

Comparison of Calf Muscle Blood Flow Responses to Rhythmic Exercise between Mean Age 25- and 74-Year-Old Men (40915)¹

DANIEL RICHARDSON AND RICK SHEWCHUK

Department of Physiology and Biophysics, University of Kentucky College of Medicine, Lexington, Kentucky 40536

Abstract. These studies compared calf muscle strength and calf muscle blood flow response to rhythmic exercise, as gauged by postexercise hyperemia, between a group of young adult males (mean age 24.7 years) and an older group (mean age 73.7 years). All subjects were trained to exert maximum voluntary contractions (MVC) of their calf muscles. MVC values averaged 502 ± 16 (SEM) pounds in the young adult group and 362 ± 53 (SEM) pounds in the older group. This difference was significant ($P \leq 0.05$). Calf muscle blood flow was measured by strain gauge plethysmography before and after 3-min bouts of rhythmic isometric calf muscle exercise. Contraction frequency ranged from 20 to 80 contractions per minute (cpm) while the force per contraction ranged from 7.5 to 30% of MVC. In the resting state there were no significant between-group differences in blood pressure or calf muscle blood flow. For each percentage MVC and cpm exercise combination tested, there were no significant between group differences in postexercise hyperemia. These results indicate that the fundamental relationship between MVC and muscle blood flow is not modified as a function of age.

Alterations in the cardiovascular system associated with aging have for the most part been observed with the subject in a resting state (1, 2). This raises a fundamental issue as to the effects, if any, of aging on the ability of the cardiovascular system to adjust to a change in physical activity. In this regard it has been shown that the cardiac output response to a given level of bicycle ergometry (3), and postexercise hyperemia following rhythmic plantar flexor contractions (4) are higher among men in their 60s and 70s when compared to men in their 20s and 30s. This indicates that the tendency for intrinsic vascular resistance in leg muscles to increase with age (5) does not affect the ability of the muscle circulation to adjust to an exercise demand.

As to why muscle blood flow response to a given work load would be higher among older people, a simple explanation is that each muscle contraction represents a higher percentage of an older subject's maximum strength, i.e., their maximum voluntary contraction (MVC). This hypothesis is consistent with the observation that blood flow

response to brief muscle contractions grades according to percentage MVC (6) and that MVC is lower in subjects past 65 years of age when compared to subjects in their 20s and 30s (7). If this hypothesis is true then blood flow responses to muscle work at a given percentage of a subject's MVC should essentially be the same in all age groups. In the present study, this hypothesis was tested by comparing postexercise hyperemia between older and young adult males in response to rhythmic contractions of the calf muscles with force per contraction being a given percentage of the subject's MVC.

Materials and methods. Two groups of male subjects were used. One group of nine subjects, the "young adult" group, were students or faculty of the University of Kentucky. This group had a mean age of 24.7 years (range 21–28). A second group of six subjects, the "older" group, were derived from a list provided by the Sanders–Brown Research Center on Aging of those senior citizens in the Lexington, Kentucky community who had indicated interest in serving as subjects in human investigations. Only those subjects who had no history of cardiovascular disease, were not taking medication that would affect the

¹ This research was supported by the Sanders–Brown Research Center on Aging, Grant 6007.

cardiovascular system, and were specifically cleared for these experiments by a physician were given final consideration. The group selected for study had a mean age of 73.7 years (range 70–76). Although these subjects were retired from the work force their previous occupations were business or professional in nature. Thus, during their years of employment their life-styles were similar to those of the young adult group.

All subjects were nonusers of tobacco products, did not participate in strenuous exercise on a regular basis, and had resting arterial blood pressure of less than 140 mm Hg systolic and 90 mm Hg diastolic. On their first visit to the laboratory subjects were briefed on the methods and procedures, then signed an informed consent statement.

The method used for plantar flexor contraction was as follows: A subject sat in a chair with his right foot on a pedal the end of which was coupled to a load cell. The fulcrum upon which the pedal rested was situated beneath the ankle. The height of the chair was adjusted so that the thigh was horizontal. A padded support plate was inserted through threaded steel bars which were coupled to the floor and extended vertically on both sides of the knee. The plate was pressed against the knee and locked into place. The subject was instructed to press down on the pedal with the ball of the foot. By knowing the distance from the fulcrum to the ball of the foot and from the fulcrum to the load cell, the force applied at the ball of the foot could be determined from the load cell output.

When executing the type of contraction described above, the heel remained stationary. The contraction is therefore an "isometric plantar flexion" in that the major plantar flexors, the gastrocnemius and soleus, are the muscles being activated. This was verified in pilot studies of transcutaneous EMG activity.

All subjects were "trained" to exert their MVC in a series of four separate sessions each carried out on a separate day. For each training session the subjects exerted a series of 10 short-duration (2 sec) maximum isometric contractions of the calf muscle. A

rest period of 1 min was interposed between contractions, and the highest of the 10 contractions was considered the MVC for *that session*. The young adult subjects experienced a 5% increase in MVC between the first and third sessions with essentially no further increase occurring in the fourth session. The older subjects showed a 14% increase in MVC between the first and third sessions, but only a 1% increase between the third and fourth sessions. Thus, by the third session our subjects had evidently "learned" the task. Therefore the highest contraction of the third or fourth sessions was considered the subject's true MVC.

Calf muscle blood flow was measured by venous occlusion strain gauge plethysmography (8). A mercury-in-rubber "Whitney" gauge was placed around the widest part of the calf muscle and coupled to a bridge circuit (Parks Model 270). Venous occlusion was achieved by inflating a pneumatic cuff placed around the thigh to a pressure of +60 mm Hg. The resultant rate of venous volume change was measured from the output of the Whitney gauge, then normalized per 100 ml of tissue volume as described by Whitney (8). In these studies arterial input to the foot was not occluded by an ankle cuff during flow measurements since in a pilot series of experiments this procedure had no significant effect on either resting calf muscle blood flow or postexercise hyperemia. These observations are consistent with those of Williams and Lind (9) who reported that occlusion of flow to the hand is not necessary for accurate flow measurements in the forearm.

Experimental protocol. Each subject participated in three experimental sessions each conducted on a separate day. A given session consisted of three successive bouts of rhythmic exercise for a total of nine exercise bouts per subject.

The force per contraction was different for each of the three daily sessions being either 7.5, 15, or 30% of the subjects' predetermined MVC. The force was controlled by having subjects monitor load cell output on an oscilloscope. The sequence of contraction forces (i.e., sessions) was varied for each subject.

The three exercise bouts within a daily

session consisted of rhythmic contractions conducted in cadence to a metronome at a frequency of 20, 50, or 80 contractions per minute (cpm) for 3 min each. A minimal 5-min recovery period was interposed between each exercise bout, and the sequence of contraction frequencies was varied with each daily session. In a separate treadmill test it was determined that for a normal 6-ft man 20 cpm was equivalent to a slow walk at 1 mile per hour, 50 cpm a brisk walk at 4 miles per hour, and 80 cpm a run at about 6.5 miles per hour.

Two measurements of resting calf muscle blood flow and one measurement of resting arterial blood pressure (by standard sphygmomanometry) were obtained prior to each of the nine exercise bouts. The two resting flow measurements were respectively made before and after the measurement of blood pressure.

Calf muscle blood flow was again measured immediately upon cessation of exercise, and at 15, 30, 60, 90, and 120 sec into the postexercise period. Blood flow was not measured during the rhythmic exercises as others have done with the Whitney gauge (10), because oscillations of the gauge during exercise were such that reliable flow measurements could not be made.

Between-group variables were tested for significant differences by the *t* test for independent variables; whereas, within-group comparisons utilized the dependent *t* test. The 5% probability level was used in all tests.

Results. Body weight, calf circumference, and MVC. These results are presented in Fig. 1. While both subject groups had similar body weights, calf circumference and calf muscle MVC of the older group were significantly lower than values of the young adult group. The elderly subjects also had a smaller MVC when expressed in pounds per centimeter of calf circumference. However, on the basis of dimensional measurements alone it cannot be determined if this lower ratio in the elderly is due to less force exerted per unit of muscle mass or less muscle mass per se since percentage lean body mass varies as a function of age (2).

Resting blood pressure, and blood flow.

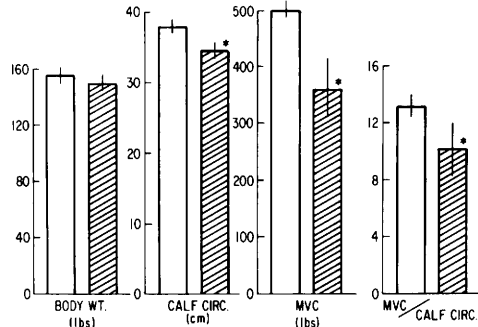


FIG. 1. Body weight, calf circumference, maximum voluntary contraction (MVC) of the calf muscle, and ratio of MVC to calf circumference in the young adult (open bars) and older (hatched bars) groups. Data presented as group means \pm SEM. *Significant between-group difference, $P \leq 0.05$.

As previously mentioned two measurements of resting blood flow were made prior to each exercise bout. For both subject groups corresponding flow measurements of a given preexercise pair were not significantly different. Also for both groups there were no significant variations in resting blood flow or blood pressure among the different preexercise measurements.

To compare resting values between the two groups average resting flow and average resting pressure values were obtained for each subject by pooling all preexercise measurements of each variable for that subject. The average subject values were then pooled to obtain group means. These results, presented in Fig. 2, show that systolic and diastolic pressures were similar in both groups. Resting blood flow and calculated vascular resistance were slightly higher and lower respectively in the older group but between-group differences were not significant.

Postexercise blood flow. Examination of the data showed that with the highest level of exercise used (30% MVC, 80 cpm) several of the subjects in the older group did not consistently achieve 30% MVC with each contraction. Therefore, the results of the 30% MVC–80 cpm level of exercise were not included in the final data analysis. Group mean postexercise blood flow values associated with the remaining eight levels



FIG. 2. Preexercise resting values for systolic blood pressure (P_s), diastolic blood pressure (P_d), calf muscle blood flow (BF), and calf muscle vascular resistance (R) in the young adult (open bars) and older (hatched bars) groups. Data presented as group means \pm SEM.

of exercise are presented in Fig. 3. With all levels of exercise postexercise flows were similar between the groups, and with the exception of the peak postexercise blood flow following the 15% MVC-80 cpm exercise, between-group differences were not significant.

To quantitatively compare the magnitudes of the postexercise hyperemic responses, the area under the postexercise hyperemic curve down to resting flow values was calculated for each subject at each exercise level. For those cases in which blood flow was not followed all the way back to resting levels, the tail end of the

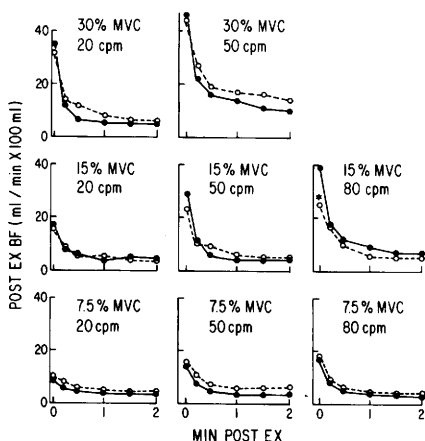


FIG. 3. Postexercise blood flows following each exercise bout. Data presented as group means. (●—●) Young adult group, (○---○) older group.

hyperemic curve was estimated from semilog plots of flow vs time as described by Dornhorst and Whelan (11). The area under the postexercise flow curve, which we chose to call the "hyperemic blood volume" (HBV), measures the volume of blood in excess of resting flow that traversed the calf muscle circulation in the postexercise period (12). Group average values for HBV are presented in Fig. 4. Note that while HBV measurements in the older group tended to be slightly higher than those of the young adult group between-group differences were not significant at any level of exercise.

Discussion. The results of this study demonstrate that calf muscle blood flow response to rhythmic exercise, as gauged by postexercise hyperemia, is essentially the same in young adult and older males when contraction force is matched at a certain percentage of a subject's maximum voluntary contraction (MVC). This indicates that the fundamental relationship between post-contraction hyperemia and percentage MVC of muscle force (6, 13) is not modified as a function of age.

It is known that calf muscle contractions considerably impede muscle blood flow (14) such that with rhythmic contractions even at relatively small force most of the blood flow occurs between contractions (10). This being the case, the results of the present study indicate that the ability of the calf muscle circulation to obtain flow between

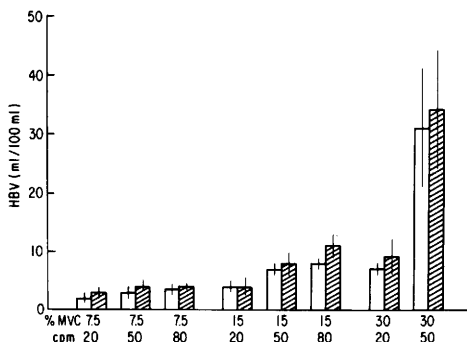


FIG. 4. Postexercise hyperemic blood volume (HBV) for the young adult (open bars) and older (hatched bars) groups. Data presented as group means \pm SEM.

contractions is not affected by age. This can be seen in examining the hyperemic blood volumes, a measurement of the entire post-exercise hyperemic response (Fig. 4). At each exercise level there were no significant between-group differences in HBV. Had flow recovery between contractions been significantly less in the older group, then this group should have acquired a higher blood flow debt and/or deficit during the exercise periods. This would have been manifested in a significantly higher post-exercise HBV (13).

Thus, the aging process does not seem to affect the ability of the calf muscle circulation to gain flow between rhythmic contractions when the contraction force is a given percentage of the subjects' MVC. On the other hand, when exercising at the same absolute work loads elderly subjects show higher blood flow during (3) and after (4) rhythmic contractions when compared to young adults. A modified blood flow response to rhythmic exercise at a given work load is not exclusive to the elderly. Tobacco smokers showed an increase in post-exercise hyperemia in the calf muscles following rhythmic contractions at a given work load when compared to age-matched nonsmokers (15). Marathon runners when rhythmically contracting their calf muscles at slightly higher work loads than control subjects displayed a smaller postexercise hyperemia (16). It would be interesting to learn if these groups had similar post exercise hyperemias when force per contraction is matched at a given percentage of MVC.

The significantly smaller calf muscle MVC observed in the elderly subjects (Fig. 1) is consistent with what has recently been noted by Ordway and Wekstein (7) with comparison of handgrip strength between young adult males and men of more than 65 years of age. One of the consequences of a lower calf muscle MVC, is that the simple act of lifting the body during walking would be a more demanding effort. For example, from the ratios of body weight to MVC calculated from the data in Fig. 1, it can be seen that our young adult subjects would utilize 32% of their calf muscle MVC in lifting the body with plantar flexion. The corresponding figure for the older group

would be 45% of their MVC. This suggests that the higher overall energy cost of moderate treadmill walking in older persons (17) is at least in part due to the fact that body weight represents a higher percentage of an older subject's calf muscle MVC.

As to possible factors related to the lower calf muscle strength in older subjects, it should be noted that our older subjects and those of Ordway and Wekstein (7) were retired from the work force. On the other hand, Petrofsky and Lind (18) compared hand grip strength in men ranging in age from 22 to 62 years who were employed in the same machine shop and found no age related differences in maximal strength or muscular endurance. These comparisons suggest that the tendency for muscle strength to decrease with age (19) may be more a function of reduced physical activity than intrinsic properties of biological aging. This notion is consistent with the observations of Wessel and Van Huss (20) that age associated losses in human performance variables seem to be more related to a decreased physical activity than to age itself. In this regard exercise programs which increase muscular strength in older persons (21) should result in similar blood flow responses to absolute work loads between young adults and older subjects if, as the present data indicate, differences between these two groups at similar work loads are simply manifestations of subjects operating at different levels of their MVC.

The authors would like to acknowledge the valuable contributions of Dr. Jay Kearney, Dept. HPER, University of Kentucky, in the design of these experiments.

1. Amery, A., Wasir, H., Bulpitt, C., Conway, R., Fagard, F., Lijnen, P., and Reybrouck, Acta Cardiol. 33, 443 (1978).
2. Masoro, E., in "Epidemiology of Aging" (A. M. Ostfield and D. C. Gibson, eds.), p. 137. DHEW Publ. (NIH), 75-711 (1972).
3. Becklake, M. R., Frank, H., Dagenais, G. R., Ostiguy, G. L., and Guzman, C. A., J. Appl. Physiol. 20, (1965).
4. Richardson, D. R., Wekstein, D. W., and Althoff, H., Fed. Proc. 37, 882 (1978).
5. Allwood, M. J., Clin. Sci. 17, 331 (1958).
6. Lind, A. R., and Williams, C. A., J. Physiol. 228, 529 (1979).

7. Ordway, G. A., and Wekstein, D. R., *Proc. Soc. Exp. Biol. Med.* **161**, 189 (1979).
 8. Whitney, R. J., *J. Physiol.* **121**, 1 (1953).
 9. Williams, C. A., and Lind, A. R., *Fed. Proc.* **38**, 1135 (1979).
 10. Barcroft, H., and Dornhorst, A. C., *J. Physiol.* **109**, 402 (1949).
 11. Dornhorst, A. C., and Whelan, R. F., *Clin. Sci.* **12**, 33 (1953).
 12. Black, J. E., *Clin. Sci.* **18**, 89 (1959).
 13. Lind, A. R., and McNicol, G. W., *J. Physiol.* **192**, 575 (1967).
 14. Barcroft, H., and Millen, J. L. E., *J. Physiol.* **97**, 17 (1939).
 15. Richardson, D. R., Althoff, H., and Kearney, J. T., *The Physiologist* **21**, 99 (1978).
 16. Mahler, F., Koen, L., Johannsen, K. H., Bernstein, E. F., and Fronek, A., *Angiology* **27**, 721 (1976).
 17. Durin, J. V. G. A., and Mikulicic, V. Q., *J. Exp. Physiol.* **41**, 442 (1956).
 18. Petrofsky, J. S., and Lind, A. R., *J. Appl. Physiol.* **38**, 91 (1975).
 19. Fisher, M. B., and Birren, J. E., *J. Appl. Psychol.* **31**, 490 (1947).
 20. Wessel, J. A., and Van Huss, W. D., *J. Sports Med.* **9**, 173 (1969).
 21. de Vries, H. A., *J. Gerontol.* **25**, 325 (1970).
-

Received January 8, 1980. P.S.E.B.M. 1980, Vol. 164.