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Aortic Aneurysm: DIAGNOSIS, MANAGEMENT, EXERCISE TESTING, AND TRAINING

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Invited Review

Aortic Aneurysm

DIAGNOSIS, MANAGEMENT, EXERCISE TESTING, AND TRAINING

Jonathan K. Ehrman, PhD; Antonio B. Fernandez, MD; Jonathan Myers, PhD; Paul Oh, MD; Paul D. Thompson, MD; Steven J. Keteyian, PhD

Background: Some patients who participate in cardiac rehabilitation have aortic abnormalities, including abdominal and thoracic aneurysm (AAA and TAA, respectively). There is scant guidance on implementing exercise training in these individuals. This article reviews the epidemiology, diagnostic process, medical issues, and the available exercise training literature, and provides recommendations for performing regular exercise.

Clinical Considerations: Patients with aortic abnormalities are at risk for enlargement, aneurysm development, dissection, and rupture. During exercise, individuals with large aneurysms may be at greater risk of an adverse event. The available literature suggests little increased risk of complications when training at low and moderate intensities in those with an AAA, and exercise may be protective for aneurysm expansion. There is little exercise data for TAA, but the available literature suggests training at lower intensities and avoidance of excessive increases of blood pressure.

Exercise Testing and Training: When exercise testing and training are performed, the intensity should be controlled to avoid complications. It is prudent to keep systolic blood pressure <180 mm Hg in most patients and <160 mm Hg in those at greater risk of dissection or rupture (eg, women and larger sized aneurysm) during aerobic training. During resistance training, patients should avoid sudden excessive blood pressure increases (ie, avoid the Valsalva maneuver), and keep intensity below 40-50% of the 1-repetition maximum. Existing data suggest these patients may improve functional capacity and reduce the rate of aneurysm expansion.

Summary: Most patients with AAA can safely perform exercise training when conservative guidelines are followed. Additional research is needed to fully determine whether exercise is protective against aneurysm expansion, and the effects of exercise in those who have had surgical repair. More research is necessary to provide specific recommendations for those with a TAA.

Key Words: aortic disorder • cardiac rehabilitation • exercise training

An aneurysm is a dilation and weakening of an area of the arterial vessel (eg, the aorta), which increases the risk of tearing and hemorrhage into its wall (ie, dissection) or surrounding tissue (ie, rupture). Noted as a silent killer, an aortic aneurysm often presents as an acute dissection or rupture without prior symptoms. Dissection or rupture of an aortic aneurysm may be more likely to occur in situations, such as exercise, where there is a sudden increase in blood pressure (BP). Although isolated thoracic and abdominal aortic aneurysms (TAA and AAA, respectively) are not reimbursable indications for referral to cardiac rehabilitation (CR), patients with these comorbid disorders routinely participate. It is a common recommendation that all patients with cardiovascular (CV) disease perform regular physical activity, but guidance for persons with an aortic aneurysm is limited, particularly for TAA.[1,2] This review provides information and opinion on the issues associated with the diagnosis and the exercise testing and training of patients with an aortic aneurysm.

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EPIDEMIOLOGY

ABDOMINAL ANEURYSM

AAA occurs at a lower rate than many other diseases and conditions of the CV system. The prevalence of AAA in the United States is ~1-2% in women and higher in men (1.5-9%).[3] Risk factors associated with the development of AAA include age (>65 yr), tobacco use, uncontrolled hypertension, and atherosclerosis. AAA occurs more commonly in whites than in blacks.[4] The risk of dissection or rupture is related to the size of the aneurysm (Figure). Without immediate treatment a ruptured AAA is fatal, whereas mortality rates are approximately 43-46% and 26-32% for ruptured AAA repair using open surgery and endovascular techniques, respectively.[5] Today, most elective AAA repairs are performed using the endovascular technique and 30-d mortality rates are <1.5%.[6] Despite a lower incidence, women typically fare worse than men (3- to 4-fold higher rupture risk) and tend to rupture at a smaller aneurysm size.[7] Dissection is more likely to occur in males, accounting for 67% of all occurrences.[8]

THORACIC ANEURYSM

TAA occurs in 5-10/100 000 person-yr.[9] Up to 60% occur at the aortic root (ie, aortic root dilation) or in the ascending aorta, and the remainder in the descending thoracic aorta.[10] Risk factors include hypertension, increasing age, tobacco use, atherosclerosis, and congenital lesions (eg, bicuspid aortic valve and aortic coarctation). TAAs occur at a higher prevalence in men, but women have a higher risk of aortic dissection or rupture and subsequent death.[11] Limited available data show no difference in incidence between blacks and whites.[12]

Most individuals with an aortic aneurysm are asymptomatic, and the diagnosis is often made as an incidental finding during an imaging study for another medical issue. Despite increased screening in developed countries, both AAA and TAA demonstrate an overall reduction in prevalence in recent years for the screened population.[13] Although not adequately understood, a possible reason is a reduced prevalence of smoking occurring over the same period.

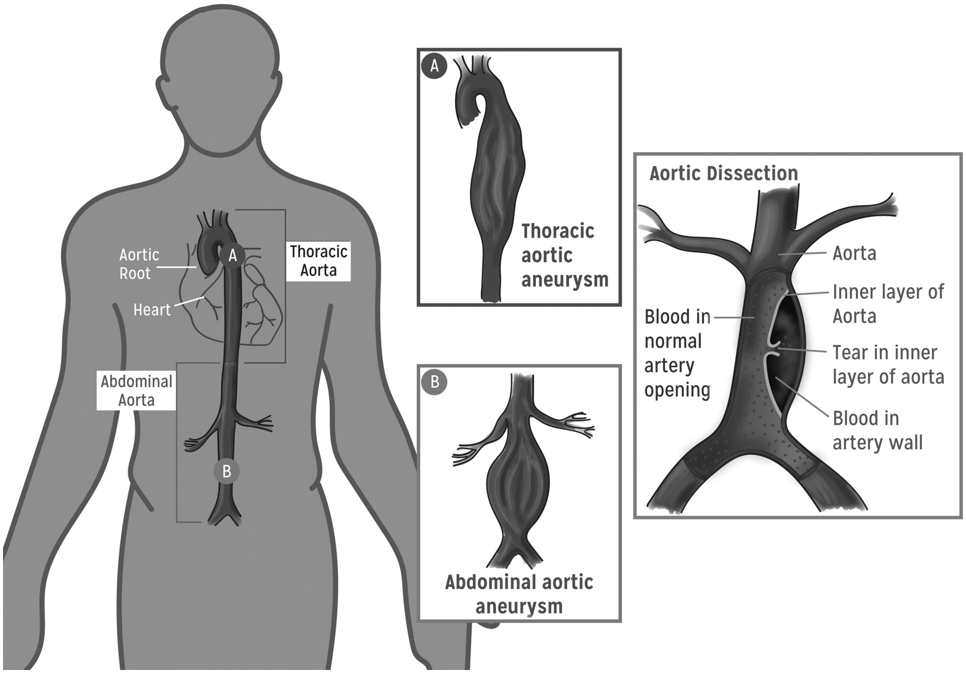

Figure. Anatomy of a normal aorta along with a thoracic and abdominal aortic aneurysm.

Currently, the prevalence of either type of aortic aneurysm in CR participants is unknown. Since aortic aneurysm alone is not an eligibility criterion for enrollment into CR, any patient with an aortic aneurysm that is in CR is participating because they have another type of CV disease. For instance, previous myocardial infarction and peripheral artery disease are common comorbid conditions for which a patient with an AAA may be exercising in the CR setting.[14]

CLINICAL CONSIDERATIONS

ETIOLOGY

Abdominal Aneurysm

Aortic aneurysms have multiple etiologies (Table 1). An AAA is primarily caused by degenerative diseases such as atherosclerosis and hypertension, but in some cases may be the result of trauma, a congenital condition, or can occur in conditions such as Marfan syndrome (but in the case of Marfan syndrome often appear later than the ascending aortic aneurysm).

Thoracic Aneurysm

There are more potential causes for TAA than for AAA. The primary causes include genetic syndromes (eg, Marfan, Loeys-Dietz, and Turner), familial TAA /dissection (eg, bicuspid aortic valve and aortic coarctation); infections (eg, syphilis); degenerative disease from atherosclerosis and hypertension; mechanical trauma; and inflammatory conditions (eg, giant cell arteritis, Takayasu's arteritis, Kawasaki disease, Behcet's syndrome, and Reiter syndrome). There are also rare, idiopathic cases. Many syndromes include a genetic predisposition to aortic aneurysm and dissection.

HISTORY AND PHYSICAL EXAMINATION

ABDOMINAL ANEURYSM

Seventy percent of all infrarenal AAAs are asymptomatic when first detected.[15] Detection most often occurs during an imaging study performed for some other reason. Abdominal palpation during physical examination is another important means of AAA detection, accounting for ~33% of new diagnoses.[16] AAAs can cause symptoms because of rupture or expansion, pressure on adjacent structures, embolization, dissection, or thrombosis.[15,17] The classic manifestations of a ruptured AAA include severe mid or diffuse abdominal pain, shock, and a palpable, pulsatile abdominal mass. The pain may radiate to the groin or thigh, is more commonly felt on the left side, and tends to be severe and steady. Abdominal distension is common, often preventing palpation of the pulsatile mass. Oftentimes, a bruit could be noted on auscultation of the abdomen. The diverse and nonspecific nature of the pain caused by expanding and leaking aneurysms often

Table 1

Definitions of Aortic Aneurysm[a]

Disorder/Recommendation	Description
Abdominal	
Aneurysm	>3 cm localized, segmental, full-thickness enlargement from diaphragm to bifurcation to right and left iliac arteries
Surgery recommended	Size >5.4 cm
Thoracic	
Aortic root dilation	>3.7 cm
Ascending aortic and arch aneurysm	>3.6 cm
Descending aortic aneurysm	>2.5 cm
Surgery recommended	Size >5.4 cm; elective surgery recommended for Marfan with size 4-5 cm

[a]Note that based on the source, these definitions can vary. Aortic dimensions are strongly and positively correlated with age, male sex, and body size. Normal cut-off values vary slightly, depending on the imaging modality used.

leads to errors in diagnosis. Physical examination can detect most large aneurysms >5 cm in diameter.[18]

THORACIC ANEURYSM

Clinical management depends on phenotyping using the patient and family history (eg, bicuspid aortic valve history with or without cerebral aneurysm; connective tissue disorder; and aortic dissection, sudden death), physical examination to recognize various syndromes, and imaging. Evaluating individuals requires integrating clinical findings. Most individuals with a TAA are asymptomatic and detected incidentally during imaging of other thoracic structures. Symptoms rarely occur with aortic dilation alone but are usually a sign of rapid expansion or dissection. Pain is often a deep visceral discomfort in the upper anterior chest or in the back between the scapula. It is not typically triggered by physical exertion (unless dissection or rupture occurs during exercise), is often constant, and not influenced by body motion or position. The rupture of a TAA usually causes excruciating pain and may be accompanied by profound dyspnea if there is movement of blood into the chest cavity. Large ascending aortic aneurysms may also result in dysphagia (due to esophageal obstruction) or stridor (due to airway obstruction). Compression of the recurrent laryngeal nerve can cause hoarseness (Ortner's syndrome).[19] The physical examination is usually unremarkable, although the presence of a diastolic murmur suggestive of aortic regurgitation should raise suspicion of ascending aortic aneurysm, as should physical features of congenital conditions such as Marfan syndrome.

DIAGNOSTIC STUDIES

Imaging is the gold standard for both types of aortic aneurysm diagnoses. Advances in imaging techniques and the development of imaging modality-specific guidelines have dramatically advanced the diagnosis and treatment of aortic aneurysms. On chest radiography, widening of the mediastinum or bulging of the ascending aorta to the right of the upper mediastinal border should raise the suspicion of a TAA.

ULTRASOUND

Transthoracic and transesophageal ultrasound are essential in the initial evaluation of TAAs. Transabdominal ultrasound is used to evaluate AAAs. There is typically a 2- to 4-mm difference in aneurysm size between measurements obtained using ultrasound and those obtained with cardiac magnetic resonance (CMR) and computed tomography (CT).[20] Echocardiography can be used to follow the aneurysm sequentially if the echocardiogram can accurately view the full extent of the dilatation.

CARDIAC MAGNETIC RESONANCE IMAGING AND COMPUTED TOMOGRAPHY

The aorta is more comprehensively and accurately evaluated with CMR and CT since aortic diameter can be evaluated along its entire length. These modalities yield images that can clarify the presence, location, size (upper limits of normal by CT) and extent of aneurysmal disease, and/or intimal dissection (Table 1).[21] CT and magnetic resonance imaging (MRI) have nearly equal capability to identify an aneurysm. For symptomatic aneurysms, MRI and CT also are better than echocardiography for their ability to identify the location and extent of an aneurysm.

SCREENING

The current Society of Vascular Surgery Guidelines recommend echocardiography-based screening for all men >65 yr, and women ≥65 yr who have smoked or have a family history of aortic aneurysm.[20] It is reasonable to also recommend screening for all first-degree relatives of any patient with a previous aortic aneurysm or dilation diagnosis based on the known genetic relationships.[22]

MEDICAL MANAGEMENT

The recommended management plan for aortic aneurysms is dependent on aneurysm-specific factors including size, location, rate of growth, origin, and patient-specific factors such as risk factors, comorbidities, surgical risk, and presence of complications. The range of therapeutic options includes open and endovascular surgical approaches, medical therapies, and lifestyle modification.[23]

IDENTIFICATION AND MANAGEMENT OF RISK FACTORS

Genetics are an important feature in approximately 20% of TAAs and 12-19% of AAAs. While genetic inheritance is not modifiable, identification of family members at future risk may be possible with subsequent enhanced attention on screening and surveillance for aortic aneurysms and attention to modifiable risk factors.

For all patients with either type of aortic aneurysm, the guidelines have consistently endorsed the importance of smoking cessation, control of CV risk factors (hypertension, lipids, and diabetes), and use of appropriate antiplatelet therapies.[24-26] Treatment with a statin to achieve a target low-density lipoprotein cholesterol of <70 mg/dL is reasonable for patients with a coronary heart disease risk equivalent.[24] Smoking cessation and avoidance of exposure to tobacco smoke at work and home are recommended.[24]

MEDICAL THERAPY

Prior investigations suggested that several interventions showed promise in influencing the natural history of aortic aneurysms.[23] For instance, β-blockers were thought to be beneficial for reducing the rate of aortic dilatation by reducing left ventricular pressure load and reducing shear stress. Antibiotic treatments were postulated to be helpful through inhibition of matrix metalloproteinase and anti-inflammatory effects. Statins were proposed to mitigate aneurysm growth through their pleotropic effects and reduction in oxidative stress. Also, given the many effects of angiotensin II on the CV system, it was thought that angiotensin-converting enzyme inhibitors or angiotensin receptor blockers would have beneficial effects on aortic aneurysms.[23,24] For TAAs, some of these concepts have been borne out by trials and β-blockers are recommended particularly in the presence of aortic dissection, and angiotensin receptor blockers may offer additional benefit in aortic root dilation over time. However, several recent trials have failed to confirm any significant benefits on AAA growth or complications.[23,25]

SURGICAL APPROACH

Vascular surgery societies have provided guidance for the management of TAAs and AAAs.[24,25] Any ruptured aortic aneurysm requires emergent repair, while a symptomatic unruptured aortic aneurysm should be repaired as urgently as possible. The guidelines for AAA suggest that small asymptomatic lesions (<4.0 cm in maximal diameter) are at low risk of rupture and should be regularly monitored, whereas those of large diameter should be repaired (Table 1). Endovascular aneurysm repair (EVAR) has become the preferred approach for the treatment of AAA for most patients because of its advantages over traditional open surgery approaches in terms of peri-operative complications, post-operative care, and recovery.[25,27] Open surgical repair of AAAs is used for patients who do not meet requirements for EVAR, or if complications occur after an endovascular approach.[25]

There are analogous guidelines for TAAs. For most chronic asymptomatic TAAs, patients should be evaluated for surgical repair when the ascending aorta or aortic sinus diameter is large. TAAs related to conditions like Marfan syndrome or other genetically mediated disorders should undergo elective operation at smaller aortic diameters (Table 1).[24]

Post-operative recovery may be slow for both AAA and TAA patients, especially following open procedure repairs. In one cohort study, about one-third of patients experienced a reduced functional ability after open AAA surgery.[28] For both endovascular and open approaches in both patient groups, systematic follow-up is important with attention to potential complications (endoleak, device migration, limb occlusion, and graft infection).[25] Other issues post-surgery leading to readmissions include cardiac events and failure to thrive.[29] No guidelines exist regarding recovery time before entry into a CR program. Considerations should include an adequate period for wound healing, pain control, and general functional status, analogous to other open-heart surgery.

EXERCISE TESTING

EXERCISE TESTING RESPONSES

Although an exercise test is typically not required before starting a low-intensity (<40% of heart rate [HR] reserve or $\dot{V}O_{2peak}$) exercise program such as walking, for sedentary patients with AAA or TAA interested in moderate- (40-59%) or vigorous-intensity (≥60%) exercise (brisk walking and jogging) it is prudent to receive medical clearance before engaging in such, which might include completion of an exercise stress test. This section summarizes the cardiorespiratory, hemodynamic, and exercise capacity responses during an acute bout of exercise in patients with aortic dilation or aneurysm (Table 2).

AGING, THE AORTA, AND EXERCISE

To better appreciate the physiologic responses of patients with aortic dilation or dissection to an acute bout of exercise, it is important to first review the adjustments of a normal and aging aorta to exercise. During a bout of dynamic exercise, the ascending aorta and aortic arch accommodate a ≥3- to 6-fold increase in blood flow and a 40-55% increase in central pulse pressure (systolic - diastolic pressures). In addition, among people free of aortic disease, central pulse wave velocity increases during exercise, consistent with an increase in arterial stiffness. Aortic stiffness (ie, loss of distensibility) is also increased with age at rest due to fragmentation or calcification of the elastin fibers in the arterial wall, increased collagen formation, endothelial dysfunction, dietary issues (eg, sodium intake), and other factors. This increased stiffening with age is inversely associated with exercise capacity, reported to be ~30% reduction in the presence of aortic stiffening.[30] Among patients with heart failure with preserved ejection fraction (diastolic heart failure), the stiffening likely contributes to their even greater reduction in exercise tolerance (beyond normal aging).[31]

ABDOMINAL ANEURYSM

Unlike the dearth of information for abnormalities of the thoracic aorta, a bit more information is available regarding the acute exercise responses of patients with an AAA. To date, the most comprehensive work is by Myers et al,[32] who compared 306 patients with an AAA between ≥3.0 and ≤5.0 cm to 2155 Veterans referred for exercise testing for clinical reasons. Mean peak HR and $\dot{V}O_{2peak}$ were similar (127 vs 129 bpm and 20.0 vs 20.3 mL·kg^{-1}·min^{-1}, for patients with AAA and age-matched US Veterans, respectively). $\dot{V}O_{2peak}$, expressed as a percentage of age- and sex-predicted, were similar at ~78%. Mean peak exercise systolic BP was higher in patients with AAA (184 vs 176 mm Hg), but the increase in exercise systolic BP (above rest) in both was generally consistent with the expected increase of 8-10 mm Hg/MET (patients with AAA: ~9 mm Hg/MET, Veterans: ~7 mm Hg/MET). Finally, the absolute frequency of hypotensive (2.9% vs 0.2%) or hypertensive (3.6% vs. 0.6%) responses was very low in both groups, but more common in the AAA group. There were no major adverse clinical events reported.

A 2012 meta-analysis investigated whether information derived from a cardiopulmonary exercise test (CPX) conducted in patients prior to undergoing repair of an AAA could be used in a prognostic manner to predict subsequent risk for health outcomes after surgery.[33] The authors concluded that the paucity of data (6 studies) precluded recommending the adoption of such a test for risk stratification purposes. However, subsequent commentary[34] and ensuing

Table 2

Summary of Physiologic Responses and Considerations During Exercise in Patients With Aortic Aneurysm

Abdominal aneurysm

- In patients with AAA between 3 and 5 cm, peak HR and $\dot{V}O_{2peak}$ are similar to a comparison group, and the increase in SBP similar between groups and consistent with normal. Frequency of a hypotensive response appears to be low (3.6%) in patients with AAA, but significantly higher than the comparison group
- Assessment of $\dot{V}O_{2peak}$ (<15 mL·kg^{-1}·min^{-1}) and ratio of minute ventilation to carbon dioxide production at anaerobic threshold (>42) prior to surgical repair of AAA may be independent predictors of mortality
- Use of CPX for risk stratification prior to surgery requires further study

Thoracic aneurysm

- During dynamic exercise such as walking, the normal thoracic aorta accommodates a 3 to 6-fold increase in blood flow and an ~50% increase in pulse pressure; this results in a mild increase of aortic dimensions
- Very little data exist describing the exercise response in patients with TAA
- Thoracic aorta stiffness increases with increasing age and this increase is inversely associated with exercise capacity ($\dot{V}O_{2peak}$)
- Among patients having undergone surgical treatment, exercise SBP response is generally normal, increasing ~8- to 10-mm Hg/MET increase in workload
- Among patients having undergone surgical treatment, a consensus guideline defining when to stop an CPX based on either measured peak SBP magnitude or increase in SBP has not been advanced to date

Abbreviations: AAA, abdominal aortic aneurysm; CPX, cardiopulmonary exercise test; HR, heart rate; MET, metabolic equivalent of task; SBP, systolic blood pressure; TAA, thoracic aortic aneurysm; $\dot{V}O_{2peak}$, peak oxygen uptake.

studies[35,36] have challenged that conclusion. For example, 503 patients were prospectively studied (mean age 73 yr) prior to elective repair of their AAA.[36] They showed that a $\dot{V}O_{2peak}$<15 mL·kg^{-1}·min^{-1} and a ratio of minute ventilation to expired carbon dioxide at anaerobic threshold >42 were both independent predictors of survival. The use of CPX for risk stratification prior to AAA surgery represents an area requiring further study.

THORACIC ANEURYSM

Regarding patients who have undergone surgical correction for a type A aortic dissection (ie, involving the ascending aorta), there is limited information describing exercise responses. Additionally, patients surgically treated often have physical activity restrictions due to lack of knowledge about BP changes during exercise. Hornsby et al[37] recently published the results of 28 patients who underwent CPX 3.6 mo after type A acute aortic dissection repair. No adverse events were noted for patient performing metabolically maximal exercise (peak RER = 1.12). $\dot{V}O_{2peak}$ averaged 18.7 mL·kg^{-1}·min^{-1} and the $\dot{V}O_{2peak}$ was 60% of age-/sex-predicted maximum. HR (~65-113 min^{-1}) and BP (systolic ~130-156 mm Hg) responses were normal. Another 49 patients with TAA and a bicuspid aortic valve, along with 51 patients with TAA and a tricuspid aortic valve, also performed an CPX. All CPXs were performed without incident and in general the physiologic responses (ie, HR and BP) to exercise were similar to the surgical repair group. These patients had a similar ability to reach a maximal exercise effort, although they achieved a significantly higher percentage of their predicted $\dot{V}O_{2peak}$ (~68% vs 60%).

A retrospective study[38] described the exercise BP and exercise capacity responses in 10 patients who underwent surgical correction for type A aortic dissection. During exercise mean systolic BP increased from 143 mm Hg at rest to 200 mm Hg at peak exercise, consistent with the increase of ~8-10 mm Hg/MET expected in healthy people during dynamic exercise.[39] However, this response was greater than the Hornsby et al group reported. These same patients also participated in an exercise-based CR program, with a mean $\dot{V}O_{2peak}$ of 23.5 mL·kg^{-1}·min^{-1} at baseline that increased ~22% following CR.[37]

EXERCISE TRAINING

There are limited data in the literature regarding the application of exercise training in patients with TAA or AAA. This is likely due to concerns that an increase in BP with exercise might be associated with risk of rupture. Recent studies, however, suggest that there is no higher risk among patients with AAA during either exercise testing or training.[40-46] Undoubtedly, many patients with heart failure, myocardial infarction, or undergoing revascularization with occult small AAA (pre-surgical; typically defined as 3.0-5.5 cm) have previously participated in CR programs. From the available data, the benefits of regular exercise in AAA are like those of other patients with CV disease, including improved function and modulation of risk factors. Benefits of regular exercise may also include localized hemodynamic benefits to the abdominal aortic vasculature by triggering biologic processes that lead to protection from the progression of atherosclerosis.[47-49]

ABDOMINAL ANEURYSM

In recent years, $\dot{V}O_{2peak}$ has been used to estimate risk before and after vascular surgery and suggest that patients with an AAA and preserved exercise capacity have better outcomes after surgery. In the UK Small Aneurysm Trial (UKSAT),[50] patients with a small AAA who were of poor fitness benefited from early surgery, with a 44% higher survival when expressed as aneurysm-related mortality. Also, sedentary behavior is associated with an increased risk of developing AAA.[51-53] In addition, one of the major conclusions of the Endovascular Aneurysm Repair II (EVAR II) trial was that improving patient cardiorespiratory fitness, particularly CV, pulmonary, and renal function, should be the focus of treatment prior to considering repair.[54] In a follow-up analysis in which EVAR I and EVAR II data were combined, the benefit of endovascular repair was demonstrated to be most convincing in the fittest patients.[55] With the emerging concept of pre-habilitation, it is suggested that, in addition to modifying conventional risk markers, efforts to improve cardiorespiratory fitness should be included as prevention and treatment strategies for AAA.

There are several notable findings from studies assessing exercise training in small, pre-surgical AAA (Table 3). First, all studies demonstrated a significant improvement in measures of exercise capacity. Second, moderate training regimens were generally used, similar to standard CR programs, and several included resistance training. It is noteworthy that two of the studies assessed exercise tolerance only up to the ventilatory threshold for safety reasons. Third, no AAA-related adverse events were reported suggesting that patients with pre-surgical AAA can safely participate in rehabilitation programs. Finally, the AAA-STOP trial observed no differences in growth rate in a hybrid (home and/or center-based) exercise program versus usual care.[56] This was contrasted by Nakayama et al,[43] who reported that exercise training resulted in a slower AAA growth rate versus usual care subjects (2.1 ± 3.0 vs 4.5 ± 4.0 mm/yr). These investigators suggested that the protective effect of regular exercise on AAA expansion may have occurred through a suppressive effect on BP elevation during exercise. This is a critical issue in terms of the efficacy, safety, and appropriateness of exercise therapy in these patients, and further studies are needed. Aside from the issue of AAA growth rates, there is now consistent evidence that exercise therapy in patients with small, pre-surgical AAA is safe and effective in improving physical function.

THORACIC ANEURYSM

Data are sparse regarding the safety and efficacy of exercise therapy in those with a TAA. Like AAA, patients with small aortic aneurysms have undoubtedly participated in CR programs for many years. Only one study has assessed the safety and efficacy of exercise-based CR in patients with a thoracic aorta abnormality. Corone et al[57] studied 33 patients after a thoracic aortic dissection and who underwent 6 mo of CR soon after surgical repair. Exercise training was performed on a cycle ergometer using a moderate-intensity (~11 or "fairly light" on the Borg 6- to 20-point scale) exercise. Exercise training workload increased from 63-92 W after 6 mo (P = .002). After 1 yr there were 3 overall complications, including 2 patients who required additional surgery. A recent review identified 26 studies and 12 case reports of various thoracic aortic conditions related to sports or exercise and suggested that BP elevations occurring with exercise may be associated with aortic dissection.[58] Despite the need for more studies in this area, this review suggests that moderate-intensity aerobic exercise is safe and effective for selected post-aortic dissection patients. A recent article that proposed a CR program study for those with thoracic aortic disease (including aneurysm and dissection) states that exercise intensity will be prescribed at a light-to-moderate intensity of 55-65% of maximal HR and keeping systolic BP ≤160 mm Hg.[59] Preliminary data in patients

Table 3

Exercise Training Studies in Those With Abdominal Aortic Aneurysm

Study Population	Frequency (d/wk)	Duration, min/session	Intensity	wk, n	Comments
Myers et al (2014)[41]; small AAA (2.5-5.0 cm); n = 140	3	45	60-80% HRR RPE 12-14	Up to 156	• Randomized trial; hybrid home and center-based aerobic and resistance training; daily exercise encouraged for 1 yr • Goal expenditure of 1000-2000 kcal/wk • Also resistance training: 10 min/session • No adverse events • 10% ↑ in $\dot{V}O_2$ at VT
Tew et al (2012)[46]; AAA (30-50 mm); n = 28	3	35-45	RPE 12-14	12	• Randomized trial; 12-wk moderate endurance training; pre-/post-testing only to VT • No adverse events • 94% exercise session adherence • $\dot{V}O_2$ at VT ↑ 2.5 mL·kg^{-1}·min^{-1}; reductions in hs-CRP and systolic BP
Barakat et al (2014)[45]; pre-surgery for infrarenal AAA; n = 20	3	60	Not provided	6	• Aerobic and resistance training for 6 wk • No adverse events • 70% exercise session adherence • ↑ in peak $\dot{V}O_2$ (9%); $\dot{V}O_2$ at VT (18%); and exercise time (59%)
Nakayama et al (2018)[48]; small AAA (30-55 mm); n = 212	1-3	30	At anerobic threshold 0.2 Karvonen factor level, which is $< \sim 50\%$ HR_{max}; BP <150/100 mm Hg	21	• Moderate aerobic training, 30-min sessions, 1-3 d/wk for 3 mo; exercise session not started when resting BP >130/90 mm Hg • No strength training • No mention of potential adverse events • Slower AAA growth rate in the exercise group vs usual care
Kothmann et al (2009)[44]; AAA <5.5 cm; n = 30	2	30	RPE 12-14 or moderate intensity	6	• Randomized trial; moderate training for 7 wk; pre-/post-testing only to VT • 3 dropouts, one was cardiac arrest during exercise; no other adverse events • 10% ↑ in $\dot{V}O_2$ at VT

Abbreviations: AAA, abdominal aortic aneurysm; BP, blood pressure; HRR, heart rate reserve; hs-CRP, high-sensitivity C-reactive protein; RPE, rate of perceived exertion; $\dot{V}O_2$, oxygen consumption; VT, ventilatory threshold.

with Marfan syndrome affecting the thoracic aorta found that exercise rehabilitation was both safe and effective in increasing functional capacity.[60]

EXERCISE TRAINING RECOMMENDATIONS

ABDOMINAL ANEURYSM

Despite a paucity of available data (~500 subjects), a reasonable conclusion is that moderate-intensity exercise, typical of standard outpatient CR programs, is safe and beneficial in patients with AAA. It is important to note that there are limited data evaluating exercise training responses and precautions in those who have had surgical repair. Therefore, these recommendations are most relevant to those with an intact aneurysm but can likely be used for those who have had a recent surgical repair.

Recently updated American College of Cardiology (ACC)/American Heart Association (AHA) Practice Guidelines[61] recommend modest physical activity in AAA patients, in part to counteract the reduced cardiorespiratory fitness that is associated with poor outcomes among patients who eventually require surgery.[32,54,55] Other practice guidelines recommend that, during surveillance for patients with small AAA, management should include counseling that moderate physical activity does not precipitate rupture and may limit AAA growth rate.[62] Information regarding types of exercise is found in the classification of sports figure in the 2015 AHA/ACC Scientific Statement, which categorizes activities based on their static (likely to affect BP) and dynamic (likely to affect $\dot{V}O_2$) components.[63] It is suggested that, depending on risk of dissection or rupture, individuals perform exercises with a low static component at any level of dynamic component. Those at lower risk of rupture can perform moderate static/low to moderate dynamic component exercises.

THORACIC ANEURYSM

The Canadian CV Society Position Statement on the Management of Thoracic Aortic Disease strongly recommends (although based on very low-quality evidence) the avoidance of strenuous resistance and isometric exercise.[64] A multi-organization guideline document on thoracic aortic disease provides a similar recommendation suggesting the avoidance of strenuous lifting, pushing, or straining that would require a Valsalva maneuver.[61] In general, these recommendations are designed to reduce the risk of aortic dissection, which may occur with a sudden/abrupt, substantial rise in aortic pressure. Each of these guidelines does recommend (as similar for AAA) regular endurance or aerobic activity as part of a lifestyle designed to limit the risk of aneurysm growth, rupture, or dissection by the control of BP and body weight.

Table 3 provides general information about the exercise prescription used in studies evaluating the training response in those with AAA and can be used to inform recommendations for exercise training. For patients with an aneurysm, in general, the American College of Sports Medicine recommends moderate aerobic exercise, 20-40 min/session, 3-4 d/wk, with an emphasis on exercise duration over intensity.[65] The recommendations for small AAA also include low-resistance strength training as a complement to aerobic exercise.

Specific recommendations for exercise prescription reflect what is known for AAA, as there is insufficient information to make recommendations for TAA (Table 4). Although most of the exercise training studies did not use BP to guide exercise intensity, it is prudent to consider evaluating BP during exercise training, particularly during the first several sessions, in those performing upper-body exercise and in those at higher risk of dissection or rupture. It would be appropriate to perform a CPX, particularly for patients wishing to engage in vigorous activities (eg, running or biking) and those with pre-existing hypertension, both to assess the physiologic response to exercise and to ascertain that the patient does not have an excessive BP response.[65] The test should be performed while the individual remains on the usual β-blocker and/or other antihypertensive medication regimen, and recommendations for activity should be targeted below a systolic BP rise of 180 mm Hg on the CPX.[65] For those patients with a borderline elevation in BP (ie, 175-185 mm Hg), assessing BP during exercise training for a period, to ensure the avoidance of an excessive rise, is recommended.

Table 4

Exercise Prescription Recommendations for Patients With Aortic Aneurysm

Training Parameter	Recommendation
Aerobic/cardiorespiratory	
Type of activity	Any aerobic mode; note if upper body exercise is used consider evaluating BP in all patients, particularly during initial bouts, to assess for excessive rise
Intensity	If HR guided: 40-59% HRR, only increasing higher with physician clearance and BP below recommendation
	If RPE guided: 12-14
	If BP guided: <160-180/100-110 mm Hg
	Note that more conservative values might be considered for higher risk groups for dissection and rupture (ie, larger size aneurysms and women)
Frequency of session/wk	≥3
Duration/session, min	30-60
Precautions	Avoid contact sports; no vigorous-intensity exercise
Muscular strength/endurance	
Type of activity	Any (machines, free, bands, and body weight) can be used; exercises for shoulders, chest, biceps triceps, quadriceps, hamstrings, and gastrocnemius are suggested (ie, the large muscle groups)
Intensity	Low resistance levels (<40-50% estimated 1 RM)
Frequency	2-3 nonconsecutive d/wk
Duration	1-2 sets/exercise for 10-15 repetitions
Precautions	Highly encouraged to avoid Valsalva maneuver or excessive straining, as these are associated with sudden, large increases in BP

Abbreviations: BP, blood pressure; HR, heart rate; HRR, heart rate reserve; RM, repetition maximum; RPE, rate of perceived exertion.

SUMMARY AND FUTURE DIRECTIONS

CR programs have been broadening their referral base in recent years to include patients other than those with coronary heart disease. Patients with concurrent AAA or TAA, diagnosed or undiagnosed, participate in CR to an unknown degree. Patients with isolated small AAA or TAA are good candidates for CR programs, although these alone are not eligible diagnoses for insurance reimbursement. However, given that CR has evolved from traditional exercise-based programs to comprehensive secondary prevention and chronic disease management centers,[66] AAA patients are ideal candidates for intervention since AAA is a disease strongly associated with cardiometabolic risk.[47,67] Concerns about risks associated with moderate levels of exercise appear to be unfounded. More studies are needed to explore the role of CR for those with a TAA, as well as for those following surgical intervention for both abdominal and thoracic aneurysms. Finally, another question for future investigation is whether there is a role for pre-operative exercise training (ie, pre-habilitation) to possibly lower the operative and post-operative risk and enhance recovery rate.

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