rehabilitation typically commences within 1–3 weeks following hospital discharge [1]. Phase II is offered as a hospital- or center-based outpatient program of 2–6 months duration; however, residential programs prevail in some countries—e.g., in France, Germany and Poland [10]. Residential cardiac rehabilitation programs include medically supervised exercise sessions 5–6 days a week and last for 3–5 weeks. They are particularly suitable for high-risk patients—i.e., [2]:

- Those with severe in-hospital complications after acute coronary syndromes, cardiac surgery, or percutaneous coronary intervention;
- Those with complications after the acute event or with serious concomitant diseases at high risk of cardiovascular events;
- Clinically stable patients with advanced congestive heart failure, in New York Heart Association class III and IV, and/or who are in need of intermittent or continuous drug infusion and/or mechanical support and/or after device implanted;
- Patients who have undergone a recent heart transplantation;
- Patients discharged very early after the acute event, particularly if they are older, a woman, or frail;
- Patients who are unable to attend a formal outpatient cardiac rehabilitation program due to logistics.

Indications for exercise training include [2]:

- Condition after an acute coronary syndrome or chronic coronary artery disease with or without coronary artery bypass graft surgery or percutaneous coronary intervention;
- Stable coronary artery disease with multiple risk factors;
- Diffuse coronary artery disease or incompletely revascularized coronary artery disease (complete revascularization not possible) with ischemia;
- Stable heart failure;
- Pulmonary hypertension;
- Congenital heart disease that has been surgically corrected;
- Having undergone the implantation of an assistance device or heart transplantation;
- Having undergone the implantation of a resynchronization device, defibrillator, or pacemaker;
- Having undergone valve surgery or the percutaneous implantation of prosthetic valves or clips;
- Having undergone surgery on the aorta.

Contraindications to supervised exercise training [11]:
Absolute contraindications:

- Myocardial infarction < 2 days or unstable angina not previously stabilized;
- Severe and uncontrolled cardiac arrhythmias;
- Uncontrolled symptomatic heart failure;
- Severe and symptomatic obstruction to ventricular outflow;
- Acute deep vein thrombosis with or without pulmonary embolism;
- Acute myocarditis, pericarditis, or endocarditis;
- Acute aortic dissection;
- Intra-cardiac thrombus with a high risk of embolism;

- Inability to exercise adequately or patient refusal;
- Significant pericardial effusion.

Relative/temporary (at the discretion of the cardiologist):

- Significant left main artery stenosis;
- Ventricular aneurysm;
- Supraventricular tachycardia with uncontrolled ventricular rate;
- Recent stroke or transient ischemic attack;
- Uncorrected medical condition (marked anemia, electrolyte imbalance);
- Severe arterial hypertension (resting BP > 200/100 mmHg);
- Hypertrophic cardiomyopathy with outflow tract obstruction at rest;
- Lack of patient cooperation.

4.2.2. Components of the Exercise Training

Exercise training should include the following components [12]:

- **Aerobic** (treadmill walking; outdoors walking—e.g., Nordic walking with sticks; biking on leg cycle ergometer; combined upper and lower extremity training on cycle ergometer; training on a stepper or rower; running; and swimming);
- **Resistance** (utilizing multi-weight machines, free weights, dumbbells, or elastic bands);
- **Flexibility;**
- **Neuromotor.**

An exercise training session comprises [8]:

1. **Warm-up**, usually 5–10 min of light-to-moderate intensity exercise at 30%–40% of heart rate reserve, <11 points at RPE Borg scale. The warm-up allows for gradual body adjustment to the physiological demands and precludes the sudden increase in catecholamines level [13]. By the end of the warm-up phase, an exercise intensity level of 40% of the heart rate reserve (or Borg scale 10) should be attained. The warm-up should include pulse-raising activities (for 3–5 min)—e.g., marching on the spot, walking, or low-intensity cycling. It can be followed by the stretching of the major muscle groups (3–5 min) with a subsequent re-warm-up [8].

2. **Conditioning phase,** of 20–60 min duration. The conditioning phase can be executed by utilizing one piece of equipment (e.g., a treadmill) or can take the form of circuit (station) training. Circuit training encompasses training on aerobic stations (usually for 30 s to 2 min each), followed by the use of an active or passive recovery station in the form of resistance work.

3. **Cool-down phase**, of 5–10 min duration, includes light- to moderate-intensity exercises and provides for the gradual recovery of heart rate and blood pressure. A graded cool-down phase precludes post-exertional ischemia, arrhythmia, or

hypotension, which can occur within 5–30 min of exercise cessation. The cool-down phase basically should be a reverse of the warm-up phase. All patients should be supervised for a minimum of 15 min after the cool-down phase [14].

4.3. Exercise Prescription Formula

Exercise training parameters should adhere to the FITT-VP principle: frequency, intensity, time (duration), type, volume (total amount), and progression as presented in Table 24 [12].

Table 24. The FITT-VP principle of exercise prescription [12].

Training Parameter	Description
Frequency (F)	Number of exercises or sessions per day or week
Intensity (I)	Direct (METS, oxygen uptake, watts), indirect (training heart rate, Borg scale)
Time (T)	Training time or total time during a week
Type (T)	Rhythmic, involving large muscle groups (e.g., biking, walking, swimming)
Volume (V)	Total energy expenditure in time $V = F \times I \times T$
Progression (P)	Load increase rate

Source: Adapted from [12].

Frequency

Physical activity is recommended on most days of a week.

Intensity

The exercise intensity should ideally be determined from the cardiopulmonary exercise testing with relation to ventilatory or lactate thresholds [15]. Suggested exercise intensity domains based on the CPET parameters and potential method limitations considering recent studies are described in a separate chapter. As the availability of cardiopulmonary gas analysis in cardiac rehabilitation centers is still limited, alternative methods of exercise intensity determination have been recommended.

These are based on [16]:

- The rating of perceived exertion, determined utilizing the Borg Category Scale or the Borg Category Ratio Scale.
- Training heart rate, with the calculation of the so-called heart rate reserve according to the Karvonen formula or as a % of the maximal heart rate. According to the Karvonen training heart rate = % of intensity (maximum heart rate-resting heart rate) + resting heart rate).

- % of MET reserve %—i.e., training MET reserve = % of (peak MET-resting MET) + resting MET, considering resting MET equals 1.
- % of peak work rate on cycle ergometer—i.e., training work rate (watts) = % of peak work rate.

Reserve calculations—i.e., heart rate reserve or MET reserve—are utilized for precise exercise intensity prescription and provide the patient's resting values [17]. Therefore, these methods may be more appropriate for use in patients with chronotropic incompetence [18].

Time

The goal for aerobic training duration is 30–60 min of the conditioning phase, plus a few minutes of warm-up and cool-down.

Type

Aerobic training should preferably be rhythmic in nature, repetitive, involve large muscle groups, and not require great experience. In view of this, the best training modes are walking, cycling, jogging, and swimming. Walking is a suitable mode of training for obese patients or untrained patients with a poor functional capacity. Exercise intensity is determined by walking speed, with brisk walking corresponding to moderate intensity [2]. Nordic walking—i.e., walking with poles—is recommended for elderly patients with gait or balance problems [19,20]. The most effective form of aerobic endurance training is jogging, and this is suitable only for patients with very good functional capacity. Stationary leg cycle ergometers allow for blood pressure and heart rate monitoring and for the recording of ECG; thus, they are suitable for group training.

Volume

Exercise volume is the product of frequency, intensity, and time (Volume = Frequency × Intensity × Time). Energy expenditure can be estimated according to the suggested equations [19]: x (kcal) = 3.5 × MET × body mass × time (min)/200 or according to the formula:

$$x\ (\text{kcal}) = \text{MET} \times \text{body mass} \times \text{time (h)}.$$

Example: An 80 kg patient is walking briskly for 30 min at a speed equal to 5 MET; therefore, his/her energy expenditure equals 5 (MET) × 80 (kg) × 0.5 (h) = 200 kcal.

Progression

Exercise progression rate depends on a patient's clinical status, fitness level, and training response [1]. It is reasonable to increase training duration by 5–10 min over 1–2 weeks [12]. Progression should take place gradually and only if tolerance to the current training parameters has been attained. Typically, the training duration is increased prior to the load or frequency being increased [8,21]. Table 25 exhibits the aerobic exercise prescription recommended by the AACVPR.

Table 25. AACVPR aerobic training recommendations [1].

Intensity	40%–80% of maximal heart rate or oxygen uptake reserve or RPE 11–16 10 beats per minute below event-heart rate (heart rate at start of angina or ecg ischemic changes)
Duration	20–60 min per session
Frequency	4–7 days/week
Type	rhythmic, involving larger muscle groups (walking, cycling, stair climbing)

Abbreviations: AACVPR—American Association of Cardiovascular and Pulmonary Rehabilitation; DBP—diastolic blood pressure; RPE—rating of perceived exertion; SBP—systolic blood pressure. Source: Adapted from [1].

4.4. Aerobic Training Intensity

4.4.1. Indices of Exercise Intensity

The exercise intensity prescription is recommended based on assessment with the cardiopulmonary exercise test (CPET), which is the gold standard for assessing exercise capacity. Alternative objective methods for prescribing exercise intensity based on heart rate may be affected by medications lowering heart rate, such as *beta-blockers* or chronotropic incompetence, defined as the inability to increase the heart rate adequately during exercise to match the cardiac output to metabolic demands. Subjective methods for determining exercise intensity include the rate of perceived exertion and the talk test; these methods should only be considered as an adjunct to the objective methods mentioned above [4].

Objective Indices

A. Indices of Peak Effort:
1. % of Peak Oxygen Uptake (VO_{2peak}):
The gold standard for assessing cardiovascular fitness.
Training maximal oxygen uptake = % of maximal oxygen uptake.
2. % of Peak Work Rate:

1—Estimating peak work rate during incremental cycle ergometry.

Training work rate (watts) = % of peak work rate.

2—Estimating peak work rate during incremental treadmill:

% of metabolic equivalent (MET) reserve %.

Training MET reserve = % of (peak MET − resting MET) + resting MET (resting MET = 1).

3. % of Peak Heart Rate:

This method is not recommended for patients undergoing treatment with beta-blockers.

Training heart rate = % of maximal heart rate.

4. % of Heart Rate Reserve:

Heart rate reserve (HRR) based on the Karvonen formula (HRR in %)

Training target heart rate (THR) = % of (maximum heart rate − resting heart rate) + resting heart rate. The THR intensity percentage usually ranges from 40% to 80%. Peak values of these indices represent the highest values attained during the last 20–30 s of a symptom-limited cardiopulmonary stress test. Typically, a so-called peak respiratory exchange gas ratio (RER) > 1.1, a plateau of oxygen uptake, and/or heart rate with increasing effort are used as determinants of maximal or near-maximal effort [22,23]. Aerobic exercise intensity indices are presented in Table 26.

Table 26. Aerobic exercise intensities [12].

Intensity Level	Maximum Oxygen Uptake (%)	Heart Rate Reserve (%)	Energy Supply
Low	<40	<40	Aerobic
Moderate	40–69	40–69	Aerobic
High	70–85	70–85	Aerobic and lactates

Source: Adapted from [12].

However, the major limitation of this is that not all patients with cardiovascular diseases achieve maximal or near-maximal effort during CPET. Moreover, a major concern has recently emerged with regard to a discrepancy between exercise domains based on peak exercise indices and individual responses to exercise, as described in a chapter regarding intensity domains [24].

B. Ventilatory Thresholds

The first ventilatory threshold represents a transition point from aerobic metabolism to lactate rise in the blood, with steady-state and blood lactate levels of 1.5–2.0 mmol/L [21,25]. The increase in blood lactate accumulation elicits fast breathing to remove the extra carbon dioxide produced by the buffering of acid metabolites. Therefore, before VT1 intensity, relatively small amounts of lactate are produced.

The second ventilatory threshold, or respiratory compensation threshold or "critical power", reflects the exercise intensity at which rapid lactate increase occurs, with a blood level of 3–5 mmol/L. As a result, the rise in carbon dioxide output (VCO_2) is disproportionate to the carbon dioxide output.

The two most-popular methods of VT1 determination are the relationship of the nadir of VE/VO_2 to the work rate—i.e., the lowest point in the curve before an increase in VE/VO_2—and the V-slope method. VT2 represents the nadir of the VE/VCO_2 to work rate relationship—i.e., the lowest point in the curve before the VE/VCO_2 increases [21]. These thresholds are extrapolated to the corresponding heart rates and work rates, determining exercise intensity domains. It has been postulated that exercise intensity is low at heart rates and work rates below VT1, moderate to intensive at heart rates and work rates between VT1 and VT2, and high at heart rates and work rates above VT2 [4,21,25]. Exercise prescription based on ventilatory thresholds improves the peak oxygen uptake more effectively than if based on the % of peak oxygen uptake in healthy individuals [26,27]. These data, however, should be confirmed in patients with cardiovascular disease. A major limitation of ventilatory threshold-based exercise prescription remains the lack of ergo-spirometry in many cardiac rehabilitation facilities. Other restrictions—e.g., substantial inter-and intra-observer variability—are reported using the V-slope method [28].

Another disadvantage of the extrapolation of ventilatory thresholds is that it cannot be translated directly into constant-load exercise training. This can be explained by the so-called lag-time—i.e., the initial oxygen uptake on-response delay between the onset of the ramp and the onset of linear increase in oxygen uptake [29]. Therefore, it has been proposed that the constant-load exercise prescription should be 10 watts lower than one executed by the 10 W/min incremental protocol at the beginning of cardiac rehabilitation [21].

Subjective methods (1):

1. The Rating of Perceived Exertion (RPE): Borg Category Scale, with recommended values of 11–16 from the Borg 6–20 scale or Borg Category Ratio Scale.

The Borg Scale [30]:

7: very, very light;
9: very light;
11: fairly light;
13: somewhat hard;
15: hard;

17: very hard;
19: very, very hard.

The alternative scale of perceived exertion is the 0–10 Borg Category Ratio Scale, which is more intuitive and allows for better patient cooperation than the 6–20 scale.

0–10 Borg Category Ratio Scale:

0: nothing at all;
1: extremely weak, just noticeable;
2: very weak;
2.5–3: weak;
4–5: moderate;
6–7: strong;
8–10: very strong.

RPE scales reflect the subjective feeling of aerobic exercise intensity a person experiences during exercise [30]. Despite their feasibility, many studies have demonstrated the insufficient correlation of RPE scales with % of peak oxygen uptake, lactate level, and respiratory rate. RPE may also be influenced by psychological and environmental conditions [31]. In clinical practice, ratings of perceived exertion are predominantly used in the case of patients without a reliable heart rate, i.e., patients with atrial fibrillation, who have undergone heart transplantation, or with chronotropic incompetence [4].

Interestingly, it has been postulated as a useful tool for maximal symptom-limited stress test termination cut-off in healthy individuals. Sirco et al. assessed the exercise test endpoints that coincide best with ECG changes in a healthy population (85% of maximal age-based heart rate, RPE, and METS). The rating of perceived exertion appeared to be the most significant endpoint, with an average value of 17 at peak exercise [32].

2. The Talk Test

The talk test has gained popularity as a simple subjective tool for monitoring appropriate exercise prescription. As a safe method, it has been widely utilized, predominantly in home-based cardiac rehabilitation [33]. In clinical practice, the talk test facilitates maintaining an exercise intensity at which conversation is still comfortable. Several studies have tested the effect of the talk test on the breathing rate; several have reported that a rapid increase in breathing rate beyond the second ventilatory threshold causes difficulty in talking during exercise; however, these studies are inconsistent. In addition, it has been documented that talk tests have a weak correlation with ventilatory thresholds [34]. In contrast, the stronger relation of the talk test to physiological and perceptual variables analogous to the lactate threshold than to the ventilatory threshold has been demonstrated [35]. Furthermore, as the talk test is linked to an increased breathing rate related to the second ventilatory threshold, it cannot be used to determine the first ventilatory threshold; thereby, it is not utilized in guiding low-intensity exercise. Consequently, besides RPE, the talk test should be used as an adjunct to guide exercise intensity in patients with cardiovascular diseases in activities such as their activities of daily living [6].

4.4.2. Aerobic Intensity Domains

Range-Based Approach

The range-based exercise prescription principle is based on extrapolating the percentage of the peak oxygen uptake into a corresponding percentage of the peak heart rate. The suggested training heart rate "zones" for healthy individuals' range between 70 and 85% of the peak heart rate, and for patients with cardiovascular diseases, training intensities range between 40 and 80% of the peak oxygen uptake [36, 37]. The well-known Karvonen method, which utilizes a percentage of the heart rate reserve, with heart rate reserve equal to 60%, has been demonstrated to correspond with the first ventilatory threshold [38]. The Karvonen method gained popularity worldwide and was adopted by the American College of Sports Medicine as the gold standard for exercise intensity. The evaluation of the recommended training HRR zone using the Karvonen method can provide an indirect assessment of the training HRR zone of 60–80% of the heart rate reserve for healthy individuals and 40–70% of the heart rate reserve for patients with cardiovascular diseases.

Threshold-Based Approach

In 2013, Mezzani et al. promoted a threshold-based approach because exercise intensity can be determined more accurately in relation to the first and the second ventilatory thresholds than when it is expressed as a percentage of the peak exercise capacity [21]. This approach represented a shift from range-based to threshold-based aerobic training prescription. According to the study of Mezzani et al., the first ventilatory threshold, which is reached at around 50–60% of peak VO_2 or 60–70% of the peak heart rate, is a point between the light-to-moderate-intensity and moderate-to-high-intensity effort domains [39]. The second ventilatory threshold, usually attained at around 70–80% of peak VO_2 and 80–90% of peak HR during incremental exercise, marks the upper intensity limit for prolonged aerobic exercise [40]. Both ventilatory thresholds allow for the identification of four exercise intensity domains: light to moderate, moderate to high, high to severe, and severe to extreme.

According to this concept, there are four domains of exercise intensity:

1. The first ventilatory threshold reflects very light exercise as presented in Table 27. Exercising in this domain is generally well tolerated and sustainable for a long period (>30–40 min).

Table 27. Very light exercise intensity parameters.

Borg scale	6–9
VO_2 max	45–55%
HRR	45–55%
Blood lactate level	<2 mmol/L

Source: Adapted from [21].

2. Between the first and the second ventilatory thresholds reflecting light to moderate exercise (with both aerobic and anaerobic energy supply) as exhibited in Tables 28 and 29:

Table 28. Light exercise intensity parameters.

Borg scale	10–12
VO_2 max	55–70%
HRR	55–70%
Blood lactate level	2–3 mmol/L

Source: Adapted from [21].

Table 29. Moderate exercise intensity parameters.

Borg scale	13–14
VO_2 max	70–80%
HRR	70–80%
Blood lactate level	3–4 mmol/L

Source: Adapted from [21].

3. The second ventilatory threshold reflects heavy exercise, as presented in Table 30:

Table 30. Heavy exercise intensity parameters.

Borg scale	≥14
VO_2 max	>80%
HRR	>80%
Blood lactate level	>4 mmol/L

Source: Adapted from [21].

In this intensity domain, only interval aerobic training can be used for exercise prescription [41].

4. The next domain reflects severe-to-extreme-intensity exercise, with a tolerable exercise duration of less than 3 min.

Many recent studies have revealed inconsistencies between exercise intensity prescriptions based on the ventilatory thresholds and indicators derived from peak exercise parameters in cardiac patients [24,42,43]. Hence, position statements on aerobic exercise intensity have evolved over the last few years, and some concepts have been modified subsequently [25]. Hansen et al. compared the exercise training parameters measured at the first (VT1) and second (VT2) ventilatory thresholds with exercise intensity domains following the existing cardiac rehabilitation guidelines (% of peak oxygen uptake (% of peak VO_2), % of peak heart rate (% of peak HR), % of peak watts (% of peak W), and % of heart rate reserve (% of HRR)). A total of 272 cardiovascular disease patients performed a maximal cardiopulmonary exercise test on a bike (peak respiratory gas exchange ratio > 1.09). The VT1 and VT2 were determined and extrapolated to % of peak VO_2, % of peak HR, % of HRR, and % peak W. Surprisingly, the results revealed a significant discrepancy between individuals' response to exercise and the guideline-based exercise intensity domains. VT1 was noted at 62 $\pm$ 10% of peak VO_2, 75 $\pm$ 10% of peak HR, 42 $\pm$ 14% of HRR, and 47 $\pm$ 11% peak W, which corresponded, in fact, to the high-intensity-exercise domain (for % peak VO_2 and % of peak HR) or the low-intensity-exercise domain (for % of peak W and % of HRR). Inconsistency related to the VT2 was also noted at 84 $\pm$ 9% of peak VO_2, 88 $\pm$ 8% of peak HR, 74 $\pm$ 15% of HRR, and 76 $\pm$ 11% of peak W, corresponding to the high-intensity-exercise domain (for % of HRR and % of peak W) or the very-hard-exercise domain (for % of peak HR and % of peak VO_2). The use of % of peak W in only 63% and 72% of all patients for VT1 and VT2, respectively, corresponded to the same guideline-based exercise intensity domain, whereas it only corresponded in 48% and 52% of patients when using the % of HRR and % of peak HR, respectively. In particular, peak VO_2 was related to significantly different guideline-based exercise intensity domains [24].

4.4.3. Current Guidelines

Published statements on aerobic exercise intensity have recently been modified regarding previously reported inconsistencies [25]. The current recommendations emphasize optimizing total energy expenditure rather than one specific training feature (e.g., exercise intensity). Nevertheless, determining the exercise intensity in patients with cardiovascular diseases remains important for making exercise programs more time-efficient and achieving short-term clinical benefits. A personalized patient-centered approach should be utilized (with self-selected rather than imposed intensities regarding long-term adherence). Moreover, peak indices, such as peak oxygen uptake or heart rate, should be carefully applied. If CPET is performed, the assessment of the first and second ventilatory thresholds should be carried out for the determination of the aerobic exercise intensity in most patients with cardiovascular disease.

The talk test and Borg RPE scale should only be used as adjuncts to objective aerobic exercise intensity determination. Progression should be made with the targeted exercise session duration achieved before the exercise intensity is increased. Although cardiopulmonary exercise testing represents the gold standard in functional capacity assessment and exercise prescription, many cardiac rehabilitation centers still lack access to cardiopulmonary testing equipment. Thereby, for the EAPC, the minimum requirement is a cycle ergometry test, with the determination of the exercise intensity based on the % of peak workload or peak heart rate (considering all the described limitations), while the ultimate requirement would be to execute a CPET with the subsequent exercise intensity domain determined based on ventilatory thresholds [44]. Subsequent exercise intensity adjustment after 3 months based on CPET or ergometry is recommended [25].

Different exercise intensity domains for different groups of patients with cardiovascular disease have been recently suggested [21].

The Table 31 shows the initial exercise prescription by the AACVPR for cases without performed exercise test [1].

Table 31. Initial exercise prescription without exercise test.

Warm-up	Mode: Stretching and low-level calisthenics Duration: 5–10 min
Aerobic	Intensity: 2–4 METS, RPE 11–14 Duration: 20–30 min Frequency: 3–5 days/week Mode: walking, biking, range of motion exercises
Resistance	All major muscle groups.
Cool-down	Duration: 5–10 min

Abbreviations: AACVPR—the American Association of Cardiovascular and Pulmonary Rehabilitation; METS—multiples of resting metabolic equivalent; RPE—rating of perceived exertion. Source: Adapted from [1].

4.5. High-Intensity Interval Training

4.5.1. Concept of High-Intensity Interval Training

High-intensity interval training (HIIT) consists of alternating periods of intensive aerobic exercise with periods of passive or active recovery [45]. Recovery phases are usually of low intensity (below the first ventilatory threshold). HIIT was used by athletes for several decades [46,47] before it was applied in patients with coronary artery disease and chronic heart failure in the 1990s in Germany by Katharina Meyer [48,49]. Many studies show that significant physiological differences exist between exercising at a continuous moderate intensity versus HIIT. The greater utilization of carbohydrates during HIIT in comparison with MICT ultimately causes a greater increase in the mitochondrial content of the skeletal muscles. A substantial increase in the total time at high intensity will cause the skeletal muscles to be exposed more to intense exercise training. As expected, it has been demonstrated that HIIT enables exercise time to be maintained for longer periods in comparison with moderate-intensity continuous modes; hence, it has emerged as a promising alternative training method [50]. Moreover, it is postulated that patients may feel more confident performing HIIT, and they may find it an attractive form of training, as the protocol is more diverse than it is during a constant workload. In addition, in a study conducted by Wisloff, reverse left ventricular remodeling after HIIT was found [51].

4.5.2. HIIT Protocols

In practice, the prescription of HIIT is complex, allowing for an unlimited number of potential exercise/recovery interval combinations, with the operation of up to nine variables (work interval intensity and duration, recovery intensity and duration, exercise modality, number of repetitions, number of series, and between-series recovery duration).

The recovery phase is crucial and has a powerful impact on performance [50, 52]. The most applied HIIT model comprises 10 min of warm-up followed by four hard segments lasting for 4 min each at an intensity above the second lactate threshold (typically at 90% of peak HR), divided by 3 min recovery segments [53]. Passive recovery segments have an intensity below the first lactate threshold, and the intensity of active recovery segments is set beyond the first lactate threshold—i.e., at 70% of peak heart rate.

Guiraud et al. compared the use of different HIIT protocols for patients with CAD:

- Model A: 15 s active phase at 100% of maximal aerobic power/15 sec of passive recovery phase.
- Model B: 15 s active phase at 100% of maximal aerobic power /15 sec of active recovery phase (50% of maximal aerobic power).
- Model C: 1 min active phase at 100% of maximal aerobic power /1 min passive recovery phase.
- Model D: 1 min active phase at 100% of maximal aerobic power /1 min of active recovery phase (50% of maximal aerobic power).

All training models included 8 min of warm-up. As a result, the longest time to exhaustion was seen in model A and was significantly longer than in models B and D. In other words, short (15 s) bouts of high-intensity exercise with a passive recovery phase have emerged as the most effective. Moreover, model A showed superiority in terms of perceived exertion, patient comfort, and time spent above 80% of maximal oxygen uptake. Thus, passive recovery models seem to allow for the better utilization of energetic substrates [54].

The same group of researchers suggested HIIT as a strategy for CAD patients with preserved left ventricular ejection fraction and exercise tolerance > 5 METs, as follows:

Two introductory sessions at 60% of peak power output, subsequent progression to 80% of peak power output, and further progression to 100% of peak power output if well-tolerated. In the case of patients with reduced left ventricular ejection fraction, these researchers recommend beginning in continuous mode for at least 2 weeks (or 8–10 sessions), then progressing training to HIIT, as described above. Fifteen-second phases at 100% of maximal aerobic power interspersed with short phases of passive recovery have been well tolerated in patients with coronary artery disease [50,54]. In addition, the complete disappearance of clinical and ECG signs of ischemia has been observed, with no recurrence seen. This finding may mimic the phenomenon of ischemic preconditioning [55]. The use of successive phases of high-intensity exercise interspersed with periods of rest may favorably affect the myocardium. Recent studies conducted in animal models have demonstrated that intermittent ischemia provoked by HIIT results in the formation of collateral coronary vessels [56]. Many studies have demonstrated that HIIT can be an attractive alternative for patients with CAD and HF [57,58]. A popular HIIT protocol for heart failure individuals was introduced by Meyer, with the progression of the training occurring through the shortening of active phases with a concomitant intensity increase up to 80% of the maximal short-term exercise capacity. Exercise intensity has been characterized as the percentage of so-called maximal short-term exercise capacity (MSEC), while MSEC has been determined by utilizing the steep ramp cycle ergometer test. The most popular protocol incorporates 30 s exercise phases at 50% of MSEC and 60 s phases of active recovery (at 10 watts). The gradual shortening of exercise phases with concomitant increases in intensity (to 15 s at 70% of the MSEC, then to 10 s at 80% of the MSEC) has been used without changes in the recovery period [59].

4.5.3. HIIT versus Moderate-Intensity Continuous Exercise

In the last decade, debate has emerged as to whether HIIT is more effective than moderate-intensity continuous exercise (MICE) regarding improvements in functional capacity. In answer to this, multiple studies have been performed in cohorts of patients with coronary artery disease and in heart failure patients with a reduced or preserved left ventricular ejection fraction [60–62]. A meta-analysis evaluating 24 studies with over 1000 participants demonstrated a more significant improvement, of 1.4 mL/kg/min, in peak oxygen uptake after the use of HIIT compared to MICE. In an attempt to confirm these beneficial effects of HIIT, two large multicenter studies comparing HIIT versus MICE in patients with coronary artery disease (the SAINTEX-CAD study) and in patients with heart failure with reduced left ventricular ejection fraction (SMARTEX-HF) have been conducted. More than 200 patients with reduced left ventricular ejection fraction were included in the SMARTEX-HF study, and the SAINTEX-CAD study encompassed 200 patients with coronary artery disease and normal left ventricular ejection fraction. In contrast to earlier findings, SAINTEX-CAD and SMARTEX-HF demonstrated no superiority of HIIT versus MICE in terms of improving peak oxygen uptake [63,64]. The effect of HIIT has also been investigated in heart failure patients with preserved left ventricular ejection fraction [65]. HIIT has been found to induce a greater improvement in aerobic capacity in this group compared with MICE. These data, however, should be interpreted with caution due to the small study group used (19 patients). Further large studies appear to be necessary to confirm the beneficial effect of HIIT in this group. In summary, HIIT appears to be safe and non-inferior versus MICE in patients with coronary artery disease and in heart failure patients and incorporating HIIT may be beneficial for fostering long-term adherence to physical activity, as its interval nature appears to make it more attractive to patients. Larger trials are warranted to confirm optimal HIIT models and the groups of patients that should be targeted.

The idea of a combined approach—i.e., beginning with moderate-intensity continuous training, followed by a high-intensity interval approach—has been successfully implemented as presented in Figure 5 [66].

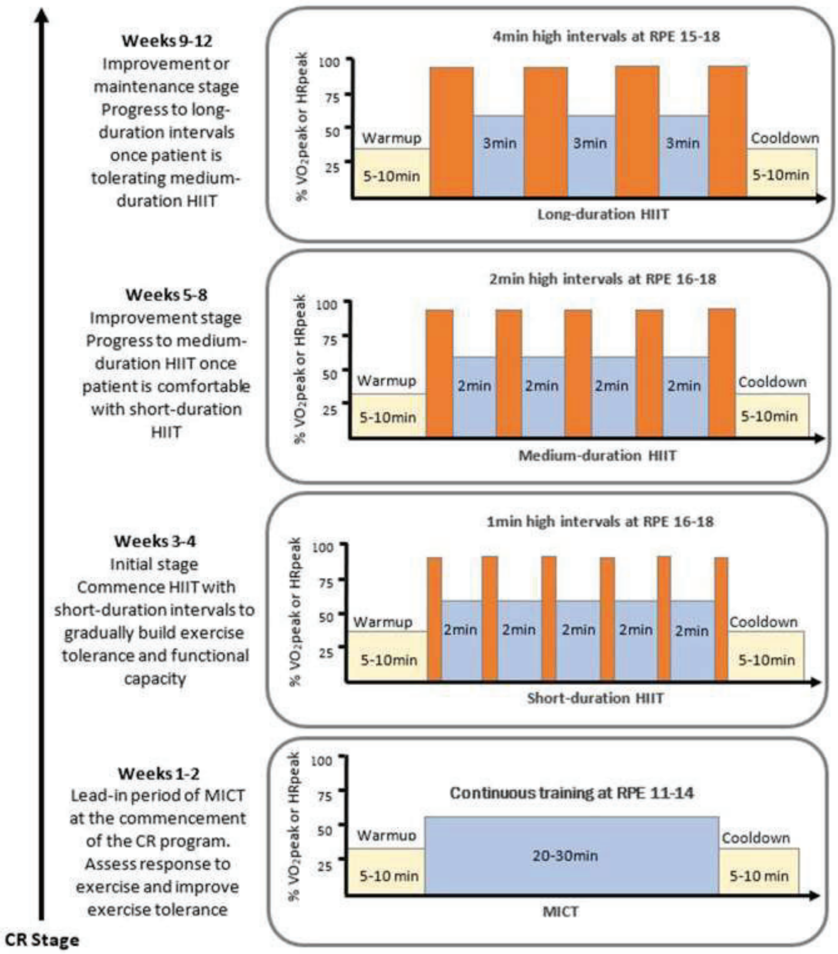


Figure 5. Progression of MICE into HIIT. Source: Reprinted from [66].

4.6. Aerobic Training Protocols

4.6.1. Introduction

Aerobic or cardiorespiratory training is rhythmic in nature and involves large muscle groups. There are two types of aerobic training: continuous and interval [1]. Currently available cardiac rehabilitation software provides for the following training modes [21,67]:

1. Continuous, load-controlled training: After a few minutes of warm-up, the load is constant, followed by a cool-down. Training intensity requires manual adjustment.

2. Interval load-controlled training: This involves blocks of active/hard and recovery phases. Training intensity requires manual adjustment.

3. Continuous, heart-rate-controlled training: This is the most advanced option. After setting the training heart rate range, the system automatically adjusts the exercise intensity to keep the programmed heart rate within this range.

Constant-workload exercise, up to 45–60 min, typically at moderate or moderate-to-high intensity, is currently the most widely recommended aerobic exercise modality.

Interval-mode exercise at low, moderate, or moderate-to-high intensity is usually conducted on leg cycle ergometers; typically, the intensity of the first few hard/active segments is reduced, allowing for an adequate warm-up. With a gradual increase in intensity over a few weeks, patients with good adaptation can be switched to steady-state exercise and subsequently to high-intensity interval training [21].

4.6.2. Parameters of Training Protocols

A. Leg cycle ergometer:

1. Continuous watt-controlled training.

Used in patients with good functional capacity. Stress testing using a cycle ergometer is preferred. Training intensity: 30% (40%)–80% of peak work rate/heart rate reserve.

2. Interval watt-controlled training.

Used in patients with low functional capacity (as low-intensity interval training) or patients with moderate-to-high- or high functional capacity (as moderate- or high-intensity interval training). Prior to training, a stress test on a cycle ergometer is recommended.

Training intensity:

- Active phases for low-intensity training, typically below 50% of maximal power from the bicycle test.
- Active phases for moderate-intensity training: above 50% (typically 50%–80%) of the peak work rate/heart rate reserve.
- Recovery phases 0 (0–10) watts for low-intensity or moderate-intensity training, called passive recovery.
- Recovery phases up to 50% of peak work rate for high-intensity training.

Phase duration:

- Duration of 30 s for active phases and 60 s for recovery phases for low-intensity training.
- Duration of hard/active phases of 1–4 min and recovery phases of 1–3 min for high-intensity interval training.

3. Continuous, heart-rate-controlled training.

Preferable for patients with good functional capacity. Training intensity: 30%–70% of heart rate reserve.

B. Treadmill:

1. Continuous MET-controlled training.

Suitable for patients with good or very good functional capacity. Training intensity is typically up to 70% of MET reserve, with a resting MET equal to 1.

2. Interval MET-controlled training.

Suitable for patients with moderate or high functional capacity. Training intensity:

- Active phases typically between 50% and 80% of heart rate reserve/MET reserve.
- Recovery phases with a treadmill speed of 1–2 km/h as passive recovery, with an intensity below 50% of the heart rate reserve/MET reserve in the case of active recovery.

Active phase durations of 2–4 min and recovery phase durations of 1–3 min are recommended.

3. Continuous heart-rate-controlled training.

Used in patients with good functional capacity. Training intensity: up to 70% of heart rate reserve.

4.6.3. Training Protocols in Practice

Cardiac rehabilitation is commonly divided into either three or four phases, with the content of these phases varying across different countries [68]. The recommended exercise intensity varies significantly between countries, from light-to-moderate intensity (e.g., in Australia) to moderate intensity (in the United Kingdom). The European Association of Preventive Cardiology endorsed the exercise prescription principle in relation to the patient's risk [2]:

A. Low-risk patients.

Low-risk patients encompass patients who have undergone elective percutaneous coronary intervention, have an uncomplicated course of acute coronary syndrome, have primary PCI, have undergone coronary artery bypass grafting, or have undergone valve surgery.

Characteristics of low-risk patients [2]

- Clinical stability (CCS 0, NYHA I, no complex arrhythmias documented);
- Exercise capacity > 50% of the predicted value.
- Normal left ventricular function;

- No signs of residual ischemia—i.e., after complete revascularization, without diffuse coronary disease;
- Controlled arterial hypertension;
- Absence of comorbidities such as chronic kidney disease, chronic obstructive pulmonary disease, or diabetes mellitus;
- No cardiac electrical devices implanted.

Cardiac rehabilitation programs can be provided in the form of early outpatient or home-based programs or as a combination of both approaches. Prior to commencing exercise training, a symptom-limited exercise test should be performed. If the low-risk characteristics of the patient are obvious, no cardiopulmonary test is necessary. The testing modality should preferably match the exercise modality. Thus, bicycle exercise testing should be used for patients with walking problems and if exercise training on a bicycle is planned. A ramp protocol starting at 20–50 watts with an increase of 10–20 watts per min is recommended [9]. Treadmill testing is suitable for obese patients with sitting problems in the case of patients with rate-adaptive cardiac pacemakers and when treadmill exercise training is planned. Aerobic training modalities for low-risk patients include walking, walking with a stick (known as Nordic walking), or training on a stationary bicycle. Exercise regimens for deconditioned patients start with 10 min of very-light-/light-intensity training, whereas patients with good functional capacity can begin with 20 min of light-to-moderate-intensity sessions. Continuous-mode training is suitable for very-light-, light-, and moderate-intensity training, whereas high-intensity training should be performed in interval mode [69]. Moderate-intensity continuous exercise (MICE) is typically recommended for low-risk patients, and the intensity can be enhanced with the toleration of the training load—i.e., with a lower heart rate and/or rate of perceived exertion for the same load. Further transition to a high-intensity interval protocol can be implemented for selected patients [2].

B. High-risk patients

The definition of a high-risk patient encompasses patients with:

- Symptoms of advanced disease—i.e., dyspnea, NYHA class II–III, or hypotension.
- Arrhythmias (e.g., atrial fibrillation, non-sustained ventricular tachycardias);
- Signs of pleural or pericardial effusion;
- Frailty;
- Poor exercise capacity (<50% of the predicted value);
- Clinical manifestation of comorbidities.

These patients should manifest clinical stability prior to commencing supervised exercise training program to minimize the risk of left ventricular decompensation and complex ventricular arrhythmias. Exercise training for high-risk patients can be delivered as early outpatient or residential programs [4].

Cardiopulmonary exercise tests are recommended for all patients with advanced heart failure to determine exercise intensity in relation to their ventilatory threshold. Diagnostic stratification for patients with heart failure based on CPET-derived parameters has been widely described [15].

Cardiopulmonary exercise testing-derived parameters represent the best basis for exercise prescription. As discussed earlier, exercise intensity zones corresponding to a recovery zone, a light-to-moderate-intensity exercise zone, and a high-intensity exercise zone have been identified.

Cardiopulmonary exercise testing has limited availability; therefore, alternative methods for guiding exercise prescription—i.e., methods based on heart rate and subjective indices such as the Borg scale or talk test have been used. The biggest limitation of the heart-rate-based approach, however, remains the possible impact of chronotropic incompetence or medications that lower the heart rate. Exercise training principles for high-risk patients include the use of low-intensity interval training, moderate-intensity continuous training, or a high-intensity interval approach [12]. The low-intensity interval mode on a bicycle allows precise load changes, and the use of hard and recovery segments of 30 and 60 s duration, respectively, is suggested. The initial intensity of the hard segments should not surpass 50% of the maximum Watts attained during the incremental bicycle test. After a few weeks of well-tolerated training progression, a continuous workload can be implemented. Continuous moderate-intensity exercise is the most popular mode of training executed in cardiac rehabilitation centers, with the intensity set between ventilatory thresholds, or between 50% and 80% of the heart rate reserve. For selected patients with very good physical capacity and good tolerance of steady workloads, a high-intensity interval mode can be offered [55,57].

4.6.4. The Authors' Approach

The authors endorse the "ABCD" exercise training model proposed by Rudnicki for different groups of patients stratified by risk. This model provides a meticulous exercise training prescription for four separate training groups of patients as exhibited in Table 32.

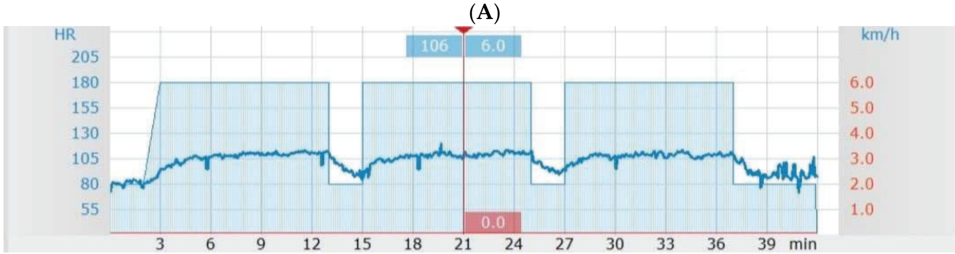
Table 32. Aerobic exercise training models proposed by Rudnicki.

Model	Risk	Functional Capacity	Exercises	Frequency	Intensity
A	Low	Good >7 METS >100 W	Aerobic continuous	3–5 days/week	60%–80% of HRR
B	Intermediate	Good and intermediate >5 METS >75 W	Aerobic continuous for good capacity or interval for intermediate capacity	3–5 days/week	50–60% of HRR
C	Intermediate High	Low 3–5 METS 50–75 W Good >6 METS >75 W	Aerobic interval or continuous (5–10 min)	3–5 days/Week	40%–50% of HRR
D	Intermediate High	Very low <3 METS <50 W Intermediate, low, and very low <6 METS <75 W	Individual exercises	3–5 days/week 2–3/day	Resting HR+10–15%

Abbreviations: HR—heart rate; HRR—heart rate reserve; METS—multiples of resting metabolic equivalent; W—watts. Source: Adapted from [70].

The D model is assigned for patients at the highest risk and with the lowest functional capacity; therefore, individual training is applied with an acceptable heart rate increase of up to 20 bpm above resting heart rate. This model is used by the authors in patients who are unable to perform exercise testing. Typically, patients progress from moderate- to vigorous-intensity aerobic endurance exercise over the course of the program. The authors initially implemented a moderate-intensity interval training protocol (MIIT) on treadmills or cycle ergometers. Further progression to moderate-intensity interval-to-continuous (MIITC), or steady-state exercise (MICE) was implemented a few weeks after the patient's adaptation to the current workload (Figure 6).

(**A**)



(**B**)

Figure 6. Training progression model from moderate-intensity interval training (**A**) to moderate-intensity interval-to-continuous training (**B**) conducted at the authors' center. Source: Figure by authors.

A summary of the exercise prescription progression suggested by the European Association of Preventive Cardiology and the modified approach developed by the authors is provided in Table 33.

Table 33. Exercise training progression.

Patient's Risk	Initial Protocol	Final Protocol
Low-risk patients	EAPC: MICE Authors: MIIT	EAPC: MICE/HIIT * Authors: MIITC/HIIT *
High-risk patients	EAPC: LIIT Authors: LIIT/MIIT	EAPC: MICE/HIIT * Authors: MIITC/MICE

Abbreviations: EAPC—the European Association of Preventive Cardiology; HIIT—high-intensity interval training; LIIT—low-intensity interval training; MICE—moderate-intensity continuous exercise; MIIT—moderate-intensity interval training; MIITC—moderate-intensity interval-to-continuous. *—in selected patients. Source: Table by authors.

4.7. Training Heart Rate in Practice

The adequate prescription of exercise training results in heart rate reduction, both at rest and at any given workload [21]. This physiological principle serves in a practice as a strong indicator of maximal aerobic fitness improvement. As discussed in detail earlier, an optimal exercise prescription principle should be based on the extrapolation of the percentage of the cardiopulmonary test-derived indices into corresponding heart rate values [25]. The limited availability of CPET, however, results in utilizing an alternative approach for training heart rate calculation. Training heart rate can be determined in a few steps [8]:

1. Maximal heart rate is calculated from a symptom-limited stress test or by age-related formulas (e.g., 220-age, Tanaka, Inbar). Note that the "220-age" formula underestimates the maximal heart rate in patients over the age of 45, as demonstrated in Table 34.

Table 34. Maximum heart rate calculation formulas.

Age	220-Age	Inbar	Tanaka
20	200	192	194
30	190	185	187
40	180	178	180
50	170	172	173
60	160	165	166
70	150	158	159
80	140	151	152

Source: Adapted from [8].

2. In cases where no exercise test is performed, subsequent heart rate deduction is required if the patient is on beta-blocker therapy. Beta blockade blunts heart rate response and thus affects the maximal heart rate. There is no consensus as to how much should be deducted from the maximal heart rate in the case of beta blockade [71,72]. The authors of this publication deduct between 10 and 30 bpm depending on the beta-blocker dose [8].

3. The next step is to determine the heart rate reserve using the Karvonen formula [1,12], considering HR max from the symptom-limited test or from the age-based formula after potential beta-blockade correction.

$$\text{training heart rate} = ((\text{HR max} - \text{resting HR}) \times \%\ \text{required}) + \text{resting HR}$$

For patients with heart failure, Keteiyan established a separate formula [73]:

$$119 + (0.5 \times \text{resting heart rate}) - (0.5 \times \text{age}) - (0 \text{ if test on treadmill}/5 \text{ if bike}).$$

When utilizing Keteiyan's formula, there is no need for beta-blockers to be considered.

The use of heart rate calculations in practice has been demonstrated below:

Example 1. *A 50-year-old male patient underwent a symptom-limited stress test. A resting heart rate of 60 bpm was recorded, and the patient attained a maximal heart rate of 140 bpm. The test was terminated due to fatigue.*

Heart rate reserve = 140 − 60 = 80 bpm. Planned exercise intensity of 40–50% of heart rate reserve. Thus, 40% of 80 is 32, and 50% of 80 is 40. These values should be added to the resting heart rate (60 + 32 = 92, 60 + 40 = 100), giving a recommended training heart rate range of between 92 bpm and 100 bpm.

Example 2. *A 60-year-old female patient on beta-blocker therapy (low dose of beta-blockers) with a resting heart rate of 70 bpm. An exercise test on a treadmill was terminated prematurely due to pain in the left knee. A bicycle exercise test was unavailable. The planned exercise training intensity was 50–60% of the heart rate reserve. The maximal heart rate calculated by the Inbar equation was 160 bpm (220-age). As a next step, 10 bpm was deducted due to the use of beta-blockers in her therapy. Thus, a maximal heart rate of 150 bpm as calculated (220 − 60 = 160, and 160 − 10 = 150 bpm). Heart rate reserve = maximal predicted heart rate minus resting heart rate—i.e., 150 − 70 = 80 bpm. The planned exercise intensity was 50%–60% of the heart rate reserve; therefore, 80 × 50% = 40, and 80 × 60% = 48. Considering her resting heart rate, a training heart rate range between 110 and 118 bpm should be applied (70 + 40 = 110, 70 + 48 = 118).*

Example 3. *A 70-year-old male patient with heart failure and a resting heart rate of 80 bpm. A stress test on a treadmill utilizing the Naughton protocol was terminated early (after 30 s) due to fatigue. The maximal attained heart rate of 95 bpm was documented at the test termination.*

Planned initial training heart rate of 40% of heart rate reserve. Maximal heart rate calculation according to Keteiyan's formula:

$$\textit{maximal heart rate} = 119 + (0.5 \times 80) - (0.5 \times 70) - 0 = 124 \text{ bpm}$$

Heart rate reserve calculation: 124 − 80 = 44. A planned training heart rate of 97 bpm was calculated (44 × 40% = 17, 80 + 17 = 97).

4.8. Resistance Training

4.8.1. Rationale

Resistance training has been implemented relatively late both for healthy individuals and especially for patients with cardiovascular diseases. Firstly, in 1990 the American College of Sports Medicine recommended resistance training as an important component of fitness programs for healthy adults. Concerns regarding the safety of resistance training (including potential complications—e.g., uncontrolled rises in blood pressure) precluded the early implementation of strength exercise components into cardiac rehabilitation. Notwithstanding the concerns mentioned above, a growing body of evidence suggests that improved muscular strength is associated with significantly better cardiometabolic risk factor profiles [74]. Consequently, improvements in the blood glucose level and insulin sensitivity have been demonstrated, and resistance training in the elderly has been shown to result in the promotion of independence and the prevention of falls [75,76]. Other favorable effects of strength exercise have been confirmed in the case of patients with muscle wasting following cardiac surgery and patients with heart failure and weakness in their peripheral muscles [77,78]. Furthermore, it has been demonstrated that resistance training has favorable effects on bone density, blood pressure, and lipid profile [79].

4.8.2. Contraindications

Contraindications to resistance training include [75]:
Absolute contraindications:

- Unstable coronary heart disease;
- Decompensated heart failure;
- Uncontrolled arrhythmia;
- Severe pulmonary hypertension;
- Severe, symptomatic aortic stenosis;
- Acute myocarditis, pericarditis, endocarditis;
- Uncontrolled hypertension > 180/100 mmHg;
- Aortic dissection;
- Marfan syndrome;
- Active proliferative retinopathy (for high-intensity resistance training);
- Intracardiac thrombus.

Relative contraindications:

- Uncontrolled hypertension > 160/100 mmHg;
- Low functional capacity < 4 METs;
- Musculoskeletal limitations.

Resistance training should be stopped in cases of:

- Chest pain;
- Dyspnea;
- Significant fatigue;
- Dizziness;
- Heart rate exceeding upper limit planned;
- Decrease in heart rate;

- Lack of increase or decrease in blood pressure, with symptoms (angina, dyspnea, fatigue);
- Increase in systolic blood pressure of >200 mmHg and/or diastolic blood pressure of >110 mmHg.

4.8.3. Recommendations

Equipment for resistance training typically includes:

- Free weights (barbells, dumbbells, medicine balls);
- Weight machines;
- Elastic bands.

An initial intensity of 30–40% of 1-RM for upper body and 50–60% of 1-RM for the lower body is recommended. The general recommendations for resistance training according to the American College of Sports Medicine (modified) are given in Table 35 [12].

Table 35. ACSM resistance training recommendations.

Frequency	2–3 days/week
Intensity	60%–70% of 1-RM (moderate to vigorous intensity) for beginners to improve strength; 40%–50% (very light to light intensity) of 1-RM for older patients beginning exercise to improve strength, as well as for sedentary individuals beginning a resistance program; <50% (light to moderate intensity) of 1-RM to improve muscular endurance; 20%–50% of 1-RM in older adults to improve power
Time	Not specified for effectiveness
Type	Involving each major muscle group Targeting agonists and antagonists
Repetitions	8–12 to improve strength 10–15 to improve strength in older patients 15–20 to improve muscular endurance
Sets	2–4 for most adults 1 set can be effective for older patients
Pattern	Rest of 2–3 min between each set of repetitions Rest > 48 h between sessions
Progression	Gradual (greater resistance or more repetitions or increasing frequency)

Abbreviations: ACSM—American College of Sports Medicine; 1-RM—one repetition maximum. Source: Adapted from [12].

The AACVPR and ACSM recommendations for the commencement of resistance training and acceptable load are summarized in Table 36 [1,12].

Table 36. Commencement of resistance training and acceptable load.

Diagnosis	AACVPR	ACSM
CABG	Beginning 5 weeks after surgery and following 4 weeks of an aerobic program 1–3 lb. (0.5–1.5 kg) hand weights on program entry. Upper body resistance training is included after 3 months.	1–3 lb. (0.5–1.5 kg) during convalescence and recovery. A range of motion exercises is included 24 h after CABG, with typical upper body resistance training starting 3 months after surgery.
MI	Begins with 1–3 lb. (0.5–1.5 kg) on program entry. Upper body resistance training is included 5 weeks after MI if 4 weeks of an aerobic program are completed.	1–3 lb. (0.5–1.5 kg) hand weights are used 2 weeks after MI. Range of motion exercises begin at 48 h after MI. Typical upper body resistance training commences at 4–6 weeks.
PPM	No specific guidelines	Patients must avoid raising their arm on the PPM side above shoulder for 2 weeks.

Abbreviations: AACVPR—American Association of Cardiovascular and Pulmonary Rehabilitation; ACSM—American College of Sports Medicine; CABG—coronary artery bypass graft surgery; MI—myocardial infarction; PPM—permanent cardiac pacemaker. Source: Adapted from [1,12].

Resistance training can be implemented a few weeks after myocardial infarction (after at least 1 week of well-tolerated aerobic training); however, it should be postponed following cardiac surgery until full sternum stability—i.e., for 3 months. In the case of individuals with a very low functional capacity or muscular atrophy, resistance training should commence simultaneously or before the aerobic component to increase muscle power. Resistance training can be performed as an independent session or may be used as part of warm-up or cool-down phases. Sessions should be performed 2–3 times a week with at least 48 h separating training for the same muscle groups [80].

Considering the findings of recent studies, high-intensity dynamic strength training is recommended, as it leads to greater muscle strength improvement than low-intensity exercise, and, if executed properly, has been demonstrated as safe [81]. It has been postulated that dynamic high-intensity resistance training elicits enhanced myofibrillar protein synthesis, subsequently leading to greater gains in muscle mass compared to dynamic low-intensity training [82,83].

4.8.4. Strength Testing

Strength testing prior to the commencement of resistance training enables appropriate load assessment. Typical approaches to determining appropriate resistance training intensity include [8]:

- Maximal strength test, which has not been recommended recently due to safety reasons;
- Graded stress test (estimated % of 1-RM), based on load–repetition relationship [84]:

60% of 1-RM = 17 repetitions possible;
70% of 1-RM = 12 repetitions possible;
80% of 1-RM = 8 repetitions possible;
90% of 1-RM = 5 repetitions possible;
100% of 1-RM = 1 repetition possible.

Based on recent studies, for a precise 1-RM estimation, the use of no more than 10 repetitions has been suggested during strength testing [84]. In addition, the rating on the perceived exertion scale can be a valuable adjunct to control the intensity of resistance training [85].

To facilitate load estimation, dedicated equations for 1-RM estimation from multiple RM tests have been proposed [86,87]—e.g., 1-RM = $(1 + 0.0333 \times \text{repetitions}) \times$ applied weight.

Typically, 8–12 repetitions improve muscle strength, whereas 15–20 repetitions improve endurance.

4.8.5. Strength Training

Prior to the commencement of strength training, preliminary instruction should be given regarding the appropriate weight loads, adequate lifting technique, range of motion for each exercise, and appropriate breathing pattern. Progression should be achieved by increasing the number of repetitions and training intensity and shortening the rest period.

A resistance training circuit should include [12,83]:

- Chest press;
- Shoulder press;
- Triceps extension;
- Biceps curl;
- Pull-down (upper back);
- Lower back extension;
- Abdominal crunch;
- Quadriceps extension or leg press;
- Calf raise.

Patients with cardiovascular diseases should complete such training in 15–20 min. Exercise with a hand raised above shoulder level is not recommended for a patients recently after cardiac surgery (for a three months) and for an individuals with heart failure. Typical resistance training for major muscle groups is demonstrated below (Figures 7–13).

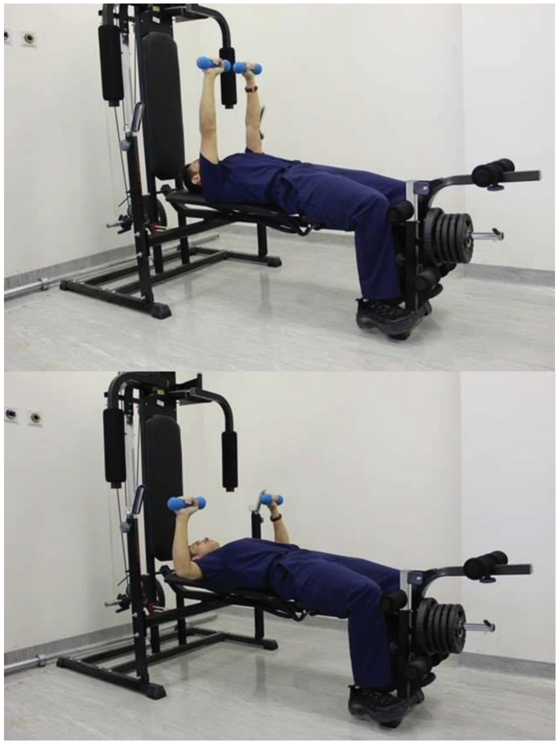


Figure 7. Chest press. Source: Photos by authors.

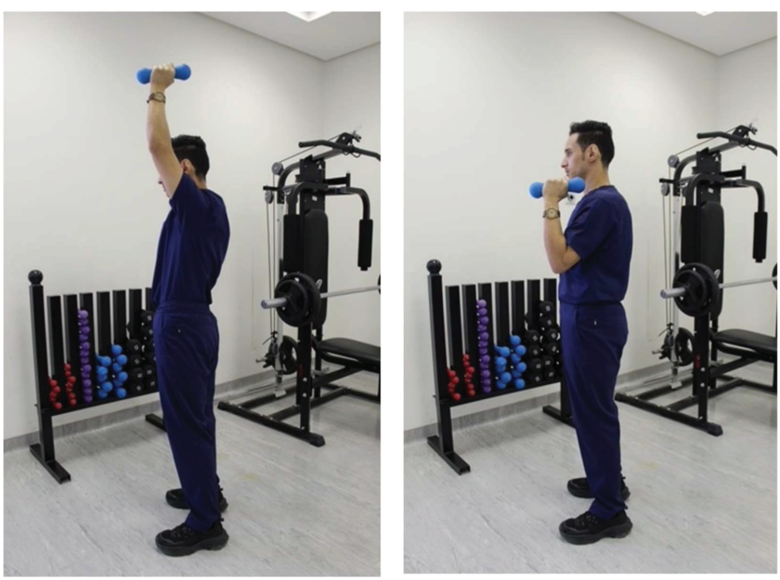
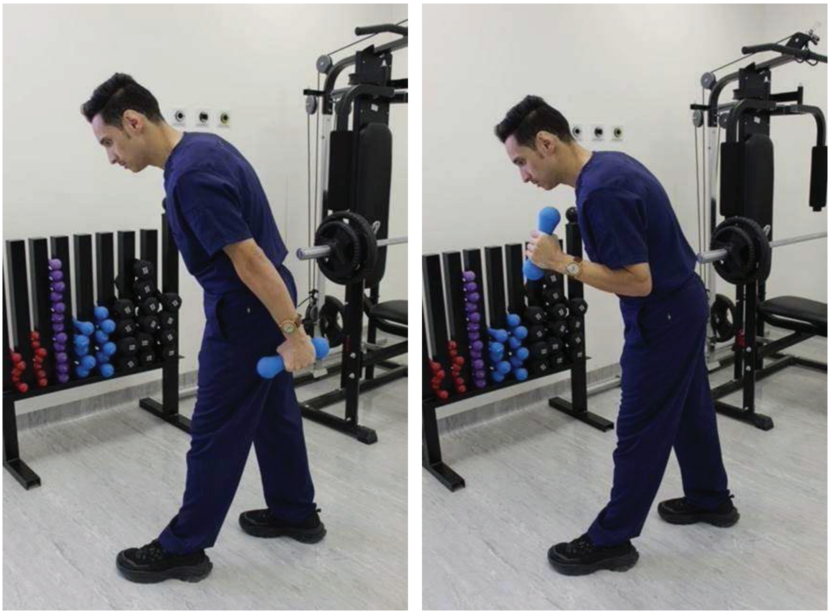
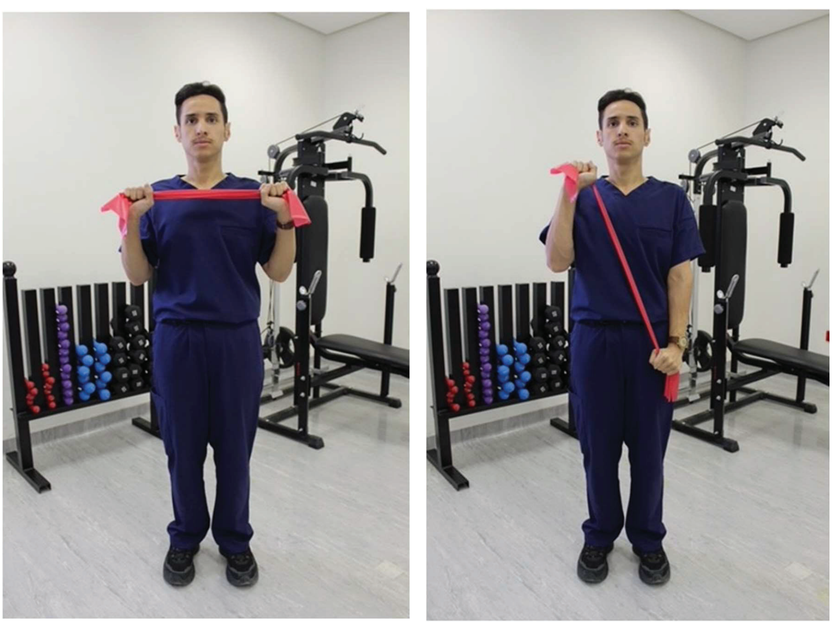


Figure 8. Shoulder press. Source: Photos by authors.



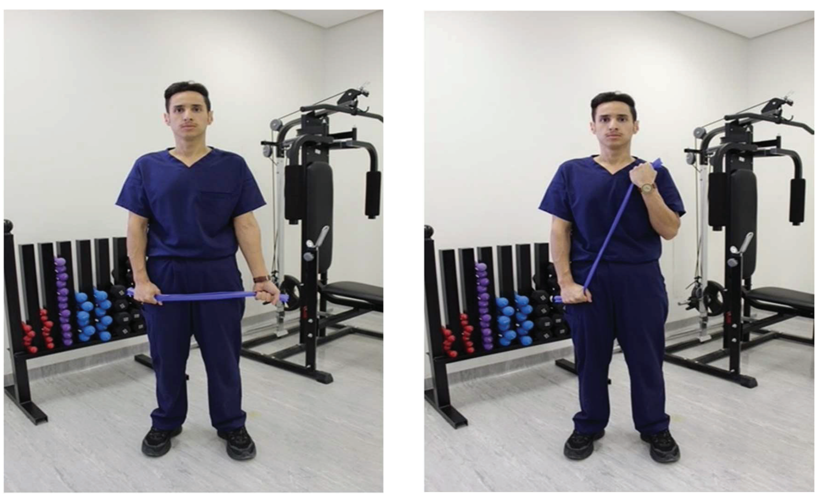
(**A**)



(**B**)

Figure 9. Triceps extension (**A**); triceps extension with Thera-band (**B**). Source: Photos by authors.

(**A**)



(**B**)

Figure 10. Biceps curl (**A**); biceps curl with Thera-band (**B**). Source: Photos by authors.

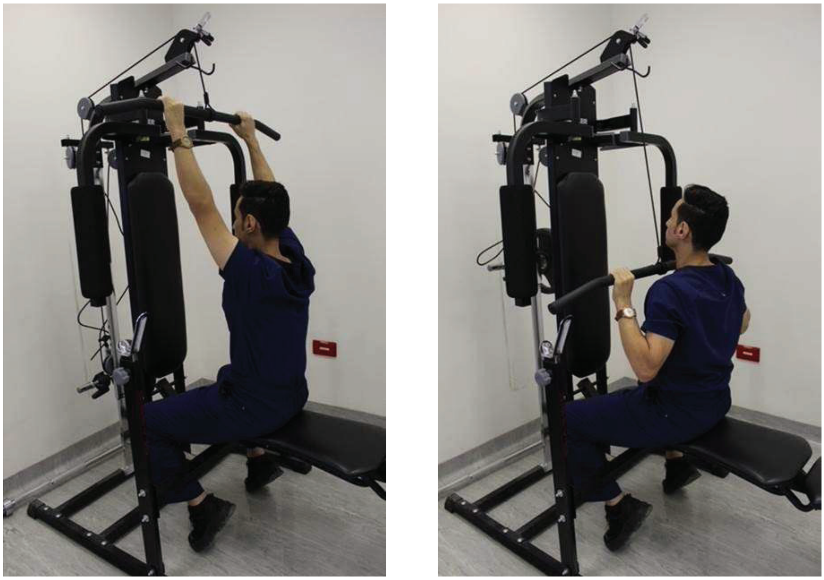


Figure 11. Pull-down (upper back). Source: Photos by authors.

(**A**)

Figure 12. *Cont*.

(**B**)

Figure 12. Quadriceps extension (**A**); quadriceps extension with Thera-band (**B**). Source: Photos by authors.

Figure 13. Calf raise. Source: Photos by authors.

General rules for resistance training performance include [88]:

- Lifting weights in a rhythmic manner through a full range of motion;
- Lifting load at a moderate to low speed;
- Alternating between upper and lower body exercises;
- The use of a proper posture;
- Avoidance of gripping weights and holding breath (exhaling during exertion and inhaling during the relaxation phase is recommended);
- Training opposite muscles.

It is crucial to train opposite muscle groups, e.g., through low back extension and abdominal crunches, or leg presses and leg curls, to exercise quadriceps and hamstring muscles. Such an approach minimizes the risk of injuries due to muscle imbalance.

Holding one's breath during muscle contraction induces a Valsalva maneuver—i.e., a sudden rise in venous return, thus leading to an uncontrolled increase in blood pressure.

4.8.6. Training Progression Utilizing OMNI Scale

During the early stage of resistance training, emphasis is placed on practicing good technique to reduce the risk of injuries. Initial load should be set at a level where it is possible to achieve the number of repetitions prescribed without straining—e.g., <40% of one repetition maximum. The same recommendation applies to patients with frailty [89]. Training progression can be achieved by increasing the load, repetitions, or number of sets, or by reducing the amount of rest between sets. In practice, an increase in repetitions is recommended before an increase in weight. Once the upper range of expected repetition is achieved, load may be increased by 5% [88].

The OMNI-RES scale was developed to facilitate strength training progression and can be utilized to track the perceived intensity during strength training [89,90]. The OMNI-RES scale includes visual, numerical, and verbal perceptual exercise intensity descriptors from "extremely easy" (0 points) through to "easy" (2 points), "somewhat hard" (6 points), "hard" (8 points), and "extremely hard" (i.e., 10 points). Gearhart et al. demonstrated the effectiveness of the use of this scale in the elderly for tracking the strength changes from a resistance exercise program using RPE from the OMNI-RES [91,92]. The OMNI-RES scale can also be a useful tool for a resistance training beginner, as it provides a simple and subjective intensity guide. There is a need, however, for a periodic evaluation to accurately adjust the program intensity. In view of this, the <10 RM test can be used once every few weeks. Moreover, a growing body of evidence supports the idea of a shift into functional strength training during phase III of cardiac rehabilitation and focusing on the muscle groups needed for the activities of daily living [25].

4.9. Flexibility Training

Flexibility has been described as the intrinsic ability of body tissue to move a joint through its complete range of motion without causing injury [12]. In practice, it is executed by sports participants and plays a key role in performing the activities of daily living (e.g., reaching, turning). Many factors impact the range of motion, including the distensibility of the joint capsule, whether an adequate warm-up has been used, and muscle viscosity. Moreover, level of physical condition, age, and training parameters also affect flexibility performance [93]. Flexibility training (stretching) is typically recommended 2–3 times a week and should involve the shoulder girdle, neck, trunk, lower back, hips, and legs (Figures 14–17).

Figure 14. Upper back stretch. Source: Photos by authors.

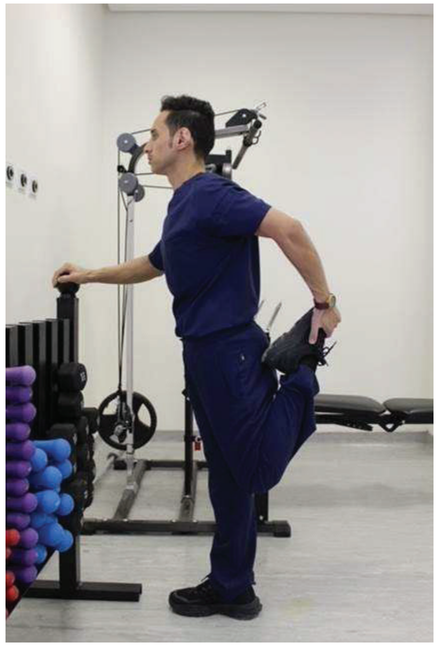


Figure 15. Quadriceps stretch. Source: Photo by authors.

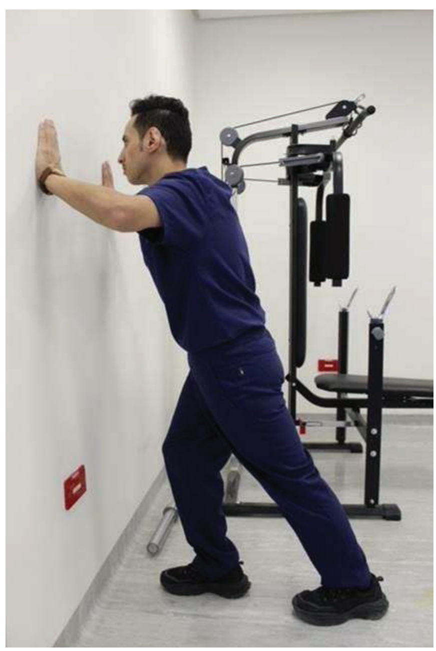


Figure 16. Calf muscle stretch. Source: Photo by authors.

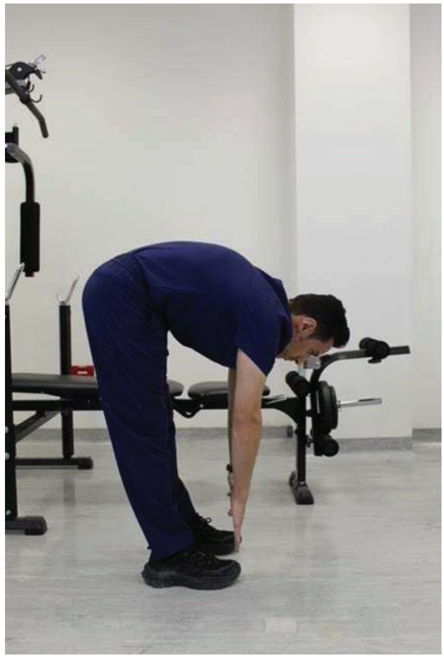


Figure 17. Hamstring muscle stretch. Source: Photo by authors.

Stretching a chest is contraindicated for a three months after cardiac surgery. There are several types of flexibility exercises (dynamic, static proprioceptive neuromuscular facilitation stretches). Active static stretching is executed by holding a position using the contraction of agonist muscle(s), whereas during passive static stretching the position is held without the involvement of agonist muscles—e.g., using another person or a stretching aid. During dynamic stretching, stretching is performed with a slow movement, and, through repeated movements, a progressive increase in the range of motion is attained. The proprioceptive neuromuscular facilitation technique includes an isometric contraction component (20–70% maximal voluntary contraction held for a few seconds), followed by a 10–30 sec static stretch. During flexibility training, one stretch is typically held for 10–30 s to the point of tightness or slight discomfort [8,12]. Holding a stretch for 30–60 s may be more beneficial in older patients [1,12]. Typically, stretching sessions last for 10–15 min. It is important to perform flexibility training after warm-up when the muscle temperature is increased. As stretching may result in an immediate, short-term muscle strength decrease, a flexibility session should not be directly performed prior to resistance training. Regular stretching has been shown to help prevent musculotendinous injuries [94].

The ACSM and AACVPR flexibility recommendations are summarized in Tables 37 and 38.

Table 37. ACSM flexibility training recommendations [12].

Frequency	2–3 days/week
Intensity	Holding to the point of tightness
Time	10–30 s for stretch Up to 60 s in older individuals
Type	Static, dynamic, ballistic, proprioceptive neuromuscular facilitation
Volume	60 s for each exercise
Pattern	2–4 repetitions
Progression	Unknown

Source: Adapted from [12].

Table 38. AACVPR flexibility training recommendations [1].

Intensity	Holding to the point of mild discomfort (but not pain)
Duration	Gradual increase to 30 s, then, if tolerable, to 90 s for each stretch Up to 5 repetitions for each exercise
Frequency	2–3 nonconsecutive days/week
Type	Static, with a major emphasis on the lower back and thigh regions

Abbreviations: AACVPR—American Association of Cardiovascular and Pulmonary Rehabilitation. Source: Adapted from [1].

4.10. Neuromotor Training

Neuromotor training comprises balance, gait, and coordination exercises. Examples of such training are standing with the feet together or on one leg; displacing the body mass center—e.g., by stepping over an obstacle; or walking with closed eyes in order to limit visual or proprioceptive feedback [12]. It has been demonstrated that neuromotor exercise improves control of posture by challenging the alignment of the body's center of gravity regarding the feet [95]. Such training should be applied to the elderly, as with age changes in the neuromuscular system negatively affect static and dynamic postural control and has also been demonstrated in healthy older adults [96]. Neuromotor training should be performed 2–3 times a week. There is no consensus regarding the optimal duration or number of repetitions; however, a total duration of at least 60 min per week is recommended [12]. A summary of ACSM neuromotor training recommendations is provided in Table 39.

Table 39. ACSM neuromotor training recommendations [12].

Frequency	2–3 days/week
Intensity	Not determined yet
Time	>20 min/day
Type	Involving balance, gait agility, coordination
Volume	Unknown
Pattern	Unknown
Progression	Unknown

Abbreviations: ACSM—American College of Sports Medicine. Source: Adapted from [12].

Tai chi is a traditional Chinese mind–body exercise that has been practiced for many centuries; it has been called "meditation in motion" due to its slow movements with simultaneous deep breathing [97–99]. The movements are typically circular and performed during muscle relaxation. Tai chi has emerged as a promising exercise, and, considering recent studies, it has been suggested as a suitable training mode for the elderly. Reductions in the risk of falls, balance improvement, enhancement of range of motion, and improved quality of life following tai chi training have been documented [100]. Tai chi training for older patients entails performing progressively more difficult postures, reducing the base of support (through a semi-tandem stand, tandem stand, one-legged stand), heel stands, toe stands, and standing with closed eyes. Tai chi has been demonstrated to be safe and efficacious in patients following myocardial infarction or coronary artery bypass graft surgery, with in patients with stable heart failure, and following a stroke. Moreover, a reduction in the resting and post-exertional blood pressure and decrease in the blood glucose level following tai chi exercises have also been described [101,102].

4.11. Relaxation Training

Permanent stress negatively affects the cardiovascular system and may be responsible for increased heart rate, elevated blood pressure, increase in respiratory rate, muscle tension, sleeplessness, and emotional problems [103]. These detrimental effects of stress can be counterbalanced by relaxation techniques, such as deep breathing or meditation [104] Relaxation techniques have been proven efficacious in reducing the respiratory rate, heart rate, and blood pressure; alleviating muscular tension; and improving sleep pattern, thus positively affecting well-being [105]. Thus, relaxation techniques have been incorporated in cardiac rehabilitation to induce an effective improvement in mood [106].

The most popular relaxation techniques utilized in cardiac rehabilitation are deep breathing, cardiac yoga, and music therapy.

Indian-origin Yoga is characterized as a combination of specific body postures (so-called asanas) and associated breathing techniques, with almost 100 asanas still being utilized. A deep breathing pattern with the use of the abdominal muscles and the diaphragm is followed by breath hold in full inspiration and is continued as slow and spontaneous exhalation [107]. The efficacy of cardiac yoga in the primary and secondary prevention of ischemic heart disease and post-myocardial infarction rehabilitation has been extensively studied. Interestingly, practicing yoga induces an antihypertensive effect, enhanced heart rate variability, reduction in serum total cholesterol and triglyceride, and significant improvement in cardiovascular fitness [108–110]. There is no consensus regarding the duration and frequency of relaxation techniques; however, most forms of relaxation are practiced for more than 20 min once or twice daily [111]. Yoga appears to be an efficacious alternative technique suitable for patients with cardiovascular disease, especially for those not adhering to conventional exercise. More research is needed to assess the beneficial effects of yoga in the primary and secondary prevention of cardiovascular disease.

4.12. Training Safety

Beneficial effects of cardiac rehabilitation have been demonstrated, including a significant reduction in cardiac mortality by 26–36% in patients after myocardial infarction [112]. Exercise testing and training can, however, trigger an exercise-induced cardiac response with, e.g., subsequent ischemia, complex arrhythmia, or heart failure decompensation [113]. In the light of published studies, appropriately conducted exercise training is safe. The risk of major adverse events during exercise sessions is very low, with the reported occurrence of cardiac arrest, myocardial infarction, and fatal events being 1 per 116,906, 1 per 219,970, and 1 per 752,365 patient-hours of training, respectively [114]. The highest rate of complications was observed in patients diagnosed with coronary artery disease. Furthermore, the mortality was six times higher in the case of exercise facilities without the ability to promptly manage cardiac arrest [115]. In view of the potential complications, the importance of a pre-training cardiovascular risk assessment, including detailed medical history, physical examination, and scrupulous electrocardiogram monitoring during exercise testing, can clearly be seen. Thus, it is essential to comply with a safety principle during exercise testing and training through [1,8]:

- Symptom control;
- Physical examination;
- Employing talk test;
- Appropriate training progression utilizing RPE scale and control of vital signs;
- Adequate training supervision and monitoring.

The guidelines of the American Association of Cardiovascular Prevention and Rehabilitation specify a minimum number of directly supervised sessions, depending on the risk level, and describe a progression from continuous to intermittent ECG monitoring according to the risk level. ECG monitoring is advised only for high-risk patients, such as those who have undergone the implantation of a cardioverter-defibrillator and patients with heart failure and a history of complex arrhythmias. The European Association of Preventive Cardiology specifies the use of ECG monitoring during initial exercise training sessions and for patients with new symptoms [1,45]. Heart rate monitoring and/or the Borg Rating of Perceived Exertion Scale are frequently recommended, along with the observation of signs and symptoms, such as significant fatigue, chest pain, or dizziness [16]. Exercise sessions should be terminated if the patient feels unwell, experiences the symptoms mentioned above, if complex arrhythmia or significant ischemia is recorded in ECG, or in the case of an excessive increase in heart rate or blood pressure. Exercise intensity should be reduced if the training heart rate significantly exceeds the programmed value. Specific symptoms may relate to an excessive volume of exercise and typically include persistent fatigue, sleeplessness, or muscle cramps. Therefore, patients should be notified about the potential side-effects of exercise and should notify staff if present. Training safety also depends on having an adequate staff-to-patient ratio. The ratio of 1 exercise specialist to 5–10 low- or intermediate-risk patients/session is suggested as optimal, as is 1 professional to 2–3 high-risk patients. In the case of medical emergencies, trained staff should be immediately available and with adequate equipment to respond [1,116].

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5. Phase III—Long-Term Exercise Training

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5.1. General Rules

Phase III, or the maintenance phase, contains a program that typically starts within the cardiac rehabilitation center and is continued at the local fitness center, gym, or the patient's home.

The objective of phase III is to provide guidance and support for a continuous lifestyle change [1]. Phase III involves more independence and self-monitoring, shifting a center-based program into a home-based environment. Therefore, the transition between structured phase II and long-term phase III can be a vulnerable point due to the risk for non-adherence to recommended pharmacological treatment and lifestyle modifications, including physical activity. As expected, adherence to phase III of cardiac rehabilitation is poor, and barely 20–30% of patients continue exercise after a year of discharge from phase II [2]. This relates to individual- and environmental-level barriers that lead to poor adherence to physical activity plans. These barriers include, e.g., lack of time, lack of motivation, work tasks, social obligations, or unfavorable weather [3].

Prescribing an individually tailored physical activity plan that takes into consideration the underlying cardiac condition and cardiorespiratory fitness level is essential. Utilizing digital tools, e.g., wearable physical activity monitors, should help to maintain long-term adherence to physical activity. The authors recommend the ABC model of phase III by Rudnicki, with analogous rules to those for phase II [4]. Patients with an intermediate level of risk and very low functional capacity, as well as high-risk patients with an intermediate, low, or very low functional capacity, should be treated equivalently to model D of phase II cardiac rehabilitation. Tables 40–42 exhibit the A, B, and C models of exercise prescription.

Table 40. Suggested A model of phase III exercise prescription for low-risk patients.

	Duration	Frequency	Exercise Type	Intensity
Stage 1	2–3 months	3 × 45 min/week	Medically supervised training on cycle ergometer or treadmill, interval or continuous Calisthenics at gym	60%–80% of heart rate reserve
Stage 2	3 months	3 × 45 min/week	Exercise training on cycle ergometer or treadmill, interval or continuous Calisthenics at the gym Resistance circuit training, 2–3 sets	60%–80% of heart rate reserve
Stage 3	Unlimited	3 × 45–60 min/week	Walking, cycling, swimming	60%–80% of heart rate reserve

Source: Adapted from [4].

Table 41. Suggested B model of phase III exercise prescription for intermediate-risk patients with good exercise tolerance.

	Duration	Frequency	Exercise Type	Intensity
Stage 1	2–3 months	3 × 30–40 min/week	Medically supervised interval training (initially with ECG monitoring) on cycle ergometer or treadmill Calisthenics at gym	40%–50% of heart rate reserve
Stage 2	3 months	3 × 45 min/week	Medically supervised interval exercise training on cycle ergometer or treadmill Calisthenics at gym Resistance circuit training, 1 set.	50%–60% of heart rate reserve
Stage 3	Unlimited	3 × 45–60 min/week	Walking, cycling	50%–60% of heart rate reserve

Source: Adapted from [4].

Table 42. Suggested C model of phase III exercise prescription for a patient with intermediate risk and low or intermediate functional capacity and for high-risk patients with good exercise tolerance.

	Duration	Frequency	Exercises Type	Intensity
Stage 1	2–3 months	3 × 30 min/week	Individual, medically supervised (with continuous ECG monitoring) interval exercise training on cycle ergometer or treadmill Calisthenics at gym	40%–50% of heart rate reserve
Stage 2	3 months	3 × 45 min/week	Individual, medically supervised interval exercise training on cycle ergometer or treadmill Calisthenics at gym	50%–60% of heart rate reserve
Stage 3	Unlimited	3 × 45 min/week	Walking, cycling, swimming, dancing, gardening	50%–60% of heart rate reserve

Source: Adapted from [4].

5.2. Telerehabilitation

5.2.1. Background

Patients' adherence to the center-based cardiac rehabilitation model remains suboptimal, with rate of participation in phase II being 40% in Europe and 30% in the United States, both an insufficient referral rate by medical professionals and a suboptimal enrollment for referred patients [5]. Multiple cardiac rehabilitation barriers have been identified, including a lack of adequate patient and healthcare provider awareness, a lack of rehabilitation center availability, and a lack of financial remuneration. Patients report that their main barriers to cardiac rehabilitation attendance are related to work and family responsibilities, financial costs, lack of motivation, or the long distance from home to cardiac rehabilitation facilities. Thus, up to one third of participants prematurely drop out of the program—these are mainly patients with coronary artery disease, older age, and lower economic status [6–8]. Alternative strategies have been developed accordingly, to resolve several barriers impeding the utilization of cardiac rehabilitation programs and creating a more active role for the patient in the whole system [9]. Historically, physical activity has been evaluated by pedometers and accelerometers, with a further rapid development of online applications providing activity tracking by smartphones and smartwatches, including heart rate, distance covered, and energy expenditure calculation [10,11]. The recent COVID-19 pandemic has affected the traditional model of center-based cardiac rehabilitation delivery due to restrictions imposed by the authorities to prevent the spread of the infection, along with unit closure and staff redeployment [12–14]. This emergency triggered the rapid development of telemedicine and highlighted the role of cardiac telerehabilitation as an efficacious, safe, and essential part of cardiac rehabilitation [15]. Cardiac telerehabilitation is based on ECG-monitored exercise training at home and is controlled and modified remotely by the cardiac rehabilitation team. It entails telemonitoring, tele-advice, and direct interaction with the patient [16]. Cardiac telerehabilitation may be a continuation of an outpatient or residential program and is suitable for the following groups of patients [17]:

- Those living far from the cardiac rehabilitation facility;
- The elderly;
- Patients with social or financial issues creating barriers to regular attendance.

5.2.2. Technical Aspects

Patients utilize remotely controlled devices for tele-ECG monitoring, with the ECG signal being transmitted from precordial leads to a mobile phone through, e.g., Bluetooth technology. The data are then typically transmitted through a mobile phone network to the monitoring center [18]. Patients communicate with their supervising team via a mobile phone (Figure 18). Prior to commencing telerehabilitation sessions, patients initially attend an outpatient program (typically for 5–10 sessions) with clinical examination, individual training prescription, and the supervision of training progress [19]. Remote telerehabilitation sessions start with questions regarding the patient's current clinical status, followed by the transmission of resting ECG and reporting values of blood pressure and weight. Personalized training programs applied by the supervising cardiac rehabilitation team can be executed in the form of marching on the spot, walking, or training on a stationary bike. Exercise training sessions of 45–60 min duration are typically prescribed, comprising 2 to 5 sessions per week, including a warm-up phase and a cool-down phase [20]. In the case of interval training, the device notifies patients about the transition between phases through sounds, voice commands, or light signals. In addition, an alarm system will be triggered if an abnormal situation occurs, alerting the monitoring team.

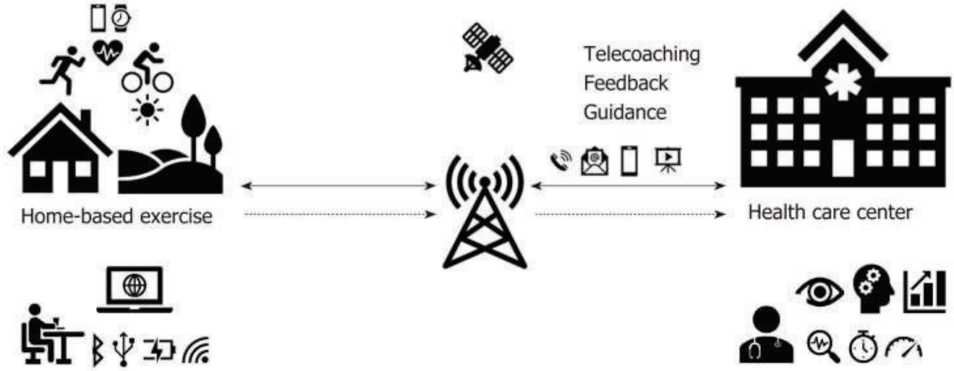

Figure 18. Principles of remotely monitored cardiac telerehabilitation. Source: Reprinted from [19].

5.2.3. Efficacy of Cardiac Telerehabilitation

Meta-analyses have demonstrated that home-based cardiac telerehabilitation is not inferior to outpatient cardiac rehabilitation in terms of mortality, cardiac events, improvement in exercise capacity, modifiable risk factors, or improvement in the quality of life in patients with coronary artery disease or heart failure [21,22]. The main purpose of the study conducted by Batalik was to compare the feasibility and effectiveness of telerehabilitation and conventional outpatient programs [23]. The study group included 56 patients with coronary artery disease who participated in a 12-week phase II program randomized into telerehabilitation and outpatient groups. After 12 weeks, the patients' average intensity adherence, defined as the total average of training intensity, did not differ statistically between the groups (74.8% of heart rate reserve for the telerehabilitation group compared to 75.3% of heart rate reserve for those in the outpatient program). Moreover, the time spent at the prescribed training intensity was similar. A considerable number of studies have been published on the effectiveness and safety of cardiac telerehabilitation [24–26]. In a study by Hwang et al. involving 53 patients with heart failure receiving a 12-week, remotely monitored home-based exercise training program, there was no significant difference in the group's 6-min walk distance gains compared with those of a group participating in an outpatient program. A recent influential account of the effectiveness of telerehabilitation in heart failure patients was provided by the Telerehabilitation in Heart Failure Patients (TELEREH-HF) study, which demonstrated a significant improvement in the New York Heart Association (NYHA) class and quality of life after a 9-week remotely monitored exercise training program [27].

5.3. Long-Term Physical Activity

Physical inactivity remains one of the leading causes of death around the world, according to the World Health Organization [28]. The level of adherence of the general population to recommended levels of physical activity remains unacceptably low [29,30]. On the other hand, aerobic capacity is a strong prognostic marker in healthy individuals, with each 1 MET increase in aerobic fitness reflecting a 13% decrease in all-cause mortality and a 15% decrease in the incidence of cardiovascular events [31]. Moreover, individuals with a functional capacity of less than 5 MET had a relative risk of fatal events that was four times greater compared with that of individuals with an exercise capacity of 10.7 MET or more over a period of six years [32]. Long-term physical activity after completing cardiac rehabilitation program is fundamental. Current international guidelines on physical activity recommend that individuals with increased cardiovascular risk perform at least 150 min of aerobic exercise at a moderate intensity or 75 min of high-intensity exercises three to five days a week and that individuals use a combination of moderate- and vigorous-intensity exercise to reduce all-cause mortality, cardiovascular mortality, and morbidity [2]. Moderate-intensity activities (3–5.9 MET) entail, e.g., brisk walking (4.8–6.5 km/h), slow cycling (15 km/h), and gardening, whereas examples of vigorous activities ($\geq$6 MET) are jogging, running, and bicycling > 15 km/h. Exercise intensity prescription given in absolute measures (i.e., MET) does not take into account individual factors; older individuals exercising at a vigorous intensity of 6 METs may become exhausted, while a younger person working at the same absolute intensity may only be exercising moderately. In addition to the endurance component, moderate-intensity resistance training involving large muscle groups is recommended twice a week [1]. Those who cannot perform 150 min of moderate-intensity physical activity each week should as be active as their health condition allows, as even a low volume of moderate to vigorous exercise has been demonstrated to be sufficiently effective to reduce mortality by 22% in older adults [33]. Furthermore, to maintain an adequate physical activity level, motivational interventions should be applied. These include behavioral strategies, such as goal setting; the re-evaluation of goals; and self-monitoring utilizing new technologies—e.g., wearable activity trackers [34,35].

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6. Exercise Prescription for Specific Populations

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6.1. Acute Coronary Syndromes

Acute coronary syndromes (ACSs) represent a spectrum of clinical presentations, including acute ST-segment elevation myocardial infarction (STEMI), acute non-ST-segment elevation myocardial infarction (NSTEMI), and unstable angina (UA) and are typically associated with the rupture of an atherosclerotic plaque and partial or complete occlusive thrombosis [1]. Exercise-based cardiac rehabilitation has been evaluated comprehensively in patients referred after acute MI. A meta-analysis of 36 randomized control trials, including 6111 patients after myocardial infarction, demonstrated that cardiac rehabilitation was clearly associated with a 36% reduction in cardiac deaths, a 26% reduction in total mortality, and a 47% reduction in reinfarction rate [2]. The recent meta-analyses conducted by Anderson and Ji have supported these findings [3,4]. Potential mechanisms responsible for mortality reduction entail an reduced sympathetic, then enhanced parasympathetic tone or ischemia-induced preconditioning [5]. Cardiac rehabilitation following acute coronary syndromes has received a class I indication (i.e., mandatory) in the international guidelines. It is typically delivered in the form of an outpatient program, whereas a residential cardiac rehabilitation program is recommended for:

- Patients with event- or procedure-related complications;
- Patients with severe left ventricular dysfunction;
- Patients with frailty;
- Patients who cannot attend outpatient sessions.

A phase II program following acute coronary syndrome should incorporate patient assessment, including the evaluation of the arterial puncture site; functional capacity and angina threshold assessment based on a symptom-limited exercise test; exercise training; dietary counseling; body mass control; lipid management; blood pressure management; smoking cessation; and psychosocial support. The scope of early mobilization was described earlier in this book. Phase II should begin as soon as possible after an acute event. Patients diagnosed with myocardial infarction or unstable angina who have undergone percutaneous coronary intervention should optimally commence a cardiac rehabilitation program within the first 14 days after hospital discharge, and this period can be prolonged in the case of patients with multiple risk factors, with a complicated course of disease, or who are at high risk [6].

Phase II with medically supervised exercise training typically includes 2–3 sessions per week for outpatients and 5–6 sessions per week for residential and hybrid cardiac rehabilitation patients. Each session usually lasts 30–60 min. General rules of exercise training following the FITT-VP formula have been described elsewhere [7]. Moderate-intensity aerobic exercise (45–59% of peak oxygen consumption, 55–69% of peak heart rate, 40–59% of heart rate reserve, 4–6 METs, or 12/20–14/20 on the Borg scale) is initially recommended for low-risk patients. Intermediate- and high-risk patients should begin exercise at an intensity of 40% of heart rate reserve [7,8]. High- and maximal-intensity interval training for patients following acute coronary syndromes has recently been an object of research. After 2 weeks of moderate-intensity training (as an adaptation phase), patients exercised at 95–100% of their heart rate reserve (maximal-intensity training) or at 85% of their heart rate reserve (high-intensity training) 3 days per week for 4 weeks. The primary outcome was maximal oxygen uptake. The secondary outcomes were major cardiovascular complications. After six weeks of aerobic interval training, maximal oxygen uptake increased significantly in both groups, with a greater increase seen in maximal-intensity effort. Furthermore, no major cardiovascular or musculoskeletal complications were noted [9].

6.2. Chronic Coronary Syndromes

Chronic coronary syndromes are defined as occurring in patients with stable angina, patients who are symptomatic >1 year after initial diagnosis or revascularization, and patients with angina and suspected vasospastic or microvascular disease [7]. The most frequently observed clinical picture of stable coronary artery disease is the occurrence of recurrent, transient episodes of chest pain at a certain level of exertion that can be relieved with rest or nitroglycerin. Thus, stable angina reflects a mismatch between demand and supply [10]. The beneficial effect of regular physical exercise as part of a multifactorial intervention in terms of improving symptom-free exercise tolerance and myocardial perfusion in patients with stable coronary artery disease and the deceleration of the disease progression over time have been documented [11,12]. One of the most influential accounts came from a study by Humbrecht. A randomized study was designed with the aim of comparing the effects of exercise training versus standard percutaneous coronary intervention with stenting on clinical symptoms, angina-free exercise capacity, myocardial perfusion, cost-effectiveness, and the frequency of a combined clinical end point (death of cardiac cause, stroke, coronary artery bypass graft surgery, angioplasty, acute myocardial infarction, and worsening angina with objective evidence resulting in hospitalization). A total of 101 male patients aged $\leq$70 years were enrolled following routine coronary angiography and randomized to 12 months of exercise training—i.e., 20 min of bicycle ergometry per day—or to percutaneous coronary intervention. Compared with the coronary intervention group, 12 months of regular physical exercise in patients with stable coronary artery disease resulted in a superior event-free survival (with 70% in the PCI group and 88% in the training group). The exercise intervention was associated with a higher exercise capacity and maximal oxygen uptake after 12 months than in the PCI group (the maximal exercise tolerance increased significantly by 20%, while maximal oxygen uptake increased by 16%). It is noteworthy that no adverse events were recorded during the training sessions in any patient [13].

Exercise-based cardiac rehabilitation is recommended by the American College of Cardiology/American Heart Association and the European Society of Cardiology for patients diagnosed with chronic coronary syndromes to help them manage risk factors and to reduce recurrence of the disease; however, the referral and program participation rates remain suboptimal compared with those seen in patients after acute coronary syndromes. This relates particularly to patients with multiple risk factors, women, and the elderly [14,15]. The progress of early mobilization and exercise training for patients with stable angina depends on the clinical situation the coronary intervention has been performed for, the patient's clinical status after the procedure, their revascularization level, and the presence of complications related to the puncture site (i.e., bleeding, hematoma, fistula, infection). A moderate- or moderate-to-high-intensity exercise regimen is typically utilized [6,16]. Supervised exercise training principles were described earlier in this book in a dedicated chapter.

6.3. Coronary Artery Bypass Graft Surgery

All patients undergoing coronary artery bypass graft surgery should be referred to a cardiac rehabilitation program due to its beneficial effects, as confirmed in numerous studies [17,18]. In an observational trial of 846 patients after coronary artery bypass graft surgery (CABG), 69% of whom participated in a cardiac rehabilitation program, after a mean follow-up of 9 years, a 46% relative risk reduction and a 12% absolute risk reduction in all-cause mortality were reported. These findings were independent of age, sex, prior myocardial infarction, or the presence of diabetes [19]. In another study including 3975 patients after CABG, an all-cause mortality reduction of 20% with in-patient cardiac rehabilitation and 40% with supervised exercise training were observed [20]. The principles of in-patient prehabilitation followed by post-operative early mobilization and combined aerobic, resistance, and inspiratory muscle training have been extensively studied [21]. The details of phase I cardiac rehabilitation were depicted earlier in this book. Phase II of cardiac rehabilitation should optimally begin four weeks after coronary artery bypass graft surgery and may commence earlier in a center experienced with patients who have undergone cardiac surgery. The duration of the exercise training program should be individualized, depending on the patient's profile (i.e., age, fitness level, risk factors, adherence), but at minimum, it should include at least 24 sessions [22]. Patients undergoing coronary artery bypass graft surgery are typically older, present with comorbidities, and have a lower functional capacity level. Prior to commencing exercise training, a functional capacity assessment should be performed in the form of a six-minute walk test, symptom-limited exercise test (optimally four weeks after surgery), or submaximal exercise test (with a target of 70% of maximal heart rate). The maximal exercise test should not be executed within the four weeks following CABG. The exercise training program following CABG results in numerous cardiovascular and peripheral adaptations, including improved blood flow in exercising muscles, enhanced oxidative capacity of the working skeletal muscles, and the correction of endothelial dysfunction in the skeletal muscle vasculature. The supervised exercise training prescription should be based on clinical conditions, exercise capacity, left ventricular performance, and the type of surgery performed [6]. Thus, the postoperative rehabilitation principles are determined by many factors. The authors recommend enrolling patients after CABG into corresponding aerobic ABCD training models, as described earlier, in relation to their clinical outlook, their echocardiographic left ventricular performance, the presence of arrhythmia or ischemia, their functional capacity level, the presence of surgery-related complications, and their comorbidities (Table 43). As described earlier in a chapter concerning risk stratification, all characteristics listed must be present for patients to remain low-risk, whereas even one of characteristics listed places patients as moderate- or high-risk. The principles of strength training following cardiac surgery, including adequate timing and the acceptable load, can be found earlier in this work in the chapter dedicated to resistance training.

Table 43. Rehabilitation models for patients after cardiac surgery.

Risk Factor	Low Risk A Model	Intermediate Risk B Model	High Risk C or D Model
Left ventricular systolic function	Preserved LVEF 50% or more	Moderately impaired LVEF 36%–49%	Severely impaired LVEF 35% or less
NYHA class	NYHA I	NYHA II	NYHA III, IV
Complex ventricular arrhythmia	Absent at rest and during exertion		Present at rest and during exertion
Atrial fibrillation	Absent	Present, ventricular rate controlled	Present, ventricular rate uncontrolled
Ischemic ECG changes on exertion	Absent	ST-segment depression 1–2 mm	ST-segment depression 2 mm or more
Functional capacity	7 METS or more 100 watts or more 6 MWT > 400 m	5–6.9 METS 75–100 watts 6 MWT 250–400 m	<5 METS <75 watts 6 MWT < 250 m
Exertional hemodynamic response	Normal		Lack of increase or decrease in systolic blood pressure or heart rate during increasing intensity
Clinical data and complications			
Time from surgery	>3 weeks	2–3 weeks	<2 weeks
Type of the surgery	Mini invasive		Complex, multistage
Wound healing	Proper healing	Healing difficulties	Infected wound
Sternum	Stable	Re-fixation	Unstable
Pericardial and pleural effusion	Small effusion		Large effusion
Pneumonia, bronchitis	Absent		Present
Anemia	Mild		Severe
Comorbidities			
Diabetes mellitus	Controlled		Uncontrolled
Hypothyroidism Hyperthyroidism	Controlled		Uncontrolled
Renal failure	GFR > 60 mL/min	GFR 31–60 mL/min	GFR < 30 mL/min
Disability	Mild		High degree

Abbreviations: CABG—coronary artery bypass grafting; ECG—electrocardiogram; GFR—glomerular filtration rate; LVEF—left ventricular ejection fraction; METS—multiples of resting metabolic equivalent; 6 MWT—six-minute walk test; NYHA—New York Heart Association. Source: Adapted from [23].

6.4. Valve Surgery

6.4.1. Rationale

The epidemiology of valve disease has changed, and degenerative valve disease dominates nowadays in operating theaters, indicating the ageing surgical population and the challenges of the rehabilitation process [24]. Benefits of the cardiac rehabilitation program after valve surgery in terms of short-term physical capacity improvement and an earlier return to work have been documented, with a beneficial effect on peak oxygen uptake seen at 4 months—i.e., 24.8 mL/kg/min, compared with 22.5 mL/kg/min for a usual care group [25]. Therefore, a cardiac rehabilitation program should be offered to all patients after valve surgery, including those who have undergone percutaneous interventions, i.e., following percutaneous valve replacement, repair, the implantation of clips, etc. [7]. A multidisciplinary team should be involved in the cardiac rehabilitation program after valve surgery, particularly for patients with a postoperative course complicated by heart failure [26]. Valve surgery is typically performed during the symptomatic period, typically at the advanced stage of heart failure; thus, the improvement in the functional capacity and the left ventricular systolic function is extended over time [6]. Exercise tolerance after mitral valve replacement is much lower than that after aortic valve replacement, particularly in the presence of residual pulmonary hypertension [26]. Transcatheter aortic valve implantation (TAVI) has recently been implemented as the procedure of choice for elderly patients with severe aortic stenosis and a high perioperative mortality risk for surgical aortic valve replacement. Moreover, TAVI seems to also be non-inferior to surgical valve replacement in patients at intermediate surgical risk [27,28]. Existing data on transcatheter aortic valve replacement and exercise-based cardiac rehabilitation programs are limited (mainly due to the low enrollment, compared with surgical replacement, and a lack of consistency). In an observational trial evaluating the effects of eight weeks of combined endurance and resistance training in a group of elderly TAVI patients, compared to those given usual care without structured exercise, significant improvements in exercise capacity, muscular strength, and quality of life in the exercise group were observed. In addition, the exercise training did not affect negatively prosthetic valve function, whereas, in a recent trial, exercise training resulted in preserved long-term improvements, compared to usual care, in oxygen uptake at the anaerobic threshold but not in peak oxygen uptake, muscular strength, or quality of life [29,30].

6.4.2. Exercise Prescription

The general rules of the cardiac rehabilitation program implemented after valve surgery are analogous to those described for post-CABG. The individual rehabilitation plan is based on [6,31]:

- The patient's clinical status before the surgical correction of valve disease (symptom duration, hemodynamic abnormalities, cardiac rhythm, thrombo-embolic complications, orthopedic and vascular disorders);
- The type of surgery;
- The surgical wound status;
- The presence of early postoperative complications.

Phase I of cardiac rehabilitation taking place in the intensive care unit and in cardiac surgery departments is typically prolonged compared with post-CABG. Phase II is recommended to be implemented within a few weeks after surgery and should optimally last for 8–12 weeks. For patients with heart failure complications in their postoperative course, a residential program should be offered, if available. Patients who have undergone an uncomplicated replacement of their aortic and mitral valves can begin phase II after two and three weeks, respectively [32].

The initial assessment before commencing exercise training should involve echocardiographic assessment—i.e., assessment of the transvalvular pressure gradient, grade of valvular insufficiency, and presence of pericardial effusion [7]. Typically, the low to moderate aerobic training intensities are utilized initially. The Borg scale is a useful adjunct in the case of patients with atrial fibrillation. The anticoagulation regimen is of special importance after the implantation of mechanical valves, and patients should be educated about adequate anticoagulation rules.

6.5. Heart Failure

6.5.1. Rationale

The low exercise tolerance observed in patients with heart failure is a consequence of their diminished exertional response of cardiac output, impaired vasodilation, and increased systemic vascular resistance [33,34]. Based on physical capacity levels, patients diagnosed with heart failure can be classified into three groups [35]:

- Patients with significant impairment of functional capacity (peak oxygen uptake in CPET < 10 mL/kg/min, 6 MWT distance < 300 m);
- Patients with moderate impairment of functional capacity (peak oxygen uptake 10–18 mL/kg/min, 6 MWT distance 300–450 m);
- Patients with good functional capacity (peak oxygen uptake > 18 mL/kg/min, 6 MWT distance > 450 m).

All patients diagnosed with heart failure at NYHA class I-III, irrespective of their left ventricular ejection fraction value, should be referred to a cardiac rehabilitation program [36,37]. Improvements in exercise capacity, symptoms, and quality of life and reductions in the hospital re-admission rate after participation in a cardiac rehabilitation program in patients with heart failure have been documented [38,39]. The quantitative beneficial effects of cardiac rehabilitation have been depicted and include [40,41]:

- An increase in maximal oxygen uptake by 2.1 mL/kg/min;
- An increase in exercise duration by 2.3 min;
- An increase in peak work rate by 15 watts;
- An increase in walking distance at 6 min walk test by 40 m.

6.5.2. In-Patient Phase

In-patient rehabilitation should begin as soon as possible after hospital admission [40]. Once a patient's clinical stability is attained, gradual mobilization (calisthenics exercises with simple movements, without weights or equipment) should commence to increase body strength and flexibility. The resistance training of small muscle groups should be also implemented, with the initial intensity kept below 30% of the one repetition maximum. Inspiratory muscle training is essential [42]. The plan suggested depends on patients' hemodynamical status and the stage of the disease (as presented in Table 44).

Table 44. In-hospital early mobilization model for patients with heart failure.

Period	The First	The Second	The Third
Duration	1–3 days	4–6 days	>6 days
Exercise Duration	2–3 × 10 min	2–3 × 15–20 min	1 × 20–25 min
Mobilization Program	Passive sitting in bed	Sitting in the bed with legs outside, standing	Sitting, Standing
Respiratory Exercises	Prolonged exhaustion, exercises with resistance	Intensive inspiration and exhaustion with resistance	As in the second period

Table 44. *Cont.*

Period	The First	The Second	The Third
Exercises	Passive, active assisted exercises of the lower extremities, stretching, active dynamic exercises of of small to major muscle groups	Passive, active assisted exercises of the lower extremities, dynamic exercises of the upper and lower extremities, balance exercises	Increase in: repetitions, sets, pace
Moving		Walking around a room (10–15 m)	Increased distance of walking, intermittent walking of 30–60 m/ 3–5 times daily Climbing up stairs (up to 2 flights of stairs)

Source: Adapted from [23].

6.5.3. Phase II Initial Assessment

There is no consensus regarding the optimal timing for the initiation of exercise training, with the typical practice for most cardiac rehabilitation centers being beginning at least one month after a decompensation episode [43]. Knowledge of the underlying cause of heart failure, recent pharmacotherapy, and the current functional capacity level before commencing an exercise program is essential. Detailed physical examination should assess signs of pulmonary congestion or peripheral edema. The initial exercise intensity should preferably be based on cardiopulmonary testing (the gold standard for patients with heart failure), utilizing the Naughton or modified Bruce protocol on a treadmill or an incremental or ramp protocol on a bicycle ergometer with a load increase of 5–10 W/min [7]. The exercise intensity should be set with relation to the ventilatory threshold, as was extensively discussed in the exercise intensity chapter of this book. If CPET is unavailable, intensities of 40%–70% of heart rate reserve and Borg scale values of 10–14 are recommended.

Contraindications to the commencement of exercise training for individuals with heart failure include [32,35]:

Absolute contraindications:

- Acute coronary syndromes within 2 days;
- Lack of clinical stability within the previous 12 h, including increased shortness of breath over the previous few days, resting heart rate above 120–130/min,

uncontrolled blood pressure (SBB above 180 mmHg, DBP above 120 mmHg), hypotension, resting angina, new resting ischemic ECG changes, new onset of unstable hemodynamically atrial fibrillation, an advanced atrioventricular block without a pacemaker, and acute heart failure;
- Uncontrolled diabetes mellitus;
- Acute systemic illness or fever;
- Recent pulmonary embolism or thrombophlebitis;
- Active endocarditis or pericarditis;
- Valve insufficiency for surgical treatment;
- Moderate and severe aortic stenosis;
- Complex arrhythmias without treatment;
- Intracardiac thrombus;
- Uncontrolled thyroid function.

Relative contraindications:

- Body mass increase over 1.8 kg in the last 1–3 days;
- Intravenous inotropes infusion;
- Drop in blood pressure with exertion;
- NYHA class IV;
- Resting heart rate > 100 bpm in the supine position;
- Complex ventricular arrhythmias at rest or during exertion;
- Oxygen saturation < 85–90%;
- Severe pulmonary hypertension (mean pulmonary arterial pressure > 55 mmHg);
- New left bundle branch block.

Training should be stopped with a subsequent intensity modification in the case of excessive fatigue, a significant increase in systolic blood pressure with symptoms of exercise intolerance, a blood pressure drop with exercise, the presence of exercise-induced supraventricular or ventricular arrhythmias, a significant reduction in oxygen saturation, or after ICD intervention.

6.5.4. Exercise Prescription

The principles of exercise were described in detail in this book in a chapter dedicated to exercise prescription for high-risk patients. The initial duration and frequency of aerobic training should be based on the functional capacity level [35]:

<3 METs (<0.5 watt/kg): 5–10 min exercise in a few sessions per day;
3–5 METs (0.5–1.2 watt/kg): 15 min sessions 1–2 times a day;
>5 METs (>1.2 watt/kg): 20–30 min once a day.

For patients with very low functional capacity, frequent short bouts of low-intensity exercise are suggested initially ("start low and go slow"). Regular body weight monitoring is important so as not to ignore fluid retention. Moderate-intensity continuous endurance training is recommended as a baseline protocol. If interval training is prescribed, low-intensity bicycle ergometer training with 30 sec hard segments at 50% of workload and 1 min recovery segments below 20 watts is utilized [7].

With training progression, the primary goal in an interval regimen is to increase the duration up to 30 min and change the work-to-recovery ratio of 1:2 to 1:1 (by increasing the duration of active segments and/or shortening the recovery time). In continuous exercise, after attaining the duration of the conditioning phase of 40–60 min, exercise intensity should be increased subsequently. Selected patients can progress on to HIIT [44].

Resistance training usually includes a work-to-rest ratio of 1:2—i.e., 30–60 s of exercise with a subsequent 1–2 min rest. Resistance training progression should be phasic [7,35]:

- Stage 1 to learn the technique includes: 5–10 repetitions at 20–30% of one repetition maximum (Borg < 12), 2–3 sessions per week, 1–3 sets.
- Stage 2 to improve endurance includes: 12–25 repetitions at 30–40% of one repetition maximum (Borg 12–13), 2–3 sessions per week, 1 set.
- Stage 3 to increase muscle mass includes: 8–15 repetitions at 40–60% of one repetition maximum (Borg < 15), 2–3 sessions per week, 1 set.

Full training progression requires at least 3–4 weeks.

Inspiratory muscles training is essential, particularly during the in-patient phase. Typically, 30% of the maximum inspiratory mouth pressure is recommended initially, being increased every 7–10 days, with a target of 60%. Such training lasts for 20 min daily, 3–5 days a week, for 8 weeks [42].

The European Association of Cardiovascular Prevention and Rehabilitation summary of exercise training for patients with heart failure is presented in Table 45 [35].

Table 45. EACPR exercise training prescription for patients with heart failure.

Functional Capacity Level	<65 Years Active	<65 Years Sedentary	>65 Years Active	>65 Years Sedentary
VO_2 peak < 10 mL/kg/min or 6 MWT < 300 m	Continuous endurance Respiratory Resistance Low-intensity interval	Continuous endurance Respiratory Resistance Low-intensity interval	Continuous endurance Respiratory Resistance Low-intensity interval	Continuous endurance Respiratory Low-intensity interval
VO_2 peak 10–18 mL/kg/min or 6 MWT 300–450 m	Continuous endurance Respiratory Resistance Interval	Continuous endurance Respiratory Resistance	Continuous endurance Respiratory Resistance	Continuous endurance Respiratory
VO_2 peak > 18 mL/kg/min or 6 MWT > 450 model	Continuous endurance Respiratory Resistance High-intensity interval	Continuous endurance Respiratory Resistance High-intensity interval	Continuous endurance Respiratory Resistance High-intensity interval	Continuous endurance Respiratory Resistance High-intensity interval

Abbreviations: EACPR—European Association of Cardiovascular Prevention and Rehabilitation; VO_2—oxygen uptake; 6 MWT—six-minute walk test. Source: Reprinted from [35].

6.6. Implantable Cardiac Electrical Devices

6.6.1. General Remarks

A growing number of patients referred to cardiac rehabilitation have implanted cardiac electrical devices—i.e., a permanent pacemaker (PPM), cardiac resynchronization therapy (CRT), or an implantable cardioverter-defibrillator (ICD). Patients with PPM, CRT, or ICD are considered eligible for cardiac rehabilitation programs [45,46]. Exercise training in this group of patients can be implemented safely, and evidence shows that cardiac rehabilitation can almost double physical capacity after CRT implantation [47,48]. The exercise training of patients with implanted cardiac electrical devices requires special attention from cardiac rehabilitation staff, as apart from the supervision of the exercise training, adequate knowledge about the proper functioning of the devices is essential [49]. During phase I of cardiac rehabilitation, attention is required to prevent extensive movements on the side of the implant to avoid strain and lead fracture. Upper-body-strength-targeted exercise may cause the dislodgement of implanted lead; thus, resistance training is not recommended for 4–6 weeks after device implantation [7]. Upon admission to phase II, an initial assessment should involve evaluation of the indication for the implantation; assessment of the presence of underlying heart disease, including events that have occurred; wound inspection; and the determination of the device position. Device interrogation is essential, particularly of the firing mode for ICD or CRT with a defibrillator (CRT-D). As heart rate during exercise should not exceed the ICD therapy threshold, the upper limit of the training heart rate should be set between 10 and 20 beats/min below the detection threshold [50]. Other important device parameters include sensing, pacing threshold, pacing percentage, and arrhythmia record. Functional capacity assessment should be performed as a symptom-limited test, preferably a cardiopulmonary exercise test, in order to provide additional information about chronotropic response to exercise, exercise-induced arrhythmias, and maximum tracking rate [51]. Exercise prescription for cardiac electrical devices recipients may follow the rules for heart failure patients, considering the upper limits of the device, and should incorporate the continuous endurance or interval model, last for 30–60 min, and be performed 3–5 days a week. Resistance training can begin after 6 weeks and include 2–3 sets of 10–12 repetitions per set at 40–70% of one repetition maximum and a rate of perceived exertion of 12–15, with attention paid to shoulder movements on the side of the implant.

6.6.2. Special Considerations

Permanent Cardiac Pacemaker

Before the start of phase II, stimulation parameters should be analyzed. Patients should notify cardiac rehabilitation staff about any symptoms that may be related to incorrect stimulation (such as palpitations, syncope, or dizziness).

Cardioverter-Defibrillator

An initial assessment should include the patient's history of ICD shocks and the relation of dysrhythmias and ICD shocks to exertion. Continuous ECG monitoring is mandatory during exercise sessions involving ICD recipients, and the upper limit of the training heart rate should be set 10–20 bpm below the fire rate. Exercise training is contraindicated in the presence of uncontrolled ventricular arrhythmias. If ICD intervention occurs during exercise training, the session must be stopped, and ICD control and the consultation of an electro-cardiologist are mandatory. Exercise sessions should be resumed rapidly after a change in pharmacotherapy and/or the reprogramming of the device to avoid ICD discharge becoming a psychological barrier to physical activity [52].

Cardiac Resynchronization Therapy

Exercise training should follow the rules of training for individuals with heart failure (in the case of CRT device with defibrillation function—i.e., CRT-D—the additional rules for ICD recipients apply). The cardiac rehabilitation team should know the type of device inserted (CRT or CRT-D) and the upper tracking limit value (stimulation with conduction 1:1). Some important points should be taken into accounts during exercise in CRT recipients—e.g., that exercise can induce sinus tachycardia above the upper tracking limit, leading to the inadequate tracking of the sinus rhythm, or that changes in atrio-ventricular conduction can cause a loss of resynchronization [53].

6.7. Heart Transplantation

6.7.1. General Remarks

Heart transplantation is considered the gold-standard treatment for selected patients with end-stage heart failure despite optimal medical therapy [37]. Aerobic exercise training revokes the pathophysiological consequences related to cardiac denervation and prevents immunosuppression-induced adverse effects in heart transplant recipients [54]. Postulated exercise-induced beneficial effects include oxygen extraction, an increase in cardiac output, and reduced neurohormonal activity [55]. Numerous studies have demonstrated a significant increase in cardiorespiratory fitness following heart transplantation—e.g., in a trial of 27 cardiac transplant recipients randomized to supervised exercise training, a 4.4 mL/kg/min (49%) increase in maximal oxygen uptake was reported at 6 months, compared with the increase of 1.9 mL/kg/min (18%) seen in the control group [54,56]. Cardiac rehabilitation, however, is challenging in the early post-operative period, due to patients' physical deconditioning, muscular atrophy, and low exercise capacity. The denervation of the donor's heart results in [32]:

- An increased resting heart rate;
- Heart rate increase occurring (slowly) only by increased circulating catecholamines due to the lack of sympathetic denervation, and this increase is slow;
- The prolonged return of the heart rate to resting values after exercise;
- Silent ischemia, with denervation preventing the transplant recipient from experiencing chest pain.

6.7.2. Exercise Prescription

In-hospital phase [37,56].

Early mobilization should be initiated as soon as possible after hemodynamic stability is achieved and after the patient has been weaned from intravenous therapy [40]. Walking progressively increasing distances is typically implemented alongside the monitoring of vital signs and perceived exertion. At discharge, patients who have undergone heart transplantation should be able to walk for a period of

40–60 min, inducing moderate fatigue, 4–5 times a week [7]. In addition, the exercise regimen should include resistance (low loads), flexibility, and respiratory training [6]. Recommendations concerning personal hygiene and the importance of reducing the risk of infection should be discussed with the patient. These include good dental hygiene, frequent hand washing, avoiding contact with potential sources of infection (i.e., persons with active infection; decaying plants, fruits, or vegetables; swimming pools). Patients should be notified about the clinical symptoms of potential acute transplant rejection—i.e., changes in blood pressure, changes in heart rate, increased body mass, or impaired fitness level [7]. Prehabilitation principles prior to cardiac surgery were described earlier in this book.

Phase II

Initial assessment should entail in particular:

- Heart failure etiology and duration;
- Transplant rejection episodes and details of immunosuppressive treatment, including side-effects;
- Result of recent heart biopsy;
- Wound healing;
- Heart failure signs and symptoms.

Functional capacity assessment utilizing cardiopulmonary exercise test, if available, is recommended as the gold standard, with small increments of 10 Watts or modified Bruce/Naughton protocols implemented on a treadmill. Exercise tests can be performed safely four weeks after heart transplantation, as can exercise training programs for heart transplant recipients.

Exercise prescription for heart transplant recipients should comprise all components and occur at a residential cardiac rehabilitation department, in cooperation with the cardiac surgery department [57]. Aerobic training can begin in the second or third week after heart transplantation and should incorporate prolonged warm-up and cool-down phases with relation to the pathophysiological consequences of the denervation of the heart. An initial exercise intensity of 10% below the anaerobic threshold in the case of CPET or below 50% of the maximal workload attained during the exercise test is recommended; however, due to the denervation of the heart rate, the patient's perceived level of exertion and respiratory rate should guide exercise rather than their specific heart rate [8]. Resistance training is essential to reverse muscular atrophy and should include 2–3 sets of exercises with 10–15 repetitions per set at 50% of one repetition maximum, with breaks of at least 1–2 min occurring between the sets. Training progression should be conducted to 70% of 1-RM.

The AACVPR exercise prescription for heart transplant recipients is presented in Table 46 [6].

Table 46. AACVPR exercise prescription after heart transplant.

Type	Frequency	Intensity	Time
Warm-up, cool-down, range of motion, low-intensity aerobic	Each session	RPE < 11	>10 min
Aerobic first 6 weeks after surgery: walking, cycle ergometer at 6 weeks, including combination arm and leg ergometer, elliptical, rower, arm ergometer, jogging	5–7 sessions/week, 3 supervised, 2 or more independent	RPE 12–16 (if heart rate response to exercise has normalized, 50%–80% of HRR)	Begin with >5–10 min per session, increasing in 5 min steps to 30–60 min per session
Strength	2 or 3 sessions/week on nonconsecutive days	First 6–8 weeks after surgery: <10 lbs for upper extremities; otherwise, RPE 12–16	1–3 sets, 8–15 slow repetitions per set

Abbreviations: AACVPR—American Association of Cardiovascular and Pulmonary Rehabilitation; RPE—rating of perceived exertion. Source: Reprinted from [6].

6..8. The Elderly

6.8.1. Rationale

Ageing leads to a growing number of elderly patients with cardiac disease and increased rates of comorbidities, cognitive impairment, and frailty [58]. Although the reduced exercise capacity and risk profile of the elderly indicate their need for cardiac rehabilitation, they are often excluded from large meta-analyses and subsequently are insufficiently represented in cardiac rehabilitation programs [3]. In observational studies, cardiac rehabilitation has been found to improve functional capacity, the cardiovascular risk factor profile, and patients' quality of life. Other registries have demonstrated the reduced rates of mortality and hospitalization in the elderly, but the observational nature of these studies may be associated with selection bias [59]. The main aims of cardiac rehabilitation in the elderly are the maintenance of mobility and independence and the prevention of frailty.

6.8.2. Initial Assessment

Elderly patients typically present with a low functional capacity and reduced muscle power, which make them prone to falls. Other frequently observed comorbidities and problems related to ageing include the presence of osteoarthritis; chronic obstructive pulmonary disease; dementia; problems with sight, hearing, and balance; and urine incompetence [60]. Entry assessment should include, particularly in patients over 75 years of age, multidimensional geriatric evaluation (MGA) to exclude the possibility of disability, frailty, and cognitive problems [61]. MGA has been incorporated in programs to determine the presence of medical, psychosocial, functional, and environmental problems in elderly patients. Specific measures of MGA include:

- Basic activities of daily living—e.g., Katz activities of daily living (for an assessment of self-care and mobility);
- Instrumental activities of daily living—e.g., Lawton instrumental activities of daily living (used to assess activities such as shopping, cooking, or solving financial issues);
- Social support (social network);
- Mental health—e.g., Geriatric Depression Scale (degree of anxiety, depression, etc.) or Mini-Mental State Examination (for the assessment of cognitive function);
- Gait and balance—e.g., the get up and go test (used to assess the risk of falls);
- Nutritional adequacy—e.g., multi-nutritional assessment;
- Grip strength;
- Comorbidities.

The Fullerton test, or Senior Fitness Test, is frequently utilized to assess the strength, flexibility, coordination, speed, balance, and endurance of elderly patients [62]. It includes the 30 s chair stand test, arm curl test, chair sit-and-reach test, back scratch test, eight-foot and go test, and six-minute walk test (or two-minute step test).

The 30 s chair stand test is suitable for the assessment of lower body strength and reflects daily activities such as climbing stairs or getting out of a chair. The number of full stands completed in 30 s with arms folded across the chest is counted. The norm is eight or more unassisted stands for both men and women.

The arm curl test is suitable for the assessment of upper body strength and reflects daily tasks such as lifting and carrying things. The number of biceps curls completed in 30 s is counted (with hand weights of 5 lbs. (2.2 kg) for women and 8 lbs. (3.6 kg) for men). The norm is 11 or more.

The chair sit-and-reach test is utilized for the assessment of the lower body flexibility. From a sitting position at the front of the chair with one leg extended and hands reaching toward the toes, the distance between the fingers and the tips of the toes is measured. The norm is less than 4 inches (10 cm) for men and less than 2 inches (5 cm) for women.

The back scratch test is used for the assessment of upper body flexibility, aiming to reflect daily activities such as combing one's hair or reaching for a seat belt. With one hand reaching over the shoulder and the other up in the middle of the back, the number of inches between the extended middle fingers of both hands are counted. The norm is less than 4 inches (10 cm) for men and less than 2 inches (5 cm) for women.

The eight-foot and go test assesses agility and dynamic balance. The number of seconds required to get up from a seated position, walk 8 feet (2.44 m), turn back, and return to a seated position is counted. The norm is less than 9 s for both men and women.

The six-minute walk test and the two-minute step test principle were described earlier in this book, with norms of >320 m and 65 steps or more, respectively.

6.8.3. Exercise Prescription

If frailty and cognitive problems can be excluded, an exercise program with an individually tailored intensity and based on an aerobic component associated with resistance, flexibility, and balance training is executed. Aerobic training following the "start low and go slow" formula is recommended, with the duration of the first few sessions being as short as 15 min [16]. Training should include adequate durations of warm-up and cool-down phases. Low-intensity exercises are safe and reduce injury risk, but older patients can also benefit from moderate-intensity training. The initial workload can be increased after a few weeks of conditioning to moderate intensity, if tolerated. Due to age-related chronotropic incompetence, heart-rate-lowering drugs, and sedentary lifestyles, the maximal heart rate of elderly patients is typically lower than that of younger patients; therefore, what can be considered light exercise for younger patients can be considered moderate exercise for elderly patients. Heart rates cannot be utilized to determine workload in the case of atrial fibrillation, and the Borg scale is utilized with the goal of 11–13 [63]. A session duration of 30 min, 3–4 times a week, with a total program duration of 12 weeks is recommended. Resistance training on alternate days of aerobic session utilizing a multi-weight machine is recommended to stabilize body position when lifting weights [64]. A very low load should be used initially and increased, if tolerated, to a moderate intensity, with 8–12 repetitions. The set can be repeated once or twice, with a 10 min break between the two. If the patient has not attended several consecutive sessions, resistance training should be resumed at 50% of the previous load. A light to moderate intensity (30–70 and 1-RM) is recommended. Patients should avoid rapid postural changes so as not to evoke orthostatic hypotension. Flexibility and neuromotor exercises are integral parts of exercise programs for the elderly—e.g., tai chi, which incorporates both components, can be performed twice a week for 10–15 min.

6.8.4. Frailty

Frailty is a geriatric syndrome characterized by impairment in physical, psychological, and social abilities. Frailty has been demonstrated as a strong predictor of mortality, morbidity, and hospitalization [65]. Several models for frailty screening have been proposed, with MGA, the phenotypic Freid model, and the deficit accumulation model being widely adapted [66]. The Freid phenotype model includes nutritional status (non-intentional weight loss of at least 4.5 kg in the previous year), self-reported physical exhaustion, low energy expenditure (kcal expended per week), mobility level (gait speed for a few meters of walking), and muscular strength (assessed by handgrip). Each component is scored as 1 if present, with a total of 1–2 points for a pre-frail state and frailty recognized in those who score 3 or more points. The true incidence of frailty in cardiac rehabilitation is unknown; however, cardiac rehabilitation is recommended for frail patients with a resistance component in addition to endurance, balance, and flexibility components to improve their physical capacity and muscular strength, reduce their risk of falls, and preserve their independence [67]. Exercise sessions should be individually tailored to the patient's level of functional impairment. Patients with frailty usually cannot perform baseline exercise stress tests or cardiopulmonary tests; therefore, the intensity of aerobic training, performed on alternate days of resistance exercise, should be set at a heart rate slightly lower than that attained during the 6-min walk test. For patients who are unable to perform the 6 MWT, bed mobilization and walking with support remain training targets [68].

Resistance exercise improves muscular strength and reduces the risk of falls in patients with frailty. The strength program protocol proposed by Vigorito et al. is summarized in Table 47 [69].

Table 47. Resistance training recommendations for frail patients [69].

Type of exercise	Reduced Number of Muscle Groups Involved, Particularly Lower Extremities
Intensity	50–70% of 1-RM
Number of repetitions per exercise	4–8
Number of sets	1–2
Frequency	1–2 per week
Duration	Up to 40 min
Program length	Up to 3 months

Source: Adapted from [69].

6.9. Peripheral Arterial Disease

6.9.1. Rationale

Peripheral arterial disease (PAD) is a progressive disease caused by atherosclerosis and results in limited blood flow and oxygen delivery to the lower limbs, as well as skeletal muscle dysfunction [70]. The most recognizable symptom of PAD is intermittent claudication (IC), occurring in 30% of patients with PAD [71]. Exercise-based cardiac rehabilitation reduces symptoms, prolongs claudication distance, and improves the quality of life in patients with peripheral arterial disease by the improvement in the metabolism of skeletal muscles, blood redistribution, and rheological changes [72]. Although cardiac rehabilitation leads to significant improvements in walking distance, no clear evidence regarding mortality reduction has been demonstrated [73].

6.9.2. Exercise Testing

Exercise tests are typically performed on a treadmill. The following are recorded [74]:

- Time and distance to the onset of claudication;
- Time and distance until the moment walking is ceased due to unbearable pain;
- Functional capacity in METS.

Thus, both the pain-free walking distance and cardiorespiratory fitness level should be evaluated. The graded stress test is the preferred mode of testing, with the maximal distance (and time), rather than the onset of claudication, recorded. Numerous testing protocols exist [75]:

- Walking at a speed of 3.2 km/hour and inclination change by 3.5% every 3 min (Hiatt protocol);
- Walking at a speed of 3.2 km/hour and inclination change by 2% every 2 min (Gardner–Skinner protocol);

The ankle–brachial index (ABI) is the ratio of the blood pressure at the ankle level to the blood pressure measured in the upper arm. ABI is used to objectively classify the severity of peripheral arterial disease, with ABI < 0.5 corresponding to low physical activity and reflecting significant stenosis, ABI 0.2–0.49 corresponding to rest pain, and ABI less than 0.2 reflecting tissue necrosis [7]. A decrease in the ankle–brachial index in response to the treadmill test reflects significant stenosis [76].

6.9.3. Exercise Training

Weight-bearing exercises such as walking are preferred, and training intensity can be determined with relation to the start of claudication, achieving maximal march distance, or achieving vasodilation. Most of the existing programs utilize the model of interval walking until near maximal pain, with a modulation of speed and/or grade to induce the onset of claudication within 3–5 min and moderate to moderately severe claudication within 8–10 min. Once pain is experienced, patients are encouraged to rest and repeat the bout of exercise when their symptoms resolve. A walking exercise duration of 30–60 min and a program duration of at least 12 weeks are recommended [7,77]. Popular protocols utilize a walking speed of 4.6 km/hour, with inclination adjusted so as not to provoke pain within 3 min and a total program duration of 6 months or walking at 4 km/hour without inclination and with further speed adjustment if the patient can complete a 10 min walk without experiencing pain. Programs with walking despite pain increase claudication distance; however, patients' training adherence remains suboptimal due to pain [78]. Moreover, the potential harmful effects of this training principle include provoking inflammatory damage in the endothelium. The alternative approach of pain-free walking can elicit similar benefits, according to data derived from a small study [79] where the authors utilized a pain-free "2/3 claudication distance" formula. One cycle comprised 3 to 5 walks, with 1–3 min rests between them, 3 times a day, 5 days a week, for at least 12 weeks. With training progression and increasing claudication distance, regular re-testing can be performed on a weekly basis [80].

Although walking is the most efficacious mode of training, cycle ergometer exercise is utilized in selected patients—e.g., those with obesity or gait problems [72].

Resistance training starting with an intensity of 30%–50% of 1-RM, including 2–3 sets, and with regular progression every 2–4 weeks for a total time period of 6 months is recommended [7].

6.10. COVID-19

6.10.1. Introduction

Coronavirus disease 19, known as COVID-19, is a contagious, highly transmissible disease caused by severe acute respiratory syndrome coronavirus 2 [81]. The rapid spread of COVID-19 caused a pandemic, leading to more than 6 million deaths (March 2022), affecting global health care systems and economies, and causing governments to impose multiple restrictions. COVID-19 induces a state of systemic inflammation with enhanced oxidation; evoked systemic inflammatory status, termed a cytokine storm, can result in multi-organ failure [82,83].

The clinical picture of COVID-19 fluctuated from asymptomatic or mild respiratory symptoms to severe life-threatening pneumonia and respiratory and cardiac failure [84]. Typical COVID-19 manifestations observed in computed tomography images of the chest included ground-glass opacities and air bronchogram signs [85]. The most vulnerable group of patients were immunocompromised and older adults with underlying diseases [86]. COVID-19 affects the cardiovascular system by attachment to cells utilizing membrane protein angiotensin-converting enzyme 2, with subsequent internalization and interaction between proteins and viral ribonucleic acid [83]. As angiotensin-converting enzyme 2 is widely expressed in many human tissues—e.g., in the lungs and heart—viral penetration causes diffuse, multiorgan damage [87]. Numerous studies have found a strong link between preexisting cardiovascular disease and poor outcomes in patients with COVID-19.

6.10.2. Cardiac Manifestations of the COVID-19

It has been documented that COVID-19 is responsible for the induction of myocardial injury, arrhythmia, acute coronary syndrome, and venous thromboembolism. Cardiac injury, including elevated troponin level, and ECG or echocardiographic abnormalities have been reported in many studies, with COVID-19 cardiac involvement being documented in 7–28% of hospitalized COVID-19 patients [88]. Cardiac complications are multifactorial and may be result of myocardial damage, hypoxia, the dysfunction of the angiotensin-converting enzyme 2 receptor, or systemic inflammatory status [89]. Heart failure and myocarditis have been reported, respectively, in 10–52% and 8–12% of patients hospitalized for COVID-19 [90]. A specific COVID-19-related cardiac condition is Takotsubo stress cardiomyopathy, with the presence of mid-left ventricular segments hypokinesis [91]. Arrhythmias occurred in the acute phase of COVID-19, and the most common arrhythmia was atrial fibrillation; however, the occurrence of sustained ventricular tachycardia has been reported in 5–6% of hospitalized patients [92]. Moreover, patients with COVID-19 remained at higher risk of thromboembolic complications due to coagulopathy [93].

6.10.3. Impact of the COVID-19 on Cardiac Rehabilitation Services

The recent COVID-19 pandemic created many barriers to the implementation of center-based cardiac rehabilitation programs. Consequently, cardiac rehabilitation programs have been affected for extended periods, leading to poor patient outcomes [94].

Some cardiac rehabilitation centers remained partially operational, whereas, in other centers, staff developed remote exercise training. Over half of centers were forced to halt operations completely, with staff being redeployed. A study by Pires objectively compared physical activity and sedentary time during the COVID-19 pandemic with those in the previous two years in cardiac patients attending center-based cardiac rehabilitation and after the suspension of programs due to COVID-19, with patients continuing onto a home-based digital program. The conclusions drawn were that most patients showed significant decreases in their average daily time of moderate to vigorous training when compared with the period before COVID-19. Nevertheless, after training resumption, these patients regained cardiovascular fitness and were able to meet the recommendations for moderate to vigorous training [95]. On the other hand, COVID-19 emphasized the importance of home-based and remotely controlled cardiac rehabilitation programs. Cardiac telerehabilitation utilizing advanced technology for both monitoring and communicating with the cardiac population became an innovative alternative, helping to overcome some of the barriers preventing participation in programs, considering that remote technology delivers sufficient training information—i.e., in terms of intensity; time; distance—and allows patients' heart rate, blood pressure, and electrocardiograms to be recorded, enabling an optimal, individualized, and safe exercise prescription [96].

6.10.4. Exercise following the COVID-19

Due to the short time since the outbreak of COVID-19, there is still a lack of evidence about the effect of rehabilitation based on exercise training in COVID-19 survivors. It has been documented that appropriately prescribed physical exercise reduces inflammatory status; thus, in-hospital physiotherapy interventions should modulate the inflammatory status initiated by the virus and intervene in endothelial dysfunction [97,98]. The following conclusions can be drawn from the accumulation of clinical experience of COVID-19 in Chinese studies [99]:

Acute phase

Physiotherapy interventions should be based on the patient's condition. Early respiratory rehabilitation in severely and critically ill patients should be postponed if the patient's condition remains unstable or progressively deteriorates. Bed and bedside activities for severely and critically ill patients include positioning, early mobilization, and respiratory physiotherapy (airway clearance techniques). Exercise regimens for mildly and moderately ill patients include light exercises <3.0 METs, performed twice a day, with duration based on the patient's physical status and lasting between 15 and 45 min. The oxygen saturation, heart rate, blood pressure, and rating of perceived exertion should be constantly monitored during physiotherapy interventions. Oxygen saturation should remain above 92–93%; heart rate should not increase above more than 20 beats per minute from the baseline; systolic blood pressure should be between $\geq$90 mmHg and $\leq$180 mmHg, and the rating of perceived exertion should not exceed a score of 11–12 during exercise.

Contraindications for physiotherapy entail [100]:

- Oxygen saturation < 93%;
- Heart rate < 40 beats per minute or >120 beats per minute;
- Systolic blood pressure < 90 mmHg and >180 mmHg;
- Body temperature > 37.2 °C;
- Fatigue increasing during exercise and persisting after rest;
- Presence of severe cough, dizziness, blurred vision, palpitations, or sweating.

Post-acute phase:

A statement by Davies et al. delivers valuable recommendations for rehabilitation after the acute phase of COVID-19. A period of rest is recommended post infection, depending on the severity of disease and the left ventricular function, in order to minimize the risk of post infection cardiac failure. Patients with symptoms such as severe sore throat, muscle pain, shortness of breath, general fatigue, chest pain, cough, and fever should avoid exercises > 3 METs for 2–3 weeks after the cessation of these symptoms [101]. Post-discharge hospital-based cardiac rehabilitation consists of progressive aerobic exercises so that patients can gradually recover their level of activity before the onset of disease. Prior to exercise training, an initial assessment should be performed, including the six-minute walking test, strength assessment, and the identification of existing deficits in the basic activities of daily living. Interval training with an initial intensity of 2–3 MET, 3 to 5 times a week, is recommended. In addition, resistance training at moderate intensity should be implemented. Generally accepted exercise training exclusion criteria are a heart rate of >100 beats/min, blood pressure of <90/60 or >140/90 mmHg, and oxygen saturation of < 95% [102]. An influential account of the beneficial effects of exercise training for COVID-19 patients comes from Hermann et al. In their study, patients (mean age 66 years, average duration of stay 19.3 days before referral) participated in a 2–4-week inpatient cardiac rehabilitation program, with protocols adapted to the severity of the disease. The program typically included 25–30 therapy sessions, performed 5–6 days per week. It entailed individualized aerobic and strength training, with intensity derived from an initial six-minute walk test [103]. The aerobic program consisted of supervised walking or stationary cycling, with a pulse oximeter used for monitoring during the exercise. In addition, strength training and respiratory physiotherapy were performed. After completing exercise sessions, significant improvements in the six-minute walk test of 130 m were observed. Further studies are required to optimize exercise parameters and establish a consensus regarding the use of cardiopulmonary programs for this emerging group of patients.

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7. Management of Cardiac Rehabilitation

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7.1. Staffing

The successful delivery of cardiac rehabilitation service requires a multidisciplinary team of professionals with appropriate qualifications and experience. Optimally, a cardiac rehabilitation team should comprise [1]:

- A cardiologist (serving as the medical director);
- Exercise specialists (physiotherapists, exercise physiologists);
- Nurses;
- A psychologist;
- A nutritionist;
- A social worker;
- A smoking cessation specialist;
- Other physicians (physiatrist, cardiac surgeon, vascular surgeon).

The staff included will depend on local recommendations, staff availability, or the phase of cardiac rehabilitation. It is essential to assign specific duties to all staff members regarding staff competencies [2]. The cardiologist should serve as the medical director/be in charge of the cardiac rehabilitation department and should have sufficient experience with and profound knowledge of the management of cardiac rehabilitation centers. Medical director responsibilities include:

- establishing policies and procedures;
- coordinating emergencies;
- conducting daily briefings;
- adjusting exercise prescription;
- supervising medical procedures.

The position of medical director requires adequate organizational skills and experience to organize the program appropriately. The cardiologist evaluates a patient before commencing an exercise program, stratifies the cardiovascular risk, manages risk factors, and supervises exercise tests. Physiotherapists are responsible for the safe early mobilization of all eligible patients during phase I of cardiac rehabilitation, which typically occurs within an intensive care unit, coronary care unit, cardiology department, or cardiac surgery department. During supervised exercise sessions, exercise specialists are responsible for the proper implementation of exercise intensity and cooperate closely with a cardiologist in order to progress exercise training. Typically, one exercise specialist supervises five to ten low- or intermediate-risk patients, and for high-risk patients the ratio should be lower [3]. For safety purposes, it is essential for at least two healthcare professionals to stay at the exercise training area during each exercise session. Nursing staff play an important role in managing medical emergencies and are usually responsible for education regarding diet, physical activities, and control of risk factors. The tasks of nutritionists include the assessment of nutritional status and dietary counseling, which is of particular importance in case of patients with diabetes and dyslipidemia. Psychologists conduct screening for psychosocial abnormalities—i.e., depression, anxiety, and post-traumatic stress disorder. Additional tasks of psychologists include the management of stress workshops and instructing patients regarding relaxation techniques. If available, social workers facilitate social reintegration and deliver vocational counseling in close cooperation with cardiologists [4]. Regular meetings of personnel—e.g., every week—are essential and provide the opportunity to discuss patient treatment plans or complex clinical cases in detail.

7.2. Facility

Cardiac rehabilitation facilities should provide dedicated consultation, exercise, and education areas [1]. Consultation areas are utilized for medical assessments and investigations (e.g., echocardiography), psychological evaluations, and interventions. Exercise facilities/gymnasiums with equipment for the assessment of functional capacity and exercise training should allow for appropriate space around patients and equipment—i.e., 3.0 to 4.0 sq. m per individual [4]. There should be appropriate space for conducting the six-minute walk test. The exercise area should be covered with a non-slip floor surface and should provide temperature and humidity control (with an optimal temperature of about 22 °C). A source of water should be available on site for all exercising patients. Monitoring equipment must be available during exercise for patients at high risk, whereas low-risk patients do not need monitoring in most cases [3]. Educational areas should allow for group education/intervention and should include TV presentations and educational booklets. Centre-based phase II cardiac rehabilitation facilities should include a reception, waiting area, changing rooms with separate toilets, showers, and lockers for patients, as well as offices and toilets for personnel. An emergency call system should be available in all exercise areas. Participants with disabilities should have full access to all cardiac rehabilitation facilities.

7.3. Equipment

The equipment in cardiac rehabilitation centers can be utilized for clinical assessment, exercise testing and training (for both endurance and strength), medical evaluation, and in the case of medical emergencies [1]. The equipment used for the assessment of clinical status and the measurement of vital signs typically includes a sphygmomanometer; ECG monitoring and heart rate monitoring; a digital oximeter; a blood glucose meter; equipment for measuring height, and a weight scale.

For medical evaluation, echocardiography machines and ECG Holter monitoring equipment on site are essential. Mandatory emergency equipment in the exercise area comprises an automated external defibrillator with ECG printout, portable oxygen with nasal cannula and face mask, intubation equipment, and portable suction equipment [2].

Endurance exercise training can be performed on calibrated leg cycle ergometers, treadmills with speed and grade control, arm ergometers, elliptical machines, or rowing machines. As a minimum, treadmills and cycle ergometers should be available. Strength training equipment should include multi-weight machines, dumbbells, and elastic bands [5].

7.4. Documentation

Each patient should have an individual record with sufficient information.

Records must be completed after each session and should include [1,5]:

- Patient's data;
- Referral form;
- Medical history and physical examination report completed on admission;
- Other assessments (nutritional, psychological);
- Diagnostic tests reports;
- Informed consent for treatment;
- Progress notes.

Functional capacity assessments and the patient's progress in exercise training should be documented.

Exercise test reports should include the test modality and protocol, test duration, heart rate and blood pressure values (at rest, maximal exercise, and following exercise cessation), functional capacity assessment, reason for test termination, rate of perceived exertion, ECG analysis, and clinical interpretation [6]. Cardiopulmonary testing reports should include gas exchange and ventilatory data at peak exercise and at ventilatory threshold (if determined) in absolute values and as percentages relative to a reference [7]. Exercise sessions documentation should be completed after each training session and should include the recording of vital signs and exercise parameters—i.e., exercise modality, intensity, total session duration, and potential clinical complications [5]. Administrative records (organizational chart, policies and procedures, qualification, and health records of personnel) should be kept in a safe location.

7.5. Medical Emergencies

Properly conducted cardiac rehabilitation is safe, with a very low risk of major adverse events risk documented—i.e., 1 cardiac arrest per 116,906 patient-hours [8]. However, the potential for unpredictable complications still exists. Therefore, it is crucial for cardiac rehabilitation personnel to appropriately manage medical emergencies. All patients should be routinely screened before each exercise session regarding their change in clinical status, the presence of symptoms since the last training session, their change in heart rate and/or blood pressure, any gain in weight, or changes in their medication regimen.

Cardiac rehabilitation personnel must be familiar with the local protocol for specific emergencies—in particular, cardiac arrest—and chest pain [1]. Guidelines for managing emergencies should be included in program policies and procedures. All incidents must be adequately documented in the patient's chart. Emergency equipment should be immediately available to the exercise area. Emergency carts, resuscitation equipment, and medications must be checked regularly, and defibrillators must be checked daily before sessions commence [2]. All cardiac rehabilitation team members should have completed a valid basic life support course and at least one team member should have completed a valid advanced cardiac life support course. All emergency policies and procedures should be regularly reviewed by the program medical director, and regular emergency drills should be conducted.

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8. Special Considerations for the Middle East

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8.1. Hot Environment and Physical Activity

During exercise in hot weather conditions, if the air temperature exceeds 36 °C, the body gains heat by radiation and convection from the environment [1]. Subsequently, the blood flow through the skin and sweating increase, potentially leading to water and electrolyte imbalance, heat exhaustion, or heat stroke [2,3]. Symptoms of heat exhaustion include excessive sweating, feeling dizzy, increased heart rate, muscle cramps, nausea, and vomiting. Exercising outdoors is not recommended if temperature exceeds 39 °C (103 degrees Fahrenheit) because of risk of heat stroke. Thus, exercising indoors performed in air-conditioned facilities—e.g., in fitness centers is strongly recommended [4]. It relates particularly to individuals with cardiovascular disease.

Exercise training in hot temperature executed by sport professionals requires the implementation of adequate strategies—i.e., adequate fluid supplementation, suitable clothing, and heat acclimatization [5]. The necessary fluid replacement volume can be evaluated by body mass change—i.e., fluid intake should match sweat loss during exercise [6]. Adequate clothing—i.e., short-sleeve t-shirts, shorts, sport shoes, and head covers—is strongly recommended.

Heat acclimatization should comprise repeated exercise heat exposure over 1–2 weeks.

The first exercise sessions performed in the heat should be as short as 5–10 min, with at least a few hours of recovery between exercise bouts [7]. Heat acclimatization leads to improved sweating, improved skin blood flow, lowered body temperature, improved fluid balance, and altered metabolism [8,9]. The degree of adaptation is determined by the intensity, duration, frequency, and number of sessions of heat exposure, as well as the environmental conditions.

8.2. Physical Activity in the Middle East

Cardiovascular disease accounts for more than 45% of total mortality in the Arabian Peninsula [10,11]. The rate of physical inactivity in this region remains very high (61% and 73% for males and females, respectively). In the Kingdom of Saudi Arabia, the central country of the region, the prevalence of physical inactivity has reached a rate of 69%. Furthermore, the prevalence of obesity and diabetes in the Saudi population has reached 49% and 25%, respectively, according to the Prospective Rural Urban Epidemiology study [12].

The two main barriers to physical exercise in the Middle East region are the hot environment and sociocultural factors [13,14]. The latter include the routine use of drivers and housemaids, the lack of adequate knowledge of the topic, the lack of motivation, and the insufficient number of exercise facilities [15]. Some obstacles relate to women specifically, as traditionally women are not expected to perform physical activity in public. Thus, it is important to develop adequate strategies to improve the physical activity rate in the Middle East region through:

- The promotion of physical activity classes at primary schools;
- The development of fitness centers—e.g., in malls;
- Physical activity promotion events supported by the government, healthcare providers, and religious leaders.

8.3. Cardiac Rehabilitation during Ramadan

Ramadan is one of the five pillars of Islam, during which Muslims are not allowed to eat or drink between sunrise and sunset. Ramadan affects Muslims' diets, levels of physical activity, sleeping patterns, and adherence to medications [16]. Decreases in physical activity may be attributed to dehydration, fasting, or disturbed sleeping cycles [16]. Therefore, to prevent functional capacity impairment, adequate hydration, and the maintenance of exercise regimens are essential. Physical activity during Ramadan should preferably be performed in air-conditioned facilities—e.g., in fitness centers. The optimal timing of exercise is debated, with it being suggested that exercise be performed before the main meal (Iftar) or at night (1–2 a.m.). Each training session should consist of a 5–10 min warm-up, a main session of 20–30 min, and 5–10 min of cool-down. Endurance training intensity should be reduced (at a light-to-moderate level) and be performed at intervals. Strength training intensity should not exceed 50% of 1-RM. Adequate fluid replacement and wearing suitable clothing are essential [17].

Adherence to cardiac rehabilitation programs during Ramadan is poor due to participants' fasting and disturbed sleep patterns. According to the authors' experiences, only 15%–20% of patients regularly attend supervised exercise sessions during Ramadan. Thus, the authors suggest the following strategies:

For patients already enrolled in exercise sessions before Ramadan, the use of a light-to-moderate-intensity home- or community-based exercise program that is adjusted to the participant's sleep–wake-up cycle should be discussed. A detailed exercise plan should be prescribed that takes into account the training heart rate range, and cardiac rehabilitation personnel should stay in touch with patients.

For patients needing to commence exercise sessions during Ramadan, a home-based light-intensity exercise program should be discussed, with the commencement of supervised exercise training sessions beginning after Ramadan.

8.4. Development of Cardiac Rehabilitation in the Kingdom of Saudi Arabia

Considering the high prevalence of obesity, diabetes, and physical inactivity in the Kingdom of Saudi Arabia, efficient cardiovascular prevention and cardiac rehabilitation programs are of paramount importance. Cardiac rehabilitation has gradually evolved into a multi-factorial program that involves managing cardiovascular risk factors and delivering nutritional, psychological, and social support to improve patient outcomes. Most of these steps have been implemented at the Prince Sultan Cardiac Center (PSCC) in Riyadh from 2009 by Dr. Fahad AlNouri, an outstanding expert on familiar hypercholesterolemia who has been serving as the President of the Saudi Group for Cardiovascular Prevention and Rehabilitation. Dr. AlNouri graduated with a Master of Science diploma in preventive cardiology, with merit for his dissertation, from the Imperial College London in 2009. Upon completion of his degree and his return to Riyadh, Dr. Alnouri set up the first ever Cardiovascular Prevention and Rehabilitation Unit within the Kingdom of Saudi Arabia. This unit employs a unique preventive cardiology clinic team comprising a cardiologist, dietician, physical activity specialist, clinical pharmacist, and health education nurse. One of the routine components of the clinic's practice is patient physical activity counseling. In February 2018, the first exercise training program in the Kingdom of Saudi Arabia was established by Dr. Adam Staron. Dr. Staron, serving as the Head of the Cardiac Rehabilitation Unit at Prince Sultan Cardiac Center, implemented the protocols of the Polish School of Cardiac Rehabilitation, modified later with regards to the local conditions. Over one thousand patients completed a supervised exercise training program (October 2021), achieving excellent outcomes (average improvement of physical capacity by 2.78 MET). In 2019, a separate female exercise area was created by Dr. Jadwiga Wolszakiewicz (Figures 19 and 20).

(**A**)

(**B**)

Figure 19. Male (**A**) and female (**B**) exercise areas at Prince Sultan Cardiac Center. Source: Photos by authors.

In addition, in 2020 the curriculum of the Cardiac Rehabilitation Fellowship Program for certified cardiologists was approved by the Saudi Commission for Health Specialties (authors: Wolszakiewicz, Staron, AlSulaimi). The same authors are being involved (June 2022) in writing Saudi Cardiac Rehabilitation guidelines and curriculum of the Cardiac Rehabilitation Fellowship for physiatrists. Supervised cardiac rehabilitation is currently being delivered in other healthcare facilities in the Kingdom (Sultan bin Abdulaziz Humanitarian City Riyadh, Dr. Soliman Fakeeh Hospital in Jeddah), with several other hospitals planning to establish cardiac rehabilitation services in a near future.

Figure 20. Cardiac rehabilitation staff—Prince Sultan Cardiac Center (November 2019). Source: Photo by authors.

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