Acute Peripheral Blood Flow Response Induced by Passive Leg Cycle Exercise in People With Spinal Cord Injury

Laurent Ballaz, PhD, Nicolas Fusco, PhD, Armel Crétaul, PhD, Bernard Langella, MD, Régine Brissot, PhD


Objective: To determine the acute femoral artery hemodynamic response in paraplegic subjects during a passive leg cycle exercise.

Design: Case series.

Setting: Department of physical medicine and rehabilitation in a university in France.

Participants: A volunteer sample of 15 people with traumatic spinal cord injury.

Intervention: Subjects performed a 10-minute session of passive leg cycle exercise in the sitting position.

Main Outcome Measures: We measured heart rate, maximal (Vmax), and minimal femoral artery blood flow velocity at rest and immediately after the passive leg cycle exercise, using quantitative duplex Doppler ultrasound. We calculated mean blood flow velocity (Vmean) and velocity index, representing the peripheral resistance, for each condition.

Results: Vmax and Vmean increased (from .80±.18m/s to .96±.24m/s, P<.01; and from .058±.02m/s to .076±.03m/s, P<.01; respectively) after 10 minutes of passive leg cycle exercise. Heart rate did not change. The velocity index decreased from 1.23±0.15 to 1.16±0.21 (P=.038).

Conclusions: The results of this study suggest that acute passive leg cycle exercise increases vascular blood flow velocity in paralyzed legs of people with paraplegia. This exercise could have clinical implications for immobilized persons.

Key Words: Blow flow velocity; Doppler ultrasound; Femoral artery: Rehabilitation; Spinal cord injuries.

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THE INCIDENCE OF DEATH among people with spinal cord injury (SCI) is significantly higher than in the general population. SCI subjects are prone to severe cardiovascular disorders that present an increased risk of mortality. The risk increases with the degree of dependency, in particular for people who are totally dependent on wheelchairs for mobility. Two factors related to this risk are loss of autonomic control and lack of movement, which lead to vascular disorders. This induces an important structural and functional remodeling in the peripheral vascular system of paralyzed limbs; this remodeling includes reduced diameter of the common femoral artery (CFA), arterial stiffness, and lesser blood flow to the legs. Another factor is the high occurrence of metabolic syndromes (eg, obesity, hypercholesterolemia) caused by a lack of physical exercise, which is recognized as a cardiovascular ischemia factor.

Studies of people with long-lasting SCI have shown that the femoral artery blood flow at rest is reduced by about 50% when compared with able-bodied subjects. This adaptation has been related to muscular atrophy, and even though there is relatively little change in the flow with respect to the muscle mass, improvement in lower-extremity circulation is highly desirable because deficient lower-extremity circulation and venous stagnation lead to thrombosis. Thrombosis prevalence is higher in the SCI population than in the general population, even in the chronic phase.

This vascular remodeling may reflect the consequences of reduced activity.

Arm exercises, which subjects with SCI could easily do, neither target the vessels in the lower limbs nor promote lower-limb circulation in those subjects. The set of potential lower-limb exercises is limited in the case of wheelchair users. Since the 1990s, functional electric stimulation (FES) has shown great promise as a cardiovascular stimulus. This technique, however, has been reported to carry the risks of skin burns, autonomic dysreflexia, and bone fractures.

Ditor et al have shown that body-weight support treadmill training (BWSTT) may increase femoral artery compliance in subjects with complete motor SCI (C4-T12: American Spinal Injury Association grade A and B; years postinjury, 7.6±9.4y). Hence, use of this technique should be encouraged as a means of improving cardiovascular health in the SCI population. Its widespread use, however, is hindered because BWSTT requires both trainers and expensive equipment. This study, however, demonstrates that passive movement can lead to structural peripheral vascular adaptation.

The simple passive leg cycle exercise is easily performed by people confined to wheelchairs. Powered cycle trainers that subjects can use at home while sitting in a wheelchair are also commercially available. Very few studies have investigated the central cardiopulmonary response to passive leg cycle exercise in healthy subjects or in SCI patients. With regard to SCI subjects (T8-L1; ASIA grade A; years postinjury, 14.6±8.8), Muraki et al suggest that passive leg cycle exercise enhances the cardiac output by increasing the stroke volume, provided the exercise is performed at 40 rounds per minute (rpm). This increased cardiac output probably results from the activation of the muscular pump that increases the venous return from the passively moved muscles. In a recent study, Ter Woert et al could not find any alteration in the arterial leg blood flow either after passive leg movement by a
therapist or by passive cycling. This suggests that there is no significant effect on the peripheral vascular flow with passive limb mobilization in therapy. This assumption requires further study.

Our purpose in this study was to determine the acute peripheral hemodynamic response through passive leg cycle exercise in people with paraplegia. We assumed that passive leg cycle exercise increases the blood flow circulation and decreases the peripheral vascular resistance of CFA in subjects with SCI.

METHODS

Fifteen people (12 men, 3 women; age, 47±8y) with chronic SCI (T3-12; ASIA grades A–C; nonambulatory; years postinjury, 19±8y) were included in the study. Only 2 subjects had nerve degeneration of the lower limbs resulting in lower motoneuron lesions. This was assessed, based on a physical examination, by the level and the location of the injury. Participants who had been injured at least 6 months before were recruited from the department of rehabilitation at Rennes Hospital. Subjects with any of the following conditions were excluded: history of smoking (past or current), cardiovascular history, metabolic or pulmonary disease, and severely reduced range of motion (ROM) of hip or knee joints. Subjects did not modify their usual treatment for the trial. Four subjects were under medication: 2 used alfuzosine for sphincter hypertonia and the other 2 took baclofen for limb spasticity. The local ethics committee at Rennes approved this trial before the study was started. All patients were informed of the testing procedures and possible undesirable side effects and gave their written consent to participate. Table 1 summarizes their characteristics.

Exercise Protocol

Subjects were requested not to drink caffeine and to empty their bladders before engaging in the passive leg cycle exercise. They also underwent a medical examination by the rehabilitation physician (RB) to ensure that the inclusion criteria were met. The level of each subject’s quadriceps spasticity was measured with the Ashworth Scale.30 After the isokinetic examination, by the level and the location of the injury. Participants who had been injured at least 6 months before were recruited from the department of rehabilitation at Rennes Hospital. Subjects with any of the following conditions were excluded: history of smoking (past or current), cardiovascular history, metabolic or pulmonary disease, and severely reduced range of motion (ROM) of hip or knee joints. Subjects did not modify their usual treatment for the trial. Four subjects were under medication: 2 used alfuzosine for sphincter hypertonia and the other 2 took baclofen for limb spasticity. The local ethics committee at Rennes approved this trial before the study was started. All patients were informed of the testing procedures and possible undesirable side effects and gave their written consent to participate. Table 1 summarizes their characteristics.

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Another investigator (LB) analyzed an off-line recording of red blood cell velocities. Furthermore, from the corresponding

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<th>Subjects</th>
<th>Sex</th>
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Mean | 47 | 19 |
SD  | 8  | 8  |

Abbreviations: F, female; L, left; M, male; R, right; SD, standard deviation.
Doppler spectrum waveform, the following parameters of blood velocity were determined among 6 successive cardiac cycles and subsequently averaged: (1) peak systolic blood velocity (Vmax), defined as the highest velocity measured in the Doppler spectrum of the cardiac cycle, and (2) minimal velocity (Vmin), defined as the lowest velocity. The other postexercise measurements were used to control the return to the basal level.

The mean blood velocity (Vmean) in the CFA was calculated using the equation:

\[
\left(\frac{1}{6}\left[\frac{1}{4}V_{\text{max}} + \frac{1}{4}V_{\text{min}}\right]\right) \times (60 \times \text{HR}^{-1})
\]

where HR is heart rate. Because no dilatation of CFA during the exercise was previously reported,32,34-36 we assumed that after passive leg cycle exercise there is a variation of blood flow. We calculated a velocity index from the difference between Vmax and Vmin divided by Vmax and used it as an indirect indicator of the peripheral resistance.14 This index was a slight modification of the pulsatility index37 and was independent of possible differences in the insonation angle of the Doppler probe during recording. The heart rate was calculated from the Doppler acquisition. The interval between 6 consecutive spectral waveforms was measured manually and converted to cardiac frequencies.

Statistical Analysis
All values are described as mean ± standard deviation. We used paired t tests for dependent groups or Mann-Whitney U tests to compare variables for vascular properties of the femoral artery before and after the exercise session, depending on the presence of a normal distribution. P values less than .05 indicate statistical significance.

RESULTS

Exercise Compliance
All but 1 subject completed the 10-minute exercise session at a rate of 40rpm; the 1 subject asked to stop the rise of the pedaling rate and completed the session at 30rpm. This subject’s results were averaged with the others. There was no significant spastic muscle contraction during the passive cycling exercise.

Effect of Acute Passive Leg Cycle Exercise
Paired t tests were used for all comparisons because each parameter had a normal distribution. Maximal blood flow velocity (fig 1) and mean blood flow velocity (fig 2) in the femoral artery increased significantly after 10 minutes of exercise, from \(0.80 \pm 0.18\) to \(0.96 \pm 0.24\) m/s (\(P = .001\)) and from \(0.058 \pm 0.02\) to \(0.076 \pm 0.03\) m/s (\(P = .009\)), respectively. There were no differences in minimal blood flow velocity. Heart rate also remained unchanged after 10 minutes of exercise. The velocity index (fig 3) decreased significantly from the resting values after the exercise (ie, from \(1.23 \pm 0.15\) to \(1.16 \pm 0.20\) m/s, \(P = .038\)).

DISCUSSION

Hemodynamic Response to Passive Leg Cycle Exercise
The main finding of this study is that in an SCI population, passive leg cycle exercise significantly increased blood flow velocity in the femoral artery by about 30%, without an increase in the heart rate. At rest, heart rate and hemodynamic values (Vmean, Vmax, Vmin) reported in this study were in agreement with previously reported values in the SCI population.14,35,38

The increase in blood flow velocity after passive leg cycle exercise is not the result of an increase in heart rate, as shown in the study. The data are in accordance with other studies27,28 that found that the heart rate remained at the basal level. In able-bodied persons, the heart rate slightly increases at the onset of passive movement because of peripheral afferent reflexes from exercising muscles.23,24 In the case of nondisabled people, the heart rate value returns to a baseline24,27,28 within a few minutes after passive leg cycle exercise. In the SCI pop-
ulation, however, afferent reflexes from the paralyzed lower limbs during such exercise malfunction because the afferent pathways are interrupted. The results suggest that central cardiac factors do not play a dominant role; hence a peripheral mechanism can be hypothesized. During muscular contractions, the muscle pump promotes the blood flow by squeezing blood out of the venous capacitance vessels, thereby reducing the venous pressure with a subsequent gain in the gradient pressure across the vascular bed.

This mechanical factor may partially promote a sudden initial increase in the blood flow at the beginning of the exercise. In addition, rapid vasodilation, which occurs in the venous system, participates in the increase in the arterial blood flow at the start of exercise. The role of each factor is still under discussion, however. Radiegan and Saltin found that during passive knee extension, femoral arterial blood velocity and inflow during the relaxation phase of the movement was 3.3 to 4.4 times greater than the baseline values. This elevation, under passive conditions, results from muscle mechanical factors that can promote arterial blood flow during passive movement.

In this study, immediately after passive leg cycle exercise (<7s), increased by 30%. This increase is lower than the increase measured by Radiegan and Saltin during passive knee extension. The circulation response induced by passive movement is dependent on mechanical factors and seems to be very transient. Therefore, we hypothesized that the circulatory response is higher during the movement than at the exact time of the measurement, as this measurement is taken immediately after the movement is completed.

In the SCI population, venous pools in the lower extremities diminish the venous return. Under physiologic conditions the muscle acts as a pump that propels the blood out of the muscle toward the heart. The tissue lengthening and shortening induced by the movement of the paralyzed lower limb during passive leg cycle exercise may increase venous return and arterial circulation in a manner similar to the activity of the muscular pump during contraction, but with a smaller amplitude. Consequently, according to the Frank Starling law, this leads to an increase in the cardiac output. Studies have shown that in both SCI and able-bodied populations, passive movement such as passive leg cycle exercise increases cardiac output, whereas Figoni et al found no significant increase in cardiac output and stroke volume in SCI subjects with other kinds of passive movements, such as passive knee extensions. A cycling movement is the most efficient means by which to enhance the venous return in passive mobilization. During passive leg cycle exercise, the plantar vascular bed is compressed at each revolution of the pedal. The pressure exerted by the weight of the leg on the pedal is increased during the upward movement of the pedal. This rhythmic movement provokes an alternate effect of pumping that can be compared with a “peripheral heart.” In contrast, this mechanism does not exist during free passive knee flexion and extension.

Recently, Ter Woerds et al found that passive cycling does not alter the arterial leg blood flow in SCI subjects. Their results are not in agreement with our data from this study. Several protocol differences may explain this discrepancy. First, the cycling movement was performed at 35rpm, whereas in this study it was performed at 40rpm (except by 1 subject). Moreover, we adjusted the length of the pedal to ensure the greatest ROM. Second, in Ter Woerds’ study the blood flow in the leg was measured after 1 minute, then subsequently every 2.5 minutes during cycling. The ergometer was stopped for about 10 seconds for each measurement. The intermittent character of this exercise could limit the circulatory response.

Third, our sample included 15 people while Ter Woerds’ sample included only 8 people. The repeated-measures analysis revealed no changes over time for blood flow, with a P value at .14. With more subjects, the P value might reach the significant threshold.

### Vascular Resistance

The values of velocity index reported here are in accord with the results previously reported in the SCI population. We found a slightly significant decrease (6%) of the velocity index in the CFA in response to passive leg cycle exercise. This index is an indirect indicator of vascular resistance. It is hypothesized that passive leg cycle exercise leads to a slight decrease in arterial resistance. This is the first time that such a vascular response has been shown after passive movement in SCI subjects.

High vascular resistance has already been reported in the SCI population. De Groot et al showed that in an SCI population (N=11; ASIA grades A–B; level, T1-L1; time since injury, 11.6±7.9y), the flow-mediated dilatation was enhanced in the femoral artery of SCI subjects compared with the dilation in the control group. These authors indicated that people with SCI could have a preserved endothelial function in their inactive legs. Consequently, the increase of blood flow in CFA during passive leg cycle exercise may induce, by an endothelial mechanism, a slight dilatation of the artery, which leads to a decrease in peripheral resistance.

Muraki et al found that during passive leg cycle exercise by SCI subjects the cardiac output increased as a result of the elevation of the stroke volume without any increase in heart rate and blood pressure. Muraki also suggested that there was a decrease in peripheral vascular resistance during the exercise because peripheral resistance is determined by cardiac output and blood pressure (peripheral resistance = mean blood pressure/cardiac output). Their results support this hypothesis.

### Clinical Implications

The results of this study could have important clinical implications. According to the subjects, passive leg cycle exercise did not induce discomfort. Instead, they verbally reported a sensation of well-being. Therefore, this exercise seems to be an appropriate technique for increasing peripheral blood flow in SCI subjects. When prolonged treatment is required, this is especially important to counteract blood stasis that occurs in immobilized people. The value of increased femoral blood flow velocity induced by passive leg cycle exercise is close to the increase induced by electric stimulation in isometric conditions in healthy subjects. Electric stimulation treatment could be contraindicated for people with cardiorespiratory disorders, autonomic dystreflexia, or sensitive skin. Moreover, the electric stimulation leads to fatigue, particularly in people with SCI. Passive leg cycle exercise can be performed for a long period of time without fatigue or discomfort precisely because of its passive nature.

### Study Limitations

Doppler measurements were taken with subjects seated in the wheelchair with its back tilted back (150°). The measurement was not taken in the standard supine position because it was important that it be taken immediately after the exercise. Nevertheless, the position measurement was exactly the same for all data acquisition. The off-line analysis of Doppler spectrum waveform was performed by a single investigator who was not blinded. Hence, this methodologic problem might have affected the result. We did not use electromyography to con-
firm the passive condition during the exercise. Eight of the 15 subjects in this study, however, did not have quadriceps spasticity (Ashworth Scale score, 0). Moreover, there was no control group in this study. It is assumed that the cardiovascular system is solely evoked by passive leg cycle exercise. The cycle trainer used for the experiment is designed for self-powered home use. During this clinical trial, the subjects did not put their legs on the device so to maintain the cardiovascular parameters at their basal level.

**Perspective**

It would be interesting to know what functional and structural vascular adaptation occurs after a training period of passive leg cycle exercise. The training should take place at home so that the performance of this home-based trainer can be properly evaluated.

**CONCLUSIONS**

The main finding of this study is that a 10-minute session of passive leg cycle exercise markedly increased the femoral mean and maximal blood flow velocity in an SCI population. Furthermore, passive leg cycle exercise leads to a slight decrease in the peripheral arterial resistance. It could also have increased vascular resistance in paralyzed legs after spinal cord injury is reversible by training. J Appl Physiol 2002;93:1966-72.


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