Abstract  The purposes of this study were to compare fibrinolytic responses to moderate intensity exercise in physically active and inactive men and during morning and evening exercise. Fourteen physically inactive men (mean age, 34.7±4.0 years) and 12 regularly active men (34.8±4.0 years) performed two exercise sessions, morning and evening, at 50% of maximal oxygen consumption. Tissue plasminogen activator (TPA) and plasminogen activator inhibitor-1 (PAI-1) activity were measured before and after exercise. Data were analyzed using a three-way ANOVA with repeated measures. TPA activity increased with exercise in both groups, although the active group demonstrated greater increases than the inactive group. Postexercise TPA activity was greater with evening than morning exercise. The inactive group exhibited greater PAI-1 activity than the active group. PAI-1 activity was higher during the morning than evening but did not change with exercise for either group. We conclude that moderate intensity exercise increases TPA activity in physically active and inactive men, with greater increases seen in active men, particularly during evening exercise. Moderate intensity exercise does not appear to affect PAI-1 activity. The lower PAI-1 activity in active men may be one mechanism whereby regular physical activity lowers the risk for coronary artery disease. (Arterioscler Thromb. 1994;14:1746-1750.)

Keywords • diurnal variations • fibrinolysis • physical fitness • tissue plasminogen activator • plasminogen activator inhibitor

Enhanced fibrinolytic activity is often listed as a benefit of regular participation in physical exercise; however, little is known about the fibrinolytic responses to exercise and potential differences that may exist between physically active and inactive individuals. Although it is well documented that short-term physical exercise increases fibrinolytic activity, most studies describe global fibrinolytic activity and have not measured the fibrinolytic components tissue plasminogen activator (TPA) and its inhibitor plasminogen activator inhibitor-1 (PAI-1). In addition, few studies that examined fibrinolytic responses to exercise have controlled for the physical activity status of subjects. Studies measuring global fibrinolytic activity and the fibrinolytic components report that the activity status of subjects significantly influences the magnitude of change in fibrinolytic variables in response to maximal exercise. Furthermore, few studies have described the responses to a typical submaximal exercise session.

Resting fibrinolytic activity is lowest in the morning and increases throughout the day. Lower morning values have been attributed to low TPA activity and high PAI-1 activity. These resting diurnal variations appear to affect the fibrinolytic response to exercise. Data from our laboratory suggest that evening exercise produces greater increases in TPA activity than morning exercise. We are aware of only one other study that has examined the effects of exercise performed at different times of day on the fibrinolytic response to exercise. Rosing et al found significantly greater global fibrinolytic activity after evening exercise compared with morning exercise. However, only two subjects were tested, making it difficult for one to draw firm conclusions from their data.

The purposes of the present investigation were two-fold. First, we compared fibrinolytic responses to a moderate intensity exercise session in physically active and inactive men. Second, we examined fibrinolytic responses during morning and evening exercise. We measured TPA and PAI-1 activities to assess fibrinolytic activity.

Subjects  Subjects were 26 apparently healthy adult men 28 to 43 years of age. All subjects were nonsmokers, nondiabetic, nonobese, and had no evidence of type IV hyperlipoproteinemia. Subjects were not currently taking any medications, including aspirin. Inactive subjects (n=14) had not participated in regular physical activity for at least the previous 3 months. Regularly active subjects (n=12) had participated in regular physical activity (jogging) for approximately 30 minutes per session 3 to 5 d/wk for the previous 3 months or more. All subjects volunteered to take part in the study and gave written informed consent before participation. The protocol was approved by the university's Institutional Review Board.

Design  All subjects underwent a maximal graded treadmill exercise test to determine their maximal oxygen consumption (V̇O₂max) and then on separate days performed two 30-minute submaximal exercise sessions on the treadmill. The submaximal sessions were at 50% of their V̇O₂max, one in the morning and one in the evening. The order of the sessions was
randomized and counterbalanced. All morning testing was conducted between 6:30 and 10 AM, and evening testing was conducted between 4 and 7 PM with at least 2 days separating sessions. Subjects reported to the morning testing session in a fasted state (12 hours) and were instructed not to engage in physical activity at least 24 hours before a testing session, to refrain from ingesting aspirin and nonsteroidal anti-inflammatory drugs 14 days before a testing session, and to maintain similar eating patterns throughout the study. Instructions before an evening session were to refrain from eating at least 3 hours before the testing session and to refrain from ingesting caffeine after 10 AM.

**Blood Collection**

Blood was collected before and immediately after exercise with subjects in the seated position. Preexercise samples were obtained after 10 minutes of sitting rest. Blood samples were drawn by venipuncture from an antecubital vein with little or no stasis into 3-mL vials containing 50 µL of 15% K$_3$EDTA. The first vial was used for hematocrit and hemoglobin determinations. The second vial was used for TPA and PAI-1 determinations. Anticoagulated blood was combined 2:1 with 0.5 mol/L sodium acetate (pH 4.2) within 60 seconds of being drawn to stabilize TPA activity. Blood was centrifuged at 1000g for 10 minutes at room temperature. Plasma was separated and stored at −80°C until analyzed.

**Experimental Conditions**

**Maximal Graded Exercise Test**

A modified Balke treadmill exercise protocol designed to fatigue all subjects within 11 to 15 minutes was used. Heart rate was monitored via electrocardiography. Oxygen consumption was continuously monitored by an automated system (Rayfield Equipment) using an Applied Electrochemistry S-3A O$_2$ analyzer (Ametek), a Beckman LB-2 carbon dioxide analyzer, and a Parkinson-Cowan gasometer. VO$_2$max was defined as the highest oxygen consumption observed during any full minute of the exercise test. The criteria used for attaining VO$_2$max included a plateau of oxygen consumption with an increment of work rate, a respiratory exchange ratio ≥1.05, and/or a maximal heart rate within 5 beats per minute of age-predicted maximum.

**Submaximal Exercise Sessions**

The two submaximal sessions were performed on the treadmill for 30 minutes. Workloads were determined using the heart rate and oxygen consumption data from the maximal exercise test. To ensure subjects were exercising at appropriate intensities, oxygen consumption was monitored for 5 to 10 minutes during each exercise session.

**Blood Analyses**

**Hematocrit and Hemoglobin**

Hematocrit was measured in triplicate using the standard microhematocrit technique. Hemoglobin concentration was assayed in duplicate using the cyanmethemoglobin method. Percent changes in plasma volumes were estimated from the hematocrit and hemoglobin values.

**TPA Activity**

TPA activity (expressed in international units [IU]) was measured by chromogenic assay under the optimal conditions as described by Chandler et al. Briefly, 5 µL anticoagulated, acidified blood was added to 250 µL plasminogen-chromogen substrate reagent consisting of 75 mmol/L Tris-acetic acid (pH 8.15 at 37°C), 0.1% Triton X-100, 0.50 µmol/L human Glu-plasminogen (American Diagnostica), 0.65 mmol/L S-2251 substrate (Kabi Diagnostica), and 80 µg/mL CNBr-cleaved fibrinogen and was incubated at 37°C for 90 minutes. After incubation, the reaction was stopped by addition of 25% acetic acid to the solution. Absorbance was measured at 405 nm. A standard curve made with one-chain melanoma-derived TPA (American Diagnostica) was developed to determine TPA activity. Results were multiplied by 1.5 to correct for acetate buffer dilution and were also corrected for changes in plasma volume.

**PAI-1 Activity**

PAI-1 activity (expressed in arbitrary units [AU]) was measured by chromogenic assay according to the standardized method of Chandler et al. Briefly, plasma was diluted 1:2, 1:5, 1:10, and 1:20 with phosphate-buffered saline (PBS)/Triton X buffer containing 1 g bovine albumin and 0.6 mmol sodium azide per liter. Then, 200 µL of the diluted plasma was mixed with 200 µL of 10 IU/mL one-chain TPA reagent (diluted in PBS/Triton X buffer) and incubated for 15 minutes at 37°C to allow TPA and PAI-1 to react. The reaction was stopped and any α$_2$-plasmin inhibitor was destroyed by addition of 200 µL of 0.5 mol/L sodium acetate buffer (pH 4.2) to the solution. Residual TPA was measured as described above. Since plasma dilutions that inhibit less than 8% and more than 50% of the original TPA have produced inaccurate results, only dilutions that inhibited between 8% and 50% of the original TPA were used to determine residual TPA activity. One AU of PAI-1 activity was defined as the amount of PAI-1 that inhibited one IU of TPA under the specified conditions. Results were corrected for changes in plasma volume.

**Other Measures**

Height, weight, and skinfold thicknesses were measured on all subjects. Body fat was determined using four sites (abdomen, ilium, tricep, thigh) according to equations by Jackson and Pollock. To screen for hypercholesterolemia and hyperlipoproteinemia, total cholesterol, high-density lipoprotein cholesterol, and triglyceride concentrations were measured before participation (Abbott Vision). Blood was drawn in the morning with subjects in a fasted state (12 hours).

**Statistical Analyses**

One-way ANOVA was used to compare demographic and descriptive variables between the groups. TPA and PAI-1 activities were analyzed before and after submaximal exercise using 2 (group) × 2 (time, before versus after) ANOVA with repeated measures. Least-squares means were computed to make preplanned comparisons. Statistical significance was reached at a value of P<.05.

**Results**

**Descriptive Characteristics**

Table 1 summarizes descriptive characteristics of the subjects. As expected, the regularly active men had a significantly lower percentage of body fat and attained a significantly higher VO$_2$max than the inactive men. Table 2 summarizes results from the exercise sessions. The actual oxygen consumption measured during submaximal exercise sessions closely approximated 50% of maximum for both groups for both sessions.

**TPA Activity**

Fig 1 presents results for TPA activity (IU per milliliter) corrected for estimated changes in plasma volume before and after the submaximal exercise sessions. ANOVA found significant main effects for time of
day (P<.005) and time (P<.001). Larger increases in TPA activity were observed after evening exercise than morning exercise, and postexercise values were greater than preexercise values. Although the active group had slightly higher preexercise TPA activity, this difference was not statistically significant. Exercise produced significant increases in TPA activity in both groups for both sessions. Postexercise TPA activity in the active group for the evening session was significantly higher than all other postexercise values.

PAI-1 Activity

Fig 2 shows results for PAI-1 activity (AU per milliliter) corrected for estimated changes in plasma volume. ANOVA indicated significant main effects for group (P<.005) and time of day (P<.05). Higher PAI-1 activity values were observed in the inactive group compared with the active group, and PAI-1 activity was higher in the morning than in the evening. Preexercise PAI-1 activity was higher in the morning sessions compared with evening sessions, but this was significant in the inactive group only. PAI-1 activity did not change with exercise in either group for either session (P>.05).

Intra-assay and Interassay Variations

The intra-assay and interassay coefficients of variation for TPA were 4.7% and 5.6%, respectively, and for PAI-1 activity were 2.5% and 5.7%, respectively.

Discussion

This investigation compared the fibrinolytic responses to moderate intensity physical exercise in habitually physically active and inactive men and also compared the responses to exercise performed in the morning and evening. The major findings were that moderate intensity exercise increased TPA activity in physically active and inactive men regardless of whether the exercise was performed in the morning or evening and greater increases were observed in the active group than the inactive group. Additionally, postexercise TPA activity was greater with evening exercise than morning exercise. PAI-1 activity was significantly higher in the inactive group and did not change significantly with exercise in either group.

There is some disagreement in the literature regarding the effect of activity status or fitness status on fibrinolytic activity. Cross-sectional studies examining resting global fibrinolysis in active and inactive individuals report conflicting results. Higher fibrinolytic activity has been reported in active individuals, but not all studies agree with this finding. Few studies have measured the fibrinolytic components TPA and PAI-1. However, greater global fibrinolytic activity and greater increases in TPA activity have been reported after exercise in active individuals compared with their inactive counterparts. Exercise training studies have also reported beneficial changes in both resting TPA and PAI-1 activity; however, not all study designs included control groups, making it difficult to confidently attribute the observed changes solely to the training program.

The mechanisms responsible for increased fibrinolytic activity with short- and long-term exercise have not yet been completely resolved. Recent investigations by Chandler et al demonstrate that TPA levels in the

<table>
<thead>
<tr>
<th>Variable</th>
<th>Inactive</th>
<th>Active</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AM (n=12)</td>
<td>PM (n=12)</td>
</tr>
<tr>
<td>Age, y</td>
<td>34.7±4.0</td>
<td>34.8±4.0</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>83.5±16.6</td>
<td>79.8±10.3</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>26.2±4.8</td>
<td>24.5±2.7</td>
</tr>
<tr>
<td>Body fat, %</td>
<td>21.3±5.1</td>
<td>16.5±5.8</td>
</tr>
<tr>
<td>Total cholesterol, mmol/L</td>
<td>4.79±0.08</td>
<td>4.14±1.00</td>
</tr>
<tr>
<td>HDL cholesterol, mmol/L</td>
<td>1.07±0.28</td>
<td>1.18±0.25</td>
</tr>
<tr>
<td>Triglyceride, mmol/L</td>
<td>1.48±0.17</td>
<td>0.98±1.37</td>
</tr>
<tr>
<td>VO₂max, mL · kg⁻¹ · min⁻¹</td>
<td>38.6±5.6</td>
<td>51.4±3.9*</td>
</tr>
</tbody>
</table>

HDL indicates high-density lipoprotein. Values are mean±SD. *P<.05 between groups.

Fig. 1. Line graph shows tissue plasminogen activator (TPA) activity before and after exercise in physically active and inactive men. Exercise was performed at 50% VO₂max during the morning and evening. Values are mean±SEM. a Indicates postexercise value different from preexercise (P<.05); b, different AM and PM values (P<.05); and c, PM value in active group higher than other values (P<.05).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Inactive</th>
<th>Active</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50% AM</td>
<td>50% PM</td>
</tr>
<tr>
<td>50% VO₂max, mL · kg⁻¹ · min⁻¹</td>
<td>19.3±3.3</td>
<td>19.6±3.1</td>
</tr>
<tr>
<td>Respiratory exchange ratio</td>
<td>0.89±0.03</td>
<td>0.90±0.02</td>
</tr>
<tr>
<td>Caloric expenditure, kcal</td>
<td>233±34</td>
<td>238±36</td>
</tr>
</tbody>
</table>

Values are mean±SD.
Impaired fibrinolysis, defined as either low TPA activity or elevated PAI-1 activity, has been associated with a variety of thromboembolic diseases. Elevated PAI-1 activity has been documented in survivors of myocardial infarction and individuals with coronary artery disease. It is possible that the lower PAI-1 activity in physically active men compared with inactive men observed in the present study and by other investigators is an important mechanism mediating the cardioprotective effect afforded by participation in regular physical activity. Since thrombosis appears to be the immediate cause of most myocardial infarctions, impaired fibrinolytic activity may play a crucial role in its pathology. Participation in physical activity may be a relatively simple yet meaningful intervention to beneficially alter the fibrinolytic system.

Although moderate exercise produced significant increases in TPA activity for both groups during both morning and evening, there was a significant interaction between time of day of exercise performance and time, with evening exercise producing greater increases in TPA activity than morning exercise. The evening exercise session in the active group elicited the greatest response. The mechanism responsible for the greater increases during the evening is not completely understood, although it is most likely due to the underlying diurnal variations at rest. PAI-1 is hypothesized to be the major regulator of diurnal variations. Researchers have found that although TPA activity is lowest in the morning, TPA antigen is at its highest. This suggests that PAI-1 does not affect TPA production and/or release but rather forms an inactive complex with TPA, subsequently lowering the amount of active TPA. This may also be the case during exercise. The higher TPA activity observed during evening exercise may in part be explained by the lower PAI-1 activity, resulting in fewer TPA–PAI-1 complexes and thus more active TPA.

Whether this enhanced fibrinolytic activity during the evening is physiologically important is unknown. Unfortunately, it has been suggested, particularly in the lay literature, that morning exercise may be more likely to precipitate a cardiac event than evening exercise. This potentially misleading hypothesis is based on a number of points, including (1) the knowledge that the incidence of serious cardiac events is higher during the morning hours, (2) the finding that exercise enhances coagulation, and (3) the well-known diurnal variations in fibrinolytic activity, which is lowest during the morning. However, no data lend credibility to this allegation. On the contrary, a recent report designed to examine the safety of morning versus afternoon exercise in cardiac patients refutes this hypothesis. In fact, the incidence of severe cardiac events during submaximal exercise was very low in this high-risk group, regardless of whether the exercise was performed in the morning or afternoon. No statistically significant difference in incidence rates was observed, with 3.0 cardiac events per 100,000 patient-hours in the morning and 2.4 in the afternoon. Thus, although exercise enhances coagulation and fibrinolytic activity is lower in the morning, most available data suggest that the coagulation and fibrinolytic systems remain in balance in response to stress. Furthermore, the general consensus is that the overall risk of experiencing a cardiovascular event with exercise at any time of day is transient and very low, and the overall risk of dying is lower in physically fit individuals compared with their unfit counterparts.

In summary, the major finding of this investigation is that moderate intensity exercise increases TPA activity in both physically active and inactive men, with greater increases seen in active men, particularly during evening exercise. This may represent an increased ability to activate the fibrinolytic system in response to a stressor, such as potentially threatening microthrombi that may form in a coronary artery. These greater increases in TPA activity and the lower PAI-1 activity observed in the active men may be important factors mediating the
cardioprotective effect of regular physical activity. A well-controlled exercise training study is needed to provide more information on the role of the fibrinolytic system as a potential mechanism for the decreased incidence of coronary artery disease in physically active individuals and the amount of activity required to achieve beneficial adaptations.

Acknowledgment

This study was funded by the American Heart Association, South Carolina Affiliate.

References


18. Almers L-O, Ohlin H. Elevated levels of the rapid inhibitor of plasminogen activator (t-PAI) in acute myocardial infarction. Thromb Res. 1987;47:335-339.


Fibrinolytic responses to moderate intensity exercise. Comparison of physically active and inactive men.

L M Szymanski and R R Pate

Arterioscler Thromb Vasc Biol. 1994;14:1746-1750
doi: 10.1161/01.ATV.14.11.1746
Arteriosclerosis, Thrombosis, and Vascular Biology is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1994 American Heart Association, Inc. All rights reserved.
Print ISSN: 1079-5642. Online ISSN: 1524-4636

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://atvb.ahajournals.org/content/14/11/1746

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Arteriosclerosis, Thrombosis, and Vascular Biology can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Arteriosclerosis, Thrombosis, and Vascular Biology is online at:
http://atvb.ahajournals.org//subscriptions/