Effects of Lifestyle on Hemostasis, Fibrinolysis, and Platelet Reactivity

A Systematic Review

Kaeng W. Lee, MRCP; Gregory Y. H. Lip, MD, FRCP

The pathophysiology of atherothrombosis in cardiovascular disease is complex and multifactorial. No doubt, lifestyle habits such as exercise, smoking, diet, and alcohol consumption may have significant influence on cardiovascular disease. As the hemostatic system is assuming an increasingly prominent role in the pathogenesis and progression of atherovascular diseases, this review evaluates the effects of lifestyle habits (or lifestyle modifications) on blood coagulation, fibrinolysis, and platelet reactivity.

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The process of initiation, progression, and complication of atherothrombosis in cardiovascular disease is complex and can be influenced by multiple factors. Ischemic coronary syndromes such as unstable angina, myocardial infarction (MI), and sudden ischemic death share common pathophysiologic processes characterized by coronary plaque rupture with superimposed thrombus formation. Indeed, there is substantial experimental and clinical evidence that blood hypercoagulability or thrombogenicity promotes thrombus formation in the circulation, systemically and locally at the exposed atherogenic surface of the disrupted plaque.

A wide range of factors has been identified in prospective epidemiologic studies to have a systemic effect on blood thrombogenicity. Certainly, there is increasing evidence of a close relationship between the traditional cardiovascular risk factors such as diabetes mellitus, hypertension or hyperlipidemia, and the increased thrombogenicity, which is characterized by hypercoagulability, hypofibrinolysis, or increased platelet reactivity. Conversely, improvements of these cardiovascular risk factors have been associated with a lower prothrombotic tendency. However, the associations and the effects of exercise or physical activity, psychosocial stress, diet, and other lifestyle habits on plasma indicators of thrombogenesis are less well established.

Further evidence of the influence of lifestyle changes on cardiovascular risk factors and clinical outcomes is illustrated by data from salt restriction and blood pressure reduction and improved mortality by diets rich in oily fish. In the Gruppo Italiano per lo Studio della Sopravvenza nell’Infarto Miocardico Prevenzione (GISSI Prevenzione) trial and the Diet and Reinfarction Trial (DART), there was a significant reduction in mortality after MI by increasing dietary n-3 polyunsaturated fatty acids (n-3 PUFA) and fish intake, respectively, and the mortality reduction has been partly attributed to a reduction in sudden cardiac death. Indeed, the recent reanalysis of the course of appearance of the effects of n-3 PUFA has showed an early and highly significant reduction of sudden cardiac death. However, many instances of sudden death have a thrombotic basis, with evidence of thrombus in the left main coronary artery, and sudden death is not simply an arrhythmogenic phenomenon. The aim of this review is to evaluate the effects of lifestyle habits (or lifestyle modifications) on the plasma indices of the 3 main systems of thrombosis: blood coagulation, fibrinolysis, and platelet reactivity.
SEARCH STRATEGY
We performed a search using electronic databases (MEDLINE, EMBASE, and DARE), and additionally, abstracts from national and international cardiovascular meetings were reviewed to identify unpublished studies. Relevant authors of these studies were contacted to obtain further data.

BASIC PATHOPHYSIOLOGY AND CLINICAL PERSPECTIVES
The process of hemostasis and thrombus formation depends on the fine balance between the coagulation and fibrinolysis systems (Figure). The slower intrinsic clotting pathway depends on circulating coagulation factors, such as factors Ixa and VIIIa. The more rapid extrinsic pathway is activated when blood is exposed to an extravascular factor such as tissue factor. Factor VII (FVII) plays a key role in the initiation of this coagulation mechanism when it forms complexes with tissue factor from a disrupted atheromatous plaque. Activation of the coagulation system induces the formation of thrombin from prothrombin. Thrombin converts fibrinogen into (insoluble) fibrin and induces platelet activation.

The binding of fibrinogen to platelet glycoprotein IIb/IIIa receptor leads to platelet aggregation. Fibrinogen is also the major determinant of blood and plasma viscosity, explaining 50% of the latter. Hence, increased tendency of hemostasis and thrombosis may be reflected in high levels of plasma fibrinogen, FVII, factor VIII (FVIII), thrombin generation, platelet reactivity, and high plasma viscosity. Increased thrombin generation may be indicated by high activation markers, such as prothrombin activation fragment 1+2 (F1+2) and thrombin-antithrombin complex (TAT), associated with a decrease in clotting time.

On the other hand, activation of the fibrinolytic system induces the conversion of plasminogen to plasmin by plasminogen activators. Tissue plasminogen activator (tPA) is the main fibrinolytic stimulator. Plasmin promotes the degradation of fibrin within the thrombus, integrating clots and hence maintaining vascular patency. Fibrin degrades into soluble fibrin degradation products, including D-dimers. The primary inhibitor of the fibrinolytic process is the plasminogen activator inhibitor type 1 (PAI-1), which inhibits plasminogen activation by binding with tPA to form the PAI-tPA complexes. Therefore, impaired fibrinolytic function may be reflected in high plasma levels of PAI-1 or tPA antigen (which evaluates mainly the inactive PAI-1/tPA complexes) and/or indicated by low plasma levels of tPA activity or activation products such as D-dimer and plasmin 2-antiplasmin complex. Reduced plamin generation leads to suppression of fibrinolytic activity, thus favoring fibrin persistence and thrombosis.

Most of these variables in the coagulation and fibrinolytic systems can be readily assayed using the enzyme-linked immunosorbent assay (ELISA) technique. It is important to distinguish the difference between the measurement of activity and antigen levels of these molecules. Although the antigen levels refer to the total amount of the circulating proteins (both bound and free), activity levels refer to the functionally active portions of the proteins. Thus, elevated antigen levels of a particular molecule do not necessarily reflect an increase in its functional activity. For example, elevated tPA antigen levels are often a reflection of high levels of circulating PAI-1, resulting in a large portion of tPA antigens being bound to PAI-1 and thereby rendering it inactive.

Many of these systemic thrombogenic factors may be involved in the initiation of early atherosclerotic lesions and contribute to the progression of coronary thrombosis, plaque growth, and its clinical sequelae. For example, plasma fibrinogen has been shown to stimulate vascular smooth muscle migration and proliferation, promote platelet aggregation, and contribute to blood viscosity and thrombi. Many of these indices, including fibrinogen, FVII, von Willebrand factor (vWF, a marker of endothelial damage or dysfunction), D-dimer antigen (a marker of cross-linked fibrin turnover), and tPA antigen, have been identified as independent predictors of subsequent cardiovascular events in prospective studies in both healthy subjects and those with cardiovascular risk factors or established coronary heart disease (CHD). In addition, platelet hyperaggregation, plasma viscosity, and PAI-1 levels have also been associated with cardiovascular morbidity and mortality in both men and women in prospective studies. Thus, the potential modifications of these hemostatic or thrombogenic factors by simple lifestyle changes as both primary and secondary prevention have attracted considerable interest from the public health perspective.

The recognition that the onset of cardiovascular events is frequently triggered by physical exertion or mental stresses has lead to a possible link between neurohormonal activation and coronary ath-

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erothrombogenesis. The increase in sympathoadrenal activation may not only trigger plaque rupture but also directly induce a hypercoagulable state, leading to a rapid propagation of occlusive coronary thrombus and, hence, sudden death. Typically, an intravenous infusion of epinephrine is used to mimic sympathetic activation and to examine the adrenergic effects on thrombogenic markers. The literature suggests a dose-dependent stimulation of FVIII clotting activity, vWF antigen, tPA activity, and platelets within a 15- to 40-minute infusion of norepinephrine. Although in healthy individuals the increase in coagulability may be counteracted by a rapid rise in fibrinolytic activity, such hemostatic balance between coagulation and fibrinolysis may be impaired in subjects with atherosclerotic disease or risk factors, and hence, catecholamine surge may trigger a hypercoagulable state and enhance the odds of overt thrombosis.

### EXERCISE AND THROMBOGENESIS

Many long-term epidemiologic studies have demonstrated an unequivocal and strong relationship of increased fitness, exercise, or physical activity during leisure time with reduced cardiovascular risk. Regular exercise is known to lower body weight and blood pressure and improve lipid profile (with a decrease in serum cholesterol levels and an increase in high-density lipoprotein-cholesterol [HDL-C] levels). In addition, regular exercise enhances functional capacity and psychological well-being, as well as quality of life. The underlying biological mechanisms through which these beneficial effects are mediated must be interrelated.

There are many reports on the effects of exercise on coagulation, fibrinolysis, and platelet activation. These mainly consist of intervention studies, prospective randomized controlled trials (Table 1), and numerous large, population-based, cross-sectional studies. Several cross-sectional studies have consistently shown a positive effect toward an antithrombotic state, especially in lowering plasma levels of fibrinogen and improving fibrinolytic capacity by long-term regular exercise. However, it should be noted that most intervention or randomized controlled trials lack a comprehensive evaluation of both the hemostatic and fibrinolytic variables and thus provide only fragmentary data on the potential changes in hemostasis attributable to physical exercise. Indeed, some studies have yielded conflicting data, and this may be due to variations in exercise protocol or training programs used, populations studied (age, sex, CHD), seasonal factors, and the lack of standardization in the analytical methods used for the assessment of various hemostatic factors, particularly in the assessment of platelet reactivity.

### Health vs Disease

The available evidence from the intervention or randomized controlled trials would suggest that exercise or physical training evokes multiple effects on blood hemostasis in healthy individuals and in patients with atherovascular disease. For example, patients with atherovascular disease have higher basal levels of PAI-1 and lack a similar degree of increase in tPA activity after exercise when compared with healthy subjects. In addition, higher thrombin generation has been found in patients with peripheral vascular disease in response to exercise, whereas no such increase was detected in healthy controls.

### Effects of Short-term vs Regular Exercise on Coagulation and Fibrinolysis

While bearing in mind the considerable inconsistency of the results of various exercise studies due to methodologic variations, there are important differences between the effects of moderate endurance physical training and short-term strenuous exercise on both the hemostatic and fibrinolytic variables (Table 2). By and large, regular physical activities of moderate intensity in training programs enhance blood fibrinolytic capacity and possibly also reduce blood coagulation, although the latter remains disputable. Conversely, short-term strenuous exercise seems to induce a hypercoagulable state simultaneously with an increase in fibrinolytic capacity as evidenced by increased levels of fibrinogen, FVIII coagulant, and platelet activities, higher thrombin generation and hemoconcentration, markedly increased tPA activity, and possibly also decreased PAI-1 and tPA antigen levels. The rise in tPA activity is most apparent and seems to be directly proportional to the level of exercise intensity. However, the increased level of fibrinolytic activity seems to fall sharply dur-
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<tr>
<td>Zanettini et al, 1997</td>
<td>14 Sedentary subjects with mild HT</td>
<td>12 Weeks of aerobic exercise; 8 resumed sedentary lifestyle and were reexamined 2 mo later</td>
<td>Exercise ↓ resting and 24-h BP, LVM (echo), and Fg; FVII unchanged; 2 mo after detraining, all indices returned to baseline except LVM</td>
<td>Regular exercise ↓ BP, LVM, and Fg, improves coronary risk</td>
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<tr>
<td>El Sayed et al, 1995</td>
<td>25 Young subjects randomized: active exercise or control</td>
<td>12 Weeks of exercise (30 min, 3 times per week at 70% [6 wk] and 80% [6 wk] of maximum HR)</td>
<td>No significant differences in the ↑ of APPT, TCT, FVIII antigen and activity, and tPA activity after exercise in both groups</td>
<td>Maximum exercise transiently ↑ coagulation and fibrinolysis. Physical conditioning appears not to influence coagulation and fibrinolysis at rest or at max exercise</td>
</tr>
<tr>
<td>El-Sayed, 1996</td>
<td>18 healthy subjects; 2 groups: high- vs low-intensity exercise</td>
<td>12 Weeks of preconditioned exercise: exercise on BE for 20 min, 3 times per week at 80% or 30% ( V_{\text{max}} )</td>
<td>No difference in resting tPA antigen and activity or PAI antigen and activity; no significant change in tPA antigen and activity and PAI antigen after training; PAI activity ↓ significantly with high-intensity exercise</td>
<td>High intensity exercise conditioning significantly ↓ resting PAI activity. This may be a favorable effect of exercise conditioning</td>
</tr>
<tr>
<td>Van den Burg et al, 1997</td>
<td>20 Young sedentary men vs 19 nontraining controls</td>
<td>12 Weeks of submaximal training</td>
<td>Posttraining, FVIII activity ↑, with APPT ↓ during maximum exercise. PAI antigen and activity and basal and exercise-induced tPA antigen were ↓, and tPA activity/antigen ratio ↑ in the training group. Controls had ↑ basal PAI antigen and activity, with ↑ basal and exercise-induced PAI antigen; basal and exercise-induced tPA activity were unchanged, but tPA activity/antigen ratio ↓</td>
<td>Training promotes both coagulation and fibrinolysis during exercise and may reverse unfavorable seasonal effects on fibrinolysis</td>
</tr>
<tr>
<td>Stratton et al, 1991</td>
<td>10 Young (aged 24-30 y) and 13 older men (aged 60-82 y)</td>
<td>6 Months of intensive endurance exercise training</td>
<td>Posttraining, ( V_{\text{max}} ) ↑ by 18% in the young group and by 22% in the older group. The older group had ↑ tPA activity by 39%, IPA in active form ↑ by 141%, PAI activity ↓ by 58%, and Fg ↓ by 13% posttraining. The young group had no significant changes in any of the measured indices</td>
<td>Intensive training ↑ resting tPA activity and ↓ Fg and PAI activity in older men</td>
</tr>
<tr>
<td>Schuit et al, 1997</td>
<td>Elderly (aged 60-80 y); active exercise or controls</td>
<td>6 Months of intensive training program</td>
<td>↑ IPA activity and Fg in exercise but not in controls. The ↓ in PAI antigen was significantly associated with ↓ in TGs and insulin. ↑ Fg coincided with ↑ CRP</td>
<td>Training ↑ fibrinolysis, but may cause chronically ↑ plasma levels of acute phase proteins in the elderly</td>
</tr>
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<td>Ponjee et al, 1993</td>
<td>20 Sedentary males and 15 sedentary females</td>
<td>9 Months of intensive training, 3-4 times per week; all ran a 15- and 21-km race after 24 and 36 wk, respectively. Blood drawn before training and 5 d before and 5 d after both races</td>
<td>No significant change in FVIII activity, vWF, and TAT during training. In both groups, no change in Fg after 24 wk but ↑ before the 21-km race and still ↑ significantly 5 d later</td>
<td>Exercise induces physical stress, which has significant effects on Fg, even at rest. In contrast to acute postexercise effects, regular exercise does not induce a long-term activation of the coagulation system</td>
</tr>
<tr>
<td>Vaisanen et al, 1999</td>
<td>132 Males (aged 52-62 y) randomized to exercise or control group</td>
<td>3 Years of regular low-to-moderate intensity exercise</td>
<td>Aerobic threshold ↑ by 8.8% in exercise but ↓ by 1.1% in controls. PAI activity unchanged in either group but 4G allele homozygotes in exercise group had a 36% ↓ in PAI</td>
<td>PAI activity unchanged by regular exercise in the whole group over the 3 y but may ↑ in 4G allele homozygotes</td>
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<td>Hegde et al, 2001</td>
<td>10 Healthy men</td>
<td>Ran at 70-75% ( V_{\text{max}} ) or walked at 1.2 mph for 30 min. Blood drawn at rest, after exercise, and every 20 min for 1-h recovery</td>
<td>Exercise ↑ FVIII activity by 66% and ↓ APPT and remained the same on recovery. IPA activity and D-dimers ↑ after run. D-dimers remained ↑ but IPA ↓↓ at 1-h recovery</td>
<td>Exercise ↑ coagulation and fibrinolysis but coagulation sustained during a time when fibrinolysis ↓, thus ↓ prothrombotic risk in the first hour of recovery time</td>
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<tr>
<td>Lin et al, 1999</td>
<td>11 Moderately active young men</td>
<td>Blood drawn at rest, immediately after, and 2, 6, and 24 h after BE</td>
<td>Exercise ↑ FVIII activity, ↓ APPT. Exercise ↑ IPA antigen and activity, ↑ total fibrin/Fg DPs, but ↓ PAI activity. FVIII activity persisted 2 and 6 h into recovery while fibrinolytic activity ↓ sharply</td>
<td>↑ Fibrinolysis during exercise seems to counterbalance the ↓ in coagulation but this hemostatic balance is not maintained during recovery</td>
</tr>
<tr>
<td>Rankinen et al, 1995</td>
<td>9 Healthy men (aged 23-37 y)</td>
<td>Maximum and 2 randomized submaximum (30 min at 50% [aerobic threshold] and 78% [anaerobic threshold] ( V_{\text{max}} )) BE separated by 7 d</td>
<td>Baseline Fg, IPA, and PAI activity similar in each exercise. IPA activity ↑ after each exercise. PAI ↓ in maximum and anaerobic exercise but not aerobic exercise. All 24 h postexercise activity was similar to baseline levels. Fg unchanged in any exercise</td>
<td>Acute exercise ↑ fibrinolysis, which normalized 24 h later. Fg unchanged</td>
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(continued)
This phenomenon has been thought to possibly precipitate acute coronary thrombosis, leading to sudden cardiac death in susceptible sedentary individuals or patients with preexisting atheroembolic disease.
who may not sustain their fibrinolytic capacity (perhaps due to endothelial dysfunction) when they are exposed to unaccustomed, short-term, strenuous physical exertion. However, recent studies have suggested that functional fibrinolytic activity was similar in physically active men with and without a history of MI and in older men with hypertension when compared with normotensive subjects.

Although the results of the studies that investigated the effects of short-term exercise on fibrinolytic markers are more consistent, studies that investigated plasma fibrinogen concentration have produced conflicting data. Several studies have reported a significant increase in plasma fibrinogen after strenuous exercise,54,69,70 but others using different protocols have shown either no significant effects52,71,72 or even a reduction in plasma fibrinogen level after short-term, intense physical exercise.53 It is possible that the changes in coagulation markers depend on the type of physical exercise to which subjects are subjected. Cerneca et al demonstrated that this might be the case, since rowers, marathon runners, and healthy controls revealed a significant increase in plasma fibrinogen levels in response to exercise levels of FVIII activity and antigen in normal healthy and sedentary subjects,43,48,53,55 although 4 weeks of physical training has been shown to lower resting levels of FVIII activity and antigen in post-MI patients.84 Although high levels of plasma fibrinogen are usually found in patients with CHD or cardiovascular risk factors, randomized controlled trials have found mixed results in fibrinogen levels in response to regular physical activity.56,76,83-85 For example, 12 weeks of aerobic exercise training in sedentary hypertensive subjects lowered blood pressure, left ventricular mass, and plasma fibrinogen levels, but changes returned to baseline values (except left ventricular mass) at 2 months after detraining.44 Similarly, 6 months of intensive endurance training reduced plasma fibrinogen in elderly men but not in young men.45 On the other hand, Schuit et al reported a significant increase in plasma fibrinogen levels in elderly males after a same duration of intensive training, whereas Ponjee et al reported no change in plasma fibrinogen levels in both males and females after 24 weeks of training. Only a few reports on the effects of exercise on FVII are available and, again, with mixed results. Moderate exercise has no significant influence on FVII or at the most the effect is only relatively short-lived. Studies on the effects of exercise on fibrinopeptide A (a marker of thrombin activity and fibrin formation) have again produced conflicting results, although raised plasma markers of thrombin generation (TAT and F 1+2) with short-term exercise had been reported. The overall mechanisms underlying these changes in coagulation or fibrinolysis, in response to short-term or long-term endurance exercise, are poorly understood and still remain speculative, but interactions involving neurohormonal pathways are very likely.

Endurance Exercise or Physical Training and Fibrinolysis

Various studies have consistently reported a significant improvement in fibrinolytic capacity following regular exercise or physical training. The increase in fibrinolysis is indicated by a decrease in PAI-1 levels and also a rise in tPA activity. Indeed, Szymanski et al demonstrated that persons who are habitually active have the lowest basal PAI-1 activity but the highest increase of tPA activity in response to exercise when compared with inactive subjects. This effect has been repeatedly demonstrated using various exercise intensity and duration. One study reported lower PAI-1 levels in those participating in regular sporting activities than the respective age-matched sedentary individuals or elderly athletes and post-MI patients, but tPA activities were significantly higher after exercise in those with lower pretest PAI-1 level.

### Endurance Exercise or Physical Training and Coagulation

Most exercise studies of varying degrees of intensity and duration have been found to induce a significant increase in FVIII coagulant activity. However, others have demonstrated that regular training exercise does not seem to induce significant effect on resting or postexercise levels of FVIII activity and antigen in normal healthy and sedentary subjects, although 4 weeks of physical training has been shown to lower resting levels of FVIII activity and antigen in post-MI patients.84 Although high levels of plasma fibrinogen are usually found in patients with CHD or cardiovascular risk factors, randomized controlled trials have found mixed results in fibrinogen levels in response to regular physical activity. For example, 12 weeks of aerobic exercise training in sedentary hypertensive subjects lowered blood pressure, left ventricular mass, and plasma fibrinogen levels, but changes returned to baseline values (except left ventricular mass) at 2 months after detraining. Similarly, 6 months of intensive endurance training reduced plasma fibrinogen in elderly men but not in young men. On the other hand, Schuit et al reported a significant increase in plasma fibrinogen levels in elderly males after a same duration of intensive training, whereas Ponjee et al reported no change in plasma fibrinogen levels in both males and females after 24 weeks of training.

### Exercise Effects on Platelet Reactivity

The effects of exercise on platelet aggregation and activation have been extensively studied, but the results are highly variable. It is noteworthy that measurements of platelet reactivity either in vitro or ex vivo aggregate assays or in vivo platelet secretory products (mainly β-thromboglobulin and platelet factor 4) are associated with considerable methodologic difficulties and thus may
account for the discrepancies of results reported in the literature.

By and large, short-term, strenuous exercise induces a transient increase in agonist-induced platelet aggregation both in vitro and ex vivo and an increase in platelet counts, adhesiveness, and in vivo platelet secretory activity. Overall, these effects seem to be more pronounced in sedentary than healthy subjects. In contrast, long-term endurance physical training (preconditioned) in men and women at moderate intensity (50%-55% of peak oxygen consumption) seems to suppress platelet adhesiveness and aggregation both at rest and after short-term, strenuous exercise. However, the effects reversed back to the pretraining state after a period of deconditioning and hence the importance of regular moderate exercise to maintain such potential benefits.

Thus, as with fibrinolytic response, platelet reactivity in response to exercise also seems to be both duration and intensity dependent. However, the underlying mechanisms remain unclear. Increases in catecholamine concentrations and shear stress are probably important. Perhaps the short-term response may be related to the release of tPA from endothelial cells associated with increased catecholamine release during exercise. Interestingly, the fact that aspirin treatment had no significant influence on platelet activation induced by heavy exercise in patients with stable angina pectoris and matched healthy controls suggests that the response may not be cyclooxygenase-pathway dependent. This implies that aspirin may have a limited antithrombotic effect during physical exercise and probably also in other situations with increased catecholamine levels such as during acute psychological stress. The chronic platelet response, however, may be related to nitric oxide release as a consequence of regular low-to-moderate exercise training.

Effects of Exercise in Specific Patient Groups on Coagulation and Fibrinolysis

There is increasing evidence that patients with chronic atrial fibrillation are associated with a prothrombic or hypercoagulable state. We demonstrated that short-term exercise to exhaustion significantly increased plasma fibrinogen and lower PAI-1 levels but had no influence on vWF or soluble P-selectin levels in patients with atrial fibrillation when compared with age- and sex-matched patients in sinus rhythm. In another similar exercise study in patients with stable congestive heart failure, we also found that plasma viscosity, fibrinogen, and hematocrit levels were significantly increased, both immediately after exercise and at 20 minutes into the recovery period.

WEIGHT REDUCTION

Overweight and obesity, assessed either by body mass index (BMI), a measure of weight in kilograms divided by the square of height in meters, or waist-to-hip circumference ratio (WHR), are associated with increased cardiovascular morbidity and mortality. Indeed, there is increasing evidence that moderate weight loss could result in regression of coronary arterial lesions and significantly reduces cardiac events and total mortality.

Most of the present data on thrombogenic profile in overweight or obese persons relate to PAI-1 and tPA antigens. For example, both BMI and WHR correlate strongly and positively with hemostatic factors but negatively with fibrinolytic activity. It has been shown that women with high WHR have significantly higher fibrinogen and PAI-1 levels compared with obese women with a low WHR or with lean women. Similarly, after adjusting for other lifestyle variables, obese men (BMI >30) had 50% higher PAI-1 activity and 30% higher tPA antigen when compared with men of “ideal” BMI (<25). In addition, high fibrinogen and plasma viscosity have also been found to be associated with increasing BMI. Although, overall, there is only little evidence that weight reduction reduces plasma fibrinogen or viscosity levels. On the other hand, there is plenty of evidence that weight reduction by regular exercise and dietary changes reduces PAI-1 and tPA antigen levels, suggesting a causal relation (Table 3).

Recent evidence has shown that elevated plasma PAI-1 activity seen in obese individuals may be caused by increased PAI-1 release from visceral adipose tissue. However, a liposuction procedure that removes visceral adipose tissue and achieves a weight reduction of 5% after 3 months without change in lifestyle does not seem to significantly reduce plasma levels of vWF, fibrinogen, or PAI-1. In contrast, surgical removal of adipose tissue in 19 patients with morbid obesity with a mean body weight reduction of 50 kg at 6 months and 64 kg at 12 months has led to a significant reduction in FVII, fibrinogen, and PAI-1 activity and a slight increase in tPA activity. Therefore, it seems that a large amount of adipose tissue may need to be removed artificially before an improvement of hemostatic and fibrinolytic profiles could be detected, or it might be that a change in lifestyle, including increased exercise and dietary control leading to weight reduction, is a prerequisite for improvement in coagulation and fibrinolysis. The latter seems more likely the case, since there is evidence that limited weight loss (<7 kg) by lifestyle modifications alone could lead to a reduction of hemostatic factors, FVII, and PAI-1 levels, while increasing the tPA activity.

Indeed, obesity and syndrome of insulin resistance are inextricably linked with hypertriglyceridemia, hyperinsulinemia, hypo-HDL-cholesterolemia, glucose intolerance, and hypertension. It is known that both triglyceride and insulin resistance correlate strongly and positively with PAI-1. In fact, dietary intervention with a low-saturated-fat diet or gemfibrozil treatment lowers serum triglyceride levels which has been accompanied by improvement and even normalization of the fibrinolytic activity. Thus, it is plausible that weight reduction improves fibrinolytic capacity via modifications in both lipids and insulin resistance profiles. However, data on the interactions between physical activity and diet and hemostasis are scarce, and it is likely that moderation in both
## Table 3. Weight Reduction and Thrombogenic Factors

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<tr>
<td>Rissanen et al.¹¹³, 2001</td>
<td>51 Obese women (mean age, 44 y; BMI, 36 kg/m²)</td>
<td>DBR, 12-mo weight ↓ trial of placebo and orlistat, plus hypoenergetic diet adjusted for actual body weight at 6 mo. Measurements at 3- to 6-mo intervals</td>
<td>Weight ↓ similar in orlistat and placebo groups. Orlistat did not influence coagulation factors beyond its effect on weight ↓. PAI and FVII ↓ in first 3 mo and correlated with ↓ weight. Between 6 and 12 mo, changes of PAI and FVII paralleled changes of weight; activities ↑ with weight rebound but remained below the 6-mo values if weight ↓ continued. Serum insulin correlated with PAI and FVII at 6 mo and with PAI at 12 mo. No changes in Fg at any time</td>
<td>Maintenance of modest weight ↓ is associated with ↓ in PAI and FVII in obese women. Change of serum insulin is associated with changes of PAI. Fg is not affected by modest weight ↓</td>
</tr>
<tr>
<td>Marckmann et al.¹¹⁴, 1998</td>
<td>36 Obese patients in a 2-stranded randomized intervention study</td>
<td>Randomized: very-low-energy diet (8 wk) or low-energy diet (17 wk), both given anorectic compound, then rerandomized to 24-wk maintenance diets</td>
<td>Mean weight ↓ of 13.6 kg. After 24-wk weight maintenance, PAI antigen ↓ by 24%; TGs, 30%; FVIIc, 12%; cholesterol, 9%; Fg, 6%; but HDL-C ↑ by 5%. All changes highly significant. No differences between slimming or maintenance regimens</td>
<td>Major weight ↓ is associated with sustained and marked improvements in lipids and coagulation profile, irrespective of the tested slimming and maintenance regimens</td>
</tr>
<tr>
<td>Folsom et al.¹¹⁵, 1993</td>
<td>90 Men and 88 women; moderately overweight</td>
<td>Randomized to 1 of 4 weight loss treatment groups or controls. Measurements at baseline and 6 mo</td>
<td>Treatment ↓ weight 9.4 kg in men and 7.4 kg in women and significantly ↓ PAI, IPA antigen, and FVII. ↓. In these variables correlated with the ↓ in weight and TGs. No change in D-dimer, Fg, or protein C with weight ↓</td>
<td>Weight ↓ can improve abnormalities in hemostatic factors associated with obesity</td>
</tr>
<tr>
<td>Primrose et al.¹¹⁶, 1992</td>
<td>19 Patients underwent surgery for obesity</td>
<td>Blood drawn before and at 6 and 12 mo after operation</td>
<td>Surgery ↓ mean weight of 50 kg at 6 mo and 64 kg at 12 mo. At 12 mo, significant ↓ in TC, FVII, Fg, and PAI. IPA activity ↑ slightly. No changes in APPT, FVIII, vWF, α2AP, TAT, protein C, β2-TBG, PF 4, FPA, or platelet count</td>
<td>Surgical treatment of morbid obesity may have a long-term beneficial effect on mortality from atherosclerotic disease</td>
</tr>
<tr>
<td>Berntorp et al.¹¹⁷, 1998</td>
<td>53 Patients with Dercum disease</td>
<td>Blood drawn preoperatively, 2 and 4 wk, and 3 mo postoperatively</td>
<td>Weight ↓ of 4 kg sustained during follow-up. Slight ↑ in coagulation factors 2 and 4 wk postoperatively. At 3 mo the values ↓ to preoperative levels except for PAI, which still slightly ↑</td>
<td>Surgical removal of adipose tissue, without change in lifestyle, does not seem to improve coagulation and fibrinolysis</td>
</tr>
<tr>
<td>Sudi et al.¹¹⁸, 2001</td>
<td>20 Obese boys and 40 obese girls (mean age, 12 y)</td>
<td>Blood drawn before and after 3 wk of low-caloric diet and exercise. Body composition assessed by bioelectrical impedance</td>
<td>Estimates of adiposity, insulin, and TGs correlated with PAI and IPA antigen. WHR correlated with fibrinolytic indices only in girls. Insulin and IPA antigen contributed to PAI, whereas percent fat mass and TGs contributed to IPA antigen. Weight loss ↓ adiposity, abdominal adiposity, fibrinolytic, and metabolic indices. Initial PAI and changes in body mass contributed to ↓ in PAI. Initial IPA antigen contributed to changes in IPA antigen mass and TGs contributed to tPA antigen. ↓ in PAI and the ↓ in fibrinolytic indices</td>
<td></td>
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<tr>
<td>Lindahl et al.¹¹⁹, 1999</td>
<td>186 Obese subjects with IGT</td>
<td>Randomized to active program 1-y intensified dietary and exercise or usual-care controls</td>
<td>Active group ↓ weight (5.4 kg vs 0.5 kg), ↓ oxygen consumption by 10% (↓ by 1% in controls), ↓ PAI (31% vs 12%), and ↓ IPA antigen (14% vs 6%)</td>
<td>Intense lifestyle program has sustained beneficial effects on fibrinolysis</td>
</tr>
<tr>
<td>Mavri et al.¹²⁰, 1999</td>
<td>52 Healthy, premenopausal, obese women (33 completed the study)</td>
<td>Weight ↓ program with a hypocaloric diet. Blood drawn at entry, 1 wk, end of program, and 5 mo follow-up program</td>
<td>At end of program, PAI antigen and activity ↓. Leptin ↓ but no change in adipin. PAI associated with BMI, body fat, leptin, and insulin. At 5 mo, PAI remained ↓ in 14 women who maintained weight ↓ but ↑ in 16 women who regained weight. ↑ in PAI correlated with ↑ in body fat and leptin. BMI was the major determinant of PAI level</td>
<td>Weight loss with hypocaloric diet ↓ PAI, which is more closely related to changes in adipose tissue than to changes in metabolic variables, suggesting a significant role for adipose tissue in regulating plasma PAI</td>
</tr>
<tr>
<td>Charles et al.¹²¹, 1998</td>
<td>324 Nondiabetic patients with central obesity (aged 35-65 y; mean BMI, 32.5 kg/m²)</td>
<td>DBR 1 y; placebo or metformin groups, in addition to diet and exercise</td>
<td>PAI activity and antigen ↓ significantly but similarly in both groups. This ↓ mainly in subjects who lost weight. IPA antigen and vWF ↓ significantly more in the metformin group</td>
<td>Weight ↓ associated with ↓ in PAI. Metformin may have effect on production or metabolism of IPA antigen and vWF</td>
</tr>
<tr>
<td>Calles-Escandon et al.¹²², 1998</td>
<td>19 Elderly obese subjects (aged 60-70 y; BMI &gt;32 kg/m²)</td>
<td>11 Weeks of energy-restricted diet by 3700-4600 kJ/d deficit</td>
<td>Initially elevated PAI ↓ by 50%, with a ↓ in tPA/PAI complex but no change in IPA. FAP complex ↑ by 20%. The ↓ in PAI and the ↑ in FAP complexes correlated with weight and fat mass ↓. No correlation between fibrinolytic variables and baseline substrates or insulin, but change in PAI correlated with change in plasma triacylglycerols</td>
<td>Energy restriction induces moderate weight ↓ and leads to diminution of tPA, IPA, and relief of inhibition of fibrinolysis in elderly, obese subjects</td>
</tr>
</tbody>
</table>

Abbreviations: For an explanation of abbreviations, see footnote to Table 1.
efforts would yield a more powerful impact on coagulation and fibrinolysis systems than either lifestyle modification alone. Clearly, more studies are needed to dissect such complex interactions.

**DIETARY LIPIDS ON THROMBOSIS**

**Outcome Studies With n-3 PUFA**

The role of dietary changes in modifying CHD risk has been well established. The recent Lyon Diet Heart Study reported a 50% to 70% lower risk of recurrent heart disease as measured by different combinations of outcome measures, including cardiac death and nonfatal myocardial infarctions in survivors of first-MI patients who received a Mediterranean diet (with more fish, more fiber, but less fat) supplemented with the precursor of n-3 PUFA, α-linolenic acid (18:3n-3, derived mainly from vegetable or seed oil) when compared with controls who received usual care. The study is in parallel with the results of other secondary prevention dietary trials, namely, the DART and GISSI Prevention trials, which similarly used a diet with low intake of total and saturated fats and/or increased intake of oily fish rich in n-3 PUFA.

Indeed, at least 2 servings of fish per week, especially fatty fish, equivalent to an intake of n-3 PUFA approaching 1 g/d have been recommended by the American Heart Association.

The experimental group in the Lyon Diet Heart Study had higher plasma levels of oleic acid, α-linolenic acid, and eicosapentaenoic acid (EPA, 20:5n-3). In the GISSI Prevention trial, patients received daily doses of n-3 PUFA as 1 gelatin capsule containing EPA and docosahexaenoic acid (DHA, 22:6n-3) as ethyl esters. In the DART study, at least 3 servings of fatty fish or approximately 15 fish oil capsules per week led to a significant 29% reduction in both cardiac and total mortality within 4 months. The low incidence of cardiovascular disease among Greenland Eskimos and coast land Japanese has been related to high intake of the marine n-3 PUFA: EPA and DHA. However, how particular lipid constituents in these diets contribute to coronary risk is unknown. The rapidity of onset of the beneficial effects seen in these studies suggests that the diet might have anti-inflammatory, anti-thrombotic, and even membrane stabilizing and hence antiarrhythmic effects besides lowering the rate of progression of atherosclerosis. Indeed, the effects of dietary manipulations or supplementation with individual or complex dietary lipids on thrombogenic variables have attracted considerable interest with a particular emphasis on n-3 PUFA, although the interplay between these lipid constituents and the coagulation system remains largely unclear.

**Epidemiologic Studies**

Thus far, only indirect evidence links dietary saturated fatty acids with enhanced thrombogenesis in humans. When unsaturated fatty acids of the n-9, n-6, or n-3 families replace saturated fatty acids in the diet of experimental animals, the development of atherothrombosis was inhibited, but the doses supplemented tended to be much higher than in human clinical studies. Data from the Coronary Artery Risk Development in Young Adults study showed that usual intake of fish or dietary supplementation with α-linolenic acid, EPA, and DHA was not associated with levels of FVIII, fibrinogen, or vWF and, hence, suggests that usual customary intakes of fish and n-3 PUFA in populations that generally do not consume large amounts of these food items are not associated with these hemostatic factors. Similar results were also found in the PRIME (Prospective Epidemiologic Study of Myocardial Infarction) sub-study, which showed no relationships between fatty acids and fibrinogen, vWF, PAI-1, or FVII levels. By contrast, results from another cross-sectional study suggest that increases in dietary n-3 PUFA intake from fish is negatively associated with fibrinogen, FVIII, and vWF and positively associated with protein C levels. Such differences have been attributed to higher EPA and DHA intakes in the latter study.

**Intervention Studies**

There are a large number of intervention studies on the effect of n-3 PUFA in the form of fish oil capsules, fishmeals, or its precursor α-linolenic acid on various hemostatic factors (Table 4). We discuss its effects on coagulation, fibrinolysis, and platelet reactivity.

**Coagulation and Rheology**

The effect of n-3 PUFA on fibrinogen and blood rheology has been extensively studied. Reductions in fibrinogen (the largest contributor to plasma viscosity) and increased erythrocyte flexibility (a major component of whole-blood viscosity) would be desirable for vascular benefit. By and large, however, many studies have shown no or little improvement in fibrinogen levels after giving n-3 PUFA supplements to different types of patients. One study has reported an increase in erythrocyte flexibility but an unaltered fibrinogen level. Indeed, n-3 PUFA has been linked to improvement in erythrocyte flexibility with lower whole-blood viscosity in few studies, although others have yielded little effects. Simply measuring erythrocyte infiltration might be an inadequate method for detecting small but significant differences in erythrocyte flexibility, and this may account for the inconsistency of results among studies.

There is also little agreement on the effects of n-3 PUFA on clotting factors, such as FVII or FVIII. One author has reported reduced levels of FVIII with n-3 supplements, but most authors have found either no influence on or an increase in FVIII or FVII by fish oil ingestion or n-3 PUFA diet. Studies on the intake of n-3 PUFA and vWF concentration have also been similarly conflicting. Most studies have not been able to show an effect with these fatty acids. In addition, few studies have even suggested that n-3 PUFA, including α-linolenic acid, may have anti-thrombotic effects by enhancing protein C activity, increasing tissue factor pathway inhibitor, or reducing the expression of procoagulant tis-
Barcelli et al,153 which suggested that inconsistent. Since the initial study by PUFA on fibrinolytic activity are also
The data available on the effects of n-3 sue factor activity on monocyte ex vivo.179
Toft et al,145 Nilsen et al,147 Myrup et al,144 Prisco et al,143 Oosthuizen et Iacoviello et Shahar et al,138 Source Subjects Design Summary
Table 4. Intervention and Cross-sectional Studies of n-3-Polyunsaturated Fatty Acids on Thrombogenic Markers

<table>
<thead>
<tr>
<th>Source</th>
<th>Subjects</th>
<th>Design</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shahar et al,134</td>
<td>15 000 Subjects of the ARIC Study</td>
<td>Cross-sectional analysis adjusted for sex, race, age, BMI, smoking, alcohol, diabetes, and field center. Usual dietary intake assessed by a food frequency questionnaire</td>
<td>Dietary intake of n-3 negatively associated with Fg, FVIII, and vWF (black and white patients) and positively associated with protein C (white patients only). ↑ In n-3 intake from fish may modify several coagulation factors</td>
</tr>
<tr>
<td>Scarabin et al,137</td>
<td>283 Subjects of the PRIME study</td>
<td>Cross-sectional analysis adjusted for age, center, and BMI</td>
<td>Only tPA antigen inversely associated with marine n-3. FVII, Fg, PAI, D-dimer, and vWF were not associated with n-3. D-dimer was positively associated with ACA and eicosanoidoic acid. Marine n-3 may favorably influence tPA antigen level. Aspirin plus n-3 ↓ tPA antigen and the fibrinolytic response to venous occlusion in all subjects. PAI activity before stasis ↑ by n-3 suppl, but not affected by aspirin</td>
</tr>
<tr>
<td>Iacoviello et al,133</td>
<td>6 Healthy volunteers (aged 24-37 y)</td>
<td>DBR, cross-over study: 5.3 g EPA and DHA or n-6 (control) daily for 29 d. Aspirin (40 mg/d) then added for another 14 d; 2-mo washout before cross-over</td>
<td>No significant changes in BT, collagen-PAggr, and TxB2</td>
</tr>
<tr>
<td>Oosthuizen et al,144</td>
<td>20 Healthy young volunteers</td>
<td>DBR, cross-over study: 6 g fish oil or olive oil (placebo) daily suppf for 6 wk</td>
<td>No changes in PAI-1 activity in diabetic patients compared with controls. Despite a ↓ in TG and unchanged insulin levels, there was a significant ↑ in PAI activity after maximum EPA. In diabetic patients given n-3 suppi, PAI activity ↑ though T ↓</td>
</tr>
<tr>
<td>Boberg et al,145</td>
<td>14 Diabetic patients vs healthy controls</td>
<td>DBR, cross-over study: 10 g maximum EPA (3 g n-3) or olive oil (placebo) daily for 2 consecutive 8-wk periods</td>
<td>No significant changes in plasma Fg, PAI antigen or activity, PT F1 + 2, lipids, and Lp(a) in both groups though there was trend of ↓ in Fg, TG, and Lp(a) with n-3 during treatment and wash-out</td>
</tr>
<tr>
<td>Radack et al,146</td>
<td>10 Patients with hyperlipoproteinemia type IIb or IV</td>
<td>DBR, cross-over study: n-3 fish oil vs n-6 corn oil suppf</td>
<td>Fg ↓ in both groups. No significant changes in tPA activity, PAI, protein C antigen, ATIII activity, BT, and platelet counts</td>
</tr>
<tr>
<td>Prisco et al,147</td>
<td>20 Normolipemic healthy men (aged 27-41 y)</td>
<td>DBR study: n-3 (4-g capsules) or placebo (4-g olive oil capsules) daily for 4 mo</td>
<td>No significant changes in plasma Fg, PAI antigen or activity, PT F1 + 2, lipids, and Lp(a) in both groups though there was trend of ↓ in Fg, TG, and Lp(a) with n-3 during treatment and wash-out</td>
</tr>
<tr>
<td>Myrup et al,148</td>
<td>29 Insulin-dependent diabetic patients with nephropathy</td>
<td>DBR study: fish oil (4.6 g n-3) or placebo (olive oil) daily suppf for 1 y</td>
<td>No change in n-3 platelet lipids, transcapillary escape rate of albumin, PT F1 + 2, TAT, fibrinolytic indices, Fg, FVII antigen and activity, thrombomodulin, vWF, PF 4, and β-Tbg after 1 y of fish oil suppf compared with olive oil</td>
</tr>
<tr>
<td>Toft et al,149</td>
<td>78 Untreated hypertensive patients</td>
<td>DBR study: 4 g EPA and DHA or corn oil (placebo) daily suppf for 16 wk</td>
<td>PAI activity changed similarly in fish oil and corn oil groups, as did tPA, FVIIc, and platelet count. Fg levels ↑ with fish oil and corn oil suppf</td>
</tr>
<tr>
<td>Hansen et al,150</td>
<td>224 Healthy men (aged 36-56 y)</td>
<td>DBR study: EPA or DHA, or corn oil (placebo) daily suppf for 7 wk</td>
<td>The ↑ in PAI activity was not different between groups. No correlation between change in Tgs or PL n-3 and PAI activity. PAI associated with BMI, apoB100, TGs, and n-6 but not with n-3. Only 21% of the variation in PAI activity is attributable to these variables</td>
</tr>
<tr>
<td>Nilsen et al,151</td>
<td>20 Accepted for CABG</td>
<td>DBR study: n-3 (3.15 g EPA and 1.89 g DHA) or corn oil (controls) daily for 5-6 mo. Surgery performed mid-intervention</td>
<td>No significant changes in BT, collagen-PAGgr, and txB2 production. Indices of extrinsic coagulation, including phospholipase C-sensitive FVII and extrinsic pathway inhibitor, unchanged in both groups. TG with n-3 ↓ and Fg ↓ in controls</td>
</tr>
<tr>
<td>Hellsten et al,152</td>
<td>40 Healthy subjects</td>
<td>DBR, parallel trial: 6 g cod fish liver oil (2 g n-3) or 6 g corn oil daily suppf for 5 mo</td>
<td>PAI unchanged with fish oil but ↓ with corn oil. tPA activity and mass unchanged in both groups</td>
</tr>
<tr>
<td>Rogers et al,153</td>
<td>60 Male volunteers</td>
<td>DBR study: EPA or DHA, or corn oil (placebo) daily suppf for 7 wk</td>
<td>Fish oil ↓ TG by 54% and ↓ diastolic BP by 7%. BT ↑ by 12%, but not significant. Heparin thrombin clotting time ↑ by 14% but thrombin time, Fg, or PF 4 unchanged. Fish oil also ↓ RBC pore transit time by 23%, but not significantly. No differences between the 2 groups in TC, HDL, blood counts, or PAGgr</td>
</tr>
</tbody>
</table>

**Fibrinolysis**

The data available on the effects of n-3 PUFA on fibrinolytic activity are also inconsistent. Since the initial study by Barcelli et al,153 which suggested that n-3 PUFA may enhance plasma fibrinolysis, others had found no change in PAI-1 level or in tPA antigen after dietary intervention,145,146,180 and few even reported significant increased in PAI-1 activity.146,160,181,182 Moreover, data available on tPA activity also seem contradictory.145,146,170,181 However, a study has reported that tPA antigen level was inversely related to n-3 PUFA derived mostly from fish oil (EPA, docosapentaenoic acid, and DHA) but not with n-3 PUFA from vegetable origin (α-linolenic acid).137 This is in agreement with a large intervention study184 in diabetic subjects that showed a decrease in tPA antigen after fish supplementation but no effect on PAI-1 activity with high α-linolenic acid diet intake in a double-blind intervention trial.185

(continued)
Many studies have reported a positive correlation between serum triglycerides and PAI-1 activity. Dietary interventions, such as a low-saturated-fat diet^{27} or gemfibrozil treatment^{28} to lower serum triglyceride levels, have been accompanied by improvement and even normalization of the fibrinolytic activity. However, dietary intervention with n-3 PUFA, which is well known for its ability to lower triglyceride levels, has not been shown to be parallel with a decrease in PAI activity.\(^{146}\) indicating that a causal relationship is unlikely between levels of triglycerides and PAI-1 activity during dietary supplementation with n-3 PUFAs. In fact, by pooling data from all these studies, Hansen et al.\(^{46}\) were able to calculate that approximately a 17% increase in PAI-1 activity during intervention could be attributed to the fish oil supplementation. Notably, there are few data on the effect of n-3 PUFAs on D-dimer.\(^{184,186}\)

## Table 4. Intervention and Cross-sectional Studies of n-3-Polyunsaturated Fatty Acids on Thrombogenic Markers (cont)

<table>
<thead>
<tr>
<th>Source</th>
<th>Subjects</th>
<th>Design</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li et al,(^{136}) 1990</td>
<td>8 Healthy subjects</td>
<td>Randomized: fish oil (6 g EPA) or vegetable oil daily suppl for 25 d</td>
<td>In fish oil group, ACA, ADP, and collagen-PAggr ↑ but platelet adhesion to Fg and collagen I at low shear rates ↓ by 60%-65%. No changes in platelet adhesiveness in 5 subjects who had vegetable oil suppl</td>
</tr>
<tr>
<td>Andrioli et al,(^{131}) 1999</td>
<td>60 Healthy volunteers</td>
<td>Randomized into 3 groups: 20 mL fish oil (0.3 g n-6; 3.6 g n-3; n-6/n-3 ratio 0.1) or 25 g soy lecithin (1.5 g n-6; 0.5 g n-3; n-6/n-3 ratio 3) daily suppl or usual diet (control) for 15 d</td>
<td>Fish oil significantly ↓ stimulated adhesion with ADP and thrombin. Soy lecithin ↑ platelet adhesion in all test conditions with ADP and thrombin. No changes in controls. Platelet adhesion correlated to changes in the platelet n-6/n-3 ratio caused by the different suppl. Fish oil rich in n-3 inhibit stimulated platelet adhesiveness and soy lecithin rich in n-6 ↑ adhesion in all test conditions. n-6/n-3 Ratio is a determinant of platelet adhesiveness</td>
</tr>
<tr>
<td>Freese et al,(^{132}) 1997</td>
<td>29 Female and 17 male healthy subjects (aged 20-44 y)</td>
<td>Randomized: fish oil plus sunflower oil (EPA plus DHA: 5.2 g/d) or linseed oil (ALA: 5.9 g/d) daily for 4 wk</td>
<td>No differences between the 2 groups in collagen-PAggr and Tbx production, Aggr to the TbxA2 mimic I-BOP, urinary excretion of 11-dehydro-TBx82B, and β-thb, BT, Fg, ATIII activity, FVIII activity, or PAI activity. Suppl of ALA from vegetable oil and EPA plus DHA from a marine source have similar effects on hemostatic factors</td>
</tr>
<tr>
<td>Barcelli et al,(^{133}) 1985</td>
<td>9 Healthy subjects</td>
<td>Maximum EPA fish oil (5 g n-3) daily suppl for 2 wk</td>
<td>Vascular plasminogen activator ↑. Inhibitors of vascular plasminogen activator, of plasmin, and of PAP ↓. No significant changes in TCI, Tgs, HDL, or LDL levels</td>
</tr>
<tr>
<td>Mehta et al,(^{154}) 1988</td>
<td>8 Patients with CHD and 4 healthy subjects</td>
<td>Maximum EPA fish oil daily suppl for 4 wk</td>
<td>In both groups, TG and PAI ↓ significantly but tPA antigen was unaltered. The magnitude of ↓ in Tgs was dependent on baseline TG. PAI ↓ correlated with ↓ Tgs (r = 0.79)</td>
</tr>
<tr>
<td>Schmidt et al,(^{135}) 1990</td>
<td>10 Healthy males</td>
<td>Dose ranging: 1.3 g, 4 g, or 9 g of n-3 daily suppl for 6 wk</td>
<td>BT, PAI, and HDL ↑, while Fg and TGs ↓ in a dose-dependent fashion. Highest daily dose (9 g) ↓ Tgs, Fg, and VWF, while BT, tPA antigen, PAI, and HDL:TC ratio ↑</td>
</tr>
<tr>
<td>Miller et al,(^{156}) 1987</td>
<td>5 Insulin-dependent diabetics and 5 healthy volunteers</td>
<td>Maximum EPA fish oil given without other diet modification for 8 wk</td>
<td>ACA and collagen-PAggr ↓ equally in both groups, but TG, lipids, glucose, HbA1c, platelet count, and osmotic fragility of RBC were unchanged. Whole blood viscosity ↑ in diabetic patients at baseline, but ↓ in both groups at 8 wk. Diabetic patients ↑ VWF at baseline but ↓ in both groups at 6 wk. Addition of EPA or crude fish oil to HUVEC cultures did not change VWF in the supernatant</td>
</tr>
<tr>
<td>Schmidt et al,(^{137}) 1992</td>
<td>24 Healthy volunteers</td>
<td>4 g n-3 Daily suppl for 9 mo</td>
<td>BT and Fg ↑, while VWF and fibrinolysis ↓. Tgs and a trend ↓ of HDL, while no changes in TC, LDL, and apolipoproteins A1 and B after 9 mo. Systolic and diastolic BP ↓ with n-3 supple</td>
</tr>
<tr>
<td>Smith et al,(^{158}) 1989</td>
<td>40 Patients with previous MI</td>
<td>1 g Fish oil capsules (3.4 g EPA and DHA) daily suppl for 4 wk; 22 of 40 subjects had concomitant long-term oral anticoagulants</td>
<td>TG ↑ by 25%, TC ↑ by 5%, and HDL unaltered. Ivy BT also ↑. Blood glucose and PAI and FVIII-PL complex showed a ↓ trend. Fg ↑ significantly, but clotting time in the combined PT ↓ in patients who had oral anticoagulants</td>
</tr>
<tr>
<td>Li et al,(^{138}) 1999</td>
<td>17 Male vegetarians</td>
<td>All had a low-ALA diet for 14 d; then randomized to either a moderate- or a high-ALA diet for 28 d</td>
<td>EPA, DHA, total n-3, and n-3:n-6 ratio significantly ↑, whereas ACA-EPA ratio ↓ in platelet PLs, plasma PLs, and triacylglycerols after moderate-ALA or high-ALA diet compared with the low-ALA diet. No differences in thrombotic markers. ALA from vegetable oils (canola and linseed) has a beneficial effect on n-3 concentrations of platelet PLs and plasma lipids in vegetarian males</td>
</tr>
<tr>
<td>Emeis et al,(^{160}) 1989</td>
<td>76 Healthy males</td>
<td>Fish (mackerel) or meat (control) paste with daily main meal for 6 wk</td>
<td>No changes in plasminogen, PAP, IPA antigen, and egulbulin IPA activity in both groups. In the fish group, total PAI activity ↑ by 45% due to a 71% ↑ in PAI-1. This ↑ could not be ascribed to a diet-induced acute-phase reaction and changes in serum Tgs or insulin. No change of PAI activity in controls</td>
</tr>
</tbody>
</table>

Abbreviations: For an explanation of abbreviations, see footnote to Table 1.
Platelet Reactivity

The effects of n-3 PUFA on platelet reactivity have been extensively investigated. Studies of Greenland Eskimos have shown that very high intake of marine n-3 PUFA markedly inhibited platelet reactivity, lowered platelet count, prolonged bleeding time, decreased the ratio of proaggregatory thromboxanes to antiaggregatory prostacyclins, and caused favorable changes in lipid and lipoprotein profiles. These findings are of importance for their low incidence of CHD. Although few studies have shown no significant influence on platelet reactivity with n-3 PUFA supplementation, most other intervention studies have demonstrated significant inhibition in platelet reactivity of one sort or another but with conflicting combinations of effects with different agonists in vitro or ex vivo. It seems that platelet aggregation induced by low-dose collagen was the most commonly reported index to be influenced. One study has demonstrated no significant difference between supplemented α-linolenic acid from vegetable oil and n-3 PUFA from a marine source (EPA and DHA) in their effects on collagen-induced platelet aggregation and thromboxane production, aggregation to the thromboxane A2 mimic, urinary excretion of 11-dehydro-thromboxane B2 and β-thromboglobulin, bleeding time, plasma fibrinogen concentration, antithrombin III activity, FVII coagulation activity, or PAI-1 activity. However, another study has shown that a high α-linolenic acid diet has no significant effect on thromboxane production and platelet aggregation with collagen. Notably, data from studies on other fatty acids (mainly n-6 PUFA), such as linoleic acid on platelet reactivity, were highly variable, especially in the in vitro assessment of platelet aggregations. Similarly, there was also lack of agreement on the effect of n-3 PUFA on platelet adhesiveness. Novel, well-validated methods for measuring platelet aggregation are desperately needed to solve current controversies.

Thus far, it seems that there is little evidence to support the hypothesis that changes in coagulation, platelet reactivity, or fibrinolysis systems could account for, at least, some of the beneficial effects afforded by a Mediterranean diet with n-3 PUFA supplementation in the secondary prevention trials mentioned herein. The major effect of n-3 PUFA may be antiarrhythmic rather than antithrombotic. It remains unsettled whether the diverse effects of n-3 PUFA supplementation on thrombogenic indices are due to different time of supplementation, patient type, or separate effects of EPA and DHA in a mixture of fish oils. It is likely that fish oil and n-3 PUFA have multifaceted actions in the secondary prevention of cardiovascular disease.

ALCOHOL

Light-to-moderate alcohol consumption (<30 g/d, ie, 1 to 2 drinks per day) is associated with 10% to 40% lower risks of MI and cardiovascular death compared with abstinence. However, heavy alcohol consumption or binge drinking increases such cardiovascular risks, including stroke. The reduction in cardiovascular risks with moderate alcohol intake has mainly been attributed to an increase of HDL-C levels, but this only accounts for 50% of the protective effect. Increasing evidence has indicated that thrombogenic factors may play an important role in mediating such a complex association independent of HDL-C levels.

Epidemiologic Studies: Coagulation and Fibrinolysis

The mass of the previously published data on alcohol consumption and hemostasis comes from epidemiologic studies, with only few experimental data reported. Generally, most cross-sectional studies have shown that light-to-moderate alcohol intake is associated with a more favorable coagulation and fibrinolytic profiles as indicated by lower levels of fibrinogen, white blood cell count, plasma viscosity, FVII, and vWF, as well as lower platelet count and activity. However, heavy or binge alcohol intake is associated with lower fibrinolytic capacity with relatively greater increase in PAI-1 and tPA antigen than tPA activity. In addition, heavy alcohol consumption also seems to shift the pendulum toward a more procoagulant state, with a rise in the plasma levels of FVII, fibrinogen, and viscosity. Indeed, this may sufficiently predispose individuals to thrombosis, and in the presence of an impaired fibrinolytic state, this may contribute to the increased incidence of ischemic stroke seen in heavier or binge drinkers. Thus, the results from these studies seem to partly explain the complex relationship between level of alcohol consumption and cardiovascular risk seen in large epidemiologic outcome studies on alcohol.

Experimental Studies: Coagulation

The results from experimental studies on the effects of moderate alcohol consumption in both healthy subjects and subjects with CHD are contradictory (Table 5). In particular, the alcohol effects on fibrinogen are variable. For example, Pellegrini et al found a decrease in fibrinogen level after consumption of 30 g of alcohol that consisted of red wine and alcohol diluted in fruit juice for 4 weeks but found no change in fibrinogen level after consumption of deacoholized red wine. Because alcohol diluted in fruit juice had an effect similar to that of red wine, it seems that alcohol is the effective mediator in alcoholic drinks. On the other hand, Gorinstein et al studied the effect of beer (20 g/d of alcohol) over 30 days and found no change in fibrinogen levels. It could be argued that there may be other substances in beer that inhibit the beneficial effect of alcohol on fibrinogen. However, this may also be due to differences in study design, timing of blood samplings, quantity or regularity of intake (besides type of beverage used), and interpatient and interpatient variability in alcohol metabolisms. A recent meta-analysis of all experimental studies that assessed the effects of moderate alcohol intake on lipid lev-
els and hemostatic factors has concluded that moderate alcohol intake of 30 g/d is causally related to an overall 24.7% lower risk of CHD through favorable changes in lipids (higher HDL-C level) and hemostatic profile (lower plasma fibrinogen levels). However, the precise mechanism(s) by which moderate alcohol intake decreases fibrinogen and increases HDL-C levels is not known.
Experimental Studies: Fibrinolysis

Most reports seem to indicate that short-term alcohol ingestion leads to inhibition of the fibrinolytic system through a rise in circulating PAI-1 levels.\(^{211,212,216,217,220,221}\) Notably, a recent study\(^{217}\) has shown an acute, dose-dependent rise in PAI-1 antigen level with a parallel prolongation of whole blood clot lysis time after intake of the high dose of red wine. In addition, there was also a tendency for tPA antigen to increase dose dependently, although this was only significant for the high-dose wine group. In the case of binge drinking, this inhibition in fibrinolysis effect persists into the morning following the evening of alcohol ingestion,\(^{216}\) and when it coincides with the physiologic morning dip in fibrinolytic activity, this may predispose susceptible individuals to sudden cardiac death. However, the exact reason for decreased fibrinolysis after short-term alcohol intake is still unresolved. Indeed, several studies have discussed whether it is the ethanol component itself or other mediators in red wine (or beer) that induce acute changes in tPA or PAI-1. Veenstra et al\(^{221}\) and Hendriks et al\(^{218}\) have pointed out that the red wine effect on t-PA and PAI-1 antigen levels is probably caused by the effect of ethanol but not the effects of other mediators, such as the phenolic compounds in red wine or port wine, although these constituents might contribute to the effects on platelet function. However, it is difficult to distinguish between the effects of red wine and alcohol per se. Notably, in a study\(^{211}\) with longer-term consumption of beer (4 weeks), the tPA antigen and PAI-1 levels were increased markedly.

Experimental Studies: Platelet Reactivity

Alcohol has also been thought to reduce CHD risk by decreasing platelet reactivity. Indeed, several studies in humans and animals have demonstrated that the immediate effect of light-to-moderate alcohol, either added in vitro to platelets or 10 to 20 minutes after ingestion, can inhibit platelet aggregation to most specific agonists (adenosine diphosphate [ADP], thrombin, collagen, epinephrine) in platelet-rich plasma. This platelet inhibitory effect seems to persist for several hours after alcohol intake.\(^{214}\) However, such beneficial effect is not seen in binge drinkers or in individuals with alcoholism after alcohol withdrawal; instead, a rebound phenomenon of platelet hyperaggregability (especially toward thrombin agonist in vitro)\(^{225}\) and loss of the normal circadian periodicity of the hemostatic system is observed.\(^{219}\) This may explain the increased ischemic strokes or sudden deaths that are known to occur after episodes of binge or heavy drinking.\(^{226}\) Intriguingly, such a rebound phenomenon is not observed after moderate red wine consumption in humans and, in fact, this protection afforded by red wine has been duplicated in rats by alcohol with grade tannins added, which contain the polyphenolic compounds with which red wines are richly endowed. However, it is still unclear how red wine or wine phenolics in particular could significantly inhibit platelet aggregation.

In an interesting study by Lacoste et al,\(^{222}\) rather than evaluating platelet function and platelet inhibition, the authors assessed the effect of alcohol directly on platelet-dependent thrombosis in 12 healthy subjects in an ex vivo model that simulates a deep arterial wall injury exposed to shear forces typical of flow at sites of stenosed arteries, reflecting the in vivo situation of coronary thrombosis. The study demonstrated for the first time that moderate alcohol consumption (24 g of alcohol) in humans had a potent extracorporeal antithrombotic effect both at the time of peak alcohol concentration and 6 hours after alcohol ingestion when blood alcohol level has returned to baseline. Overall, the balance of anticoagulant, procoagulant, and fibrinolytic effects in any individual in response to alcohol intake may vary, depending on quantity and type of alcoholic beverage ingested and other variables.\(^{204,227}\) The lower level of plasma fibrinogen with moderate alcohol intake may well contribute to the apparent protection alcohol confers against ischemic coronary and cerebral events. On the other hand, consistent evidence suggests that the relatively greater increase in PAI-1 and tPA antigen than tPA activity and the rebound phenomenon of platelet hyperaggregability with short-term alcohol (binge) intake may attenuate this benefit, resulting in a net antifibrinolytic effect of ethanol consumption,\(^{205}\) predisposing individuals to coronary thrombosis and contributing to the increased incidence of ischemic stroke.

SMOKING

The direct effects of smoking on athrothrombogenesis are still unclear. This may be mediated by its many adverse effects on endothelial function, vascular tone, hemo-, stasis, lipid profile, and inflammatory cells. Much of the data regarding the effects of smoking on thrombogenic factors have been derived from epidemiologic and cross-sectional studies. However, intervention studies are accumulating and have reported an increase in blood coagulability but impaired fibrinolysis in habitual smokers when compared with nonsmoking controls (Table 6). It seems that higher plasma levels of fibrinogen and viscosity are the main contributors to higher coagulability found in smokers, whereas the lower fibrinolytic potential is mainly attributed to an increase in PAI-1 activity and possibly also a decrease in tPA activity and lower plasminogen levels.\(^{107,228,229,244}\)

Coagulation

In cross-sectional epidemiological studies, lifetime duration of smoking is a strong determinant of initial plasma fibrinogen levels. The effects of smoking on the hemostatic system remain for many years before an exsmoker reverts to a plasma level similar to that of a lifetime nonsmoker,\(^{229,245}\) although a decrease in fibrinogen levels follows quickly after cessation of smoking.\(^{246}\) In prospective data, smoking cessation and the adoption or resumption of smoking are associated with a decrease or
Table 6. Effect of Smoking on Thrombogenic Factors

<table>
<thead>
<tr>
<th>Source</th>
<th>Methods</th>
<th>Main Results</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eliasson et al,238 1995</td>
<td>Cross-sectional study; 604 men and 662 women (aged 25-64 y): smokers, ex-smokers, snuff dippers, and nonsmokers</td>
<td>Male smokers had 0.34 g/L ↑ Fg than nonsmokers. Numbers of cigarettes smoked correlated with Fg. Fg not affected by snuff dipping. Tobacco use had no relationship with IPA or PAI activity and no influence on glucose and postload insulin levels.</td>
<td>Cigarette smoking is associated with ↑ Fg, unaltered fibrinolysis, and normal glucose tolerance and insulin levels. Moist oral snuff does not seem to affect these cardiovascular risk factors.</td>
</tr>
<tr>
<td>Meade et al,229 1987</td>
<td>Cross-sectional; 2023 white men</td>
<td>Duration of smoking is a determinant of initial Fg level, which ↓ soon after cessation but returned to normal levels only after 5 years. Smoking cessation and the adaption or resumption of smoking associated with a ↓ or an ↑, respectively, of -0.15 g/L in plasma Fg equivalent to a ↓ or an ↑ in the risk of IHD by ~20%</td>
<td>A substantial part of the relation between smoking and IHD seems to be mediated through the Fg concentration</td>
</tr>
<tr>
<td>Simpson et al,230 1997</td>
<td>Cross-sectional study; 54 healthy individuals; current, ex-smokers, or nonsmokers (aged 25-40 y)</td>
<td>PAI antigen ↑ in smokers vs nonsmokers with intermediate levels in ex-smokers. IPA and platelet pool PAI were not different in the 3 groups. IPA:PAI ratio similar in ex-smokers and nonsmokers but ↓ in smokers. PAI antigen and activity correlated with pack-years of cigarettes smoked. PAI correlated strongly with IPA and TGs. IPA correlated strongly with TGs.</td>
<td>Smokers associated with ↓ fibrinolysis as reflected by ↑ PAI. Smoking cessation seems to normalize fibrinolysis. Platelet pool of PAI not quantitatively affected by smoking. Effect of chronic smoking on PAI may be mediated by TGs and insulin resistance</td>
</tr>
<tr>
<td>Enderle et al,231 2000</td>
<td>30 Healthy smokers (mean age, 40.6 y) vs nonsmokers. FMD as marker of ET dysfn</td>
<td>FMD significantly ↓ and IMT tended to be ↑ in smokers. TAT, Fg, PAP, IPA, and PAI activity did not differ between smokers and controls.</td>
<td>Peripheral ET dysfn is common in smokers even without major alterations in markers of coagulation and fibrinolysis</td>
</tr>
<tr>
<td>Newby et al,232 1999</td>
<td>12 Smokers (5-20 cigarettes per day) and 12 nonsmokers (aged 25-55 y). Forearm blood flow assessed by venous occlusion plethysmography following infusions of substance P</td>
<td>Substance P caused a dose-dependent ↑ in blood flow and local release of IPA antigen and activity in smokers and nonsmokers, but the ↑ was significantly lower in smokers that the release of IPA antigen and activity ↓ by 51% and 53%, respectively. PAI did not change.</td>
<td>Smoking caused marked inhibition of substance P–induced IPA release in vivo. ET dysfn may ↑ the risk of atherothrombosis through a ↓ in the acute fibrinolytic capacity</td>
</tr>
<tr>
<td>Newby et al,233 2001</td>
<td>15 Ex-smokers or current smokers vs 10 nonsmokers (mean age, 56 y). Saline, substance P, or SNP infused into LAD; blood flow measured by IVUS and with arterial and coronary sinus sampling.</td>
<td>Substance P and SNP ↑ LAD blood flow, but ↑ coronary sinus IPA antigen and activity only with substance P. Release of active IPA strongly inversely correlated with LAD plaque burden. Smoking associated with ↓ coronary release of active IPA.</td>
<td>Coronary plaque burden and smoking are associated with ↓ acute local fibrinolytic capacity. There may be a direct link between endogenous fibrinolysis, ET dysfn, and atherothrombosis in the coronary circulation</td>
</tr>
<tr>
<td>Allen et al,234 1985</td>
<td>30 Healthy men (aged 30-40 y): smokers (=20 cigarettes per day) vs nonsmokers. Fibrinolysis was studied at rest and after infusion of DDAVP</td>
<td>Smokers had ↓ baseline fibrinolytic activity as indicated by dilute blood clot lysis, euglobulin-fibrin plate assay, and IPA activity. No differences between the groups in various fibrinolytic inhibitors or in the intrinsic fibrinolytic activation pathways. The ↑ levels of IPA activity and FVIII R antigen in response to DDAVP also ↓ in smokers.</td>
<td>Smokers have ↓ fibrinolytic capacity both at rest and in response to DDAVP compared with nonsmokers</td>
</tr>
<tr>
<td>Belch et al,236 1984</td>
<td>10 Habitual smokers vs nonsmokers. Blood drawn before and 10 min after smoking 3 cigarettes over 30 min</td>
<td>Smokers had ↑ plasma Fg and viscosity but ↓ plasminogen and tPA. After smoking 3 cigarettes, smokers had an ↑ in ADP-PAggr and ↑ in a2M and FVIII antigen but plasma viscosity and red cell deformability ↓.</td>
<td>↑ Hypercoagulability in smokers compared with controls, which becomes more pronounced immediately after smoking 3 cigarettes</td>
</tr>
</tbody>
</table>

(continued)

Fibrinolysis

Impaired fibrinolytic potential has been found in smokers with CHD and peripheral vascular disease, with higher levels of PAI-1 activity and tPA antigen than in nonsmokers or light smokers. However, other groups have reported no difference in markers of fibrinolysis and coagulation, although endothelial function has been found to be significantly impaired in healthy smokers compared with nonsmoking controls. Interestingly, smokers may have markedly impaired acute substance P–induced endothelial release of active tPA in vivo from coronary and brachial arteries and was closely related to impaired endothelial function in the correspondence arterial beds, which suggests a possible direct link among impaired endogenous fibrinolysis, endothelial dysfunction, and arterial atherothrombosis in smokers.232,233,249 However, although the basal level of PAI-1 activity is higher in long-term smokers, rapid smoking of 2 cigarettes in these patients neither stimulated fibrinolysis nor changed levels of tPA or PAI-1 activities.236 Plasma PAI-1 antigen seems to correlate with cumulative smoking in pack-years,230,236 and on the other...
Table 6. Effect of Smoking on Thrombogenic Factors (cont)

<table>
<thead>
<tr>
<th>Source</th>
<th>Methods</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Haire et al, 1989</td>
<td>5 Healthy male smokers (aged 35-45 y)</td>
<td>TPA antigen release in response to venous occlusion was intact at both 8 am and 3 pm. Rapid smoking of 2 cigarettes neither ↑ fibrinolysis nor changed tPA or PAI. Functional PAI and ECLT ↑ in smokers vs matched controls. Plasma and platelet PAI were similar in both groups.</td>
<td>Smoking did not acutely alter fibrinolysis in chronic smokers, but they had abnormal fibrinolysis with ↑ PAI activity. Abnormal fibrinolysis may contribute to the thrombotic diathesis of smokers.</td>
</tr>
<tr>
<td>Brockmann et al, 2001</td>
<td>54 Healthy subjects into 4 groups: nonsmoking and smoking males and females. Effect of smoking on PHC with an in vitro analyser was examined within 4 h of blood sampled</td>
<td>Smokers had ↑ Fv vs nonsmokers. No differences between smokers and nonsmokers in PHC, for neither the collagen/epinephrine nor the collagen/ADP cartridges. PAggr assays performed in parallel also showed no differences.</td>
<td>In habitual smokers, PHC and the agonists-induced PAggr assays are not significantly influenced or ↑ compared with healthy nonsmokers. An immediate effect of smoking cannot be excluded.</td>
</tr>
<tr>
<td>Modesti et al, 1989</td>
<td>8 Male healthy smokers (≥20 cigarettes per day) vs 9 healthy controls (aged 30-55 y). Platelet TxA2 receptors assessed by a radioligand binding method</td>
<td>Smokers had a significantly ↑ number of Tbx2 platelet receptors vs nonsmokers. No differences in the receptor affinity between the 2 groups.</td>
<td>Changes could contribute to the ↑ responsiveness of platelet from smokers to external aggregating stimuli.</td>
</tr>
<tr>
<td>Pernerstoffer et al, 1998</td>
<td>20 Healthy smokers (≥20 cigarettes per day) vs 20 healthy nonsmokers (mean age, 30 y). DRRB, aspirin (100 mg/d) or placebo; cross-over; 2 wk wash-out period</td>
<td>Smokers had ↑ sP-sel expression on platelets than nonsmokers. sP-sel expression on platelets and circulating sP-sel unchanged by aspirin.</td>
<td>P-sel expression on platelets ↑ in smokers but low-dose aspirin does not ↓ platelet activation in smokers.</td>
</tr>
<tr>
<td>Blache et al, 1992</td>
<td>12 Fasting smokers. Blood drawn before and at 10 min after inhaled smoke 1 cigarette. Experiment repeated 1 wk later except that subjects had aspirin before smoking.</td>
<td>Before aspirin: PAggr to thrombin and ADP, plasma nicotine, β-Tbg, and CECs all ↑ significantly after smoking, but PAggr ratio ↓. After aspirin: except for plasma nicotine, all smoking-induced changes were abolished by ingestion of aspirin.</td>
<td>Data indicate an interrelationship between platelet hyperactivity and ET injury. Aspirin inhibits smoking-induced changes. Aspirin may offset several of the deleterious acute effects of smoking. Long-term effects of both smoking and aspirin treatment remain unclear.</td>
</tr>
<tr>
<td>Blann et al, 1998</td>
<td>20 Smokers vs 10 nonsmoker controls (aged 21-55 y). Blood drawn before, immediately after, and at 10 and 30 min after rapid smoking of 2 cigarettes in sequence</td>
<td>Smokers had a transient ↑ in leucocyte count and neutrophil activation, but vWF ↑ steadily at each time point. No changes in neutrophil elastase, sICAM-1, Fg, platelet count, or sP-sel.</td>
<td>Rapid smoking of 2 cigarettes in succession activates leukocytes and causes ET cell damage but will not immediately influence platelet activity.</td>
</tr>
<tr>
<td>Gleerup et al, 1998</td>
<td>10 Smokers and 11 nonsmokers, all with mild HT (diastolic BP, 90-110 mm Hg). Successive measurements after erect posture for 10 min and after a 5-min exercise test</td>
<td>ADP PAggr ↑ in smokers at rest vs nonsmokers and persisted both in upright posture and after exercise. (β-Tbg also ↑ in smokers. No difference of ECLT and PAI between the 2 groups.</td>
<td>Smoking adds a further element of ↑ platelet activity to that inherently present in HT.</td>
</tr>
<tr>
<td>Davis et al, 1985</td>
<td>20 Healthy nonsmokers. Smoked 2 tobacco cigarettes in 20 min and at cross-over 1 wk later smoked 2 cigarettes made from wheat, cocoa, and citrus plants</td>
<td>Mean ET cell counts before and after tobacco cigarettes were 2.3 and 4.8; before and after nontobacco cigarettes were 2.5 and 3.0. The corresponding mean PAggr ratios were 0.80 and 0.65, 0.81, and 0.78, respectively.</td>
<td>Much greater effects of tobacco smoking on ET cell counts and PAggr ratios suggest that nontobacco smoking may be less harmful to the cardiovascular system than tobacco smoking.</td>
</tr>
</tbody>
</table>

Abbreviations: For an explanation of abbreviations, see footnote to Table 1.

hand, other studies have suggested that smoking cessation of at least 6 months was associated with a decrease in plasma PAI-1 activity.

Platelet Reactivity

Smoking is also known to be associated with increased platelet thrombus formation, but studies on the effects of smoking on platelet reactivity have produced conflicting data. For example, rapid smoking of 3 cigarettes in habitual smokers increased ADP-induced platelet aggregation in vitro in one study, but others have shown no differences in various agonist-induced platelet aggregations in vitro compared with nonsmokers. Certainly, no immediate influence in platelet activity (as indicated by platelet count and soluble P-selectin) occurs after rapid smoking of 2 cigarettes in sequence compared with nonsmoking controls, despite evidence of endothelial damage (indicated by elevated vWF level). On the other hand, increased P-selectin expression on platelets has been demonstrated in young, healthy, habitual smokers compared with nonsmokers, underlining the increased platelet activation in nicotine-abusing subjects. Importantly, 100 mg/d of aspirin did not reduce platelet activation as measured by unchanged P-selectin expression on platelets and circulating P-selectin plasma levels. This could indicate that enhanced thromboxane A2 production may not be the primary mechanism for increased P-selectin expression in smokers. Similarly, dipyridamole alone or in combination with aspirin did not have any significant effect on plasma concentrations of β-thromboglobulin, platelet factor 4, the circulating endothelial cell count (indicates endothelial damage), and the platelet aggregate ratio in habitual, male smokers with CHD. Smoking cessation for 6 weeks, however, has resulted in a 29% reduction of circulating P-selectin.
plasma levels in healthy smokers and a decrease in platelet count 2 weeks after cessation. Furthermore, aspirin abolished the major cigarette smoke–induced endothelial damage and platelet hyperactivity in the presence of high plasma nicotine levels. Notably, passive exposure to tobacco smoke also seems to raise the endothelial cell count and platelet aggregate ratio in a manner similar to that previously observed with active smoking.

**PSYCHOSOCIAL STRESS**

The increase in mental stress, demands at work, anger, or low socioeconomic strain has been associated with an increased risk of atherovascular disease. The increased cardiovascular risk may be secondary to excessive cardiovascular reactivity to stress but may also involve activation of the coagulation and fibrinolysis systems.

Coagulation and Fibrinolysis

Indeed, an association between psychological factors and several of the coagulation and fibrinolysis variables related to atherosclerosis has provided a plausible psychobiological link to CHD. The characteristic patterns of coagulation and fibrinolysis activation in response to various psychological stressors seem to follow closely that of physical or exercise-induced changes in markers of thrombogenesis. Accordingly, as in short-term, strenuous exercise, acute mental stress simultaneously activates the coagulation system, with increased levels of fibrinogen, total plasma protein, hematocrit, FVII, and FVIII, and enhances fibrinolysis with increased activity of tPA within a physiological range in healthy subjects. In patients with atherosclerosis and impaired endothelial anticoagulant function, however, procoagulant responses to acute stressors may outweigh anticoagulant mechanisms and thereby promote a hypercoagulable state.

Similarly, long-term psychosocial stressors, such as prolonged job stress or low socioeconomic strain that provoked a state of vital exhaustion, have been independently associated with hypofibrinolysis, with an increase in PAI-1 and a decrease in tPA activities. In addition, such long-term mental stress is also independently related to an increase in prothrombic tendency, with increased levels of fibrinogen, FVII antigen, and activity. Changes in hemostatic variables in response to psychosocial job stress are particularly interesting. Significant elevation in coagulation FVII and FVIII levels, fibrinogen level, thrombocyte count, thrombin level, and ADP-induced platelet aggregation has been reported during a period of increased workload compared with a calm work period. High job demands have also been significantly related to decreases in tPA activity (ie, lower fibrinolytic capacity, independent of other traditional cardiovascular risk factors) and hence increase the likelihood of fibrin deposition. The mechanism(s) underlying these changes is unknown, but impaired fibrinolysis in people with long-term psychosocial stress has been linked to insulin resistance, obesity, and triglyceride levels.

**Platelet Reactivity**

Platelet reactivity also seems to be affected by a variety of psychosocial stressors. Acute mental stresses significantly induce all platelet reactivity variables, such as platelet activation or secretion and in vitro or ex vivo platelet aggregation, in parallel to a concomitant incremental increase of various hemodynamic indices that follow during mental-stress testing. Such a response has been consistently shown in almost every study. Furthermore, these changes seem to be more pronounced in patients with atherovascular disease compared with healthy controls. Hence, such a response may precipitate acute ischemic coronary events in patients at high risk of cardiovascular events, including individuals with sedentary lifestyle. One group has reported that dipryridamole attenuated the platelet hyperreactivity in post-MI patients but had no effect on stress-induced increase of hemodynamic variables and epinephrine levels. Aspirin has only a minimal effect on physical, psychosocial, or norepinephrine stress–induced platelet activation, which suggests that platelets are not being stimulated through the cyclooxygenase-dependent pathway. However, the mechanism(s) responsible for the increased of prothrombic tendency secondary to psychosocial stress may be related to the sympathoadrenal pathways, but clearly this needs further exploration.

**COFFEE, TEA, OR CAFFEINE CONSUMPTION ON THROMBOGENESIS**

**Coffee**

The possible link between coffee or caffeine consumption and the risk of CHD is far from settled, but its effects on various thrombogenic factors might be relevant. However, limited data from intervention study are currently available.

**Coagulation**

Two well-described randomized controlled trials have reported that brewed or boiled coffee, caffeine-containing drinks, and decaffeinated drinks did not have any effects on hemostatic variables, such as fibrinogen level, FVII activity, FVIII antigen, and protein C and S levels. Another experimental study seems to support such observations, but another cross-sectional study reported an increased in plasma fibrinogen levels with increased coffee consumption.

**Fibrinolysis**

The available evidence seems to suggest that coffee enhances fibrinolytic potential as whole blood fibrinolysis time is shortened and PAI-1 levels are decreased, whereas tPA activity increases after consumption of coffee and such effects are blunted during caffeine abstinence. However, one study did not find an effect of abstinence from caffeine on blood clot lysis time.

**Platelet Reactivity**

The effects of caffeine intake on platelet activity are more variable. Several in vitro and in vivo studies have reported increased...
platelet activation and release after coffee consumption, but others have found the opposite effects.\textsuperscript{271,272,277} Again, this may be due to the lack of standardization in the analysis methods used to assess platelet reactivity.

**Tea: Coagulation, Fibrinolysis, and Platelet Reactivity**

Previous epidemiologic studies have suggested that tea consumption is associated with a decreased risk of cardiovascular events, but a recent meta-analysis\textsuperscript{278} has reported no significant association and, in contrast, the risk may be even increased for CHD in the United Kingdom and for stroke in Australia with increasing tea consumption. Indeed, the antioxidative polyphenolic flavonoids found in tea have been shown to prevent oxidation of low-density lipoproteins both in vitro and in vivo\textsuperscript{279} and to inhibit platelet aggregation in vitro.\textsuperscript{280,282}

However, recent randomized controlled trials\textsuperscript{283-285} of black or green tea or tea extracts have found no effects on both hemostatic and fibrinolytic variables (eg, fibrinogen, vWF, or FVII and PAI-1, tPA, or urokinase-type plasminogen activator) or on inflammatory markers such as C-reactive protein. Similarly, no significant difference was found from black tea consumption on ex vivo platelet aggregation in patients with CHD\textsuperscript{286} and on in vitro platelet aggregation in healthy subjects\textsuperscript{287} when compared with drinking hot water. Interestingly, in the same study, the latter group had found significantly lower (15%) soluble P-selectin levels (but not other adhesion molecules) in those who drank black tea; however, whether such a finding is of any clinical significance is unclear. Thus, it seems that the putative protective effect of tea against development of CHD may not be mediated through effects of tea consumption on hemostasis, fibrinolysis, or platelet activity.

**CARDIAC REHABILITATION AND THROMBOGENESIS**

A recent Cochrane Systematic Review has concluded that cardiac rehabilitation with either exercise alone or exercise as part of a comprehensive rehabilitation program in post-MI and postrevascularization patients significantly reduced all-cause or total cardiac mortality by at least 26% to 31\%.\textsuperscript{287} In addition to the reduction of cardiovascular morbidity and mortality, cardiac rehabilitation also significantly improves functional capacity and quality of life and lipid profile and blood pressure.\textsuperscript{288}

Thus, given all the evidence discussed herein, it is highly plausible that lifestyle modifications through a program that incorporates stepwise increment of physical training or exercise, patient education and advice, dietary modifications, and psychosocial stress management would have a significant impact on patients’ thrombogenic profile and hence may beneficially influence the overall cardiovascular risk.

However, so far, to our knowledge, no study has been reported on the overall effects of such a comprehensive cardiac rehabilitation program on changes of the various variables of hemostasis, fibrinolysis, and platelet reactivity. Previous studies have mainly focused on the effects of short-term or regular physical activities on fibrinolytic responses in post-MI or post–coronary artery bypass grafting patients who participated in cardiac rehabilitation exercise programs (Table 7).

In keeping with epidemiologic data, patients with CHD have higher basal levels of PAI-1 and tPA antigen, suggesting impaired fibrinolytic activity compared with healthy subjects. Although healthy subjects tended to have a marked fibrinolytic response to exercise, patients with CHD have a lower increase in the fibrinolytic potential as evidenced by changes in tPA activity and PAI-1 levels after regular physical training.\textsuperscript{292} Although the increase of fibrinolytic capacity may be counterbalanced by an increase in blood coagulability and platelet activity during short-term exercise,\textsuperscript{91} lower plasma fibrinogen level has in fact been found in both post-MI and post–coronary bypass grafting patients who engage in regular aerobic exercise during cardiac rehabilitation.\textsuperscript{52,85}

**CONCLUSIONS**

The hemostatic system is assuming an increasingly prominent role in the pathogenesis and progression of atherosclerotic diseases. Human lifestyle or physical activities have diverse effects on coagulation, fibrinolysis, and platelet reactivity. There have been abundant studies of the effects of exercise, weight loss, dietary lipids (especially n-3 PUFA), smoking, alcohol, and psychosocial stress on the 3 main systems of thrombogenesis. The data from intervention and randomized clinical trials are largely fragmented, rarely complete, and inconsistent, mainly due to the differences in study design and the inherent complexity of subjects’ confounders and the lack of standardization of the various analytical methods used in the assessment of coagulation, fibrinolysis, and platelet function. The in vivo significance of examining one portion of the complex overall system is unclear. How much could one correlate the in vitro or ex vivo findings to the true in vivo biological activities in many of the human biological systems is largely unknown. Nevertheless, these data have provided us with important preliminary explanations for the relative contribution of the various thrombogenic markers in relation to lifestyle habits to clinical outcomes reported in epidemiologic studies. Available evidence from these studies support lifestyles that adopt strategies to lose weight, stop cigarette smoking, engage in regular moderate exercise and relaxation, and regularly consume light-to-moderate alcohol and fatty fish should significantly lower coagulability, promote fibrinolysis, and reduce platelet reactivity. The overall effects ought to translate into an improved cardiovascular or other beneficial clinical outcome in healthy individuals, those with cardiovascular risk factors, or those with established CHD. It follows that a cardiac rehabilitation program that incorporates a stepwise increment of physical training or exercise, patient education and advice, dietary and personal habit modifications, and psychosocial...
Table 7. Controlled or Intervention Clinical Trials of Cardiac Rehabilitation Exercise on Thrombogenic Factors

<table>
<thead>
<tr>
<th>Source</th>
<th>Subjects</th>
<th>Exercise</th>
<th>Main Results</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weiss et al, 1998</td>
<td>12 Males with CHD without MI within the preceding 6 mo (aged 55 ± 9 y) vs 12 healthy male controls (aged 52 ± 7 y)</td>
<td>Blood drawn before and after rehab group exercise session lasting 1 h</td>
<td>CHD patients had ↓ PTF F1 + 2 and remained unchanged after exercise, whereas a significant ↑ occurred in controls. Postexercise platelet count, β-Tbg, TAT, and FPA ↑ in both groups but was more pronounced in controls. Exercise ↑ PAP complexes in both groups. Repeated experiments after aspirin given to controls did not alter results</td>
<td>Patients and controls similarly ↑ coagulation and fibrinolysis induced by exercise. Rehab exercise in CHD patients beyond the immediate post-MI period has no detrimental effects on thrombin, fibrin, and plasmin formation</td>
</tr>
<tr>
<td>Suzuki et al, 1992</td>
<td>56 Active exercise post-MI patients vs 30 post-MI patients without training</td>
<td>Blood drawn before and after 1 mo of systematic physical training</td>
<td>Training ↓ Fg, FVIII, vWF, TAT, plasminogen activity, hematocrit, platelet counts, and α2AP. APTT prolonged with training. In 20 patients with training, resting α2AP, TAT, protein C, PAI, and FVII significantly ↓ after 1 mo, but PAI activity unchanged</td>
<td>Training ↓ coagulation in post-MI patients: ↓ in Fg, FVIII, vWF, FVII, and TAT. The ↓ in plasminogen, tPA antigen, α2AP, PAI, and protein C after training may result from the ↓ coagulation</td>
</tr>
<tr>
<td>Wosornu et al, 1992</td>
<td>55 Men (aged 32-70 y) within 12 mo of CABG randomized to aerobic or power exercise or controls</td>
<td>6 Months of aerobic or power exercise on treadmill (3 times per week) in training patients</td>
<td>Both trained groups ↑ exercise capacity at 6 mo. Aerobic exercise improved earlier at 3 mo. Fg ↓ with aerobic exercise but ↓ slightly with power exercise. Gradual ↑ in FVII activity in aerobic and control groups but small ↓ in the power group. No consistent changes in FPA</td>
<td>Aerobic training post-CABG improves exercise capacity and ↓ Fg, which is maintained with further training. Power exercise causes delayed benefit in treadmill performance and a small ↓ in Fg. These changes may ↓ cardiovascular morbidity</td>
</tr>
<tr>
<td>Fernhall et al, 1998</td>
<td>13 Post-MI patients</td>
<td>2 Maximal exercise on treadmill and BE. Blood drawn before and after each test</td>
<td>VO2peak, uptake, HR, and ventilation greater on treadmill than BE. Blood lactate similar between the 2 modes. tPA activity ↑ but a trend in ↓ PAI activity with exercise</td>
<td>Fibrinolysis ↑ similarly in both modes. Exercise intensity, but not the mode, seemed to be the primary determinant of fibrinolytic response to acute exercise</td>
</tr>
<tr>
<td>Speiser et al, 1988</td>
<td>71 Males: 2 pairs of age-matched groups. (1) Athletes, (2) not engaged in any sports, (3) regularly practicing sports, and (4) post-MI patients in a rehab sports program</td>
<td>BE exercise</td>
<td>At baseline, those doing regular sporting activities showed ↓ PAI vs the respective age-matched controls. During exercise tPA activity similar between the age-matched groups but tPA activities ↑ after exercise in groups with lower pretest PAI. No change on D-dimer in any group</td>
<td>(1) Regular vigorous exercise ↑ fibrinolysis by ↓ PAI in healthy individuals; (2) rehab sport does not ↓ PAI in post-MI patients compared with age-matched healthy subjects regularly exercise; and (3) activation of fibrinolysis during exercise has no systemic fibrinolytic effect</td>
</tr>
<tr>
<td>Estelles et al, 1989</td>
<td>Post-MI patients, active exercise vs controls</td>
<td>Rehab program with BE. Blood drawn at end of hospitalization and at 3 and 6 mo</td>
<td>At 6 mo, tPA activity ↓ in controls but slightly ↑ in active group. PAI ↑ in controls but remained constant or ↓ slightly in active group</td>
<td>Patients in rehab program showed a slight ↑ in fibrinolytic capacity but ↓ significantly in controls</td>
</tr>
<tr>
<td>Paruno et al, 1998</td>
<td>30 (M/F; 22/8; mean age, 47 y). Survivors of a first MI vs 30 healthy controls</td>
<td>9 Months of cardiac rehab. Blood drawn before and at 3 and 9 mo after program</td>
<td>Marked ↓ in functional PAI after 3 and 9 mo in MI patients. Also significant ↑ of HDL-C and ↓ of Lp(a) after the program</td>
<td>Cardiac rehab improved fibrinolysis and lipid profile in post-MI patients</td>
</tr>
</tbody>
</table>

Abbreviations: For an explanation of abbreviations, see footnote to Table 1.

We acknowledge the support of the City Hospital Research and Development Programme for the Haemostasis, Thrombosis, and Vascular Biology Unit, Birmingham.

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stress management would have a significant impact on patients' hemostatic profiles and hence beneficially influence the overall cardiovascular risk.

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