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Review

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Augmentation of the skeletal muscle pump alleviates preload failure in patients after Fontan palliation and with orthostatic intolerance

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Abstract

While the pathophysiology affecting patients after Fontan palliation versus those with orthostatic intolerance is quite different, a common therapeutic approach exists. Exercise training, specifically augmenting the lower extremity skeletal muscle pump, improves the suboptimal haemodynamics of "preload failure" and thus clinical outcomes for each patient group. In this review, we will describe the problematic physiology affecting these patients, examine the anatomy and haemodynamics of the skeletal muscle pump, and finally review how exercise benefits both groups of patients through augmentation of musculovenous force.

Introduction

Amongst the most vexing patients seen in paediatric cardiology clinic are those doing poorly after Fontan palliation and those with complaints related to orthostatic intolerance/postural orthostatic tachycardia syndrome. The former is often a long-term patient, one seen since infancy, and now their decline is difficult on all in involved—the patient, the parents, and even the physician who has grown close to the family along the way. The latter can also be quite difficult—a myriad of complaints in a previously healthy teenager with significant consequences including missed school and family exasperation. While these patients might seem quite different in terms of the pathophysiology underlying their presentation and thus treatment strategies, it is our experience that a common therapeutic pathway is helpful for each. Exercise and restoration of physical fitness, with focus on the lower extremity muscles—the "skeletal muscle pump"—is effective in improving symptoms and preventing physical decline in both groups. In this review, we will describe Fontan failure and orthostatic intolerance, explain the physiology of the skeletal muscle pump, and finally discuss how exercise can be effectively applied to these patients to improve outcomes.

The clinical problems

Orthostatic intolerance is the inclusive term for symptoms, ubiquitously including light-headedness/dizziness but also often tachypalpitations, syncope, fatigue, nausea, and headaches, that occur while upright and are relieved by recumbence.[1] Orthostatic hypotension, which occurs in older adults, is not typical in paediatrics, and instead, orthostatic tachycardia and its chronic form, postural orthostatic tachycardia syndrome, predominate. Orthostatic intolerance is quite common—in this calendar year it has been a more common new referral complaint than chest pain or heart murmur to our paediatric cardiology practice. Typical patients are adolescent girls, usually between 12 and 16 years old at time of presentation.[1] Interestingly, a high percentage of these patients will have hypermobile joints, and some even meet criteria for hypermobile Ehlers-Danlos syndrome, which helps to explain the physiology.[5,6] Specifically, hypermobility in the joints marks one as having laxity in connective tissue, and thus laxity in the support of blood vessels, leading to increased gravitational pooling of venous blood in dependent parts of the body (leading ultimately to decreased cerebral perfusion, the stimulus for orthostatic symptoms).

As gravity potentiates venous pooling in the pelvis and lower extremities, there is decreased preload to the heart and therefore decreased cerebral perfusion.[2,3] This causes lightheadedness in the patient.[6] In response, the sympathetic nervous system is activated to address the drop in

cerebral perfusion, specifically by inducing peripheral vasoconstriction and increasing cardiac output. This often is insufficient, however, so lightheadedness is not alleviated and instead the patient experiences the unpleasant effects of this "adrenaline surge," both in the moment and throughout the day depending on how often the necessary circumstances are met.[2–4]. The excessive sympathetic activation causes the additional bothersome symptoms—palpitations, fatigue (excessive daily adrenergic activity), nausea and other symptoms of gastrointestinal intolerance (gut underperfusion in a hyperadrenergic state), and eventually syncope if a vasovagal reflex occurs.[7,8] Teenagers are particularly at risk for this due to their higher metabolisms and thus higher needs for fluid and salt intake to maintain adequate blood volumes. This all begins with inadequate preload back to the heart—preload failure. Fortunately for human beings who must remain upright throughout the day, we have a skeletal muscle pump (particularly the muscles of the legs) that can augment preload back to our central cardiovascular system. Unfortunately for the most affected patients, this is often a weakness due to deconditioning as a result of feeling poorly for months or even years prior to presentation.[9] It is not unheard of to see previously healthy patients now presenting to clinic in a wheelchair due to severe leg weakness and excessive sympathetic activity. Fortunately, through dedicated exercise, the skeletal muscle pump can be restored, which leads to significant improvement in symptoms.

The Fontan operation is the final palliative procedure for patients with single ventricle heart disease, designed to route systemic venous return directly to the lungs to allow the heart to solely supply blood to the systemic arterial circuit.[10,11] Once completed, pulmonary blood flow passively flows following a favourable pressure gradient, augmented by negative inspiratory pressure and the peripheral skeletal muscle pump. Survival after Fontan has improved over time; however, morbidity in many forms, including Fontan failure, remains.[11–13] Fontan failure is a term describing deterioration of clinical status in these patients due to various causes, but often characterised by elevated central venous pressure and decreased cardiac output.[11,14–16] Pathology underlying this derangement can be cardiac, pulmonary, hepatic, or lymphatic; often, a combination of these pathologies is present and additive to overall poor status. A common theme, however, is that augmentation of cardiac output is difficult, given the lack of a subpulmonary ventricle to offload elevated venous pressure or improve pulmonary blood flow—preload failure. This is particularly noteworthy during exercise, as cardiac output to exercising muscles is known to be limited due to inadequate systemic ventricular preload.[17,18] It is here that augmentation of the skeletal muscle pump is advantageous, as strengthening this pump specifically combats the deleterious effects of gravity on these patients' main limiting factor in improving cardiac output.[19] Unfortunately for many Fontan patients, the skeletal muscle pump is not a strength. Patients are often less active than other children, not participating in sports, or frankly sarcopenic.[20,21] Again, this can be addressed through dedicated exercise with focus on the lower extremities.[19]

In the sections that follow, we will discuss the physiology and function of the skeletal muscle pump and how exercise focused on lower extremity muscles improves physiology and outcomes. The accompanying Figure 1 dramatises these findings. Finally, we will discuss practical ways to implement exercise counselling and participation in these seemingly divergent but therapeutically congruent groups.

The skeletal muscle pump

Tall, upright animals such as giraffes and horses have tight leg fascia, which prevents venous pooling and dependent oedema.[22–24] Humans rely on a different mechanism, a well-developed skeletal muscle pump. Physiologists in the early twentieth century had already recognised the dynamic nature of venous return to the heart related to changes in body position, respiratory muscle use, splanchnic vascular tone, exercise, and even digestion.[25] It was not until the 1940s that academic description of the skeletal muscle pump (and its effects on venous return) began to appear.[26,27] The term skeletal muscle pump refers to the mechanism, present at rest but particularly important during exercise, whereby muscle contraction enhances venous return by squeezing local blood centrally toward the heart.[28] When a person is standing, postural muscles in the legs alternately contract and relax to keep the body in balance. This muscle activity promotes venous return and helps to maintain central venous pressure while also keeping venous pressure low in the lower legs and feet.[29–31] The force of this pump exceeds the effects of gravity—consistent with this finding is that exercise performance as measured by peak oxygen uptake is 5–10% higher in the upright versus supine position.[32] In addition, skeletal muscle relaxation causes vascular suction that increases blood flow from arteries and more distal veins into that muscle prior to the next contraction. This vascular flow pattern maintains a favourable perfusion gradient in the legs during upright exercise by emptying the distal veins and keeping venous pressure low.[33–38]

To understand the skeletal muscle pump, it is important to understand what it must overcome. Compared to arteries, veins are thin-walled vessels with less smooth muscle and elastin.[39] Venous compliance is up to 30 times that of arteries,[40] which explains why even as 2/3 of total blood volume is present in the systemic veins, central venous pressure remains low.[41] Gravity further exacerbates resting conditions, as 70% of the circulating blood volume is below the level of the heart when a person is upright.[42] The anatomy of the veins aids unidirectional blood flow. One-way valves, present particularly in peripheral veins located in large skeletal muscles, help direct flow away from the limb and toward the heart by preventing backflow. As evidence of their importance, studies show that patients with venous incompetence demonstrate inferior leg blood flow response to exercise during upright posture.[43–45]

During exercise, physiology is further altered—while skeletal muscle comprises around 40% of the body mass, muscle-specific blood flow can increase almost 100-fold during intense exercise.[46] This increased muscle perfusion occurs through multiple overlapping mechanisms. Adrenaline leads to increased oxygen demand, which is met by augmentation of skeletal muscle perfusion via local vasodilators, including nitric oxide and adenosine triphosphate, and blunting of local sympathetic vasoconstriction in the contracting muscles.[28,46] It is against this cascade of hyperaemic recruitment that the skeletal muscle pump must work. To begin, a particular physiologic consequence occurs that indirectly improves venous return. Specifically, as skeletal muscles are engaged and blood flow recruited, this necessarily means that perfusion of "less recruitable" venous beds, for example the splanchnic venous plexus, decreases. As the skeletal muscle pump can augment venous return more readily, overall net venous return increases. Increased adrenergic tone during exercise improves muscular contraction, which promotes more effective squeeze of venous blood back toward the heart. A single peripheral muscle contraction can move 40% of the local intramuscular venous blood volume centrally.[47]

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Contraction of the leg musculature may provide upwards of 30% of the energy needed to pump blood while running.[34] While thigh and even foot muscles contribute to the skeletal muscle pump, the calf muscles are particularly important. The calf is comprised of two muscles, the gastrocnemius and soleus, with the soleus having the larger volume and surface area. During contraction, the intramuscular pressure within the calf can exceed 200 mmHg.[33,48] While the gastrocnemius muscle (and its tendons) spans the ankle and knee joints, allowing it to contract only during knee extension, the soleus muscle contracts regardless of knee angle. Thus, it provides consistent compression of the lower leg veins and is the predominant muscle augmenting venous return.[43] Calf raises, running, and jumping all engage and strengthen the soleus muscle, improving its ability to ultimately provide preload.

Exercise training improves the strength of the skeletal muscle pump and thereby venous return to the heart.[43,49–51] Verma et al.[52] published a statistical confirmation of the causal relationship of augmentation of skeletal muscle strength to improvement in preload, with the intent of highlighting the importance of preventing sarcopenia in patients at risk for orthostatic hypotension.[52] As exercise capacity increases in response to training, there is increased muscular capillary density, increased blood volume in general and locally, and increased muscle content of mitochondria. Conversely, patients with sarcopenia and decreased calf muscle mass will have worse venous return, placing them at risk for complications including orthostatic hypotension and syncope.[51,53]

Augmentation of the skeletal muscle pump benefits patients with orthostatic intolerance

Muscle deconditioning is a key and perpetuating component of orthostatic intolerance, which makes exercise particularly difficult.[9] In studied patients, there is low calf blood volume as well as low muscle mass.[47] Furthermore, the reduced calf blood volume lessens calf muscle size and is associated with decreased muscular capacity to pump venous blood out of the legs.[22] Tendency toward venous vasodilation in these patients exacerbates lower extremity blood pooling and thus intolerance of position change—this is why more effective exercise counselling emphasises recumbent or semirecumbent position during exercise and focus on resistance training during the early stages.[9,54]

While researchers have reported smaller left ventricular muscle mass in patients with postural orthostatic tachycardia syndrome[55], it must be emphasised that it is not a cardiac-centric diagnosis, and instead noted cardiac changes occur secondary to chronic intravascular and thus intracardiac volume depletion, deconditioning, and lack of physical exercise. Terms such as "Grinch heart"[55] are harmful to a patient's self-image and miss the mark on the causative physiology. Instead, it is primarily preload failure that leads to decreased cardiac stroke volume.[54] This is deleterious over time, as the heart remodels within the setting of chronically low intracardiac volume. As these cardiac changes solidify, orthostatic intolerance is potentiated. Cardiac muscle deconditioning and reduced filling capacity then further lower stroke volume, contributing to tachycardia as a reflex response when the patient stands.[55] Low resulting stroke volume in these patients has also been associated with reduced peak oxygen uptake and delivery.[9] All of this creates negative feedback within the patient, as the above changes often lead to further exercise avoidance and thus more significant deconditioning.

The benefits of exercise in orthostatic intolerance have been demonstrated. In a report on military recruits with postural orthostatic tachycardia syndrome, those assigned to a 3-month exercise regimen were significantly less likely to report orthostatic symptoms subsequently. Additionally, more than half the patients in the exercise group no longer met criteria for postural orthostatic tachycardia at follow-up.[56] In a study of 100 participants meeting postural orthostatic tachycardia syndrome criteria who completed a programme of mild-to-moderate intensity progressive endurance training, 71% significantly improved to the point that they no longer met the diagnostic criteria at follow-up.[57] Lower resting heart rates, improved stroke volume, and faster heart rate recovery after exercise compared to baseline were all reported. The effects were even noted in a 6–12 month follow-up after intervention. Finally, Fu et al.[58] performed a double-blind drug trial ($n = 19$ patients) comparing propranolol treatment to placebo for 4 weeks, followed by exercise training for 3 months, in patients meeting criteria for postural orthostatic tachycardia syndrome. Upright haemodynamics, symptoms, renal-adrenal responsiveness, and quality of life improved with exercise training, but not after propranolol.

Additional studies are worth highlighting. A small study involving 17 patients with orthostatic intolerance showed that short-term exercise training decreased upright hyperadrenergic state and resting heart rate, in part due to increasing sensitivity of the baroreceptor reflex.[59] A larger study of 77 patients showed a significant reduction in the number of patients that had orthostatic tachycardia after a 6-month unsupervised outpatient cardiovascular exercise programme.[60] This programme also reduced frequency of syncope and improved perceived quality of life based on EuroQol scaled assessment. Finally, Wheatley-Guy et al.[61] compared outcomes in orthostatic intolerance patients undergoing a 3-month period of semi–supervised exercise sessions to standard of care. The exercise sessions consisted of a graded exercise regimen building to a target of 150 minutes/week of exercise that started with recumbent exercises. Utilising exercise testing at follow-up, the exercising orthostatic patients demonstrated significant improvement in oxygen consumption at peak exercise, workload time, and time until onset of symptoms. The exercising patients also tested superiorly in orthostatic intolerance domain score in the COMPASS tool, which assesses autonomic symptoms.[61]

Exercise training benefits patients after Fontan palliation

Exercise limitation is exceedingly common after Fontan palliation.[62] Numerous studies have demonstrated that Fontan patients have decreased maximal exercise capacity compared to the general population.[18,19,62,63] Furthermore, the extent of limitation is an important predictor of morbidity and mortality.[18,63–65] In counselling these patients, it is not hyperbole to state that maintaining exercise capacity does much to maintain life itself, even during the young adult years after Fontan.

A prevailing explanation for exercise limitation is a restricted ability to augment cardiac output given the absence of a subpulmonary ventricle, a specific form of preload failure.[62] During exercise in patients with biventricular physiology, cardiac output is augmented to match metabolic demand by both increasing heart rate and increasing stroke volume from both the left and right ventricle.[62] Furthermore, a subpulmonary ventricle offloads systemic venous pressure and maximises pulmonary blood flow, thereby recruiting additional pulmonary

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vasculature and matching perfusion to ventilation.[66] In Fontan patients without a subpulmonary ventricle, there is increased systemic venous pressure at rest and exercise and a "starved" pulmonary vascular bed for blood flow, especially during exercise; this must be overcome as able with the "lesser" pumps including the skeletal muscle pump.[66] Investigators have specifically examined the role of both the skeletal muscle pump and the ventilatory pump (decreasing intrathoracic pressure during inspiration) in augmenting Fontan cardiac output. In a case-control study, Shafer et al.[62] utilised exercise testing protocols systematically to isolate the relative contribution of the respective pumps and reported that much of the increase in stroke volume and cardiac output was due to systemic muscle pump augmentation, with a small additional contribution from the respiratory pump.

Cordina et al.[19] examined whether patients with Fontan circulation have altered muscle mass and metabolic dysfunction compared to healthy controls. Subjects underwent both cardiopulmonary exercise testing and magnetic resonance spectroscopy to assess skeletal muscle activity, as well as dual X-ray absorptiometry scans to assess lean mass. The study found that Fontan patients had significantly reduced lean mass, decreased aerobic muscle activity, and diminished exercise capacity.[19] Furthermore, muscle mass positively correlated with peak exercise capacity and stroke volume—undergirding recommendations for physical fitness in these patients.[19] Avitabile et al.[67] also reported this link via a prospective analysis comparing 50 Fontan patients to 992 healthy controls to identify risk factors for decreased lean mass and its link with exercise capacity. Not surprisingly, the Fontan patients had significantly lower total body lean mass and leg lean mass. Furthermore, leg lean mass was positively associated with peak oxygen consumption and exercise capacity.[67] Avitabile et al.[68] separately evaluated this relationship in an additional study comparing leg lean mass and exercise performance. By utilising exercise testing and cardiac magnetic resonance imaging, the authors reported a positive relationship between leg lean mass and change in cardiac output from rest to exercise. Finally, the lack of pulsatility in the Fontan circuit is theorised to lead to less recruitment of the pulmonary vasculature compared to biventricular physiology.[66] However, a case study by Cordina et al.[69] suggests that pulsatile flow (demonstrated by pulsed wave Doppler) can be generated in the Fontan circuit, specifically by engaging the skeletal muscle pump during lower leg exercise.

While there is much evidence demonstrating that patients with Fontan circulation have diminished exercise capacity, this is not universally true. In fact, some so-called "Super Fontans" have normal to supraphysiologic testing results.[70] This has prompted further exploration to explain the contributing mechanisms. Tran et al.[70] compared so-called "Super Fontan" patients to Fontan patients with impaired exercise performance. While there was no difference in level of self-reported activity as adults, there was a significant difference in self-reported childhood physical activity, with Super Fontan patients having higher activity levels.[70] This serves as a warning to paediatric cardiologists—encourage physical activity in your patients unless there is a compelling reason for restriction.

Given the evidence that greater lean muscle mass is associated with improved exercise capacity, researchers have examined whether a weightlifting regimen might improve exercise capacity after Fontan. Cordina et al. performed a prospective study involving adult Fontan patients and controls enrolled in a resistance training programme with the goal of improving calf muscle mass and exercise capacity. At follow-up, lean mass was significantly higher in the weightlifting exercise Fontan group. Interestingly, the proportion of respiratory dependent venous inflow (during inspiration) decreased in the patients who underwent the exercise programme, meaning flow occurred more favourably at other times presumably due to improved musculovenous propulsion. Peak oxygen consumption was significantly higher in the patients who went through the training programme as well.[19] Scheffers et al.[71] evaluated the effects of 12 weeks of resistance training on Fontan patients. At follow-up, peak oxygen consumption and 6-minute walk test improved significantly.[71] Additionally, stroke volume, aortic flow, and inferior caval venous flow all improved after exercise participation. Interestingly, superior caval vein flow was not significantly different, suggesting that lower leg muscles were the major driver in the improvements seen. Sutherland et al.[72] conducted a prospective study in teenage Fontan patients who were divided into home-based versus hospital-based exercise groups. Both groups participated in 2 months of aerobic activity and resistance training. The authors reported improvement in exercise capacity as measured by oxygen consumption and 6-minute walk test in all patients after training.[72] Importantly, there was no difference in exercise testing between the groups, suggesting that home-based exercise programmes can be as effective as hospital-based routines.[72] Finally, Scheffers et al.[65] performed a systematic review of exercise training after Fontan palliation, which included 22 articles with a total of 264 patients. There were 16 cohort studies, seven of which were paediatric. Described training regimens included aerobic and resistance training, and three of the studies involved only inspiratory muscle training. Peak oxygen consumption increased significantly in 56% of the studies after the ascribed training programme. This is impressive considering these exercise interventions were not uniform and variable in efficacy and implementation. All the studies that analysed 6-minute walk times reported improvement, half of the studies looking at estimated cardiac output by magnetic resonance imaging or echocardiogram showed benefit, and all the studies looking at parent report of quality of life were positive. None of the studies reported negative outcomes associated with an exercise intervention. The authors concluded that exercise training in Fontan patients has positive effects on exercise capacity, cardiac function, and quality of life and therefore should be encouraged.[65]

Exercise counselling, training, and prescription

Effective exercise counselling depends on prudent explanation of the benefits of exercise, as well-informed patients make the best decisions for their health. The myriad health benefits of exercise—improved bone health, reduced adiposity, improved psychosocial well-being, reduced risk of depression, etc., are true for our patients as well.[73–77] Beyond strengthening the skeletal muscle pump, consistent exercise is particularly beneficial for orthostatic patients due to the favourable vascular adaptations that take place. Endurance training increases plasma volume, thus mitigating the risk of volume depletion.[78] Improved preload to the heart is also achieved by this adaptation, leading to improved cardiac output which is matched by more rich capillary development in the exercising muscles, allowing better oxygen delivery.[79,80] With this knowledge in mind, a provider does well to convey this information to patients with a positive tone and expectation. Many orthostatic patients have tried to exercise previously and

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Figure 1. Figure is the original artwork of Ms. Julia Moore, created specifically for this manuscript and edited further for this purpose.

failed to see success—making it clear that this time will be different, because particular strategies that will be employed, can help patients overcome their trepidation to try again. Next comes specific advice to help patients navigate around pitfalls. *For patients with orthostatic intolerance, the most important advice is dizziness during exercise should be avoided.* Patients may be counselled that symptoms such as heart racing, shortness of breath, and fatigue can be "pushed through," as these often go with physical conditioning; however, lightheadedness should not be ignored. As mentioned previously, dizziness signals decreased cerebral perfusion, which leads to a disproportionate increase in adrenaline production and effect. This is deleterious to progress, as patients will report excessive fatigue after exercise and thus not follow a consistent exercise plan to improve. Instead, the plan should be to increase fluid and salt intake significantly ~ 30 minutes prior to exercise, stop exercising when importantly dizzy, further increase fluid and salt intake if dizziness is occurring too soon into exercise, and try to do exercise that is easiest orthostatically when starting out. This is where aquatic type exercise and aquatic physical therapy are particularly helpful.

Exercising in water is advantageous to orthostatic intolerance patients and those after Fontan palliation. This advantage comes from the effect of water pressure on blood pooling—when standing or exercising in water, less blood can pool in the lower extremities compared to standing on land.[81–83] This is particularly helpful for patients after Fontan who have lower extremity venous stasis and orthostatic patients with excessive venous compliance. While older studies have theoretically cautioned Fontan patients from diving, recent reports evaluating Fontan haemodynamics during swimming or diving found similar physiology to controls without adverse events.[84,85] As the skeletal muscle pump is augmented, preload is increased which will increase cardiac output and importantly cerebral perfusion. This translates ultimately into further ability to exercise. We see this in practice often, particularly in orthostatic intolerance patients, who finally make progress through aquatic exercise. Exercising in water can take the form of swimming, water aerobics, or in those who need additional guidance, aquatic physical therapy.

Aquatic physical therapy

Aquatic physical therapy is offered through many physical therapy providers. Patients can check with local practices to see where this is offered, and insurance coverage is typically obtained utilising ICD-10 codes Q24.0 for congenital heart disease, R55 for syncope, R53.1 for weakness, and G90 for autonomic nervous system dysfunction, depending on the situation. A typical prescription reads:

Frequency: 2 times weekly

Duration: 30–60 minutes

Number of sessions: 12–18

Goals: improve aerobic conditioning, strengthening of calf muscles

Activity limitations: stop exercise if significant dizziness

In patients who are hesitant to utilise aquatic physical therapy, counselling regarding its benefit is important. From a cardiac standpoint, it has been shown to favourably affect heart rate variability, which is an important marker of cardiac health, among postmyocardial infarction patients.[86] From a musculoskeletal standpoint, the benefits include reduced pain in exercising joints, easier balance, and consistent resistance training as extremities are moved through the water.[87,88] A recent meta-analysis and systemic review concluded that aquatic exercise benefits these domains, as well as overall quality of life and physical function compared to "no exercise" or land-based exercise.[89] Typically, patients can make progress with physical therapy and then eventually transition to independent exercise involving swimming or other aquatic activities going forward.

For patients and physical therapists that need a more structured plan, Children's Hospital of Philadelphia has modified the Dallas protocol for orthostatic intolerance patients and provided detailed guidelines on types of exercise and calendars of advancement.[90] Again, even if using a protocol, therapists should be instructed that pushing patients through dizziness is counterproductive and can even lead to vasovagal syncope. Specific exercise prescriptions can also be utilised. Within these prescriptions, calculated maximal steady state heart rate, heart rate-based training zones, and exercise

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modes (i.e. recumbent activity, upright stationary bike, treadmill with and without incline) can be explicitly written for an individual patient and followed for progress.[89–93] It must be remembered, however, that heart rate in these specific populations is often confounded by factors other than training and effort during exercise (i.e. beta-blocker use, chronotropic incompetence in Fontan patients, or suboptimal hydration status in those with orthostatic intolerance). For this reason and for ease of use in young patients, using symptomatic limitation (dizziness) is often preferred. For Fontan patients, building up exercise capacity dutifully might be a superior strategy, as studies have shown benefits of even submaximal exercise training.[91] Fontan exercise protocols have been described.[92] As mentioned previously, these range from closely supervised hospital-based interventions to telemedicine-supported home-based sessions, and high-intensity interval training to deliberate submaximal limitation. While the best regimen to follow is up for debate, the salient point is to exercise, to exercise often, and to benefit from this exercise in all the ways described.

Conclusion

As cardiologists, we are focused on augmenting pumps. The cardiac ventricles have our full attention, with detailed examination of their status being part of any patient encounter. In patients with orthostatic intolerance and Fontan status, however, the heart often is not the central issue. Instead, preload failure, as described above, limits cardiac output and potentiates symptoms. Refocus on extracardiac pumps, particularly the skeletal muscle pump, can be an answer to this predicament. Exercise training to fully realise the potential of each patient's lower extremity skeletal musculature improves musculovenous return to the heart and helps to alleviate suboptimal haemodynamics and thus symptoms. As cardiologists treating these patients, we do well to also focus on this recruitable circulatory pump and counsel patients accordingly.

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