Go with the flow: sympathetic control of blood flow during recovery from heart failure

In 1995 Chad Carvin was a world-class distance swimmer at the University of Arizona training for the Olympic Games in Atlanta when he started to become more and more fatigued. His times in training deteriorated and even mild physical activity left him exhausted. Initially it was thought that this was just an extreme manifestation of overtraining, a mysterious illness, or a psychological crisis. But in fact, Carvin had developed severe (life threatening) idiopathic cardiomyopathy of unknown etiology and was exhibiting symptoms of congestive heart failure. Fortunately, Carvin recovered and won a silver medal at the 2000 Olympics at Sydney and continued to excel in international competition for many years. How did this happen?

Congestive heart failure (CHF) and ventricular dysfunction are almost always marked by reductions in exercise capacity. For many years it was believed that the primary factor associated with reduced exercise capacity in CHF was simply the reduced pumping capacity of the heart. In the last 10–20 years, mounting evidence has demonstrated that exercise intolerance in heart failure is due to a complex collection of events, including altered reflex control of the circulation, relative sympathetic vasoconstriction in the active skeletal muscles, metabolic myopathy and vasculopathy in the muscles themselves, and CHF-associated changes in pulmonary function. Together, this means that every organ system essential for exercise is adversely affected by CHF.

Central to this “perfect storm” of physiological disintegration is increased sympathetic outflow to the skeletal muscles and sympathetically mediated restraint of skeletal muscle blood flow. The general idea is that with ventricular dysfunction, the ability of the skeletal muscles to vasodilate during exercise is an even bigger threat to systemic arterial blood pressure regulation than under normal circumstances and that there is increased baseline sympathetic vasoconstriction in CHF. There is also likely additional sympathetic vasoconstriction superimposed on the active muscles during exercise (2, 5–7, 9, 12). Additionally, the normal ability of metabolites released from contracting muscles to limit this sympathetic constrictor influence may be attenuated. In previous studies, Augustyniak and colleagues, working in the O’Leary laboratory at Wayne State University, have used pacing-induced experimental CHF in conscious dogs to show that in CHF excessive activation of group 3 and 4 afferents in the active muscles is central to this increased sympathetic vasoconstriction in the active muscles during exercise in CHF (1).

A key question that has emerged from this work is whether or not the changes in the blood pressure regulating “autonomic strategy” during exercise in CHF are generally reversible or whether chronic changes occur that are irreversible. Clearly the story of Chad Carvin suggests that if ventricular performance recovers the altered reflex control of the circulation, relative sympathetic vasoconstriction in the active skeletal muscles, metabolic myopathy and vasculopathy in the muscles themselves, and CHF-associated changes in pulmonary function can recover too.

To study this question, the group at Wayne State studied chronically instrumented dogs before, during, and after pacing-induced CHF (1). They used the “Seattle model” (3, 4, 10, 11) to evoke graded reductions in terminal aortic blood flow during treadmill exercise to study muscle metaboreflex (group 3 and 4 afferents) control of the circulation during exercise with and without heart failure.

As expected, pacing-induced CHF was associated with reduced cardiac output and stroke volume responses to exercise along with augmented heart rate responses. Additionally, mean arterial pressure was also lower than during control conditions, and hindlimb blood flow was also lower. There was also marked vasoconstriction in the kidney. Again, all of these observations were expected. However, during recovery there was an almost immediate return of normal cardiovascular function, and within a few weeks it appeared that the autonomic nervous system was completely back to normal. Two other observations that were particularly interesting included that hindlimb blood flow during exercise returned to normal values within a day or two but that the mean arterial pressure responses to exercise were depressed for several weeks during recovery from CHF. This suggests that once the pacing was stopped there was an abrupt withdrawal of excessive vasoconstrictor tone in the active muscles and that the muscle was able to once again “receive” and use high levels of blood flow. There was also evidence of ongoing renal vasoconstriction that, at rest and during exercise, took at least a week to recover. This suggests that there was some sort of chronic resetting of baroreflexes that defended a lower blood pressure during exercise perhaps at the expense of renal blood flow (8).

Together, these data demonstrate that different organ systems and different physiological control mechanisms recover at different rates from CHF, but the key finding is that all systems recover if there is not irreversible damage to the myocardium. These data also demonstrate that vasoconstriction in the active skeletal muscles, perhaps the most obvious contributor to exercise intolerance, is not permanent.

In this context, Chad Carvin’s case shows that not all ventricular dysfunction is permanent in humans. Although the most common causes of CHF in the developed world are caused by coronary artery disease, hypertension, diabetes, and “traditional” lifestyle-associated risk factors, there are idiopathic (viral?) cardiomyopathies with a mysterious onset that sometimes resolve, and frequently these patients recover dramatically. So, CHF is not always a never-ending downward spiral of vasoconstriction and exercise intolerance, and the work of Augustyniak and colleagues (1) shows us why this does not have to happen and explains in part the remarkable recovery of Chad Carvin.

REFERENCES


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