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

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**Abstract**

When added to endurance training, dynamic strength training leads to significant 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-intense strength training (≥70% of one-repetition maximum) is more effective to acutely increase myofibrillar protein synthesis, cause neural adaptations and, in the long term, increase muscle strength, when compared to low-intense strength training. Moreover, multiple studies report that high-intense strength training causes less increments in (intra-)arterial blood pressure and cardiac output, as opposed to low-intense strength training, thus potentially pointing towards a sufficient medical safety for the cardiovascular system. The aim of this review is therefore to discuss this line of evidence, which is in contrast to our current clinical practice, and to re-open the debate what dynamic strength training intensities should actually be applied.

Keywords: cardiovascular rehabilitation, strength training, guidelines

**Introduction**

Cardiovascular rehabilitation is a type 1A intervention in the treatment and (secondary) prevention of cardiovascular disease:1-3 in diverse populations of patients with coronary artery disease such intervention leads to significant reductions in fatal events and hospitalisations, while in patients with heart failure significant reductions in hospitalisations due to cardiac reasons and a trend towards reductions in mortality are observed.4,5 In these programs, 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 cardiovascular disease. However, dynamic strength training protocols are less consensual. The question thus rises what dynamic strength training intensity is the best in order to induce the greatest benefits? In this manuscript, the impact and application of isometric strength training will not be discussed, as very different physiological responses may be provoked in patients with cardiovascular disease.

**Physiological and anatomical changes after endurance vs. strength training**

The elicited physiological and clinical adaptations derived from endurance vs. 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 (AMPK), which in effect will lead to enhanced muscle respiration capacity to resynthesize 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 activation of mammalian target of rapamycin (mTOR), 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 also neurological adaptations are 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 vs. neurological adaptations. It is thus apparent that skeletal muscle physiology and anatomy adapts differently when exercise stimuli are provided on different intensities.

**Importance of strength training in cardiovascular rehabilitation**

Dynamic strength training for the peripheral skeletal muscles is a crucial part of a rehabilitation program 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 cardiovascular disease. 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% CI: 1.12-1.20) for all-cause mortality, 1.21 (95% CI: 1.14-1.29) for cardiovascular diseases, 1.09 (95% CI: 1.05-1.14) for stroke, and 1.07 (1.03-1.11) for coronary heart disease.10 These associations did not differ by sex and remained significant after excluding participants with cardiovascular disease or cancer at 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 cardiovascular disease 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 1 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 to specifically 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 cardiovascular disease 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/week). On the other hand, recommendations for strength training intensities were highly inconsistent: these intensities ranged from <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 actually is no consensus on what appropriate dynamic resistance/strength training intensities should be applied in the rehabilitation of patients with cardiovascular disease. Hence, what exercise intensity should be selected during strength training in cardiovascular disease 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 cardiovascular disease, both the ambitioned 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 significant 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 to truly understand the independent influence of exercise intensity), it has been shown in an elegant study that changes in 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 (MAPK) and mammalian target of rapamycin (mTOR) complex 1-dependent pathways are significantly activated, and to a significantly lesser extend after LIST.18 Such enhanced myofibrillar protein synthesis may hereby lead to greater muscle mass gains. This may help to explain why greater increments in muscle mass are sometimes noticed after HIST vs. LIST. Even if muscle mass gains are comparable after a LIST vs. 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) vs. a long-term LIST intervention (at 30% of 1-RM), greater neural adaptations occurred after HIST (as evidenced by greater increases in percent voluntary activation and electromyographic amplitude during maximal force production), which may explain the disparate increases in muscle strength despite similar muscle hypertrophy following HIST vs. LIST.19 However, it must be noticed that in patients with cardiovascular disease it remains to be established what would be the effects of HIST vs. 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 from these distinct physiological and neurological changes, which are promoted best as 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 vs. LIST should then be systematically evaluated in greater detail.

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

Obviously, when patients with cardiovascular disease are exposed to HIST, there may be an increased risk for cardiovascular events. However, when patients with cardiovascular disease engage in a rehabilitation program, it is assumed that these patients are directly guided/supervised by trained clinicians.20 These clinicians should be aware of formal contra-indications 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 for 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 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 into (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 Valsalva manoeuvre can thus be avoided by exhaling during muscular contraction (which is well-known by trained clinicians). If such Valsalva manoeuvre is avoided, evidence is mounting that actually HIST (high load, low number of repetitions) induces smaller increments in blood pressure and cardiac output as opposed to LIST.22-25

*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. PubMed and Web of Science was consulted to search studies that 1. Examined healthy persons or patients with cardiovascular disease, and 2. 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-cardiovascular disease (e.g. pulmonary disease, cancer, neurologic 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 exclusion of duplicates). Abstracts were limited to human studies and studies in adults (aged ≥18 years) only. 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.

*Results*

There is no doubt that acute dynamic strength exercises will lead to increments in blood pressure and cardiac output. However, as shown in Table 1, the majority of studies (in which cross-over designs were applied, except for reference 24) indicate that the increase in the systolic blood pressure is more pronounced when LIST is applied, when opposed to HIST.22,23,25-27 Moreover, studies also reveal that the cardiac output followed similarly discrepant changes between HIST vs. LIST.25,27 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.22,23,25-27 The findings from de Sousa et al.24 are however in contrast to the other studies.22,23,25-27 The discrepancy in results between these studies can be related to the applied study design: in the study of de Sousa et al.24 the different strength training sessions at different intensities (going from low- up to high-intense) were executed subsequently (although with a 2-minute rest between sets) allowing the cardiovascular response to these exercise 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, hereby avoiding this follow-order effect on key cardiovascular parameters.22,23,25-27

**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 cardiovascular disease. To put it 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 cardiovascular diseases. However, what strength training intensity should be selected remains under intense debate. Evidence now points out that high-intense dynamic strength training (at ≥70% of 1-RM) is more effective to increase muscle strength (as opposed to low-intense strength training), while the acute cardiovascular demand is lower (see Fig. 1). These findings should thus re-open the debate what strength training intensities should be applied, and trigger researchers to investigate the impact of the addition of low- vs. high-intense dynamic strength training during a cardiovascular rehabilitation program.

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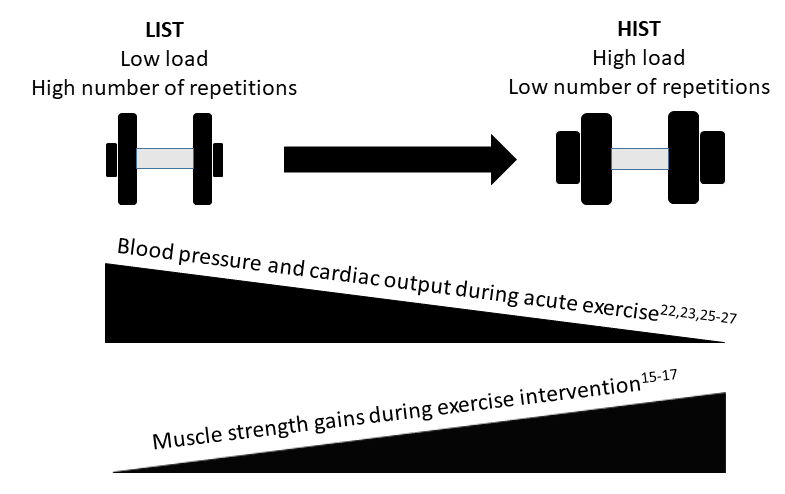
**Tables**

**Table 1** Studies assessing the cardiovascular response to a single session of high- vs. low-intense strength training

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| --- | --- | --- | --- | --- |
| Study | Participants | Outcomes & methods | Resistance training sessions | Findings |
| Lamotte et al.22 | 14 patients with coronary artery disease or valve disease | Heart rate was recorded by ECG. Blood pressure 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 blood pressure during low-intense resistance training were always larger than during high intensity (p<0.001). |
| de Souza Nery et al.23 | Ten hypertensive and ten normotensive subjects | 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 blood pressure was greater during exercise performed at 40% of 1RM than at 80% of 1RM (hypertensives: +86±4 vs. +74±4 mmHg; normotensives: +63±3 vs. +60±3 mmHg; p<0.05). |
| de Sousa et al.24 | Seven normotensive healthy men | The blood pressure and heart rate were measured simultaneously by a photoplethysmographic method. | Incremental 1-min stages at different percentage of 1-RM, with 2-min recovery between sets, starting with 10% of 1RM and followed by 20, 25, 30, 35, 40, 50, 60, 70, and 80% of 1-RM or until exhaustion. | The increase in systolic blood pressure 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.25 | Males (n=11) and females (n=4) treated with PCI or CABG | Beat-to-beat systolic and  diastolic blood pressure, 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 blood pressure 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.26 | 21 healthy elderly | ECG monitoring for heart rate variability analysis, finger photoplethysmography for blood pressure 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 blood pressure 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. |
| Gløvaag et al.27 | Thirteen healthy men | 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 blood pressures 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-1) vs. 4-RM (10.8±2.6 L min-1) (p<0.01). |

Abbreviations: 1-RM, one-repetition maximum.

**Figure 1** High- vs. low-intense strength training in cardiovascular disease: expected acute and chronic physiological effects based on current literature



LIST, low-intense strength training; HIST, high-intense strength training