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**ORIGINAL ARTICLE**
*Miscellaneous*

# Individualized exercise prescription and cardiac rehabilitation following a spontaneous coronary artery dissection or aortic dissection

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**Aims** Prescribed aerobic-based exercise training is a low-risk fundamental component of cardiac rehabilitation (CR). Secondary prevention therapeutic strategies following a spontaneous coronary artery dissection (SCAD) or aortic dissection (AD) should include CR. Current exercise guidance for post-dissection patients recommends fundamental training components including target heart rate zones are not warranted. Omitting fundamental elements from exercise prescriptions risks safety and makes it challenging for both clinicians and patients to understand and implement recommendations in real-world practice. We review the principles of exercise prescription for CR, focusing on translating guidelines and evidence from well-studied high-risk CR populations to support the recommendation that exercise testing and individualized exercise prescription are important for patients following a dissection.

**Methods and results** When patients self-perceive exercise intensity there is a tendency to underestimate intensities within metabolic domains that should be strictly avoided during routine exercise training following a dissection. However, exercise testing associated with CR enrolment has gained support and has not been linked to adverse events in optimally medicated post-dissection patients. Graded heart rate and blood pressure responses recorded throughout exercise testing provide key information for developing an exercise prescription. An exercise prescription that is reflective of medical history, medications, and cardiorespiratory fitness optimizes patient safety and yields improvements in blood pressure control and cardiorespiratory fitness, among other benefits.

**Conclusion** This clinical practice and education article demonstrates how to develop and manage a CR exercise prescription for post-acute dissection patients that can be safe and effective for maintaining blood pressure control and improving cardiorespiratory fitness pre–post CR.

**Keywords** SCAD • exercise training • fibromuscular dysplasia • Type 1 SCAD • Type 2 SCAD • Type 3 SCAD • Type A aortic dissection • Type B aortic dissection

## Introduction

Blood flow that enters and collects between arterial wall tissue layers can quickly lead to the development of a dissection where the accumulation of blood forms a pressurized false lumen wedging between the inner two-thirds and the outer third layer of the tunica media. In some cases, dissection expansion in the radial and axial directions leads to inward compression of the true lumen and obstructed blood flow. In other cases, the thin outer third tunica media and adventitia layers containing the dissection rupture. While urgent care involving aggressive anti-pressor pharmacological therapy is necessary for any acute dissection due to high fatality rates that worsen as time to treatment

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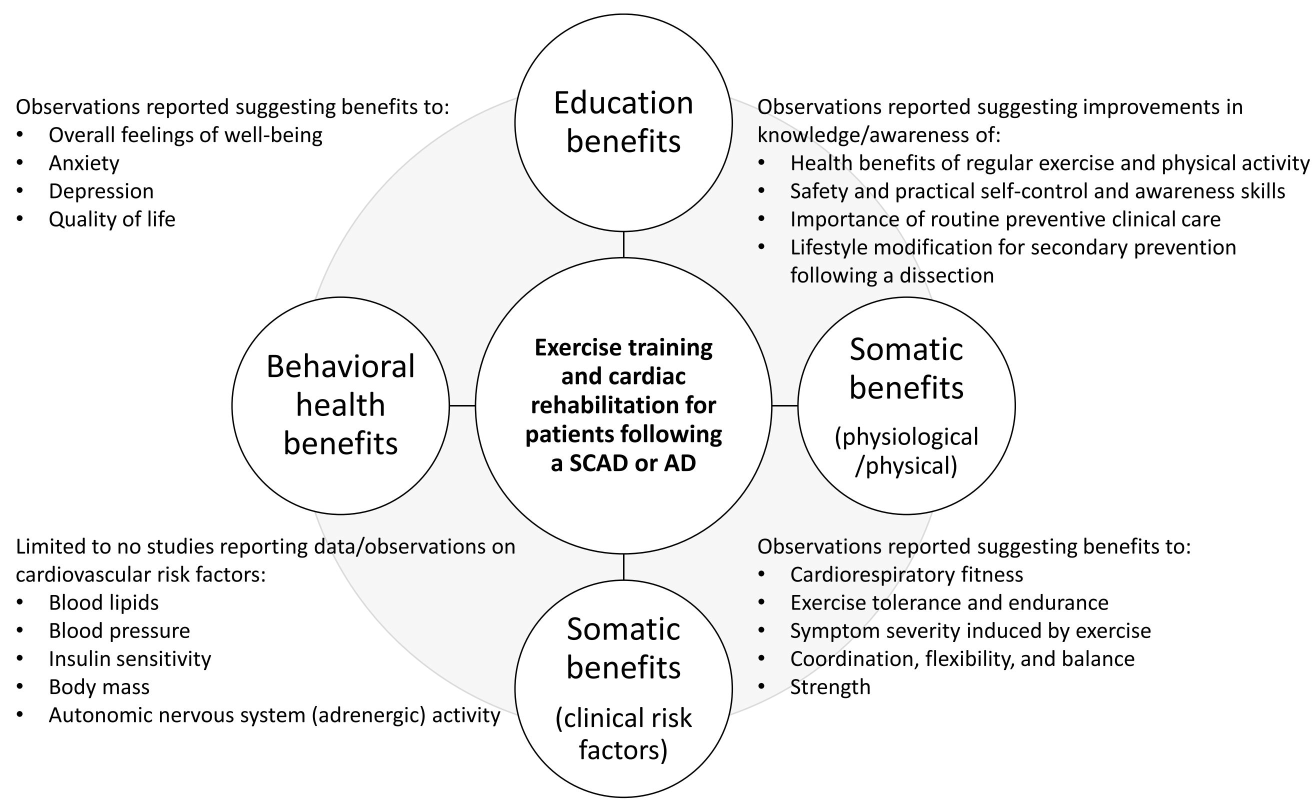



**Figure 1** The proposed benefits associated with incorporating exercise training and cardiac rehabilitation as a core component of the secondary prevention therapeutic strategy for stable patients recovering from a spontaneous coronary artery dissection or aortic dissection.

increases, not all dissections require the emergency open heart surgery that is nearly always recommended for acute Type A aortic dissections (AD).[1–4] Non-surgical conservative medical care is appropriate as an acute management option for some dissections, an approach generally favoured in cases involving a spontaneous coronary artery dissection (SCAD).[5–7] Moreover, after patients stabilize and leave the hospital, the contemporary view is that in addition to the prognostic benefits of adhering to anti-pressor pharmacological regimens for the lifelong maintenance of heart rate and blood pressure control, post-acute dissection patients of either type also benefit from incorporating non-pharmacological lifestyle therapies such as exercise-based cardiac rehabilitation (CR) into the secondary prevention therapeutic strategy (*Figure 1*).[5–17]

A modern focus of CR advocates has been the drive to extend support for exercise-based CR as a medically necessary intervention for treating and managing high-risk cardiovascular conditions not meeting traditional CR qualifying criteria.[5–17] Support for these efforts has been guided mainly by expert opinion,[5–7,13,14,16] but also aligns with a key reason why exercise-based CR is recognized as a comprehensive secondary prevention strategy for improving cardiovascular prognosis among traditional qualifiers.[18–22] In particular, exercise-based CR prioritizes the need to satisfy the principle of specificity of training, inclusive of patient medical history, pharmacological regimen, familiarity with exercise training, motivation and goals, and cardiorespiratory fitness level.[18,19,23] Thus, an exercise prescription developed for CR can easily avoid recommending the type of quick, impulsive, and high-intensity exercise types that act as the concerning mechanical stressors that need to be intentionally avoided among individuals who in the weeks-to-months prior experienced a life-threatening SCAD or AD.[5,8–12,14–19,23]

Other than general information that is available on the benefits of physical activity, exercise, and CR, there is a paucity of widespread practitioner understanding of processes involved in how to provide post-acute dissection patients individualized guidance on exercise training for secondary prevention that is appropriate for their level of risk.[5–7,13,15–17] To date, a lack of randomized clinical trial data coming from exercise-based CR studies on dissection survivors combined with unclear information on how to translate traditional CR guidelines to these high-risk patients has meant most individuals and their families do not receive personalized education on the beneficial role exercise training and CR can play in recovery.[5–17] When education on exercise-based CR has not occurred by the time of routine outpatient follow-up, this also typically means no referral has been or will be placed for post-acute dissection patients to enrol in centre-based CR.[10–13,15,16] An exact number of patients who could benefit from post-dissection CR is not known, but recent data suggest that the incidence of SCAD may be higher than previously estimated, and there are no signs suggesting that the incidence of AD has lessened since early reports of the 1980s (*Table 1*).[2,24–29]

Clarifying what should be expected of CR and exercise prescription and training guidance as part of secondary prevention care for post-acute dissection patients remains an unmet clinical need. Current exercise and physical activity recommendations are too general and challenging to translate for clinical implementation and patient understanding.[1,5–7,13,16,30] There is a lack of clarity in how to prescribe patients individualized exercise plans that can be both safe and effective. Neither practitioners nor patients are able to clearly interpret recommendations suggesting that CR and exercise training are important following a dissection, but implementing classical training elements

**Table 1 Key epidemiology, clinical features, and risk factors of patients diagnosed with spontaneous coronary artery dissection (SCAD) or aortic dissection (AD)**

| Estimated prevalence | SCAD<br>1%–4% of all acute coronary syndrome cases | AD<br>4.4 per 100 000 person years[a] |
|---|---|---|
| Mortality | Low[b] | 21.3 per 1 million[c] |
| **Sex** | | |
| Women (overall) | ↑ | ↓ |
| Early-to-middle adulthood | ↑ | ↓ |
| Middle-to-late adulthood | ↓ | ↑ |
| Men (overall) | ↓ | ↑ |
| Early-to-middle adulthood | ↓ | ↓ |
| Middle-to-late adulthood | ↓ | ↑ |
| **Predisposing risk factors** | | |
| Pregnancy/postpartum/pre-eclampsia | ++ | ++ |
| Fibromuscular dysplasia | ++ | |
| Genetics/connective tissue disorders | ++ | ++ |
| Autoimmune/inflammatory diseases | ++ | ++ |
| Sex hormone disruptions/therapy | ++ | |
| **Stimulating risk factors** | | |
| Extreme/severe intensity exercise | ++ | ++ |
| Extreme/severe intensity physical activity | ++ | ++ |
| Extreme/severe physical torque movements | ++ | ++ |
| Intense psychological stress | ++ | ++ |
| Excessive Valsalva engagement | ++ | ++ |
| Recreational amphetamine use | ++ | ++ |
| **Cardiovascular risk factors** | | |
| Atherosclerosis | + | ++ |
| Hypertension | + | ++ |
| Dyslipidemia | + | ++ |
| Smoker/ex-smoker | + | ++ |
| Type II diabetes | + | + |
| Overweight/obese | + | ++ |

[a]Overall age- and sex-adjusted incidence 1995 to 2015 (DeMartino *et al.*[27]).
[b]In-hospital and 30-day outcomes, 1 death reported out of 750 cases (Saw *et al.*[28]). Overall mortality rate among all patients in the general population uncertain.
[c]Overall age-adjusted mortality rate in 2019 (Nazir *et al.*[24]).
+Unlikely causative associations.
++Reported among case/observational data and current expert opinion suggests either known associations or possible associations of high clinical/research interest among patients.
↑ More likely to be observed among patients.
↓ Less likely to be observed among patients.

such as target heart rate zones when prescribing exercise lacks utility and can be largely counterproductive.[6,7] The scientific and clinical basis supporting the need for clinical exercise testing and prescribing individualized exercise training as fundamental components of CR for patients following a dissection are discussed in this review.

# Overview of pathogenesis and risk factors

Specific stimulating factors have been identified as explaining certain cases of SCAD or AD as briefly outlined in *Table 1*.[1–3,5–7,14,26,29] Mechanical stress associated with general exercise participation has traditionally been highlighted as being particularly concerning for patients at risk for a first dissection, and among those who are survivors practicing secondary prevention. However, despite concerns over the causal association between exercise and dissection, the existing evidence does not support nor suggest exercise training performed to the specifications expected of CR is the primary underlying cause of original events or event recurrence (*Table 2*).[5,7–12,17,28,31–36] There are multiple lines of ongoing exploratory research aimed at identifying and clarifying phenotype, genetic, and clinical traits that may make individuals susceptible to SCAD or AD (*Table 1*).[1,2,5–7,25,26,29]

Medically stable post-acute dissection patients should not look to avoid participating in individualized aerobic exercise training because of generalized concern that exercise of any type, intensity, and modality provokes inappropriate Valsalva engagement, physical strain, and mechanical stress leading to excessive hemodynamic shear stress and pressure development. Committing to a sedentary lifestyle out of fear of potential exercise implications should not be considered an option for patients since participating in chronic physical inaction increases

**Table 2 Overview of studies on clinical exercise testing and/or cardiac rehabilitation participation in patients recovering from spontaneous coronary artery dissection or aortic dissection**

| Study | Participants No./%Female | Indication | Exercise test BP (mmHg) | CR exercise sessions | Aerobic training intensity | Exercise-related SAE |
|---|---|---|---|---|---|---|
| Corone et al., 2009[10] Prospective (France) | 26/NR | De Bakey Type I | NR | 3–5 weekly<br>Avg. total: 18 (range: 5–50) | Avg. 11 RPE<br>Avg. SBP: 150 mmHg | None |
| Delsart et al., 2016[32] Prospective (France) | 105/30.5 | Stanford A and B | Cycle: Avg. BP at AT: 151/77 | NA | NA | None |
| Fuglsang et al., 2017[11] Retrospective (Denmark) | 10/40 | Stanford A | Cycle: Pre-CR<br>Max Avg.: 200/95<br>Post CR<br>Max Avg.: 207/99 | 3 weekly over 12 weeks (36 sessions)<br>Avg. total NR | Referenced AHA/EAPC guidelines | None |
| Hornsby et al., 2020[33] Retrospective (USA) | 28/14 | Stanford A | 3.6 mo post-surgery<br>Treadmill: Max Avg.: 156/70 | NA | NA | None |
| Norton et al., 2021[34] Prospective (USA) | 21/14 | Stanford A | Treadmill: 3 mo post-surgery<br>Max Avg.: 170/68<br>15 mo post-surgery<br>Max Avg.: 167/75 | NA | NA | None |
| Delsart et al., 2021[31] Prospective (France) | 165/29.7 | Stanford A and B | Cycle: Max Avg.: 183/85 | NA | NA | None |
| Silber et al., 2015[9] Prospective (USA) | 9/100 | SCAD | NR | 1–3 weekly<br>Avg. total: 28 (range: 5–39) | 60%–70% HRR<br>12–14 RPE | None |
| Chou et al., 2016[8] Prospective (Canada) | 48/100 | SCAD | NR | 1 weekly<br>Avg. total: 12.4 | 50%–70% HRR<br>12–14 RPE | None |
| Krittanawong et al., 2016[12] Retrospective (USA) | 269/97 | SCAD | NR | 1–3 weekly<br>Avg. total: 18 | NR | None |
| Imran et al., 2018[17] Retrospective (USA) | 10/80 | SCAD | Modality NR<br>Symptom limited up to SBP/DBP 140 and/or 90<br>Avg. end-exercise BP NR | 3 weekly over 12 weeks (36 sessions)<br>2 of 10 patients pre-planned to complete only 20 sessions | 70%–85% $HR_{max}$<br>Exercise BP <140/90 mmHg<br>Rest to exercise rise in SBP ≤20 mmHg<br>4–6/10 RPE scale | None |

AT, anaerobic threshold; BP, blood pressure; CR, cardiac rehabilitation; $HR_{max}$, maximal heart rate achieved on pre-CR stress test; HRR, heart rate reserve; NA, not applicable/studied; NR, not reported; RPE, rating of perceived exertion (Borg, 6–20 scale); SAE, serious adverse events; SCAD, spontaneous coronary artery dissection.

the risk of an atherosclerotic cardiovascular disease event over the middle term.[37,38] The type of cardiovascular risk predicted by chronic physical inactivity could be reasonably compounded further in patients at risk of AD or among AD survivors practicing secondary prevention since hypertension and multimorbidity are risk factors for AD and are commonly observed among individuals who live sedentary lifestyles.[1,2] Moreover, although the current body of evidence does not implicate traditional cardiovascular risk factors as major causal factors for SCAD,[5–7] the prevalence of traditional cardiovascular risk factors among SCAD survivors has recently been suggested to be more common than previously thought and likely comparable to age- and sex-matched populations (*Table 1*).[28]

## Exercise prescription for CR and secondary prevention

Prescription-based exercise training is a hallmark of CR and secondary cardiovascular disease prevention. The personalized approach to educating patients on how to exercise for their individualized goal of improving heart health while participating in routine exercise training over the course of CR is well-established, promotes safety, and yields favourable effects on multiple inter-related health parameters.[18–23,39–43] Contemporary clinical guidelines also provide the class I recommendation that it is generally safe and medically appropriate for most patients to undergo maximal effort clinical exercise testing as a core component of enrolling in CR and developing an exercise prescription.[18,19,44,45] Consensus support for these complementary clinical exercise models for improving heart health and risk assessment represents guidance that has evolved from the early years of CR when only post-acute myocardial infarction patients had been allowed to participate in exercise-based CR. Not only is exercise-based CR currently recommended as part of the secondary prevention medical strategy for treating high-risk CR eligible patients with multimorbidity, but modern guidelines also strongly recommend all stable patients, even those deemed high risk, not delay enrolment in CR beyond the ideal post-hospital discharge window in order to optimize therapeutic effects and improve cardiovascular prognosis.[18,19,46]

Prescribed exercise training following a major heart event regardless of whether it is performed in CR or self-supervised is meant to largely focus on stimulating aerobic metabolic pathways to yield improvements in cardiovascular responses to both submaximal and maximal levels of metabolic demand, cardiorespiratory fitness, and cardiovascular risk.[18,19,23] Typically, aiming to achieve these CR focused exercise training goals means initially prescribing continuous duration cardio-style exercise that encourages well-controlled work intensities no greater than moderate-to-somewhat hard exertion based on both subjective and objective scaling (*Tables 3* and *4*).[18,19,23,47] As medically appropriate and as risk tolerance allows, it is further expected that CR staff guide careful patient progression in one or more principle components of the exercise prescription over time (*Tables 3* and *4*).[18,19,23,47] The cumulative results of this purposefully prescriptive dynamic approach to initiating and progressing exercise training under the directed guidance of CR professionals are gradual developments in whole body adaptations proven to benefit clinical markers of cardiovascular prognosis. Patients enrolled in CR because of traditional qualifying indications commonly demonstrate at program completion sustainable improvements in blood pressure control and cardiorespiratory fitness,[18,20,21,47–49] factors directly relevant to managing the post-acute dissection risk of a secondary event.

## Exercise training and blood pressure control

A common clinical benefit that follows the proven CR approach to a prescribed exercise training intervention includes improved blood pressure control.[18,47,49–52] For most patients, although yet to be confirmed in those following a dissection, the predominant underlying mechanism among the many contributing factors responsible for lowered blood pressure following an exercise training intervention is suggested to be a coordinated fall in systemic vascular resistance associated with improved regulation of autonomic nervous system control and decreased tonic sympathetic adrenergic drive activity.[53] Other relevant, but not yet widely clinically established moderating mechanisms influential to the blood pressure lowering effects of exercise training are suggested to stem from improvements in endothelial function and related pathways of nitric oxide-dependent dilation and arterial stiffness regulation.[53,54] More clinically observable correlates of exercise training and improved blood pressure control are known to include increased cardiorespiratory fitness and weight loss, both of which have been independently linked to favourable effects on the mechanisms underlying blood pressure control.[53,55]

Among patients with primary hypertension, it is estimated that an aerobic exercise training intervention conducted in the style of CR yields an average lowering effect on resting systolic and diastolic blood pressure at least equal to 7.6/4.7 mmHg,[47] and 3.2/2.7 mmHg in daytime ambulatory blood pressure.[56] The antihypertensive effects of exercise training alone are strong enough to potentially be more powerful than the independent effects of traditional pharmacological therapy.[52] When prescribed and taken in combination, exercise training effects can also work to further strengthen the therapeutic benefits of antihypertensive medications.[52] Thus, although randomized control trial exercise training studies have not been conducted in adults with primary hypertension following a dissection, the therapeutic effects of prescribed exercise training on lowering blood pressure and managing primary hypertension are particularly relevant for the secondary prevention of SCAD since these patients are not known to demonstrate classical cardiovascular multimorbidity as the main cause of the initial event.

In patients diagnosed with the higher risk, severe form of resistant hypertension, the aerobic exercise training lowering effect on blood pressure is suggested to be even more powerful than that observed in primary hypertension.[47,50,51] As a result of 12 weeks of supervised aerobic exercise training performed thrice weekly for up to 40 min per session, patients with resistant hypertension have been observed to safely demonstrate mean reductions of at least 6.2/4.4 and 7.3/5.0 mmHg in 24-h ambulatory and daytime ambulatory systolic and diastolic blood pressure, respectively.[50] The sizeable and clinically relevant reductions in ambulatory blood pressure following an intervention of up to 36 sessions of prescribed exercise training are achievable while keeping patients safe from exercise-related adverse events and from engaging in excessive physical exertion.[47,50,51]

Constraining exercise session workload intensities to heart rate and/or work-rate levels no greater than ranges roughly equivalent to 50%–70% of maximal/peak exercise oxygen uptake ($\dot{V}O_2$) and limiting session durations to avoid training to exhaustion are appropriate prescription features for high-risk post-dissection patients, similar to what has been prescribed for patients with resistant hypertension.[50] Even greater exercise prescription precision may be achievable when setting heart rate and/or work-rate intensities based on the first ventilatory threshold (VT1) and second ventilatory threshold (VT2) landmarks identified on cardiopulmonary exercise testing.[19] For most high-risk patients who are entering CR or beginning any exercise training intervention, regardless of past experiences with exercise, it would not be uncommon to prescribe an initial training run-in period lasting at least several weeks where heart rate or work-rate zones are set at levels falling well-below the metabolic equivalent of the VT1 point identified on cardiopulmonary exercise testing (*Table 4*). Exercise training intensity less than the VT1 point is typically considered very low risk physical and hemodynamic stress, well-tolerated by traditional CR qualifying participants, and permits patients to set a baseline level of fitness that safely allows for the natural progression in training intensity and duration to occur over the course of a multiple month training intervention.[18,19,23,47]

The high likelihood that the exercise training effect on improving blood pressure control over a wide range of hypertension grades can occur in the absence of stimulating excessive hemodynamic stress and provoking exercise-related adverse events directly addresses key secondary prevention concerns following a dissection. Prescribed exercise training may even provide an effective stand-alone alternative therapeutic strategy for chronically managing blood pressure control in post-acute dissection patients with pre-existing hypertension who may demonstrate minimal responsiveness or intolerance to traditional pharmacological regimens.[47,50–52] Patients exhibiting the worst baseline levels of blood pressure control are known to typically experience the strongest blood pressure lowering effects of exercise training.[47,50,51]

## Exercise training and cardiorespiratory fitness

Cardiorespiratory fitness represents an important modifiable clinical marker of cardiovascular prognosis among patients who meet traditional qualifying criteria for CR enrolment. Historically among CR graduates, the typical improvement in cardiorespiratory fitness in the approximate range of 0.7–1.0 metabolic equivalents (METS) as a direct consequence of exercise-based CR is sizeable and not achievable through the effects caused by a standard pharmacological regimen

**Table 3 Key principles, components, and recommendations to be considered for developing an individualized exercise prescription for patients recovering from a spontaneous coronary artery dissection or aortic dissection**

**Foundational principles of exercise prescription: F.I.T.T.—V.P.**

- **Frequency:**
  - Number of weekly sessions/bouts: ≥ 3 days weekly is minimum; preferred is all days.
- **Intensity:**
  - Aerobic/cardio exercise:
    - Optimal: determine heart rate and/or work-rates by referencing VT1 and VT2 landmarks identified on cardiopulmonary exercise testing.
    - Percentage of $\dot{V}O_2$ reserve, heart rate reserve, and/or work-rate.
  - Strength/resistance: low loads/weights.
    - Always avoid loads/weight that require sustained and/or forceful engagement of Valsalva manoeuver. Breath holding should always be avoided.
    - Avoid lifting to local muscle fatigue and/or whole body exhaustion.
    - Avoid isometric exercises (e.g. body planks).
    - Avoid explosive/plyometric movements.
  - Rating of perceived exertion (RPE, Borg scale 6–20):
    - Applicable to any form of exercise, but should not be used independently of objective training zones, such as heart rate, during aerobic/cardio exercise bouts.
- **Time** (not including time required for warm up and cool down periods):
  - Total number of weekly minutes: ≥ 150; long-term goal is to achieve 300 min weekly.
  - Total number of minutes per training day.
    - Continuous minutes are preferred if physical conditioning allows.
    - Avoid exercising to exhaustion.
  - Bout duration within a training day (e.g. deconditioned individual).
    - Multiple bouts may be needed within a chosen training day if unable to sustain continuous exercise of medium-sized length, e.g. 20 min.
    - Two-to-three 10 min bouts interspersed with rest periods as needed.
  - Very low-intensity warm up and active cool down periods.
    - Each lasting at least 8–10 min in length (more time is encouraged, as needed).
    - Should be performed with all aerobic exercise sessions.
    - The warm up should be performed using the intended training mode.
- **Type:**
  - Aerobic/cardio activities: highest priority.
  - Strength/resistance activities: if interested and time allows, up to 1–2 days weekly.
  - Flexibility: static and/or dynamic types (no breath holding), 2–3 days weekly.
  - Coordination/balance.
  - Cross-fit and/or other high-intensity training exercise regimens should always be avoided.
- **Volume:**
  - Computing kcal/week or METS-minutes/weekly is not practical and often inaccurate for estimating volume. Volume is trackable as documentation occurs for weekly session: duration, intensity, and frequency.
- **Progression:**
  - Progression should be individualized to each patient.
  - As tolerated and based on initial physical conditioning, risk level, and familiarity with exercise, training progressions are commonly considered in the order of session: duration, intensity, and weekly frequency.
  - Only one feature should be progressed at a time.
  - Cardio exercise session duration may be increased 1–5 min every 2–3 weeks until achieving the plan goal. Cardio exercise session intensity may be increased up to 5% every 2–3 weeks until achieving the plan goal.

$\dot{V}O_2$, oxygen uptake; heart rate reserve ($= HR_{rest} + [HR_{peak} - HR_{rest}] \cdot X\%$); VT1, first ventilatory threshold/lactate threshold; VT2, second ventilatory threshold/respiratory compensation point.

alone.[18–22,41] Patients of nearly any disease severity and baseline cardiorespiratory fitness level who are able to improve cardiorespiratory fitness pre-to-post CR not only benefit from increased exercise tolerance that translates well to carrying out activities of daily living, but they can also expect related reductions in major adverse cardiovascular event risk over the short-to-middle term.[18,19,21,22] As small as a 1.0 mL/kg/min rise in peak $\dot{V}O_2$ is associated with reducing both cardiac and any-cause mortality risk.[18,19,21]

In contrast to what is known of the direct link between cardiorespiratory fitness, exercise-based CR, and cardiovascular prognosis

**Table 4 Individualized exercise testing and exercise prescription recommendations for stable patients recovering from a spontaneous coronary artery dissection or aortic dissection**

| Exercise training type(s) | Clinical exercise testing | Main exercise prescription features |
|---|---|---|
| **Aerobic training:**<br>• Continuous minutes<br>• ≥150 min/weekly spread over ≥3 days of week<br>  • Eventual progression up to ≥300 min/weekly spread over all days of the week, as tolerated<br>Examples to consider:<br>• Treadmill<br>• Cycle ergometer<br>  • Semi-recumbent if hypotension is a risk<br>• Elliptical (minimize upper body involvement)<br>• Stepper<br>Examples to avoid:<br>• Rowing<br>• Cross-country skiing<br>• Hiking with weighted backpack<br>• High-intensity interval training<br>Maintain an active lifestyle on non-scheduled training days.<br>• Minimize sedentary time<br>Lifting and intensity precautions should always be followed, for example:<br>• Leisure activities<br>• Household chores<br>• Yard work/gardening | Maximal effort CPET is the optimal clinical exercise test<br>• Upright cycle ergometry using a 'ramp-slope' work-rate increase is preferred as the default.<br>Exercise stress testing is acceptable when CPET is unavailable.<br>All measurements should be acquired while patient is on optimal rate-limiting and anti-pressor medications:<br>Peak exercise:<br>• $\dot{V}O_2$<br>• HR<br>• SBP/DBP<br>• Watts or speed/grade<br>VT1 and VT2 domains<br>• $\dot{V}O_2$<br>• HR<br>• SBP/DBP<br>• Watts or speed/grade<br>CPET data should be recorded throughout testing and reviewed while interpreting both submaximal and peak response data.<br>Where appropriate, other CPET data and variables in addition to those listed above should be considered when developing the exercise prescription. | Exercise training should be performed while on optimal rate-limiting and anti-pressor medications.<br>Training intensities should correspond to exercise BP <150/<90 mmHg. Avoid intensities causing >10 mmHg rise in DBP above rest.<br>A dedicated period of ≥8–10 min for both warm up and active cool down are required.<br>Prescribe an initial low intensity phase (Min: 4 weeks, longer as needed):<br>• HR or Watts<br>  • <VT1<br>  • ≤40% $\dot{V}O_{2reserve}$<br>• ≤40% HRR<br>• RPE: 10–11<br>• Time: up to 20–25 min<br>  • Continuous or split into 2–3 ≤ 10 min bouts with rest taken, as needed<br>If exercise BP remains controlled, progress to moderate intensity phase, as tolerated:<br>• HR or Watts<br>  • ≥VT1 and <VT2<br>  • ≤70% $\dot{V}O_{2reserve}$<br>• ≤70% HRR<br>• RPE: 12–14<br>• Time: up to 30–45 min<br>  • Continuous or split into 2–3 ≤ 15 min bouts with rest taken, as needed<br>  • Exercise <60 min<br>  • Do not perform to exhaustion |
| **Strength, resistance, and other types of training**<br>• Do not consider initiating until at least 6–8 weeks of aerobic training have been completed, BP remains well controlled, and patient endorses confidence in aerobic training<br>• Performed after aerobic training<br>• Up to 1–2 × weekly, non-consecutive days<br>  • Performed after aerobic training if on same day<br>• Functional training should be emphasized<br>Modalities to consider:<br>• Body weight<br>• Free weights<br>• Weight machines<br>• Resistance bands<br>Examples to avoid:<br>• Isometric exercises<br>• Explosive and power movements, plyometrics, agility drills, etc.<br>• Cross-fit, obstacle course, and P90 × styles of training | • Lower body strength<br>  • Knee/hip extensor and flexor/abductor and adductor<br>  • Balance<br>  • Sit-to-stand<br>  • Body weight squat<br>• Upper body strength<br>  • Seated chest press<br>  • Seated shoulder press<br>  • Seated single-arm row<br>  • Seated dumbbell curls<br>  • Standing tricep pushdown<br>• Core<br>  • Crunches on back<br>  • Avoid full sit-ups<br>  • Avoid weighted ball twists<br>  • Avoid straight legged raises<br>  • Avoid hanging leg raises | • Low intensity:<br>  • Up to 3–5 exercises, non-timed circuit style<br>  • RPE: < 13<br>  • Repetitions: weight that can be lifted with perfect technique and without Valsalva strain at least 15–18 × for >1 set<br>  • Sets: up to 2<br>    • ≥2–3 min rest between sets<br>  • Do not use HR zones to guide intensity<br>  • Do not lift to the point of complete muscle fatigue<br>  • Total time and volume of training should not elicit feelings of whole body exhaustion |

CPET, cardiopulmonary exercise testing; DBP, diastolic blood pressure; HR, heart rate; HRR, heart rate reserve ($= HR_{rest} + [HR_{peak} - HR_{rest}] \cdot X\%$); RPE, rating of perceived exertion, 6–20 scale; SBP, systolic blood pressure; $\dot{V}O_{2peak}$, peak exercise oxygen uptake; VT1, first ventilatory threshold/lactate threshold; VT2, second ventilatory threshold/respiratory compensation point.

among patients with acute coronary syndrome or heart failure with reduced ejection fraction, there is not a well-developed body of evidence confirming similar associations among patients following a dissection. To date, a limited number of observational data from exercise training studies following a dissection are encouraging in suggesting cardiorespiratory fitness is modifiable and can improve as a result of participating in exercise-based CR (*Table 2*).

In an early study from France which prospectively studied the benefit of CR in patients following surgery for De Bakey type I AD (mean days after surgery program initiated, $27 \pm 21$) (*Table 2*), those who completed pre–post maximal effort exercise testing ($n = 13$) exhibited a mean increase in maximal exercise Watts achieved from 62.7 to 91.6 ($P = 0.002$) at program completion.[10] Others have reported in a Danish retrospective study of patients ($n = 10$) following surgical treatment for a Stanford type A AD (pre-CR clinical exercise testing occurred 6–12 weeks after surgery), a mean increase in peak exercise $\dot{V}O_2$ of 22% (23.5 mL/kg/min vs. 29.0 mL/kg/min) occurred at the conclusion of 12 weeks of CR (*Table 2*).[11] Likewise, in the first prospective study of CR in patients following SCAD from the United States (program starting an average of 12.3 days after event), participants ($n = 4$ of 9 completed pre–post clinical exercise testing) demonstrated an average increase of 18% in peak $\dot{V}O_2$ at program completion ($\Delta$4.4 mL/kg/min; $25.4 \pm 4.1$ mL/kg/min vs. $28.2 \pm 3.0$ mL/kg/min) (*Table 2*).[9] Similar cardiorespiratory fitness benefits have been reported from a Canadian prospective study of CR in post-acute SCAD patients ($n = 70$; program started a median 0.6 years after event) in which they observed the estimated peak exercise METS achieved increased from $10.1 \pm 3.3$ to $11.5 \pm 3.5$ ($P < 0.001$) at program completion (*Table 2*).[8]

Mechanistic reasons that can explain how cardiorespiratory fitness changes and why this type of whole-body training adaptation in response to exercise training is likely to be clinically beneficial following a dissection have yet to be elucidated. The absence of this evidence base while important to recognize, has also not been countered with a body of evidence that suggests improving cardiorespiratory fitness is not important and yields no prognostic benefits among patients following a dissection. There is also a lack of evidence that supports a pharmacological-only secondary prevention strategy following a dissection that relegates the addition of lifestyle interventions such as exercise-based CR as yielding null effects on cardiovascular prognosis and ineffective for benefitting biomarkers of cardiovascular health, such as cardiorespiratory fitness. There is likely a low probability that most post-acute SCAD or AD patients are able to self-acquire the knowledge, comprehension, and ability to develop a safe exercise prescription that yields improved cardiorespiratory fitness and maintained heart rate and blood pressure control consistent with what could be accomplished in CR.

## Exercise training and weight management

In addition to blood pressure management, weight management represents another core component included in the individual treatment plan developed for patients at the time of CR enrolment. However, the ability to achieve clinically meaningful weight loss (e.g. $\geq$1.0 kg[57]) as a result of exercise-based CR has not been directly evaluated or observed in studies of patients who participated in CR following an AD. The observations that have been reported suggesting exercise-based CR could benefit body weight and mass changes among enrollees recovering from SCAD are also limited in number.[9,17]

In the first prospective study of exercise-based CR among post-acute SCAD patients, participants ($n = 7$) demonstrated from pre-to-post CR an average total body weight loss of $1.5 \pm 1.5$ kg, but also benefitted from gains in lean mass totalling on average $0.4 \pm 1.5$ kg.[9] Among the four patients who completed pre-to-post CR cardiopulmonary exercise testing, the one patient who exhibited a nominal change in peak $\dot{V}O_2$ (0.1 mL/kg/min) also experienced increases in total body weight and fat mass, but not lean mass.[9] The other three patients who demonstrated clinically meaningful pre-to-post CR increases in peak $\dot{V}O_2$ (>1.0 mL/kg/min) each exhibited decreased total body weight and increased lean mass.[9] Similarly, in the only other study that evaluated the effects of exercise-based CR on body mass changes among post-acute SCAD participants ($n = 10$), cardiorespiratory fitness increased ($\Delta 0.8 \pm 0.04$ peak METS) and body mass index decreased (25.3–24.4 kg/m$^2$) pre-to-post CR; although the fall in body mass index did not achieve statistical significance.[17] Viewed together, the modest body weight and mass changes observed among these limited number of observations in post-acute SCAD CR participants cannot be interpreted to imply causation, but are nonetheless not unexpected.

Total training volume per session and per week over the course of a CR program among post-acute SCAD or AD participants can be expected to be purposefully less than levels expected of most traditional CR qualifiers due to the unique need to conservatively taper-in exercise duration, intensity, and frequency progressions (*Table 4*). The overall deployment of exercise-based CR taking such an approach should typically mean for most post-acute dissection patients that much of the required caloric deficit needed to lose weight over the early-to-middle weeks of CR participation could be expected to stem from diet and nutrition modification. Indeed, not only is diet and nutrition counselling another core component of the required CR individual treatment plan, but it is consistently reported in weight loss studies across the health spectra that the combined effects exercise training and diet/nutrition modification yield the strongest and longest lasting effects on clinically meaningful weight loss and maintenance.[58] The opportunity to ramp-up the contributions from exercise training to largely account for the caloric deficit required for enhanced weight loss during the course of a CR program is not a realistic option for post-acute dissection patients since this would require inappropriate sized increases and progressions in exercise session training intensity, frequency, and/or duration to meet the weekly training volume demand reported to be effective for enhanced weight loss among overweight patients with coronary artery disease eligible for CR.[59] A top priority for post-acute SCAD or AD patients participating in exercise-based CR should not be the achievement of bulk or enhanced levels of weight loss by program completion. Instead, patients should be guided towards focusing on the long-term achievement of gradual weight loss of up to 0.5 lb per week coupled with the continued maintenance of body weight upon reaching goal, which are weight management targets more consistent with the moderated post-dissection approach to exercise training.

## Exercise safety and perceived exertion

Both the safety and success of the ‘exercise is medicine’ paradigm require dedicated patient education and specific guidance focused on aerobic exercise training to contain physiological training zones reflective of current medical history, physical capabilities, cardiorespiratory fitness level, and cardiovascular medications.[18,19,23] Using vague descriptive words for intensity such as ‘moderate’, ‘brisk’, or ‘vigorous’ in the absence of concurrently providing patients with clear and concise exercise information inclusive of individualized target heart rate zones for aerobic-based training carries a likelihood of leading to unnecessary risk/danger, concern, confusion, inconsistency, and lack of results since individuals are forced to train based solely on an often times naïve subjective perception of exertion. Patient reported rating of perceived exertion is commonly lower than actual intensity, highly variable between and within days, and sensitive to confounding by unknown non-cardiovascular factors.[60–63]

Patients with heart conditions of various aetiologies and severities who are naïve to structured exercise or have not recently participated in exercise demonstrate a propensity to subjectively underestimate the intensity of physical exertion as actual exercise physiological stress reaches, and then surpasses, moderate metabolic intensity.[60] Not only does such tendency occur during rising levels of graded exercise stress, but patients can further be expected to subjectively underestimate what moderate or greater physiological exertion should feel like during more continuous bouts of exertion, such as over-ground self-paced walking or during CR.[61,63] Moreover, the presence of an optimal β-blocker therapy regimen, which is not uncommon among CR enrollees, cannot be expected to offset the subjective tendency to repetitively perform more intense exercise than what is needed to yield improved cardiorespiratory fitness as a result of CR.[62,63] An overabundance of self-reliance on subjective scoring of exertion can be dangerous in post-dissection patients since the unpredictable disconnect between perceived exertion and physiological exertion results in patient guesswork and regular training at physical stress levels that are far higher than what is recommended. Therefore, those who are deemed medically stable in the outpatient setting should be encouraged to undergo periodic (e.g. annual) maximal effort individualized clinical exercise testing while on optimal rate-limiting and anti-pressor medications in order to acquire comprehensive information on graded heart rate and blood pressure responses to be referenced for creating the exercise prescription (*Tables 3* and *4*, *Figure 2*). An accumulating body of evidence inclusive of data from both post-SCAD and AD studies suggests it is safe and not medically unreasonable for stable patients to participate in graded exercise testing in a controlled clinical environment for the purpose of developing an exercise prescription for CR (*Table 2*).[8–11,31–34] No exercise-related serious adverse events have been reported in studies of maximal effort clinical exercise testing when conducted in as little as 7 days following SCAD, or 10 days following AD (*Table 2*).[9,10]

# Individualized clinical exercise testing and exercise intensity assessment

Due to the clinical importance of needing to phenotype the cardiovascular response at each level of metabolic stress, not just peak exertion, special attention should be given to ensuring that the clinical exercise test is individualized to best reflect medical history, physical capabilities, and recent training history since an inappropriate testing protocol and/or modality can serve as an appreciable source of variance affecting the perception of exercise intensity and actual cardiovascular responses (*Figure 2*).[60,64–66] When available, the cardiopulmonary exercise test is the optimal customizable clinical exercise physiological assessment tool to precisely characterize the cardiovascular and cardiopulmonary responses during each distinct metabolic domain, commonly identifiable via the non-invasive determination of the VT1 and VT2 landmarks.[19] In instances where cardiopulmonary exercise testing is unavailable the acceptable clinical alternative is the exercise stress test performed to volitional fatigue.

Included in any exercise test protocol customization as illustrated in our example in *Figure 2*, patients should be afforded a proper 'warm-in' unloaded phase (e.g. 0.0% grade, 0.0 Watts, etc.) of at least 3-min immediately prior to performing any externally loaded exercise as this will not only help ease anxiety-driven hyperventilatory coupled cardiovascular responses, but it will also allow the cardiovascular system reach a homeostatic state and thereby avoid the rapid and sizeable exercise-induced rise in heart rate and blood pressure that are observed to coincide with impulsive loaded exercise,[67] something that always needs to be avoided by post-dissection patients. A protocol that is too aggressive at the start will also typically yield a truncated duration test not directly attributable to cardiovascular limitations and underrepresented peak exercise cardiovascular responses that will result in overly conservative calculated training zones (*Figure 2*), possibly

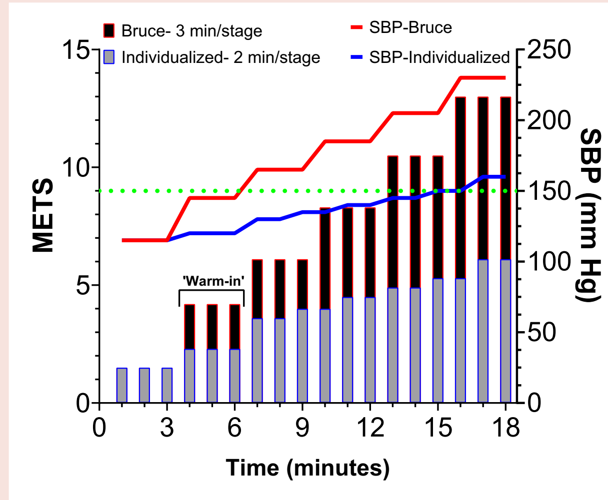



**Figure 2** Importance of individualizing the clinical exercise test. Schematic illustrating for a typical stable patient following a spontaneous coronary artery dissection on optimal pharmacological rate-limiting therapy how differences in clinical exercise testing protocols can affect stage-to-stage increases in systolic blood pressure (SBP) relative to the level of metabolic equivalent of task (METS) performed. In the absence of cardiopulmonary exercise testing which is the preferred clinical test, but less readily available than exercise stress testing, METS achieved in this example are estimated using the FRIEND[73] equation relying on treadmill belt velocity and grade. The first 3 min is pre-test for both protocols at an estimated 1.5 METS and SBP of 115 mmHg. The Bruce protocol consists of 3-min length stages where treadmill belt velocity and grade both change each stage. The starting treadmill belt velocity is 1.7 mph at a grade of 10%. Alternatively, the individualized protocol consists of an initial 3-min 'warm-in' phase at 1.0 mph and grade of 0.0%; thereafter including 2-min length stages where velocity remains constant at 2.0 mph while grade progressively increases beginning at the second stage. The horizontal dotted line is set at SBP = 150 mmHg and represents the upper level which should not be surpassed while performing continuous duration aerobic exercise training on a routine basis. The figure illustrates that by having patients participate in the conventional Bruce protocol, they would achieve the threshold SBP within 3 min at an estimated MET level of 4.2. Conventional exercise training criteria based on the conventional use of the Bruce protocol would recommend patients perform aerobic exercise training at intensities no greater than the first stage of the Bruce protocol, possibly explaining why patients might express frustration and feel discouraged in maintaining a routine.

explaining comments[6,7] suggesting patients express frustration and experience lack of results when given target heart rate training zones to follow.

Since the absolute cardiorespiratory fitness value achieved as a result of clinical exercise testing can be expected to vary greatly across individuals due to basic human features, even in the setting of meticulous protocol selection and cardiopulmonary exercise testing it is important that factors such as age, sex at birth, body size, and weight be accounted for when interpreting test data for developing the exercise prescription.[18,19,68,69] Dismissing the relevance of such detail when interpreting the clinical exercise test could have direct clinical implications, particularly since unique age periods of incidence and sex are such prominent features of SCAD and AD patient phenotypes (*Table 1*).[1–3,5,70]

Individuals who experience SCAD are more likely to be women in young-to-middle adulthood;[5,6,14,35,71] whereas AD more commonly occurs in middle-to-late adulthood, affecting women later in life than men up until 75 years of age where incidence rates are then similar across sexes (*Table 1*).[2,3,70,72] These age- and sex-related trends represent relevant information that should aid the understanding of exercise physiological responses of both SCAD and AD patients because for example, it is generally recognized that sex differences alone will always dictate lower cardiorespiratory fitness will be achieved by women than men with all else being held equal, and age-related declines in cardiorespiratory fitness start to accelerate more rapidly upon reaching the fourth decade of life for both sexes.[68,69]

Training recommendations should reflect knowledge and an in-depth understanding of how to translate both absolute and relative cardiorespiratory fitness levels to developing an exercise prescription, and prescribed training zones referencing energy expenditure in units of METS should always take into account both age and sex effects.[18,19] Broadly recommending[1,16,30] a training range of 3–5 METS for post-acute dissection patients should be avoided since for example, a patient who achieves a true peak exercise METS level of 6 would be routinely exercising in-excess at a METS level of 5 (*Figure 2*). The possibility where low cardiorespiratory fitness confounds the appropriate use of non-individualized training ranges among post-acute dissection patients is unlikely to be a rare occurrence since these individuals typically demonstrate below normal levels of relative cardiorespiratory fitness.[8–11,31–34] Thus, it is clear that the observed exercise physiological information that can be gained by participating in individualized clinical exercise testing proves invaluable for constructing each component of the individualized aerobic-based exercise training prescription regardless of whether it is carried out in CR or self-supervised.

# Concerns and other considerations

Concerns have arisen about the usefulness, and possible counterproductive effects, of providing patients with prescriptive information, such as target heart rate training zones.[6,7] Why this may be a barrier to routine exercise participation in recovering dissection patients has not been clearly explained to the extent where it is clinically reasonable to dismiss the importance and real-world application of this type of classical exercise training information.[6,7] When properly derived, there are only upsides to providing patients with clear and concise individualized objective guidance on how to routinely approach aerobic exercise training.[18,19,23] Allowing post-acute dissection patients to self-judge descriptions (e.g. ‘moderate’) of recommended exercise intensities on a routine basis runs a high likelihood of inadvertent overexertion to levels that have implications beyond the feelings of fatigue and shortness of breath. Instituting standard operating procedures consistent with secondary prevention exercise guidelines for other high cardiovascular risk patient groups can greatly lessen concerns of whether individualized recommendations such as exercise heart rate zones are reasonably safe to achieve on a routine basis and reflective of current physical conditioning levels and effects from cardiovascular medications.[18,19,23] This also means under no circumstance should exercise heart rate training zones be determined based on any type of predicted maximal heart rate equation in post-acute dissection patients. The heart rate and blood pressure responses provided by patients while on optimal rate-limiting and anti-pressor medications during individualized clinical exercise testing should be primarily used to determine target heart rate and/or work-rate training zones for aerobic-based continuous duration exercise (*Tables 3* and *4*, *Figure 2*). Other important information such as cardiorespiratory fitness should be used to characterize current physical conditioning and motivation levels to help shape appropriate target heart rate and/or work-rate training zones.

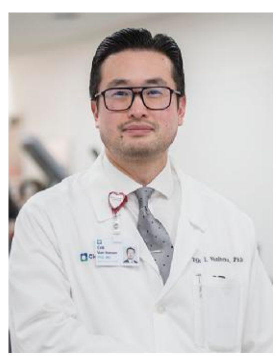
# Patient education

The final component that must be involved in developing the exercise prescription and target heart rate/work-rate zones for post-dissection patients is a detailed discussion on how individuals are to apply recommendations to routine aerobic-based exercise and how rate-limiting and anti-pressor medications may affect day-to-day exercise training responses. Such discussions are effective for clarifying and reinforcing to patients what exercises are appropriate for using target heart rate zones and what types of high-risk exercises and physical activities should be avoided. Patients should be made to clearly understand that target heart zones meant for cardio-style exercise training should not be used to guide intensity of strength/resistance training. Isometric exercise (e.g. planks), exercise and physical activities involving severe upper and/or lower body torsional movements, and high-intensity interval training must be avoided (*Tables 3* and *4*). These type of exercise precautions naturally require that training and competition for sport and athletic performance also be discontinued.

# Conclusion

When patients recovering from SCAD or AD receive clear and concise individualized council on how to participate in routine exercise training responsibly, and why this is important for lifelong heart rate and blood pressure control and secondary prevention risk management, the integrative health benefits gained are likely to be multifactorial and consistent with what is observed for those who are encouraged to enter CR because of traditional cardiovascular indications. Current evidence and expert recommendations suggest continuity of care following SCAD or AD that is inclusive of prescribed exercise training and CR yields patient improvements in psychosocial well-being, symptom severity, blood pressure control, and cardiorespiratory fitness at CR program completion.[5–15,17,23]

# Lead author biography



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