# Cardiovascular Regulation after Stroke: Evidence of Impairment, Trainability, and Implications for Rehabilitation

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**ABSTRACT**
**Purpose:** To discuss the role of the vascular system and regulation of blood flow delivery in individuals with chronic stroke. This paper will discuss mechanisms of blood flow, vascular remodeling in chronic stroke, exercise as an intervention to improve blood flow delivery, and the role of physical therapy practice in promoting exercise. **Key Points:** Evidence suggests that people with chronic stroke may experience reduced blood flow and decreased arterial diameter in the hemiparetic limb. These arterial changes may influence exercise performance and functional ambulation. However, exercise training can be an effective intervention for improving blood flow delivery in the hemiparetic limb. **Statement of Recommendations:** Physical therapists working with people post-stroke should routinely prescribe aerobic exercise training within the plan of care during stroke rehabilitation. This may minimize declines in the cardiorespiratory and vascular systems and provide greater functional capacity to perform functional activities during and after discharge from physical therapy services.

**Key Words:** blood flow, stroke, cardiovascular, exercise

## INTRODUCTION AND PURPOSE

Therapeutic mobility and exercise training after stroke presents many challenges due to an asymmetrical gait pattern, decreased walking speed, and increased energy expenditure during activity.[1] There is a need to improve cardiorespiratory fitness so that individuals participating in stroke rehabilitation can tolerate functional mobility training and activities. However, it is also important to consider other mechanisms that may affect cardiorespiratory fitness and exercise performance after stroke. The purpose of this paper is to discuss the role of the vascular system and regulation of blood flow delivery after stroke. This paper is organized into 3 distinct sections: (1) vascular function, (2) exercise as an intervention to improve blood flow delivery, and (3) role of physical therapy practice in promoting exercise.

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## VASCULAR FUNCTION

### Mechanisms of Blood Flow

Blood delivers the much needed oxygen and nutrients to all cells in the body and shuttles or removes metabolic by-products through the venous system. In order to maintain homeostasis, blood flow is simultaneously regulated by changes in pressure, peripheral resistance, and metabolic demand.[2] As rehabilitation professionals, we observe how blood flow and pressure are intricately related when a patient experiences orthostatic hypotension, when immediately upon stance (or change in position), pressure decreases instead of increases and blood flows directly towards the pull of gravity.

During therapeutic exercise, metabolic demand increases and therefore, blood flow is increased to the exercising muscle to meet that demand. Two components that influence blood flow delivery during exercise are an increase in the rate of flow (velocity) and arterial diameter enlargement (vasodilation). There is evidence that a peripheral "feedback mechanism"[3] exists directly within the arterial vessel wall that maintains a synergy between blood flow and diameter. Previous work in animal models found that during acute exercise, the demand and delivery of increased blood flow to the muscle concomitantly increases arterial diameter. One study used Doppler ultrasound to quantify changes in femoral artery diameter and blood flow velocity during an exercise bout of increasing workloads.[4] These results reported in healthy adults support the findings in animal models. However, an interesting area for physical therapists to consider is the effect of chronically decreased daily metabolic expenditure and whether lower activity levels would directly decrease the need for blood flow and oxygen delivery. To date, the literature suggests that in patient groups with chronic disease such as stroke where muscular metabolic activity is decreased, the result is a reduced demand for blood flow.[5,6] Therefore, vascular remodeling (smaller diameter) may occur to maintain the flow-diameter relationship. When physical activity is added, this narrowing can hamper overall blood flow to the working muscle.

### Vascular Remodeling After Stroke

After stroke, lower leg blood flow in the affected limb is decreased during rest[5,7,8] and exercise.[8] A seminal study revealed that blood flow in the femoral artery of the hemiparetic limb was significantly lower at rest when compared to the other limb.[8] During 1 and 2-legged steady-state cycling exercise, blood flow delivery (via femoral artery) to the hemiparetic leg was significantly lower than the other leg, which may suggest an abnormal cardiovascular regulatory response. Recent work suggests that structural vascular remodeling in the hemiparetic femoral artery may occur after both ischemic and hemorrhagic stroke.[7,9] Using Doppler ultrasound and a linear array transducer for vascular imaging, femoral artery diameter and blood flow was examined in bilateral limbs of people post stroke. The work by Billinger and colleagues[7,9] supports the previous literature that blood flow is lower (~ 36% less) in the hemiparetic leg,[5,8] but new information was found that arterial diameter was also reduced despite mean ankle brachial index values near normal (above 0.90).[9] These are unique unilateral vascular adaptations that are not observed in healthy young or older adults.[10]

## EXERCISE AND IMPROVEMENTS IN BLOOD FLOW DELIVERY

As physical therapists, we need to consider how reductions in blood flow delivery may affect people post-stroke during therapeutic exercise (ie, tissue perfusion or muscular performance) and what steps we can take to improve cardiovascular health in this specific patient population. Information presented in this section will discuss the vascular response to an exercise intervention after stroke. Peripheral vascular training effects that occur from exercise are uncertain after stroke.

In healthy adults, the use of single limb exercise (SLE) has been a training intervention that has facilitated improvements in blood flow to the exercising limb and allowed for intra-limb comparison.[11] Therefore, SLE has been proposed as a unique exercise model to use in people post-stroke as a result of the research that suggests these individuals have difficulty maintaining an equal work distribution between the hemiparetic and less affected limb.[8] In a recent study from our lab, 12 individuals with chronic stroke participated in a thrice weekly SLE training intervention for 4 weeks.[9] Using Doppler ultrasound and a linear array transducer, vascular measures (bilateral femoral artery blood flow, diameter) were taken at baseline, after 2 weeks of training, and postintervention (4 weeks) to determine if the trained limb (hemiparetic) demonstrated vascular changes. In addition, measures of cardiorespiratory fitness were assessed at baseline and posttraining for peak oxygen uptake ($VO_2$ peak) during an exercise test and oxygen uptake ($VO_2$) at submaximal effort during SLE.[12] After the SLE training intervention, significant improvements in femoral artery blood flow and diameter were reported in the hemiparetic limb (trained limb) versus the other leg (untrained limb). One possible explanation is that the increase in metabolic demand is coupled with improvements in blood flow and in order to maintain homeostasis diameter must adjust to the increases in blood flow.[9] Although $VO_2$ peak did not significantly improve with training, at submaximal efforts during SLE, a significant reduction in energy expenditure was reported.[12]

Exercise is a potent stimulus that facilitates adaptive vascular responses to meet the metabolic demands of the working muscles.[13] However, limited information is available regarding vascular changes in the affected limb after stroke. Rehabilitation researchers should work towards a better understanding of how vascular changes (ie, reduction in blood flow, diameter) may hamper daily activity, walking performance, and cardiorespiratory fitness specifically after stroke. Finally, as physical therapists we need to continue to explore the many facets of exercise-induced benefits in those individuals with cardiovascular disease, including stroke.

## ROLE OF PHYSICAL THERAPY PRACTICE

Physical therapists have a vital role in of stroke rehabilitation. While stroke recovery should emphasize a balanced multisystem approach to restore function, all too often, the cardiorespiratory system may not be sufficiently challenged because of the residual neuromotor deficits.[14] The lack of exercise early after stroke may contribute to the rapid decline in cardiorespiratory fitness.[15] However, recent work by Tang and colleagues[14] demonstrated that aerobic exercise incorporated into the subacute phase of traditional stroke rehabilitation may provide improvements not only in cardiorespiratory fitness but also functional ambulation. Furthermore, recent literature has suggested that vascular impairments may also result from physical inactivity in the chronic phases of stroke[5,7,9] and exercise may be beneficial for improving blood flow delivery to the hemiparetic leg.[9]

Physical therapists engaged in exercise prescription for people with stroke should consider walking ability, balance, trunk control, visuospatial deficits, hemiparesis, cognition, exercise tolerance, hemodynamic control, and premorbid function as important factors that may affect exercise performance. Despite the multitude of impairments that can exist for people after stroke, exercise is recommended.[15] As clinicians we are acutely aware of the benefits of bilateral exercise interventions for our patients. However, SLE may be a viable therapeutic exercise regimen for improving peripheral vascular function in the hemiparetic leg after stroke.[9,12] Physical therapists may use the *Recommended Exercise Training Intensity Guidelines for Stroke Survivors* as coproduced by the Neurology and Cardiovascular and Pulmonary Sections of the APTA for further guidance on appropriate exercise prescription. It is important that physical therapists who are experts in exercise prescription continue to move the profession forward through incorporating scientifically sound rehabilitation strategies, research, and exercise guidelines into clinical practice for people with stroke.

## CONCLUSION

Most individuals after stroke are deconditioned and have low levels of cardiorespiratory fitness.[15] In addition, the vascular system in the hemiparetic leg appears to undergo arterial remodeling (smaller diameter) and decreased blood flow delivery in people with chronic stroke. Although SLE has been reported to improve blood flow and increase arterial diameter,[9] further work is needed to identify other exercise strategies targeted at minimizing vascular changes that occur after stroke. The goal should be to obtain the optimal cardiorespiratory fitness for people post-stroke that will also lead to important functional activity gains during rehabilitation.

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