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].

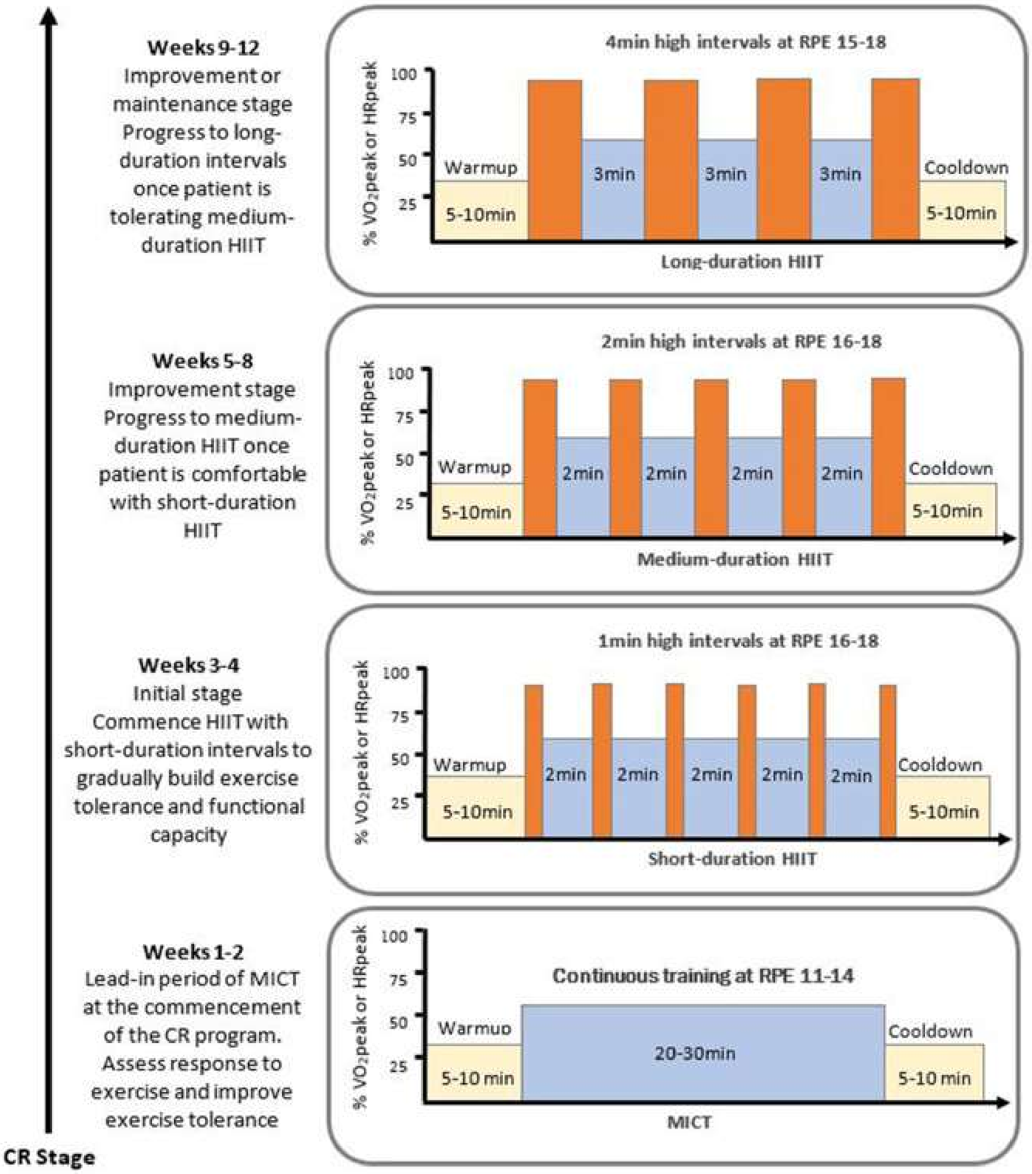


Figure 5. Progression of MICE into HIIT. Source: Reprinted from [66].

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:

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

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 $\times$ 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.

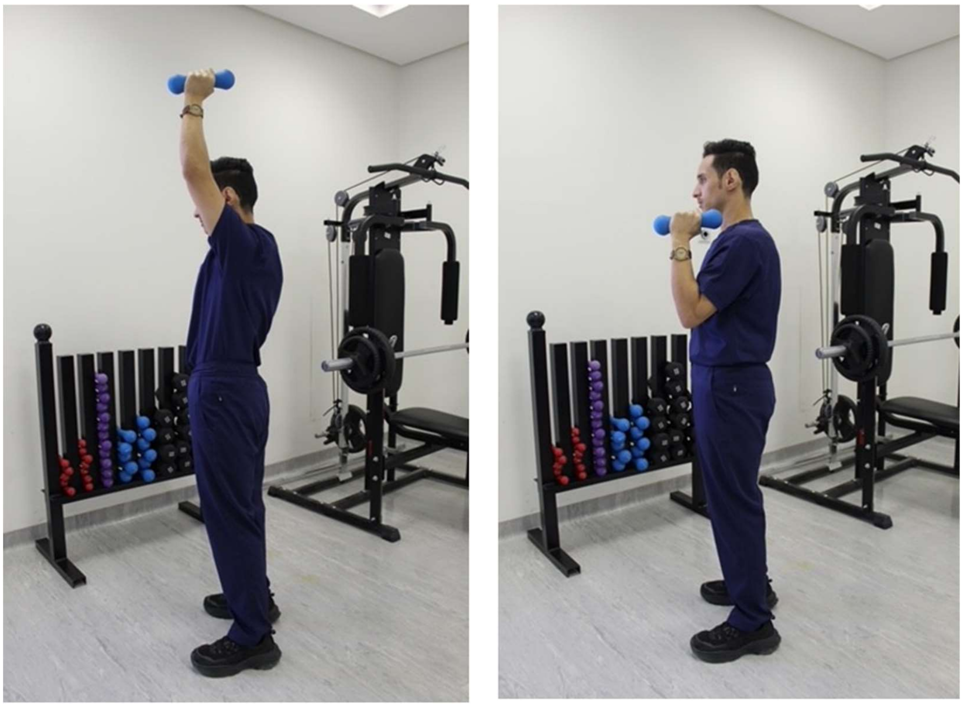
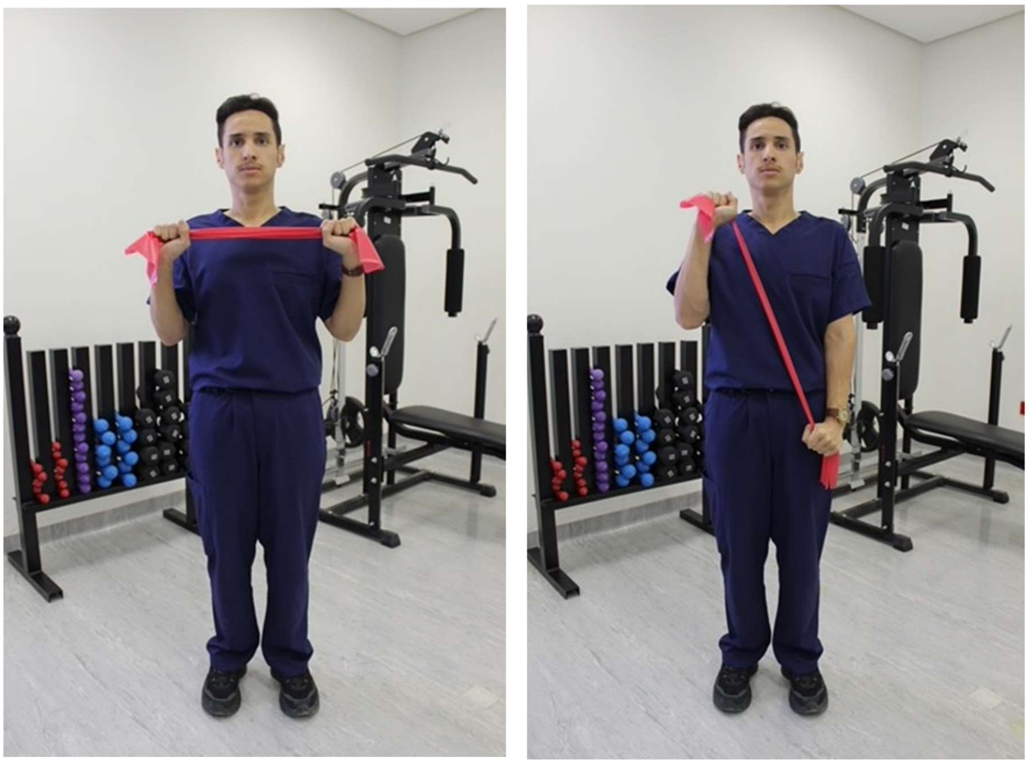


Figure 8. Shoulder press. Source: Photos by authors.

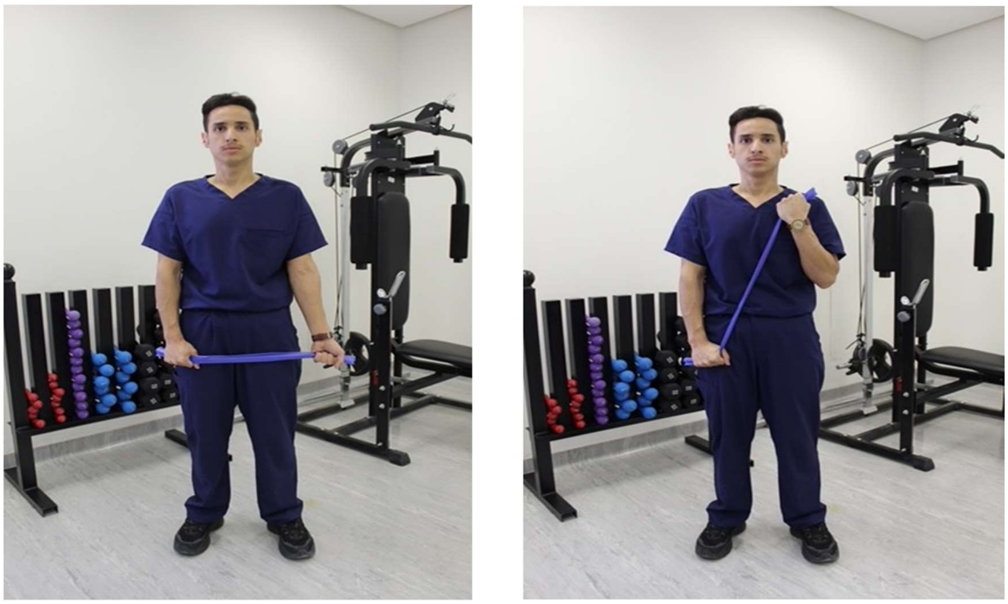
(**A**)



(**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.

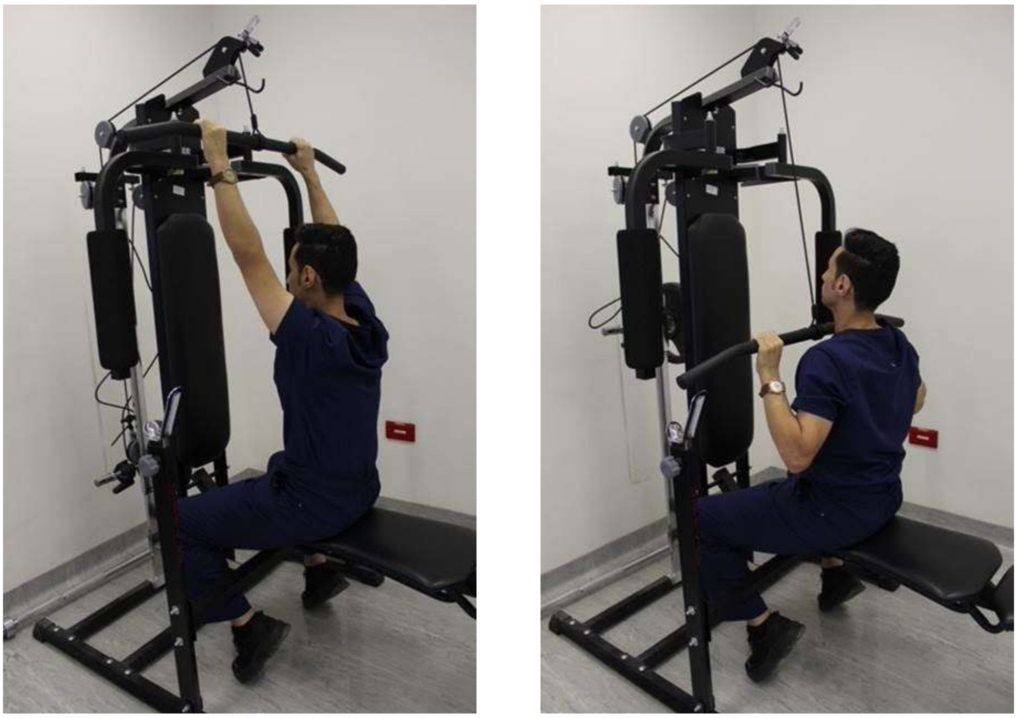


Figure 11. Pull-down (upper back). Source: Photos by authors.

(**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.

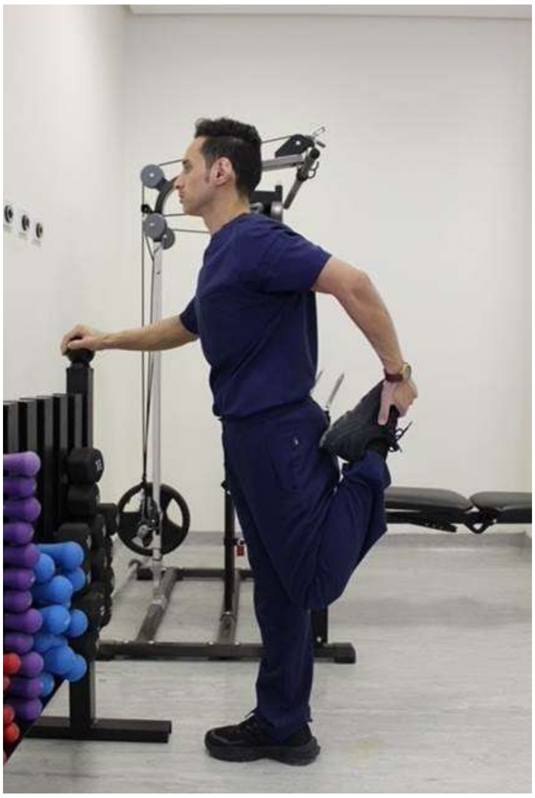


Figure 15. Quadriceps stretch. Source: Photo by authors.

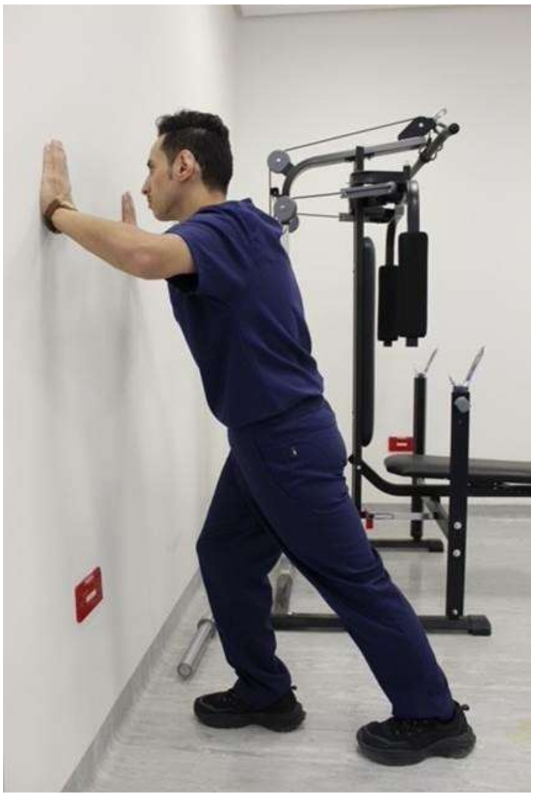


Figure 16. Calf muscle stretch. Source: Photo by authors.

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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