A prospective study of venous thromboembolism in relation to factor V Leiden and related factors

Aaron R. Folsom, Mary Cushman, Michael Y. Tsai, Nena Aleksic, Susan R. Heckbert, Lori L. Boland, Albert W. Tsai, N. David Yanez, and Wayne D. Rosamond

The aim of this study was to examine the occurrence of venous thromboembolism (VTE) in relation to factor V–related risk factors. Using a nested case-control design combining 2 population-based prospective studies, we measured factor V Leiden, HR2 haplotype, activated protein C (APC) resistance, and plasma factor V antigen in 335 participants who developed VTE during 8 years of follow-up and 688 controls. The overall odds ratio (OR) of VTE was 3.67 (95% CI, 2.20-6.12) in participants carrying factor V Leiden compared with noncarriers. APC resistance measured after predilution with factor V–deficient plasma conferred an OR of 2.58 (95% CI, 1.62-4.10). All 3 participants homozygous for the HR2 haplotype had a VTE, and the OR of VTE for homozygosity was estimated to be 5.5 (95% CI, 2.45-12.5). Carriers of the HR2 haplotype otherwise were not at increased risk of VTE overall (OR = 1.05; 95% CI, 0.64-1.72), but double heterozygotes for HR2 and factor V Leiden carried an OR of idiopathic VTE of 16.3 (95% CI, 1.7-159) compared with noncarriers. Factor V antigen also was not associated with VTE overall, but for participants with the combination of high factor V antigen plus factor V Leiden the OR of idiopathic VTE was 11.5 (95% CI, 4.2-31.4). In the general population, APC resistance and factor V Leiden were important VTE risk factors; homozygosity for the HR2 haplotype may be a risk factor but was rare; otherwise, HR2 haplotype and factor V antigen were not risk factors except in carriers of factor V Leiden. (Blood. 2002;99:2720-2725)

Introduction

In the past decade, resistance to the natural anticoagulant activated protein C (APC) has been identified as a common and important cause of venous thromboembolism (VTE), that is, deep venous thrombosis (DVT) or pulmonary embolism (PE). The most common cause of APC resistance is a mutation of factor V (Arg506Gln, factor V Leiden) at one of the cleavage sites for APC, present in approximately 5% of the US white population. Population-based case-control studies suggest that homozygosity for factor V Leiden carries a relative risk of incident VTE of approximately 3 to 8 and homozygosity carries a relative risk of 5.5 (95% CI, 2.45-12.5). Carriers of the HR2 haplotype otherwise were not at increased risk of VTE overall (OR = 1.05; 95% CI, 0.64-1.72), but double heterozygotes for HR2 and factor V Leiden carried an OR of idiopathic VTE of 16.3 (95% CI, 1.7-159) compared with noncarriers. Factor V antigen also was not associated with VTE overall, but for participants with the combination of high factor V antigen plus factor V Leiden the OR of idiopathic VTE was 11.5 (95% CI, 4.2-31.4). In the general population, APC resistance and factor V Leiden were important VTE risk factors; homozygosity for the HR2 haplotype may be a risk factor but was rare; otherwise, HR2 haplotype and factor V antigen were not risk factors except in carriers of factor V Leiden. (Blood. 2002;99:2720-2725)

Materials and methods

Study population and baseline assessments

The LITE study is a prospective study of VTE occurrence in 2 pooled, multicenter, longitudinal population-based cohort studies: the Atherosclerosis Risk in Communities (ARIC) study and the Cardiovascular Health Study (CHS). The LITE study design, methods, and VTE incidence rates have been described in detail elsewhere. In brief, 15,792 ARIC participants,
aged 45 to 64 years at baseline in 1987-1989, and 5201 CHS participants, aged 65 years or older at baseline in 1989-1990, were assessed for cardiovascular risk factors. An additional 687 African Americans were recruited to the CHS in 1992-1993. Blood was drawn from fasting participants in the morning in both studies, promptly centrifuged for 3000g for 10 minutes, and the plasma was stored in −70°C freezers. Up to 3 follow-up examinations were performed every 3 years in the ARIC study and up to 9 follow-up examinations were performed annually in the CHS. Blood was stored from both the baseline examination and 3 years later in both studies. Baseline cardiovascular risk factors included in this paper were measured comparably in ARIC and CHS, as described elsewhere and methods are not repeated here.

Nested case-control design

A nested case-control design was used to study prospective associations between VTE incidence and blood parameters measured in stored blood specimens. Potential cases of VTE were identified from baseline through September 1998. Hospital records were obtained and VTE events validated by 2 physicians as “definite DVT” (nearly always having a positive duplex ultrasound or a positive venogram), “probable DVT” (having a positive Doppler ultrasound or a positive impedance plethysmography), and “definite PE” (nearly always having ventilation-perfusion scans with multiple segmental or subsegmental mismatched defects or a positive pulmonary angiogram). Cases for this analysis included definite or probable DVT or definite PE. Cases were also classified as incident (no self-reported VTE history before baseline) or recurrent (self-reported VTE history before baseline) and idiopathic (no obvious cause) or secondary (associated with cancer, major trauma, surgery, marked immobility). From the ARIC study, 185 individuals with VTE were identified, 164 incident and 21 recurrent, 85 idiopathic and 100 secondary. Among 150 individuals with VTE events in the CHS, 120 were incident and 30 recurrent, 68 were idiopathic, and 82 secondary. Of the 335 events, 237 had venous thrombosis only, 52 had a PE only, and 46 had both. Of those with venous thrombosis only, 220 involved the veins of the legs, pelvis, or the inferior vena cava.

Controls were selected at random from the ARIC and CHS cohorts being followed. To facilitate selection, potential controls were first assigned follow-up times at random between 0 days and the maximum number of follow-up days that subjects could have participated in the study. Controls then were selected at a ratio of 2.1 per case. Frequency matched to the cases by age (5-year groupings), sex, race (African American, white), follow-up time (cases’ event date within 2 years of controls’ assigned date) and study (ARIC, CHS). This control selection process ensured that the set of potential controls included a random selection of individuals who could have been diagnosed with VTE (had it occurred) at the assigned follow-up time. Selection yielded 390 controls for the 185 incident cases in the ARIC study and 298 for the 150 incident cases in the CHS.

Laboratory methods

After selection of cases and controls, stored samples of DNA and plasma were retrieved from −70°C storage freezers. If baseline plasma samples were limited, previously thawed, or exhausted for a participant, a sample was retrieved from the plasma repository for the next visit (approximately 3 years after baseline); if neither sample was available it was considered missing. The percentages of ARIC subjects having plasma from baseline, the year 3 visit, or missing were, respectively, 65%, 25%, and 10%. The respective percentages for CHS plasma were 80%, 14%, and 6%. DNA was missing or permission to use it was not given for 8% of ARIC participants and 11% of CHS participants. For the factor V–related variables of interest in the present analysis, the percentage of missing samples did not significantly differ between cases and controls, between incident versus recurrent cases, between idiopathic versus secondary cases, or between DVT versus PE cases.

We detected the presence or absence of the factor V Leiden (1691G>A, Arg506Gln) mutation using standard methods. We identified the HR2 haplotype of the factor V gene by screening for the presence or absence of the R2 polymorphism, a 4070A>G transition in exon 13 of the factor V gene. A 703-bp fragment was amplified by polymerase chain reaction (PCR) and digested with the restriction enzyme RsaI, as previously described. Presence of the R2 allele is identified by digestion of the 703-bp fragment to fragments of 492 and 211-bp in size.

Results

Descriptive information and frequencies of factor V Leiden and HR2 haplotype

The overall samples of patients and controls at baseline were 45 years and older; 53% were women, and 76% were white. Approximately 14% of cases and 4% of controls carried factor V Leiden, but cases and controls had similar frequencies of the
HR2 haplotype (Table 1). Few African Americans carried factor V Leiden or the HR2 haplotype. Among white controls, 5% were heterozygous for factor V Leiden and 10% were heterozygous for HR2. Overall, only 5 participants (0.6% of 914) were heterozygous carriers of both mutations.

Prevalence of APC resistance and its relation with genotypes and other factors

The prevalence of APC resistance was 18.6% in cases and 12.9% in controls by the first-generation assay (APC-SR ≤ 2.57) and 14.6% in cases and 6.2% in controls by the modified assay (modified APC-SR ≤ 2.12). The prevalence of APC resistance by APC-SR was 79% among carriers of factor V Leiden and 10% among noncarriers. Using the modified APC-SR these prevalences were 98% and 2%, respectively, indicating near perfect sensitivity and specificity for factor V Leiden for modified APC-SR. The HR2 haplotype was not significantly (P > .05) associated with APC resistance.

APC-SR (continuous variable) was correlated positively at P < .05 with aPTT (r = 0.19) and was correlated negatively with protein C (r = –0.21), factor VII (r = –0.13), von Willebrand factor (r = –0.14), and factor VIII (r = –0.07). The mean APC-SR was higher (P < .05) in men (3.46) than women (3.24), in African Americans (3.44) than whites (3.31), and in current smokers (3.46) than never smokers (3.27), but did not differ by diabetes or hormone replacement status.

Factor V antigen levels and relation with genotypes and other factors

The mean ± SEM factor V antigen level was 17 ± 4.6 μg/mL in homozygous factor V Leiden carriers (n = 3), 16 ± 0.9 μg/mL in heterozygous carriers, and 13 ± 0.2 μg/mL in noncarriers (P = .03 for difference). There was no relation of factor V antigen levels with HR2 genotype (P = .28).

Factor V antigen was correlated positively at P < .05 with BMI (r = 0.22), factor VIII (r = 0.19), von Willebrand factor (r = 0.17), fibrinogen (r = 0.18), and low-density lipoprotein (LDL) cholesterol levels (r = 0.12), and was correlated negatively with high-density lipoprotein (HDL) cholesterol (r = –0.14) and alcohol intake (r = –0.12). The mean factor V level was higher (P < .005) in men (14.2 μg/mL) than women (13.0 μg/mL), and in female nonusers of hormonal replacement (13.4 μg/mL) than users (10.5 μg/mL), but did not differ by race or smoking or diabetes status.

Associations with VTE

All 3 participants who were homozygous for factor V Leiden had a VTE, and their OR using the Hardy-Weinberg equilibrium assumption was estimated to be 25 (95% CI, 10-66). Subsequently, homozygotes were pooled with the heterozygotes to compute the population-wide risk of carrying factor V Leiden. The occurrence of VTE, adjusted for age, was 3.67-fold higher in carriers of factor V Leiden than in noncarriers (Table 2). This OR was 3.69 in whites, 4.05 in ARIC, and 3.16 in CHS. The OR for factor V Leiden was about twice as high in participants with a recurrent VTE (OR = 5.79) than those with incident VTE (OR = 3.31 overall; 3.93 in ARIC and 2.36 in CHS). The OR was nearly 3 times as high in idiopathic VTE (OR = 5.91 overall; 6.16 in ARIC and 3.95 in CHS) versus secondary VTE (OR = 2.02). The OR for factor V Leiden was somewhat higher in those with DVT only (OR = 3.76) than in those with PE only (OR = 2.86), but CI’s overlapped. When adjusted for race, sex, BMI, and factor VIII level, as well as age, the overall OR was 3.56 (95% CI, 2.11-6.03), suggesting little confounding by these variables.

All 3 participants homozygous for HR2 had a VTE, and their OR was estimated to be 5.5 (95% CI, 2.45-12.47). However,
when heterozygous and homozygous carriers of HR2 were pooled, HR2 was not statistically significantly associated overall, or in any subgroups, with VTE occurrence (Table 2). Additional adjustment for race, sex, BMI, and factor VIII had no impact on the HR2 OR.

The patterns of association for APC resistance (Table 2), as expected, generally paralleled those for factor V Leiden. The age-adjusted ORs for APC resistance were larger for modified APC-SR (OR = 2.58, overall) than for APC-SR (OR = 1.54). Furthermore, considered together, APC resistance by modified APC-SR was associated independently with VTE, but APC resistance by standard APC-SR was not.

The association of VTE with percentiles of continuous APC-SR is shown in Table 3. Although most of the excess risk of VTE was related to an APC ratio in the “resistant” range, individuals with values in the lower end of the normal range (below quintile 2) also had somewhat elevated VTE risk. Additional adjustment for race, sex, BMI, and factor VIII attenuated the ORs for groupings of continuous APC-SR, but not for modified APC-SR (Table 3). After excluding participants with factor V Leiden, there was no association of continuous APC-SR with venous thrombosis (data not shown).

Factor V antigen levels in the highest quintile were associated (P < .05) with increased VTE occurrence adjusted for age (OR = 1.60 overall and even greater in recurrent and idiopathic subgroups; Table 2). The OR was particularly elevated for factor V antigen above the 95th percentile versus the first quintile (OR = 2.04), but multivariate adjustment attenuated the OR (OR = 1.84; Table 3). Six values for factor V antigen were high (> 132 μg/mL) in ARIC participants. When they were excluded, the overall age-adjusted VTE OR was reduced to 1.47 (95% CI, 0.94-2.29) for the highest versus lowest quintile and 1.61 (95% CI, 0.81-3.23) for the highest 5% versus the lowest quintile.

### Discussion

**Descriptive findings**

The frequency of factor V Leiden heterozygosity among population-based white controls in the LITE study (4%) was generally consistent with other studies,1,2,25 as was the virtual absence of factor V Leiden in heterozygous or homozygous carriers of HR2 were pooled, HR2 was not statistically significantly associated overall, or in any subgroups, with VTE occurrence (Table 2). Additional adjustment for race, sex, BMI, and factor VIII had no impact on the HR2 OR. The patterns of association for APC resistance (Table 2), as expected, generally paralleled those for factor V Leiden. The age-adjusted ORs for APC resistance were larger for modified APC-SR (OR = 2.58, overall) than for APC-SR (OR = 1.54). Furthermore, considered together, APC resistance by modified APC-SR was associated independently with VTE, but APC resistance by standard APC-SR was not.

The association of VTE with percentiles of continuous APC-SR is shown in Table 3. Although most of the excess risk of VTE was related to an APC ratio in the “resistant” range, individuals with values in the lower end of the normal range (below quintile 2) also had somewhat elevated VTE risk. Additional adjustment for race, sex, BMI, and factor VIII attenuated the ORs for groupings of continuous APC-SR, but not for modified APC-SR (Table 3). After excluding participants with factor V Leiden, there was no association of continuous APC-SR with venous thrombosis (data not shown).

Factor V antigen levels in the highest quintile were associated (P < .05) with increased VTE occurrence adjusted for age (OR = 1.60 overall and even greater in recurrent and idiopathic subgroups; Table 2). The OR was particularly elevated for factor V antigen above the 95th percentile versus the first quintile (OR = 2.04), but multivariate adjustment attenuated the OR (OR = 1.84; Table 3). Six values for factor V antigen were high (> 132 μg/mL) in ARIC participants. When they were excluded, the overall age-adjusted VTE OR was reduced to 1.47 (95% CI, 0.94-2.29) for the highest versus lowest quintile and 1.61 (95% CI, 0.81-3.23) for the highest 5% versus the lowest quintile.

### Interactions with factor V Leiden

The ORs of idiopathic VTE in relation to factor V Leiden and other factors jointly are shown in Table 4. Although both greater age and factor V Leiden increased the odds of VTE occurrence, there was no striking elevation of VTE odds in participants with both risk factors. This was also true for the combination of factor V Leiden and APC resistance. However, both HR2 and elevated factor V antigen were synergistic (ie, relative risks supra-additive24) with factor V Leiden. Although few people had these joint risk factors, the OR was 16.3 for double heterozygosity of factor V Leiden and HR2, compared to people with neither mutation, and was 11.5 for factor V Leiden plus a high factor V antigen level.

#### Table 3. Adjusted OR (95% CI) for VTE in relation to percentile of APC-SR and factor V antigen, LITE

<table>
<thead>
<tr>
<th>Percentiles</th>
<th>APC-SR* OR (95% CI)</th>
<th>Factor V antigen OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 5</td>
<td>1.66 (0.84-3.29)</td>
<td>1.0 (0.74-1.40)</td>
</tr>
<tr>
<td>5 to 20</td>
<td>1.46 (0.90-2.37)</td>
<td>1.12 (0.74-1.70)</td>
</tr>
<tr>
<td>20 to 40</td>
<td>1.22 (0.77-1.92)</td>
<td>1.61 (1.03-2.58)</td>
</tr>
<tr>
<td>40 to 60</td>
<td>1.15 (0.72-1.82)</td>
<td>2.09 (1.32-3.34)</td>
</tr>
<tr>
<td>60 to 80</td>
<td>1.08 (0.68-1.71)</td>
<td>2.46 (1.58-3.85)</td>
</tr>
<tr>
<td>Above 95</td>
<td>1.0‡</td>
<td>2.14 (1.44-3.20)</td>
</tr>
</tbody>
</table>

*Adjusted for age, race, sex, BMI, and factor VIII.
†Reference for ORs is lowest quintile.
‡Reference for ORs is highest quintile.

#### Table 4. Adjusted OR and 95% CI for idiopathic VTE in relation jointly to factor V Leiden and other factors, LITE

<table>
<thead>
<tr>
<th>Variable</th>
<th>Factor V Leiden*</th>
<th>No. of events</th>
<th>OR 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Younger than 65 y</td>
<td>No</td>
<td>58</td>
<td>1.00 Reference</td>
</tr>
<tr>
<td>65 y and older</td>
<td>No</td>
<td>52</td>
<td>1.69 0.84-3.41</td>
</tr>
<tr>
<td>Younger than 65 y</td>
<td>Yes</td>
<td>20</td>
<td>7.25 3.57-14.76</td>
</tr>
<tr>
<td>65 y and older</td>
<td>Yes</td>
<td>8</td>
<td>7.91 2.44-25.65</td>
</tr>
<tr>
<td>APC resistant by APC-SR</td>
<td>No</td>
<td>85</td>
<td>1.00 Reference</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>8</td>
<td>0.83 0.38-1.81</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>5</td>
<td>5.30 1.49-18.81</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>18</td>
<td>5.70 2.85-11.42</td>
</tr>
<tr>
<td>HR2*</td>
<td>No</td>
<td>98</td>
<td>1.00 Reference</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>10</td>
<td>1.11 0.54-2.25</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>24</td>
<td>5.29 2.90-9.64</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>3</td>
<td>16.33 1.68-159</td>
</tr>
</tbody>
</table>

Ag indicates antigen.
*Heterozygous or homozygous.
†Low factor V is in the lower 4 quintiles; high is in the upper quintile.
The frequency of heterozygosity for the HR2 haplotype among whites also was similar to other studies, but HR2 heterozygosity was infrequent among African Americans. In a separate LITE study report, we observed a higher risk of VTE among African Americans compared to whites, and given race differences in risk factors such as factor V Leiden, additional study of African American populations is needed.

The modified APC-SR assay, which incorporated predilution with factor V-deficient plasma, proved to be highly sensitive and specific for factor V Leiden, as has been previously reported. The standard APC-SR was less sensitive and specific for factor V Leiden. Regardless of method, APC resistance was not significantly influenced by HR2 haplotype. Previous studies on whether HR2 affects APC resistance have been inconsistent.

The standard APC-SR (continuous variable) was found to be correlated with several factors (aPTT, factor VIII, race, sex, smoking, and HDL cholesterol) as reported by others. Increased factor VIII, in particular, has been an increasingly recognized contributor to APC resistance. African Americans have higher factor VIII levels than whites, but paradoxically less APC resistance, presumably because factor V Leiden is rare among African Americans. APC-SR was shown here to be negatively correlated with von Willebrand factor, factor VII, and protein C. The protein C association with APC-SR is particularly noteworthy because it suggests that lower APC sensitivity may cause a compensatory rise in the protein C concentration.

There are few previous data on determinants of factor V antigen levels. Kamphuisen et al reported factor V antigen to be correlated positively with smoking and factor VIII. We corroborated the factor VIII correlation, but found no relation with smoking. We also observed higher levels of factor V antigen in men than women and in factor V Leiden carriers than noncarriers. This suggests a hypothesis that either APC resistance itself, or factors such as increased thrombin generation with subsequent platelet activation as a result of APC resistance, might increase the expression or release of factor V from platelets. There also were positive associations of factor V with von Willebrand factor, fibrinogen, and LDL cholesterol, and negative associations with alcohol intake and HDL cholesterol.

Associations with VTE

The OR of VTE in relation to factor V Leiden was similar in the LITE study to previous studies, and as might be expected for a genetic risk factor was greater in idiopathic than secondary events. Some investigators have reported that factor V Leiden is a stronger risk factor for DVT than PE. However, we found little evidence for this. We also did not corroborate a stronger association of factor V Leiden with VTE in older than in younger participants. Whether factor V Leiden is associated with recurrent events is somewhat controversial. We found factor V Leiden associated strongly with recurrent events. Recurrence here was defined from self-reported history at baseline; reanalysis based on evidence of prior VTE in the medical record gave similar results. Although the associations of factor V Leiden with incident and recurrent VTE are now becoming clear, ongoing clinical trials are required to define any role for long-term anticoagulation among heterozygotes with thrombosis.

As would be expected from its higher sensitivity and specificity for factor V Leiden, APC resistance measured by the modified APC-SR assay was a better marker of VTE risk than measured by the standard APC-SR assay. However, APC resistance by standard APC-SR did not predict idiopathic VTE after stratification for factor V Leiden. Thus, in contrast to the findings from the Leiden Thrombophilia Study, which reported that APC resistance was associated with VTE in the absence of factor V Leiden, our data do not support a role for measurement of APC-SR in addition to factor V Leiden. Reasons for this difference from the Leiden study are uncertain but could relate to our study having a smaller number of cases, an older and ethnically diverse population, or longer storage of plasma samples.

Occurrence of VTE has not been related consistently to the HR2 haplotype. We also found no increased risk for HR2 heterozygous carriers but HR2 homozygotes were estimated to be at approximately 5-fold increased risk of VTE. There also appeared to be synergy of HR2 with factor V Leiden for double heterozygotes, as was previously suggested. However, both the presence of homozygosity for HR2 or double heterozygosity for factor V Leiden and HR2 were very rare, so any clinical application of HR2 testing is questionable.

Elevated factor V antigen was associated positively with VTE incidence, although not statistically significantly after excluding 6 high values (> 132 μg/mL) or after adjusting for other risk factors. We are uncertain what accounted for the high factor V values; those participants’ values for BMI, lipids, fibrinogen, factor VIII, and von Willebrand factor were unremarkable. A high factor V also proved to be synergistic with factor V Leiden, with the joint relative risk being 11.5. The Leiden Thrombophilia Study also reported no overall association of VTE factor V antigen and possible synergism with factor V Leiden.

Study limitations

A strength of the LITE prospective study is that plasma samples for incident VTE cases, the large majority of all cases, were collected before the onset of VTE. The observed associations between VTE and nongenetic markers therefore should be less susceptible to bias than the associations reported by case-control studies. The LITE plasma samples were stored up to 12 years, which could have introduced random error and weakened associations. However, stability of numerous coagulation factors during long-term storage under similar conditions was recently demonstrated. Follow-up of cohort participants was high and VTE events were classified by standardized criteria. However, whether we ascertained all clinically recognized VTE depended on participants’ accurate reporting of hospitalizations and on their physicians’ diagnostic work-up of suspected VTE events. Of course, clinically unrecognized VTE were missed, but should have been rare enough among controls to introduce little bias.

Conclusion

In this general population study, APC resistance and factor V Leiden were important VTE risk factors; homozygosity for the HR2 haplotype may be a risk factor but was rare; otherwise, HR2 haplotype and factor V antigen were not risk factors except in carriers of factor V Leiden. Any role of clinical testing for factor V–related factors among patients with thrombosis remains to be fully defined, although the findings here provide important new data for consideration of this question.

Acknowledgments

The authors thank the staff and participants of the ARIC and CHS projects for long-term contributions and Lu Wang and Laura Kemmis for technical assistance.
References


A prospective study of venous thromboembolism in relation to factor V Leiden and related factors

Aaron R. Folsom, Mary Cushman, Michael Y. Tsai, Nena Aleksic, Susan R. Heckbert, Lori L. Boland, Albert W. Tsai, N. David Yanez and Wayne D. Rosamond

Updated information and services can be found at: http://www.bloodjournal.org/content/99/8/2720.full.html

Articles on similar topics can be found in the following Blood collections

- Clinical Trials and Observations (4514 articles)
- Hemostasis, Thrombosis, and Vascular Biology (2485 articles)

Information about reproducing this article in parts or in its entirety may be found online at: http://www.bloodjournal.org/site/misc/rights.xhtml#repub_requests

Information about ordering reprints may be found online at: http://www.bloodjournal.org/site/misc/rights.xhtml#reprints

Information about subscriptions and ASH membership may be found online at: http://www.bloodjournal.org/site/subscriptions/index.xhtml