Concise Communication

Shorter Survival of SDF1-3’Al3'A Homozygotes Linked to CD4+ T Cell Decrease in Advanced Human Immunodeficiency Virus Type 1 Infection

Andrea Brambilla,1,a Chiara Villa,1 GianPaolo Rizzardi,3 Fabrizio Veglia,2 Silvia Ghezzi,1 Adriano Lazzarin,4 Marco Cusini,3 Simona Muratori,3 Elena Santagostino,6 Alessandro Gringeri,8 Leslie G. Louie,7 Haynes W. Sheppard,8 Guido Poli,1 Nelson L. Michael,9 Giuseppe Pantaleo,1 and Elisa Vicenzi1

The SDF-1 3’A allelic polymorphism has been reported to influence either positively or negatively the progression of human immunodeficiency virus type 1 (HIV-1) disease. Therefore, the SDF-1 genotype of 729 HIV-1-infected individuals pooled from 3 distinct cohorts was determined. A statistically nonsignificant association between the SDF1-3’A/3’A genotype and accelerated disease progression was evident among seroconverters (n = 319), but a striking correlation of decreased survival after either diagnosis of AIDS according to the 1993 definition or loss of CD4+ T cell counts <200 was observed. The relative hazards for SDF1-3’A homozygotes, compared with heterozygotes and wild-type homozygotes were 2.16 (P = .0047), for time from diagnosis according to the 1993 Centers for Disease Control and Prevention AIDS case definition (AIDS-’93) to death, and 3.43 (P = .0001), for time from CD4+ T cells <200 to death. Because no difference in survival was observed after diagnosis according to AIDS-’87, the association of the SDF1-3’A/3’A genotype with the accelerated progression of late-stage HIV-1 disease appears to be explained for the most part by the loss of CD4+ T lymphocytes.

An increasing number of genetic polymorphisms of che-
In the present study, we investigated the association of SDF1 genotype on disease progression and survival in 729 seropositive patients enrolled in 3 distinct cohorts.

Methods

Study cohorts. The San Francisco Men’s Health Study is a population-based cohort of 1,034 single, mostly white men enrolled in San Francisco showing the highest AIDS incidence in 1984 and followed every 6 months until 1995. Genotyping was available for 424 individuals, of whom 377 were seroprevalents. In addition, 249 infected individuals from the Swiss HIV Cohort (SHC) and 56 long-term nonprogressors (LTNPs) of the Milan cohort were included in the study.

The individuals were followed for a median of 8.23, 7.61, and 12 years in the SFMHS cohort, respectively, and their median ages were 34, 25, and 23.5 years. There were 1, 83, and 26 intravenous drug users; 416, 95, and 15 male homosexuals; 0, 69, and 3 heterosexuals, and 0, 2, and 12 hemophiliacs in the SFMHS, the SHC, and the Milan cohorts, respectively. There were 661 whites, 22 Hispanics, and 26 blacks.

The following end points were considered for the analyses: (1) CD4 T cell counts <200 cells/µL; (2) the AIDS-87 case definition [5]; (3) the 1993 CDC AIDS case definition (AIDS-93), adding the loss of CD4 T lymphocytes <200 cells/µL to the AIDS defining conditions of AIDS-87; and (4) death.

Plasma HIV-1 RNA concentrations were available from 674 subjects [6, 7]. Viral isolation and phenotyping were performed as described elsewhere [8, 9].

CRR5 and CCR2 genotyping. The CCR5 and CCR2 genotypes were determined as described elsewhere for the SFMHS cohort [6, 8] and for the SHC and Milan cohorts [7, 10].

SDF1 genotyping. Subjects from the SFMHS cohort were genotyped by polymerase chain reaction (PCR)–restriction fragment length polymorphism (RFLP), as reported elsewhere [2]. For the SHC and Milan cohorts, an allelic discrimination assay based on the allele-specific degradation of 2 internally quenched fluorescent probes during the PCR reaction was used [11]. Wildtype-specific probe sequence was 5’-(FAM) AGG CAG ACC CGG CTC CCA TG (TAMRA)-3’, where FAM is 6-carboxyfluorescein, and TAMRA is 6-carboxytetramethylrhodamine; the SDF1-3’A–specific probe sequence was 5’-(TET) AAG AGG CAG ACC TGG CTC CCA TGT (TAMRA)-3’, where TET is tetrachloro-6-carboxy-fluorescein. The primer sequences were (sense) 5’-CCA GTC ACC CTC GGC AAA G-3’ and (antisense) 5’-TGC CTC AGC TCA GGG TAG C-3’. The PCR reaction was performed according to the manufacturer’s instructions on an ABI PRISM 7700 Sequence Detector System (PE Biosystems, Foster City, CA) and the dedicated TaqMan PCR Core Reagent Kit (PE Biosystems, Foster City, CA); the 1/1 specific probe (200 nM), the 30 A–specific probe (100 nM), the 2 primers (0.25 mM each), and 100–200 ng of DNA were extracted from peripheral blood mononuclear cells. Some test samples, plus all samples without a clear-cut signal level in at least 1 of the 2 fluorescent signals, were also characterized by the published PCR-RFLP method [2] as control; all of the 80 doubly tested genotype assignments were concordant.

Results

SDF1 genotype distribution. Twenty-two (5%) SFMHS participants were homozygous for SDF1-3’A/3’A, whereas 135 (32%) were heterozygous, and 267 (63%) were SDF1-1/+. In the SHC, SDF1-3’A homozygosity was found in 12 (4.8%) subjects and heterozygosity in 76 (30.5%) subjects, whereas 161 subjects were SDF1 +/+. In the Milan cohort, the frequencies were 3 (5%), 26 (46%), and 27 (48%) for S’A/3’, 3’, and +/+, respectively. Each cohort and the grouped study population were in Hardy-Weinberg equilibrium (P values ranging from .304 to .439; χ2 test). Genotype distribution and the effects of other genetic polymorphisms involved in HIV disease progression (CCR5-Δ32 and CCR2-64I) of these cohorts have been published elsewhere [6–8, 10].

SDF1 genotype and progression to AIDS. All the statistics were stratified by cohort, to correct for potential hidden confounding factors. Kaplan-Meier survival curves of the combined cohorts with the results of univariate Cox proportional hazards analyses are shown in table 1. Because the same pattern of progression was consistently observed in both SDF1-1/+ and SDF1-1/3’A individuals, these two groups were analyzed together. A modest increase in the relative hazard (RH) for SDF1-3’A/3’A individuals was observed when AIDS-87 and death were considered as end points, but the differences were not significant. When the analyses were repeated exclusively on the seroconverter subset (table 1), as suggested elsewhere [12], the RH of the homozygous genotype on the various end points was stronger, although still not significant (figure 1).

All the analyses were repeated after adjustment for CCR5 and CCR2 genotypes, age, risk factor, race, therapy, and seroincidence status (i.e., seroprevalents vs. seroconverters). After these adjustments, the overall association of SDF1-3’A/3’A on disease progression did not change (table 1), although a further increase of the RH of SDF1-3’A/3’A seroconverters was noted.

SDF1 genotype and survival after AIDS diagnosis. We next tested whether the SDF1 genotype could influence the late stages of infection, by analyzing survival after diagnosis of AIDS according to either AIDS-87, AIDS-93, or loss of circulating CD4+ T lymphocytes <200 cells/µL. A graduation of survival reduction was observed for time to death after AIDS-87, AIDS-93, and CD4+ T cell counts <200, with RH values of 1.19 (P = .522), 2.21 (P = .0034), and 3.18 (P = .0003), respectively (table 1 and figure 1). Thus, RH values increased and gained significance shifting from AIDS-87 to CD4+ T cell
counts <200. Adjusting the analysis for the same confounding factors above described did not alter the results (table 1).

**SDF1 genotype and viral phenotype.** Because SDF-1 binds to CXCR4, we tested whether the SDF1-3'A genotype could influence viral evolution from nonsyncytium-inducing (NSI) to syncytium-inducing (SI) strains (i.e., from CCR5 to CXCR4 usage). Ninety-three NSI viruses versus 49 SI were isolated in a sample of 142 SDF1-+/+ patients. Among 70 SDF1-+1A patients, 48 had NSI and 22 had SI viruses, whereas among 15 SDF1-3'A/3'A patients, 11 had NSI and 4 had SI viruses (data not shown). The differences among these frequencies are not significant ($P = .780$, $\chi^2$ test), which suggests that the SDF1 genotype did not influence the phenotype of HIV-1 primary isolates.

**SDF1 genotype and viremia.** A single plasma HIV-1 RNA level determination was available for each subject; the median viral loads were 30,200, 23,174, and 5688 copies of HIV-1 RNA/mL for the SFMHS, the SHC, and the Milan cohorts, respectively. We compared the mean log transformed values of viremia whose design mitigated confounding variables [3], the association with accelerated progression was clearly visible. The recently reported role of race-specific CCR5 haplotypes on HIV-1 pathogenesis further underscores the importance of controlling for confounding factors [13].

We observed a strong association between the SDF1-3'A/3'A genotype and survival reduction after either AIDS-'93 or CD4+ T cell counts <200. In contrast, all the SDF1 genotypes were indistinguishable with respect to survival after AIDS-'87. We interpret this association as a linkage between the SDF1-3'A/3'A genotype and the progressive immunodeficiency occurring after erosion of CD4+ T lymphocytes <200 cells/µL, resulting in increasing incidence of opportunistic infections and tumors.

### Table 1. Effects of the SDF1-3'A/3'A genotype on progression to AIDS and from AIDS to death in Cox proportional hazard analyses.

<table>
<thead>
<tr>
<th>End point</th>
<th>SDF1-3'A/3'A vs. 3'A+/+</th>
<th>SDF1-3'A/3'A vs. 3'A+/+</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$n$</td>
<td>Events</td>
</tr>
<tr>
<td>CD4+/200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>692</td>
<td>314</td>
</tr>
<tr>
<td>Seroconverters</td>
<td>315</td>
<td>99</td>
</tr>
<tr>
<td>AIDS-'93</td>
<td>699</td>
<td>380</td>
</tr>
<tr>
<td>Seroconverters</td>
<td>318</td>
<td>114</td>
</tr>
<tr>
<td>AIDS-'87</td>
<td>705</td>
<td>311</td>
</tr>
<tr>
<td>Seroconverters</td>
<td>319</td>
<td>71</td>
</tr>
<tr>
<td>Death</td>
<td>711</td>
<td>273</td>
</tr>
<tr>
<td>Seroconverters</td>
<td>319</td>
<td>49</td>
</tr>
<tr>
<td>Time to death since AIDS-'87</td>
<td>309</td>
<td>261</td>
</tr>
<tr>
<td>AIDS-'93</td>
<td>374</td>
<td>259</td>
</tr>
<tr>
<td>Seroconverters</td>
<td>315</td>
<td>99</td>
</tr>
<tr>
<td>CD4+ ≤200</td>
<td>314</td>
<td>211</td>
</tr>
</tbody>
</table>

Note: AIDs-'87, 1987 Centers for Disease Control and Prevention (CDC) AIDS case definition; AIDS-'93, 1993 CDC AIDS case definition; CI, 95% confidence interval; RH, relative hazard. a Adjusted for CCR5 and CCR2 genotypes, age, risk factor, race (categorized as whites vs. other races), therapy, and seroincidence status (only for the first 4 end points and for the entire data set).
The thin line represents SDF1-3, the hazard. AIDS-‘93, 1993 CDC AIDS case definition; RH, relative hazard. 1987 Centers for Disease Control and Prevention (CDC) AIDS case definition; AIDS-‘87, the Cox proportional-hazards model (univariate test), with data stratified by cohort. Summary statistics are shown in table 1. AIDS-‘87, the expanded surveillance case definition for AIDS among adolescents and adults. MMWR Morb Mortal Wkly Rep 1992;41:1–19.

In support of this interpretation, HIV disease progression in seroconverters with peripheral CD4+ T cell counts >200 cells/μL was not significantly accelerated (RH = 1.65; P = .282). When a multivariate analysis with stepwise selections of the variables was performed, only the SDF1-3A/3A genotype was identified as a prognosticator of disease progression after AIDS-‘93 or CD4+ T cell counts <200 (P = .0003 and P = .0006, respectively), whereas other strong predictors of progression, such as plasma HIV RNA and viral phenotype, were forced out of the model.

Unlike CCR5-Δ32, the biological correlates of the SDF1-3A/3A genotypes are currently unknown. Since SDF-1 is the unique ligand of CXCR4, it can be speculated that an altered expression consequent to the recessive genotype could influence the evolution of HIV quasi species in vivo by changing the rate of NSI/SI viral variants. In this regard, we and others [14] have observed that CCR2-64I, both in heterozygotic and homozygotic configuration, was positively correlated to a predominance of SI over NSI variants in 2 (SFMC and Milan cohorts) of the 3 cohorts here studied (authors’ unpublished data). In contrast, no correlation was observed between SDF1 genotypes and prevalence of SI/NSI primary isolates, which confirms previous reports [10, 15]. Because immunological parameters, including CD4+ T cell counts and concentrations of soluble cytokine receptors and neopterin, are reported to be stronger predictors of disease progression than viremia in advanced infection [16], we believe that the influence of the SDF1-3A allelic variant on disease progression is more likely related to the immune mechanisms responsible for, or affected by, CD4+ T cell depletion than to viral replication per se.

Figure 1. SDF1-3A/3A genotype and time from AIDS to death. The thick line represents SDF1-+/+ or SDF1-+3A subjects, and the thin line represents SDF1-3A/3A subjects. P values were based on the Cox proportional-hazards model (univariate test), with data stratified by cohort. Summary statistics are shown in table 1. AIDS-‘87, 1987 Centers for Disease Control and Prevention (CDC) AIDS case definition; AIDS-‘93, 1993 CDC AIDS case definition; RH, relative hazard.

References

14. van Rij RP, de Roda Husman AM, Brouwer M, Goudsmit J, Coutinho RA, Schuitemaker H. Role of CCR2 genotype in the clinical course of syn-
cytium-inducing (SI) or non-SI human immunodeficiency virus type 1 infection and in the time to conversion to SI virus variants. J Infect Dis 1998;178:1806–11.
