European Journal of
Preventive
Cardiology
ESC
European Society
of Cardiology

Clinical practice

European Journal of Preventive
Cardiology
0(00) 1–10

DOI: 10.1177/2047487319847003
journals.sagepub.com/home/ejpc
SAGE

Dynamic strength training intensity in cardiovascular rehabilitation: is it time to reconsider clinical practice? A systematic review

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Abstract

When added to endurance training, dynamic strength training leads to significantly greater improvements in peripheral muscle strength and power output in patients with cardiovascular disease, which may be relevant to enhance the patient's prognosis. As a result, dynamic strength training is recommended in the rehabilitative treatment of many different cardiovascular diseases. However, what strength training intensity should be selected remains under intense debate. Evidence is nonetheless emerging that high-intensity strength training (≥70% of one-repetition maximum) is more effective to increase acutely myofibrillar protein synthesis, cause neural adaptations and, in the long term, increase muscle strength, when compared to low-intensity strength training. Moreover, multiple studies report that high-intensity strength training causes fewer increments in (intra-)arterial blood pressure and cardiac output, as opposed to low-intensity strength training, thus potentially pointing towards sufficient medical safety for the cardiovascular system. The aim of this systematic review is therefore to discuss this line of evidence, which is in contrast to current clinical practice, and to re-open the debate as to what dynamic strength training intensities should actually be applied.

Keywords

Cardiovascular rehabilitation, strength training, guidelines

Received 25 February 2019; accepted 8 April 2019

Introduction

Cardiovascular rehabilitation is a type 1A intervention in the treatment and (secondary) prevention of cardiovascular disease (CVD).[1–3] In diverse populations of patients with coronary artery disease such an intervention leads to significant reductions in fatal events and hospitalisations, while in patients with heart failure significant reductions in hospitalisations for cardiac reasons and a trend towards reductions in mortality are observed.[4,5] In these programmes, different types, intensities and frequencies of exercise have been used in different studies and clinical settings. Endurance training has been the most intensively studied exercise modality in patients with CVD. However, dynamic strength training protocols are less consensual. The question thus arises as to what dynamic strength training intensity is the best in order to induce the greatest benefits? In this paper, the impact and application of isometric strength training will not be discussed, as very different physiological responses may be provoked in patients with CVD.

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Physiological and anatomical changes after endurance versus strength training

The elicited physiological and clinical adaptations derived from endurance versus dynamic strength exercise training are very different. As a result of sustained endurance exercise training at an appropriate level, skeletal muscle mitochondrial biogenesis is activated after phosphorylation of 5′-adenosine monophosphate-activated protein kinase, which in effect will lead to enhanced muscle respiration capacity to resynthesise adenosine triphosphate (ATP). In addition, muscle fibre type shifts may be induced (in favour of type 1 slow-twitch muscle fibres) next to enhanced capillarisation. From these molecular changes, improvements in endurance capacity and skeletal muscle fat oxidation capacity are the key adaptations. Strength training, on the other hand, induces completely different molecular and clinical adaptations. As result of strength training, skeletal muscle ribosomal biogenesis is induced after the activation of mammalian target of rapamycin, which in effect will lead to muscle hypertrophy. In addition, muscle fibre type shifts may be induced (in favour of type 2b muscle fibre). From these molecular changes, improvements in muscle strength and mass are the key adaptations. Moreover, as a result of dynamic strength training neurological adaptations are also observed, leading to enhancements in muscle strength. It is important to mention that gains in muscle mass and muscle strength can be different due to anatomical versus neurological adaptations. It is thus apparent that skeletal muscle physiology and anatomy adapts differently when exercise stimuli are provided at different intensities.

Importance of strength training in cardiovascular rehabilitation

Dynamic strength training for the peripheral skeletal muscles is a crucial part of a rehabilitation programme as evidenced from clinical guidelines and recommendations.[1–3] Robust evidence from patients with coronary artery disease and heart failure shows that combined endurance and dynamic strength training is significantly more effective than endurance training only for improving endurance capacity, cycling power output, muscle mass and strength.[6–8] Moreover, a significant dose–response relationship is present between the number of muscle strength training sets per muscle group and the magnitude in muscle mass gain in patients with coronary artery disease.[9] These additional clinical benefits may be of great value to patients with CVD. For example, in community-dwelling adults (including 3,002,203 participants), the hazard ratios with per 5-kg decrease in grip strength (as an indicator for muscle strength) is 1.16 (95% confidence interval (CI) 1.12–1.20) for all-cause mortality, 1.21 (95% CI 1.14–1.29) for CVD, 1.09 (95% CI 1.05–1.14) for stroke and 1.07 (95% CI 1.03–1.11) for coronary heart disease.[10] These associations did not differ by sex and remained significant after excluding participants with CVD or cancer at the start of follow-up. In addition, strength training also favourably affects bone health,[11] glycaemic control, blood pressure and lipid profile, at least in the elderly and/or patients with elevated CVD risk.[12] It thus follows that if optimisation of the patient's prognosis is strived for by means of cardiovascular rehabilitation, dynamic strength training for the peripheral muscles should be added to endurance training, especially in patients with muscle weakness or sarcopenia.

Strength training recommendations according to clinical guidelines

According to European guidelines, and based predominantly on expert opinion, dynamic strength training for the peripheral muscles should be executed at 30–40% of the 1-repetition maximum (1-RM) for the upper body and at 40–50% of 1-RM for lower body exercises, with 12–15 repetitions in one set repeated two to three times weekly, at least in patients with coronary artery disease.[2,3] For heart failure patients, the strength training recommendations are slightly different. It is advised to start with preparatory exercises, without or at a very low resistance (at 30% of 1-RM), followed by a 'resistance/endurance phase' (e.g. strength training with a high number of repetitions ($n = 12$–25) and at a low intensity (at 30–40% of 1-RM)), to be finally followed by the 'strength phase' (at higher intensity, e.g. at 40–60% of 1-RM) in order to increase muscle mass.[13] It is assumed that clinicians follow these guidelines and apply the recommended strength training modalities in clinical practice. It must be mentioned that terminology (in guidelines) is of key importance: strength training implies a specific focus and direction/target whereas resistance training does not. More specifically, resistance exercise is considered any exercise that causes the skeletal muscles to contract against an external resistance with the aim to increase skeletal muscle strength, tone, mass or endurance. On the other hand, strength exercises are specifically resistance exercises with the aim specifically to increase skeletal muscle strength.

However, evidence is emerging that these currently applied dynamic strength training intensities should be re-evaluated closely if we aim to achieve the most optimal clinical benefits and medical safety.

A recent systematic review revealed that the recommendations for dynamic strength training in CVD vary considerably between countries/continents and/or institutions.[14] From 13 position stands consensus is indeed reached for the number of exercise sets (one to three sets) and training frequency (two to three sessions per week). On the other hand, recommendations for strength training intensities were highly inconsistent: these intensities ranged from less than 30% up to 80% of 1-RM, which can be considered as an immense variance.[14] It can thus be concluded from this systematic review that at this moment, there is actually no consensus on what appropriate dynamic resistance/strength training intensities should be applied in the rehabilitation of patients with CVD. Hence, what exercise intensity should be selected during strength training in CVD patients is still open for debate or reconsideration.

Strength training intensity in cardiovascular rehabilitation: high and few, or low and many?

In order to set the correct dynamic strength training intensity for patients with CVD, both the planned physiological adaptation, as well as medical safety, should be set, evaluated and well balanced. Hence, it has to be decided to go for high and few (at > 70% of 1-RM, low number of repetitions: HIST) or low and many (at <50% of 1-RM, low number of repetitions: LIST), or in between.

The primary aim to include dynamic strength training in cardiovascular rehabilitation is, or at least should be, to optimise muscle mass and in particular muscle strength (see above). As a result, it remains to be debated whether patients with sufficient muscle strength really do need additional strength training. To maximise muscle mass and strength gains, evidence is emerging that HIST should be preferred above LIST. In several meta-analyses, for example, it has been shown that HIST leads to significantly greater improvements in muscle strength, as opposed to LIST.[15–17] From a physiological point of view, this makes sense. When feeding status is well controlled, and total exercise volume is matched between different strength training interventions (which is necessary truly to understand the independent influence of exercise intensity), it has been shown in an elegant study that changes in the myofibrillar protein synthesis rate are dependent on the contractile intensity of the exercises, revealing only an improvement following a single bout of HIST.[18] In accordance, only when HIST contractions are executed, the mitogen-activated protein kinase and mammalian target of rapamycin complex 1-dependent pathways are significantly activated, and to a significantly lesser extent after LIST.[18] Such enhanced myofibrillar protein synthesis may thereby lead to greater muscle mass gains. This may help to explain why greater increments in muscle mass are sometimes noted after HIST versus LIST. Even if muscle mass gains are comparable after a LIST versus HIST intervention, which can occur, the neurological adaptations are distinct between these interventions. For example, when comparing a long-term HIST intervention (at 80% of 1-RM) against a long-term LIST intervention (at 30% of 1-RM), greater neural adaptations occurred after HIST (as evidenced by greater increases in percentage voluntary activation and electromyographic amplitude during maximal force production), which may explain the disparate increases in muscle strength despite similar muscle hypertrophy following HIST versus LIST.[19] However, it must be noted that in patients with CVD it remains to be established what would be the effects of HIST versus LIST on changes in muscle mass and strength during an endurance exercise intervention, as this was not analysed in the available meta-analyses.[6–8]

As a result of these distinct physiological and neurological changes, which are promoted best as a result of HIST, dynamic strength training at higher intensities (at ≥ 70% of 1-RM) should thus be considered in cardiovascular rehabilitation. However, when doing so, the medical safety of HIST versus LIST should then be systematically evaluated in greater detail.

High or low-intensity strength training: what is the safest in cardiovascular rehabilitation from a medical point of view?

Obviously when patients with CVD are exposed to HIST there may be an increased risk of cardiovascular events. However, when patients with CVD engage in a rehabilitation programme, it is assumed that these patients are directly guided/supervised by trained clinicians.[20] These clinicians should be aware of formal contraindications to dynamic strength training and be able to estimate the patient's risk profile.[3] Moreover, rehabilitation or exercise training facilities are specifically designed and equipped to anticipate adverse events during exercise.[20] This explains, at least in part, why the likelihood of developing cardiovascular adverse events during dynamic strength training is actually very low in cardiovascular rehabilitation units, or at least not greater as opposed to endurance training.[6–8] In addition, there is no established relation between the applied dynamic strength training intensity and the incidence of adverse cardiovascular events during rehabilitation.[6–8]

On the other hand, intensive heavy weight lifting or HIST, especially when this includes substantial

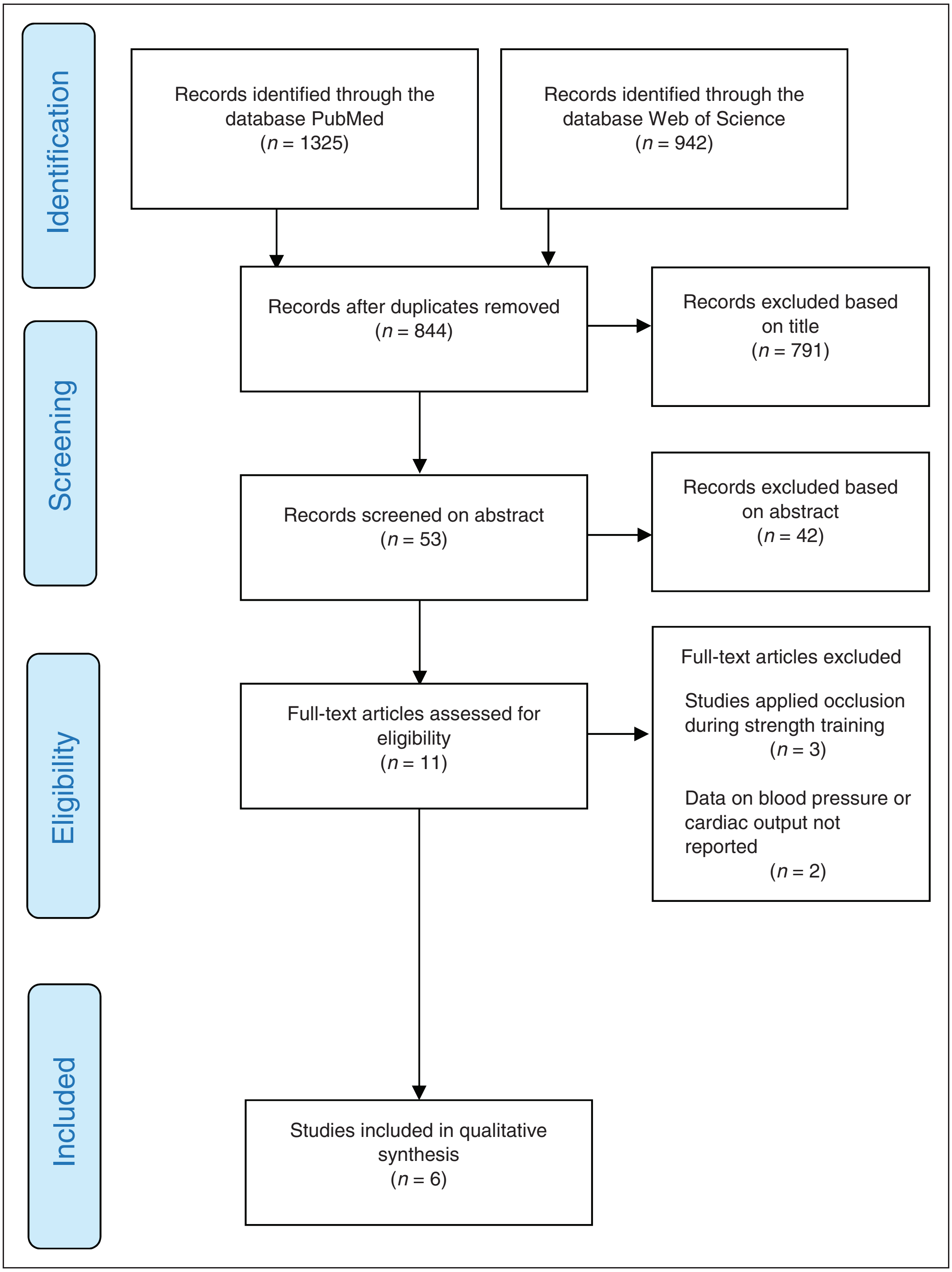

Figure 1. PRISMA flow diagram of the literature search.

isometric (static) muscle work, can induce a significant pressor effect, leading to the Valsalva manoeuvre. This manoeuvre is characterised by significant increments in the intrathoracic pressure resulting in (sometimes dangerous) elevations in (especially) systolic and diastolic blood pressure. This thus occurs when holding the breath during muscular contraction, and occurs more frequently during isometric strength exercise.[21] After the termination of this compressed breathing a large increase in venous return may be provoked and thus an increased cardiac output (through a constricted arterial vascular system). This may lead to sharp increments in blood pressure and myocardial oxygen demand. Such a Valsalva manoeuvre can thus be

Table 1. Quality assessment of the randomised controlled crossover trials ($n = 6$).

	Lamotte, et al.[24]	de Souza Nery, et al.[25]	de Sousa, et al.[23]	Gløvaag, et al.[26]	Sardeli, et al.[27]	Gjøvaag, et al.[28]
1. Eligibility criteria were specified	+	+	+	+	+	+
2. Subjects were randomly allocated an order in which treatments were received	+	+	–	+	+	+
3. Allocation was concealed	+	+	–	+	+	+
4. The groups were similar at baseline regarding the most important prognostic indicators	NA	NA	NA	NA	NA	NA
5. There was blinding of all subjects	–	–	–	–	–	–
6. There was blinding of all therapists who administered the therapy	–	–	–	–	–	–
7. There was blinding of all assessors who measured at least one key outcome	–	–	–	–	+	–
8. Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups	+	+	+	+	+	+
9. All subjects for whom outcome measures were available received the treatment or control condition as allocated or, when this was not the case, data for at least one key outcome were analysed by 'intention to treat'	+	+	+	+	+	+
10. The results of between-group statistical comparisons were reported for at least one key outcome	+	+	+	+	+	+
11. The study provided both point measures and measures of variability for at least one key outcome	+	+	+	+	+	+
Final score	6	6	4	6	7	6
Quality	G	G	M	G	G	6

+: yes; –: no; G: good; M: moderate.

avoided by exhaling during muscular contraction (which is well known by trained clinicians).

Literature search

To examine the acute impact of the intensity of a single dynamic strength exercise bout on blood pressure and cardiac output, the literature was searched systematically up to April 2019 and the authors adhered to the preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines.[22] PubMed and Web of Science was consulted to search studies that (a) examined healthy persons or patients with CVD; and (b) directly compared the effect of different dynamic strength exercise intensities on blood pressure and/or cardiac output during this exercise session. Studies that applied isometric strength exercises, examined patients with chronic non-CVD (e.g. pulmonary disease, cancer, neurological disease, orthopaedic disease), and/or applied occlusion/blood flow restriction of the lower extremities during exercise, were excluded. By using the MESH terms or keywords 'resistance exercise intensity' AND 'blood pressure' (1), 'strength exercise intensity' AND 'blood pressure' (2), 'resistance exercise intensity' AND 'cardiac output' (3), 'strength exercise intensity' AND 'cardiac output' (4), 'strength exercise load' AND 'blood pressure' (5), 'resistance exercise load' AND 'blood pressure' (6), 'strength exercise load' AND 'cardiac output' (7), 'resistance exercise load' AND 'cardiac output' (8), 436 (1), 290 (2), 125 (3), 46 (4), 93 (5), 232 (6), 24 (7) and 106 (8) hits, respectively, emerged (for PubMed and Web of Science combined, with the exclusion of duplicates, see Figure 1). Abstracts were limited to human studies and studies in adults (aged ≥ 18 years) only and abstracts from conference proceedings were excluded. Abstracts were carefully screened and relevant manuscripts were checked for additionally relevant studies in the reference lists, from which finally six relevant manuscripts were maintained for data extraction. Next, data were extracted from the included studies: study population (number of participants, age, sex, medical

Table 2. Studies assessing the cardiovascular response to a single session of high versus low-intensity strength training.

Study	Participants	Outcomes and methods	Resistance training sessions	Findings
Lamotte et al.[24]	14 Patients with coronary artery disease or valve disease (age 46–72 years)	Heart rate was recorded by ECG. BP was recorded beat by beat using a validated volume oscillometric method	Four sets of 17 repetitions at 40% of 1-RM vs. four sets of 10 repetitions at 70% of 1-RM on a leg extension machine	The heart rate and systolic BP during low-intensity resistance training were always greater than during high intensity ($P < 0.001$)
de Souza Nery et al.[25]	10 Hypertensive and 10 normotensive subjects (9 men, 11 women, mean age 46 ± 3 and 39 ± 2 years, respectively)	Intra-arterial BP was measured continuously in the radial artery	Three sets of knee extension exercises to exhaustion: 40% of 1-RM with a 45-second rest between sets, vs. 80% of 1-RM with a 90-second rest interval between sets	The mean increase in systolic BP was greater during exercise performed at 40% of 1-RM than at 80% of 1-RM (hypertensives $+86 \pm 4$ vs. $+74 \pm 4$ mmHg; normotensives $+63 \pm 3$ vs. $+60 \pm 3$ mmHg; $P<0.05$)
de Sousa et al.[23]	Seven normotensive healthy men (age 26 ± 3 years)	The BP and heart rate were measured simultaneously by a photoplethysmographic method	Incremental 1-minute stages at different percentage of 1-RM, with 2-minute recovery between sets, starting with 10% of 1-RM and followed by 20, 25, 30, 35, 40, 50, 60, 70 and 80% of 1-RM or until exhaustion	The increase in systolic BP was approximately 60% higher in 70% of 1-RM (1.3 ± 0.3 mmHg/s) than in 40% of 1-RM (0.8 ± 0.4 mmHg/s)
Gløvaag et al.[26]	Men ($n = 11$) and women ($n = 4$) treated with PCI or CABG (age 64 ± 7 years)	Beat-to-beat systolic and diastolic BP, heart rate, stroke volume, cardiac output were monitored continuously by ECG, echocardiography and finger photoplethysmograpic method	Three sets of 15-RM and 4-RM strength exercise in a randomised order on separate days	Systolic and diastolic BP were higher during 15-RM vs. 4-RM (both $P < 0.001$). Heart rate increased more following 15-RM compared to 4-RM ($P < 0.05$): a higher cardiac output following 15-RM (compared to 4-RM; $P < 0.05$) was mainly caused by higher heart rate
Sardeli et al.[27]	21 Healthy elderly (9 men, age 64 ± 5 years)	ECG monitoring for heart rate variability analysis, finger photoplethysmography for BP assessment	High load (at 80% of 1-RM) until muscular failure vs. low load (at 30% of 1-RM) until muscular failure, and a control session	Low load strength exercise prompted higher systolic and mainly diastolic BP increments in many sets. The heart rate and cardiac output increase and total peripheral resistance reduction following exercise were not different among strength training protocols

(continued)

Table 2. Continued

Study	Participants	Outcomes and methods	Resistance training sessions	Findings
Gløvaag et al.[28]	13 Healthy men (age 25 ± 4 years)	Non-invasive beat-to-beat systolic and diastolic blood pressure was measured on the finger, while non-invasive cardiac output was assessed beat to beat by impedance cardiography	4-RM vs. 20-RM leg extensions without breath holding	Exercise systolic/diastolic BP were higher during 20-RM (203 ± 33/126 ± 19 mmHg) vs. 4-RM (154 ± 22/99 ± 18 mmHg) ($P < 0.001$). Cardiac output was higher during 20-RM (13.9 ± 2.2 L/min) vs. 4-RM (10.8 ± 2.6 L/min) ($P < 0.01$)

BP: blood pressure; RM: repetition maximum; PCI: percutaneous coronary intervention; CABG: coronary artery bypass grafting.

status), study design, strength exercise characteristics (number of repetitions, exercise intensity) and outcome parameters (systolic and diastolic blood pressure and cardiac output).

Quality assessment

Quality assessment was performed by the use of the PEDro scale for randomised clinical trials (see Table 1). In this scale, 11 questions had to be answered with ‘yes’ (score 1) or ‘no’ (score 0). According to the guidelines of this scale, item 1 was not used to calculate the PEDro score, and the fourth question was not applicable to crossover designs, which resulted in a total score out of 9. A score of 8–9 out of 9 was considered as a study of very good quality, 5–7 out of 9 as good quality, 3–4 out of 9 as moderate quality and 0–2 out of 9 as low quality. Articles were not excluded based on methodological quality.

Results

In total, six randomised clinical crossover trials were maintained for final analysis, including 90 individuals, of which the majority were men and the age of the participants varied considerably. Four studies examined healthy individuals while three studies examined patients with chronic CVD (e.g. coronary artery disease, valve disease and hypertension). The study quality assessment revealed that five out of six studies were of good quality, and one study was of moderate quality. The main shortcoming in these studies was the blinding of the patients, therapists and observers.

There is no doubt that acute dynamic strength exercises will lead to increments in blood pressure and cardiac output. However, as shown in Table 2, the majority of studies (in which crossover designs were applied, except for de Sousa et al.)[23] indicate that the increase in the systolic blood pressure is more pronounced when LIST is applied, when opposed to HIST.[24–28] Moreover, studies also reveal that the cardiac output followed similarly discrepant changes between HIST versus LIST.[26,28] These results are in contrast to the widely upheld belief that HIST would lead to greater cardiovascular demands, as opposed to LIST. On the contrary, it is currently hypothesised that HIST leads to smaller increments in systolic blood pressure and cardiac output because the time duration of a HIST session is shorter, as opposed to LIST, thus preventing a full cardiovascular response to such exercise.[24–28] The findings from de Sousa et al.[23] are, however, in contrast to the other studies.[24–28] The discrepancy in results between these studies can be related to the applied study design: in the study of de Sousa et al.[23] the different strength training sessions at

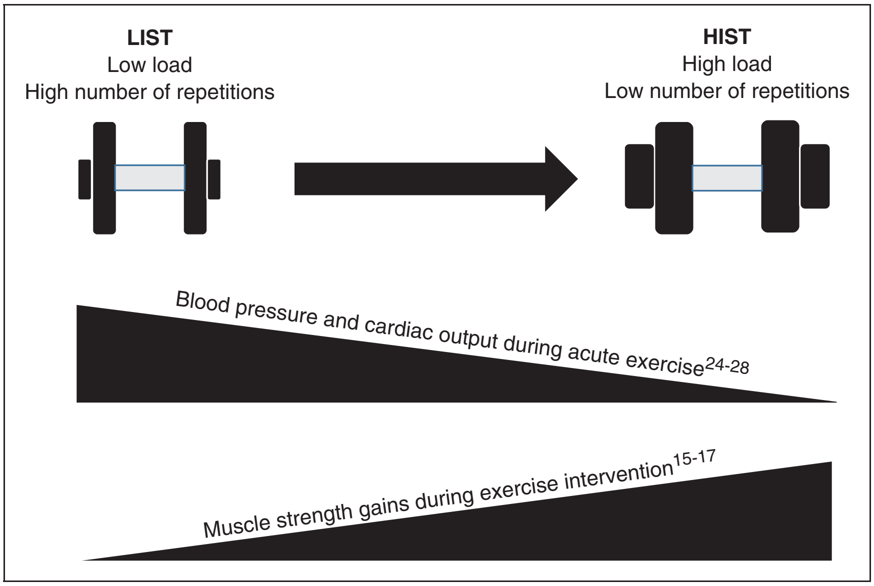

Figure 2. High versus low-intensity strength training in cardiovascular disease: expected acute and chronic physiological effects based on the current literature.
LIST: low-intensity strength training; HIST: high-intensity strength training.

different intensities (going from low up to high intensity) were executed subsequently (although with a 2-minute rest between sets) allowing the cardiovascular response to these exercises to increase over time (neural activation, increments in blood catecholamine and lactate concentrations). In the other studies, the different strength training intensities were, however, randomised, thereby avoiding this follow order effect on key cardiovascular parameters.[24–28]

This systematic review also revealed some shortcomings in the current literature. First, only 90 individuals were examined in total by crossover design, although five out of six studies reported similar findings (no matter whether healthy individuals or CVD patients were examined) and were of good quality. Second, more studies should be initiated specifically to examine the impact of a single HIST or LIST bout in patients with CVD of different types, such as chronic heart failure, peripheral arterial disease and metabolic disease, to mention a few, to validate the current findings from the literature.

Potential clinical implications of these findings

Even though HIST is more effective to increase muscle strength, with less cardiovascular demand, as opposed to LIST, HIST is hardly studied in current meta-analyses related to cardiovascular rehabilitation.[6–8] As a result, this could mean that the true clinical benefits of the addition of dynamic strength training on top of endurance training remains to be established in patients with CVD. In other words, the currently observed clinical benefits of dynamic strength training may in fact be underestimated and therefore underappreciated in cardiovascular rehabilitation. A large prospective study comparing HIST and LIST associated to endurance training in subsets of cardiovascular patients is necessary to define which is the best protocol in cardiovascular rehabilitation. New findings may lead to a further optimisation of the cardiovascular rehabilitation guidelines and of clinical practice.

Conclusions

Dynamic strength training is important in the rehabilitation of many different CVDs. However, what strength training intensity should be selected remains under intense debate. Evidence now points out that high-intensity dynamic strength training (at $\geq 70\%$ of 1-RM) is more effective to increase muscle strength (as opposed to low-intensity strength training), while the acute cardiovascular demand is lower (see Figure 2). However, more studies are needed to validate these findings in many different CVDs. These findings should thus re-open the debate about what strength training intensities should be applied, and trigger researchers to investigate the impact of the addition of low versus high-intensity dynamic strength training during a cardiovascular rehabilitation programme.

Author contribution

DH, AA, PD and HV contributed to the conception or design of the work. DH contributed to the acquisition, analysis, or interpretation of data for the work. DH drafted the manuscript. AA, PD and HV critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work ensuring integrity and accuracy.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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