Resistance Exercise, the Valsalva Maneuver, and Cerebrovascular Transmural Pressure

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ABSTRACT

HAYKOWSKY, M. J., N. D. EVES, D. E. R. WARBURTON, and M. J. FINDLAY. Resistance Exercise, the Valsalva Maneuver, and Cerebrovascular Transmural Pressure. Med. Sci. Sports Exerc., Vol. 35, No. 1, pp. 65–68, 2003. Purpose: To examine the acute effects of resistance exercise (RE) performed without a Valsalva maneuver (VM) versus a VM performed alone on systolic pressure, intracranial pressure (ICP), and cerebrovascular transmural pressure (CVTMP) (i.e., the important pressure that stresses the cerebral arterial and aneurysmal walls and calculated as systolic pressure minus ICP). Methods: The subjects for this study consisted of seven (mean ± SD, Age: 39 ± 14 yr) fully alert, cooperative, and clinically stable individuals who recently underwent various neurosurgical operations. Heart rate, systolic pressure, ICP, and CVTMP were obtained at rest, during a VM, and during submaximal (8.0 ± 3.0 kg performed for 18 ± 10 repetitions) unilateral bicep curl RE. Results: The VM resulted in a significantly greater increase in ICP (VM: 31 ± 14 mm Hg vs RE: 16 ± 7 mm Hg, P < 0.05) with a concomitant decrease in CVTMP (VM: 106 ± 22 mm Hg vs RE: 132 ± 14 mm Hg, P < 0.05) compared with unilateral bicep curl RE. Conclusions: Unilateral bicep curl RE results in a greater increase in CVTMP compared to a VM performed alone. Key Words: INTRACRANIAL PRESSURE, WEIGHT-TRAINING, SYSTOLIC PRESSURE, INTRATHORACIC PRESSURE

Resistance exercise (RE) has become a popular intervention to increase muscle strength and mass in individuals with chronic disease or disability (8). Despite its benefits on skeletal morphology and function, RE may be associated with a small risk of cerebral aneurysm rupture and subarachnoid hemorrhage in those few individuals harboring such a lesion (6).

A widely held belief in exercise physiology is that the heightened intrathoracic pressure (ITP) during RE performed with a Valsalva maneuver (VM) causes an increase in systolic pressure that stresses the cerebral arteries. However, an elevated systolic pressure may not damage the cerebral arteries if the pressure surrounding the arteries (i.e., intracranial pressure; ICP) also increases. Thus, the important pressure that stresses the cerebral arteries and aneurysmal walls is actually the cerebrovascular transmural pressure (CVTMP; equal to the systolic pressure minus ICP). In an early investigation, Hamilton et al. (5) reported that the increase in ITP during a brief (phase I) VM was transmitted directly to the intracranial compartment, resulting in a concomitant rise in ICP. Moreover, because arterial pressure and ICP were elevated equally, there was no change in CVTMP. Therefore, the heightened ITP associated with a brief VM does not appear to result in an acute alteration in CVTMP and as a consequence may not be as detrimental as believed. Paradoxically, RE performed without a VM may result in a marked elevation in systolic pressure with minimal change in ITP or ICP and as a consequence could lead to a marked increase in CVTMP. Currently, there has been no investigation that has directly measured ICP and CVTMP during RE in humans. Therefore, the purpose of this investigation was to examine the acute effects of RE (without a VM) or a VM performed alone on systolic pressure, ICP (measured in the lateral ventricle at the level of the Foramen of Munro), and CVTMP.

METHODS

Subjects. The subjects for this investigation consisted of seven fully alert, cooperative, and clinically stable patients (mean ± SD, age: 39 ± 14 yr) who previously underwent various neurosurgical operations (aneurysmal clipping (N = 1), ventriculoscopic third-ventriculostomy (N = 1), ventricular shunt removal (N = 1), tumor removal (N = 3), and drainage of a cerebellar abscess (N = 1). Ethical approval was obtained from the medical ethics committee, and informed consent was obtained before study participation in accordance with the policy statement of the American College of Sports Medicine regarding experimentation with human participants. No complications were associated with participating in this investigation.

ICP and arterial pressure monitoring. ICP was measured with a ventricular drain (Medtronic EDM ven-
tricular catheter, Minneapolis, MN) that was placed in the lateral ventricle at the level of the Foramen of Munro (as part of the neurosurgical operation) and attached to a fluid-filled system connected to a standard blood pressure transducer. The ventricular drains were removed immediately after the study. Arterial pressure was monitored noninvasively by sphygmomanometer or by a radial arterial line when available.

Performance of the VM and submaximal RE. After baseline measurements were obtained, the subjects were provided with instructions regarding the proper technique required to perform the unilateral bicep curl RE movement. Initially, the subjects lifted a 2.5-kg weight for as many repetitions as possible. After a 3- to 5-min rest period, the weight increased by 2.5 kg. This procedure was continued until the subjects could no longer lift the weight while adhering to strict technique and without performing a VM. After a 5- to 10-min rest period, subjects were provided with instructions regarding the proper technique to perform a VM. Encouragement was given to each subject to perform the maneuver for as long and forcefully as possible. Heart rate, systolic blood pressure, ICP, and CVTMP were obtained at rest, during repetitive unilateral bicep curl RE, and VM.

Statistical analysis. Statistical analysis was performed on all dependent variables using a one-way repeated measures ANOVA. The Scheffe post hoc test was applied whenever there were significant main effects. For both the ANOVA and post hoc test, the alpha level was set a priori at $P < 0.05$.

RESULTS

The subjects performed $18 \pm 10$ repetitions with $8 \pm 3$ kg during submaximal unilateral RE. Compared with rest, submaximal RE resulted in a significant increase in heart rate with no change in peak systolic pressure, ICP, or CVTMP (Table 1). The VM was associated with a significant increase in ICP, compared with rest and RE. Furthermore, the CVTMP was significantly lower during the VM compared with RE (Table 1).

DISCUSSION

The major new finding of this investigation was that submaximal RE (without a VM) resulted in a significantly higher CVTMP ($+24.5\%$) compared with a VM performed alone. The mechanism responsible for the divergent CVTMP during RE versus the VM can be primarily explained by the different ICP responses between the two conditions. More specifically, during RE the absolute increase in ICP was less than the change in systolic pressure resulting in a small increase in CVTMP. Conversely, the 2.4-fold increase in ICP during the VM occurred with minimal increase in systolic pressure leading to a decrease in CVTMP.

Although we did not examine the mechanism for the heightened ICP, the VM-mediated rise in ITP increases central venous pressure, which impedes cerebral venous
outflow via the jugular venous system and results in a simultaneous and equal rise in ICP (5). Thus, a paradox exists whereby the heightened ITP associated with a VM results in a concomitant increase in ICP and acts as a “safety” mechanism that prevents an increase in, or even decreases, CVTMP. Current RE guidelines recommend that individuals avoid a VM during lifting (8). However, it is possible that adherence to such guidelines may lead to a greater elevation in CVTMP. More specifically, RE performed without a VM has been associated with peak systolic pressures as high as 224 mm Hg in healthy individuals (1). Because a VM was avoided during lifting, the ITP (and thus ICP) would remain at resting values resulting in a marked increase in estimated CVTMP (i.e., 224 – 2 = 222 mm Hg; Fig. 1). In contrast, RE performed with a VM is associated with an increase in peak systolic pressure as great as 261 mm Hg (2). However, the measured ITP (and thus ICP) was equal to 63.5 mm Hg (2), resulting in an estimated CVTMP of 197.5 mm Hg (Fig. 2). Thus, RE performed with a VM may actually decrease the stress on the cerebral arterial walls by approximately 11% compared with similar exercise performed without this maneuver. Therefore, a VM incorporated during RE may protect the cerebrovascular system. Consistent with this finding, we recently reported that RE performed with a brief VM decreases the stress on the heart as left ventricular end-systolic meridional wall stress during sub-maximal and maximal RE performed with a brief VM was 7–15% lower than resting values (7). Unfortunately, we did not perform maximal RE with a VM as this was considered too stressful for patients who were in the early postoperative period. Therefore, future investigations with a larger sample size are required to examine the acute effects of maximal RE performed with a VM on ICP and CVTMP.

Two recent investigations have used transcranial Doppler ultrasound techniques to try to examine cerebral hemodynamics during RE (3,4). Unfortunately, this non-invasive technique can only measure blood velocity through a cerebral artery and does not allow a true understanding of cerebral hemodynamic changes associated with RE when ICP and CVTMP are not measured. The reason why ICP and CVTMP have not been previously measured, in healthy individuals, is due to the invasive surgical procedures required to obtain these pressures. Therefore, we chose to examine ICP and CVTMP in fully cooperative, alert, and clinically stable patients who had a ventricular drain as part of their surgical procedure and postoperative care. Furthermore, because our subjects were considered adequately recovered from their surgical procedure to have their ventricular drain removed after this investigation, we believe that the cerebrovascular hemodynamic responses obtained in our subjects are as close to a normal population as possible.

CONCLUSION

The results of this investigation demonstrate that RE (without a VM) results in a significantly greater increase in CVTMP compared to a VM and may increase aneurysm wall stress in the rare person bearing this intracranial abnormality. Moreover, the performance of a VM is associated with a significant acute increase in ICP with a concomitant decline in CVTMP that may actually protect against cerebrovascular damage.

REFERENCES


