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Naive T lymphocytes and recent thymic emigrants are associated with HIV-1 disease history in French adolescents and young adults infected in the perinatal period: the ANRS-EP38-IMMIP Study

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40-word summary: In youths infected with HIV during the perinatal period, CD4_N and CD4_{RTe} percentages were positively correlated with both CD4 T-cell count and past and current HIV replication, demonstrating the persistence of high-level thymic activity in long-term infection.

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Background: Children born at the start of the HIV epidemic and infected during the perinatal period are now young adults living with the virus. Naive T-lymphocyte restoration is essential for the maintenance of a diverse TCR repertoire and for immunity to pathogens.

Methods: The ANRS-EP38-IMMIP study included 93 patients infected with HIV-1 during the perinatal period. Naive CD4 (CD4_N) and CD8 (CD8_N) T lymphocytes and CD4 recent thymic emigrants (CD4_{RTE}) were quantified in the peripheral blood by flow cytometry. Wilcoxon tests, Pearson's correlation coefficients and linear regressions were used to study their associations with HIV disease parameters.

Results: Median (IQR) CD4_N, CD8_N and CD4_{RTE} percentages were 56% (44-64), 31% (22-44) and 79% (74-83), respectively. The three T-lymphocyte subsets were positively correlated with CD4 T-cell count. Patients aviremic at the time of the study tended to have a lower CD4_N percentage (55% vs. 58%, $P=0.10$), had a significantly higher CD8_N percentage (39% vs. 22%, $P<0.0001$), and a significantly lower CD4_{RTE} percentage (77% vs. 81%, $P=0.003$) than viremic patients. In aviremic patients, CD4_N percentages were positively associated with cumulative viremia over the last 10 years ($r=0.335$, $P=0.01$) and were significantly higher in patients harboring X4R5 viruses than in those harboring R5 viruses (61 vs. 44%, $P=0.001$).

Conclusion: After at least 15 years of HIV infection, perinatally infected youths had preserved CD4_N and CD4_{RTE} levels. This persistence of high levels of thymic activity potentially compensating for the deleterious effects of current and past HIV replication is remarkable.

Introduction

The first generation of patients infected with HIV-1 during the perinatal period has now reached adolescence or adulthood [1-2]. Pediatric HIV infection differs from infection during adulthood in terms of clinical progression, pathophysiology, response to treatment, and the occurrence of viral replication during immune system development [2-3]. Adolescence may be associated with poorer compliance with treatment in some patients, and physiological changes during puberty may affect the immune system [4]. The current immune and virological status of youths perinatally infected with HIV and their covariates have been the subject of limited investigations. The restoration and maintenance of the naive T-lymphocyte compartment is of importance for the future of these individuals, as it is directly associated with the diversity of the T-cell receptor (TCR) repertoire and critical for immunity to foreign antigens [5]. Previous pediatric studies have shown that CD4 T-lymphocyte recovery is driven principally by the *de novo* production of naive T lymphocytes in the thymus, and that it declines with age and with HIV infection [6-7].

Our aim, within the ANRS-EP38-IMMIP study, was to provide more detailed knowledge of the pathophysiological characteristics of youths, 15 years or more after perinatal infection. We previously reported that blood cell-associated HIV-DNA levels in these youths, aged 15-24 years, were similar to those in infected adults. However, contrary to findings for adults, we found no negative correlation between HIV-DNA level and CD4 T-cell counts in patients with suppressed viral replication [8]. This pattern of immunovirological equilibrium was observed in children and may result from sustained naive CD4 T-lymphocyte production by the thymus. We now report on the levels of naive CD4 (CD4_N) and CD8 (CD8_N) T lymphocytes, and CD4 recent thymic emigrants (CD4_{RTE}) in the HIV-infected youths included in the ANRS-EP38-IMMIP study, and on the HIV disease factors associated with these three T-lymphocyte subsets.

Patients and methods

Patients

The characteristics of the 93 HIV-infected youths included in the ANRS-EP38-IMMIP are presented in Table 1 for the aviremic and viremic groups. The study was approved by the local ethics committees. All patients, and their legal guardians for those under 18 years of age, received written information and signed an informed consent form. The inclusion criteria were (1) HIV-1 infection following vertical transmission, (2) aged over 15 years, (3) no change in treatment status (treated or untreated) during the previous six months, and (4) introduction of care for HIV infection before 1996, to ensure that all patients had similar access to HAART. A single 25 ml blood sample was taken for biological evaluations.

T-lymphocyte phenotyping

CD4 and CD8 T-lymphocyte phenotypes were determined on fresh whole blood for 82 patients, using combinations of the following antibodies: CD28-FITC, CD4-RD1, CD45RA-ECD, CD45RO-ECD, CD62L-PC5, CD27-PC5, CD4-PC7, and CD8-PC7 (Beckman Coulter, Villepinte, France). Data were collected on an FC500 cytometer and analyzed with CXP software (Beckman Coulter). CD4_N levels were defined as the percentage of CD4 T lymphocytes that were CD45RA⁺CD62L⁺, CD8_N levels as the percentage of CD8 T lymphocytes that were CD45RO⁻CD28⁺CD27⁺. For 57 patients, frozen PBMCs were available for the quantification of CD4 _{RTE}, with Live-Dead-Aqua (Life Technologies, Saint-Aubin, France) labeling of dead cells, and the following antibodies: CD3-ECD and CD31-FITC (Beckman Coulter), CD4-APC-eFluor780 (e-bioscience, Paris, France), CD45RA-V450 and CD197-PC7 (BD Biosciences, Rungis, France). Data were collected on an LSR II cytometer (BD Biosciences) and analyzed with FlowJo software (Treestar, Ashland, USA). CD4 _{RTE} levels were defined as the percentage of naive CD45RA⁺CCR7⁺CD4⁺ T lymphocytes positive for CD31.

Virological assays

HIV-1 reverse transcriptase (RT) and V3 Env sequences were obtained from blood cell HIV-DNA as previously described (<http://www.hivfrenchresistance.org/>). HIV-1 B and non-B subtypes were defined by phylogenetic analysis (<http://www.hiv-web.lanl.gov>). HIV-1 coreceptor usage was determined with the SVMGeno2pheno algorithm, with a 5.75% false positive rate [9]. HIV-RNA was quantified at the clinical sites, whereas HIV-DNA was quantified at a central laboratory, by real-time PCR with the Generic HIV-DNA Cell kit (Biocentric, Bandol, France) [8]. Serological tests for CMV were carried out on frozen plasma, with the CMV IgG Liaison II kit (Diasorin, Antony, France).

Statistical analysis

A full description of study variables has been provided elsewhere [8]. We studied univariate associations between T-lymphocyte subsets and variables defining current and past HIV disease, using the Wilcoxon test for categorical variables, and Pearson's correlation coefficients for continuous variables. Analyses were stratified on the basis of plasma HIV-RNA detection, using a cutoff value of 80 HIV-RNA copies/ml to define aviremic and viremic patients. Multivariate analyses were performed by linear regression. Separate models were built for aviremic and viremic patients, due to interactions between plasma HIV-RNA detection and variables describing HIV disease history (data not shown). For each dependent variable, one full model was adjusted for non collinear variables associated with the dependent variable in univariate analysis at $P < 0.20$. Age, as exposure factor of interest was systematically included in all models, as was current HIV-RNA level for viremic patients, whatever the P -value. Economical models including only variables with P values < 0.05 gave similar results, supporting the stability of analyses (data not shown). Variables non included in model because of collinearity are indicated in tables footnotes. Analyses were conducted with SAS statistical software (version 9.2). $P < 0.05$ defined statistical significance.

Results

CD4_N, CD8_N, and CD4_{RTE} T-lymphocyte levels differ in their association with current viral replication

Median percentages were 56% for CD4_N (interquartile range, [IQR], 44-64%), and 31% for CD8_N (IQR, 22-44%). Patients who were aviremic at the time of the study tended to have a lower CD4_N percentage (55% vs. 58%, $P=0.10$), and had a significantly higher CD8_N percentage (39% vs. 22%, $P<0.0001$), than viremic patients (Figure 1A, 1B). Naive T lymphocytes may be generated by the thymus or by peripheral proliferation. We investigated their origin by quantifying a correlate of thymic activity: the percentage of CD31⁺ CD4_{RTE} among naive CD4 T lymphocytes [10]. The median CD4_{RTE} percentage was 79% (IQR, 74-83%). Aviremic patients had a significantly lower CD4_{RTE} percentage than viremic patients (77% vs. 81%, $P=0.003$, Figure 1C). Thus, despite their shared developmental pathway, CD4_N, CD8_N and CD4_{RTE} naive T lymphocytes are differentially associated with current HIV replication.

Associations between CD4_N, CD8_N, and CD4_{RTE} T-lymphocyte levels and HIV disease history in aviremic patients

CD4_N, CD8_N and CD4_{RTE} percentages were positively correlated with CD4 T-cell count in aviremic patients (CD4_N $r=0.431$, $P=0.001$; CD8_N: $r=0.463$, $P=0.0007$; CD4_{RTE}: $r=0.520$, $P=0.0007$, Figure 1G-I), and with the CD4 T-cell percentage and CD4/CD8 ratio (Table 2). CD4_N and CD8_N percentages were positively correlated with each other ($r=0.607$, $P<0.0001$, Figure 1D), and were not correlated with CD4_{RTE} percentage (CD4_N: $r=0.278$, $P=0.12$; CD8_N: $r=0.226$, $P=0.18$, Figure 1E-F). None of the three T-lymphocyte subsets was associated with ethnicity, HIV subtype, CDC stage, age at the time of the study, age at the time of nadir CD4 T-cell percentage, or age at the initiation of first HAART (Table 2).

CD4_N percentage was positively correlated with cumulative viremia over the last 10 years ($r=0.335$, $P=0.01$). It also tended to be positively correlated with HIV-DNA level in PBMCs, and negatively correlated with the duration of the last period during which plasma HIV-RNA level was below 500 copies/ml (Table 2). Patients harboring X4R5 viruses had a significantly higher CD4_N percentage than patients harboring R5 viruses (medians: 44% vs. 61%, $P=0.001$). CD4_N percentage was not associated with sex, CMV seropositivity, nadir CD4 T-cell percentage, or the time for which CD4 T-cell percentage was below 15% during the lifetime of the patient (Table 2).

CD8_N percentage was significantly higher in female than in male patients (medians: 45% vs. 33%, respectively, $P=0.01$), and was significantly higher in CMV-seronegative patients than in CMV-seropositive patients (medians: 45% vs. 31%, respectively, $P=0.0001$). There was a trend towards a higher CD8_N percentage in patients with X4R5 viruses than in those with R5 viruses (medians: 45% vs. 35%, respectively $P=0.10$), and towards a negative correlation with the cumulative duration of HAART over the last 10 years ($r=-0.263$, $P=0.06$). CD8_N percentage was not correlated with past HIV-RNA levels or past immunosuppression (Table 2).

CD4_{RTE} percentage was higher in female than in male patients (79% vs. 73%, respectively, $P=0.002$), and CMV-seropositive patients tended to have a lower CD4_{RTE} percentage than CMV-seronegative patients (74% vs. 79%, $P=0.11$, Table 2). CD4_{RTE} percentage was positively correlated with nadir CD4 T-cell percentage and negatively correlated with the time for which CD4 T-cell percentage was below 15% during the patient's lifetime ($r=0.456$, $P=0.004$, and $r=-0.446$, $P=0.004$, respectively). CD4_{RTE} percentage was not associated with past HIV-RNA levels or HIV coreceptor usage (Table 2).

In multivariate analysis, CD4_N percentage was independently associated with CD4 T-cell count, X4 coreceptor usage and tended to be associated with cumulative viremia over the

last 10 years, after adjustment for age and CDC stage (Table 2). CD8_N percentage was independently associated with coreceptor usage and sex, and tended to be associated with CD4 T-cell count after adjustment for age, CMV serostatus and cumulative duration of HAART over the last 10 years. CD4_{RTE} percentage was independently associated with CD4 T-cell count, sex, and time for which CD4 T-cell percentage was below 15% during the patient's lifetime, after adjustment for age and CMV serostatus.

Associations between CD4_N, CD8_N, and CD4_{RTE} T-lymphocyte levels and HIV disease history in viremic patients

In viremic patients, CD4_N and CD8_N percentages were directly correlated with CD4 T-cell count ($r=0.393$, $P=0.04$ and $r=0.749$, $P<0.0001$, respectively, Figure 1G-H), and with each other ($r=0.435$, $P=0.02$, Figure 1D). CD4_N and CD8_N percentages were not correlated with plasma HIV-RNA level ($r=-0.021$, $P=0.91$ and $r=-0.285$, $P=0.13$, respectively). CD4_N percentage was not associated with demographic factors, viral characteristics or past HIV disease parameters (Table 3). CD8_N percentage was associated with CMV serostatus (medians: 27% vs. 20% in seronegative and seropositive patients, $P=0.03$), and negatively correlated with cumulative viremia over the last 10 years ($r=-0.382$, $P=0.04$), and HIV-DNA level ($r=-0.397$, $P=0.04$). CD4_{RTE} percentage was positively correlated with CD4_N percentage ($r=0.762$, $P=0.0006$, Figure 1E), but not with CD8_N percentage ($r=0.132$, $P=0.64$, Figure 1F). It was not correlated with CD4 T-cell count ($r=-0.032$, $P=0.90$, Figure 1H), plasma HIV-RNA level ($r=-0.125$, $P=0.62$) or the other study variables.

In multivariate analysis, both CD4_N and the CD8_N percentages were independently associated only with CD4 T-cell count (Table 3). In an alternative model, the CD8_N percentage was associated only with CD4 T-cell count after adjustment for age at nadir CD4 T-cell %, cumulative viremia and CMV seropositivity (data not shown).

Discussion

We found that, 15 or more years after perinatal infection, naive CD4 T-lymphocyte levels and thymic activity were preserved and positively correlated with current CD4 T-cell count. High levels of viral replication and/or viral cytopathogenicity over the patient's lifetime were associated with higher levels of naive CD4 T lymphocytes at the time of the study.

The CD4_N percentages of our study population were in the range reported for uninfected individuals, corresponding to half to two thirds of total CD4 T lymphocytes [11-12]. CD4_{RTE} values were also similar to those reported for healthy young adults [13]. Our results extend those of a previous study on 20 perinatally infected youths on suppressive HAART, which reported normal levels of CD4 T-lymphocyte subsets and thymic activity [12]. CD8_N T-lymphocyte percentages were slightly lower than those reported for healthy young adults in our aviremic patients and were lower still in viremic patients [14]. The different patterns of CD4 and CD8 T-lymphocyte restoration reflect the more robust expansion of memory CD8 than of memory CD4 T lymphocytes in response to HIV replication, chemotherapy-induced lymphodepletion and aging [6, 15-16].

CD4_{RTE} percentage was directly correlated with total CD4 T-lymphocyte count, as were the CD4_N and CD8_N percentages. In patients infected during adulthood, immune restoration involves both thymus-driven T-lymphocyte production and homeostatic proliferative expansion, and the failure of CD4 T-cell restoration despite prolonged viral suppression is associated with defective thymus function [17-18]. Two of the 93 patients included in the ANRS-EP38-IMMIP study had current CD4 T-cell counts below 350 cells/ μ l, despite being aviremic. One patient had recently experienced viral blips, whereas the other had remained continuously aviremic for more than six years and was, thus, the only patient that could have been classified as a "low CD4 responder" [18]. Overall, our results highlight

the active role of the thymus in both qualitative and quantitative immune restoration in the patients studied.

One key finding of this study was that, in patients in which HIV replication was suppressed at the time of the study, higher CD4_N levels were associated with higher levels of viral replication in the previous 10 years. Furthermore, there was a trend towards higher CD4_N percentages in aviremic than in viremic patients. The results are expressed as percentages, and this association may therefore reflect either an increase in the production of naive T lymphocytes or higher levels of memory CD4 T-lymphocyte destruction in the presence of viral replication. In this second case, higher levels of viral replication would be associated with a higher CD4_N percentage and a lower CD4 T-cell count, and we would expect a negative correlation between CD4_N and CD4 T-cell count to be observed. By contrast, CD4_N percentage and CD4 T-cell count were positively correlated. Thus, the positive correlation between CD4_N percentage and cumulative viremia probably reflects higher levels of thymic output during previous periods of HIV replication. Indeed, high levels of thymic activity have been associated with high HIV-RNA and HIV-DNA levels in pediatric patients on HAART [19-20]. A positive correlation between blood HIV-DNA and TREC levels has been reported in children with treatment-induced viral suppression [21]. These findings have been interpreted as indicating that *de novo* T-lymphocyte production by the thymus is a homeostatic response to naive CD4 T-lymphocyte destruction and/or recruitment to the memory compartment driven by HIV replication. Our results are entirely consistent with this explanation and extend observations on children by showing the cumulative effect of viral replication on CD4_N T-lymphocyte levels 15 or more years after infection.

Among patients with suppressed viral replication, CD4_N and CD8_N percentages were higher in patients harboring X4R5 viruses than in those with R5 viruses. This association is

counterintuitive, as X4R5 viruses infect thymocytes and CD4_N T lymphocytes more efficiently than R5 viruses, because of the more widespread expression of CXCR4 on these cells [17]. Given that these differences were observed only in aviremic patients, the detection of X4R5 viruses by cell-associated HIV-DNA sequencing of archived virus may reflect past events, such as deeper immunosuppression associated with higher levels of viral replication, and/or infection with more cytopathogenic viruses [22]. However, potent peripheral immune restoration has been observed in children with severe immunosuppression at treatment initiation [23-25], and the association between CD4_N percentage and viral tropism is consistent with that between CD4_N percentage and cumulative viremia.

CD4_{RTE} percentage was higher in viremic than in aviremic patients. This association may reflect the confounding effect of disease severity. However, viremic and aviremic youths did not differ in terms of previous occurrence of CDC stage C events, nadir CD4 T-cell percentage, or age at first HAART initiation (data not shown). In patients with active viral replication, CD4_{RTE} levels may increase because these cells are more resistant to HIV infection than their CD31-negative counterparts [26-27]. Finally, this association may simply reflect an increase in thymic activity to maintain T-cell homeostasis in the presence of the virus, as discussed previously. In untreated adults, several studies have shown that active thymopoiesis occurs during the early asymptomatic phase of HIV infection, at levels above those in uninfected controls [28-30]. In the early HAART period, CD4_N T-lymphocyte reconstitution was reported in children with a partially reduced viral load [19, 31-32]. Overall, our data suggest that thymic activity compensates for the destructive effect of viral replication, even after childhood. This result and the lack of correlation between age and CD4_{RTE} percentage contrast with the decline of blood thymic excision circles reported in uninfected teenagers and young adults [33]. Importantly, in patients with suppressed viral replication at the time of the study, CD4_{RTE} levels were negatively correlated with the

duration of severe immunosuppression (i.e., a CD4 T-cell percentage below 15%), suggesting that the thymus remains active, but has been damaged by past viral replication.

CD8_N and CD4_{RTE} levels were higher in female than in male patients, consistent with the higher levels of thymic activity reported for women than for men in studies of healthy donors [34-35]. However, it remains unclear why CD4_N levels were not affected by sex. CMV infection induces a large expansion of memory T lymphocytes and a decrease in the size of the naive T-cell compartment [36]. CD8_N percentages were, indeed, lower in CMV-seropositive than in CMV-seronegative patients in univariate analysis. However, this association was not statistically significant in multivariate analysis.

One limitation of our study is that treatment status was heterogeneous in the viremic patients (HAART naive, HAART interruption, HAART without viral suppression). The small numbers of patients in each category precluded independent analysis. Therefore, comparisons of patients with and without viral suppression should be interpreted with caution. The associations between higher levels of viral replication and higher levels of naive T lymphocytes were convincingly confirmed by analyses of viral history in patients who were aviremic at the time of the study. CD31 expression on naive CD4 T cells is a convenient, but imperfect marker of thymic activity. CD4_{RTE} cells may undergo proliferation in the periphery before losing CD31 expression, a process subject to interindividual and age-dependent variation [37]. However, limitations on the volumes of blood that can be drawn from adolescents have limited our ability to perform additional tests, such as TREC or telomere length assessment. For the same reasons, CD4_{RTE} data from frozen PBMC samples were available for only 60% of the patients, reducing the statistical power of the analyses.

Our data for this first generation of patients infected with HIV in the perinatal period without early access to HAART are encouraging for the future clinical management of these patients. They are also consistent with the good health status reported for perinatally infected

youths living in France [1]. The paradoxically high level of thymic activity in subjects with sustained viral replication provides an argument for longitudinal follow-up of the naive T-cell compartment in these perinatally infected youths.

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APPENDIX

This study was approved by the “Comité de protection des personnes Ile-de-France II” (registration number 06-09-08), authorized by the “Direction Générale de la Santé” (authorization number 2006-AOO142-49), and registered as an observational study at www.clinicaltrials.gov under identifier NCT01055873.

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Table 1: Characteristics of patients as a function of plasma HIV RNA detection

| | | Aviremic patients | Viremic patients |
|--|----------|-------------------|------------------|
| | | <i>n</i> =59 | <i>n</i> =34 |
| | | % (n) | % (n) |
| Sociodemographic, clinical and virological variables | | | |
| Sex | Male | 55.9 (33) | 58.8 (20) |
| | Female | 44.1 (26) | 41.2 (14) |
| Ethnicity ^a | Black | 33.9 (20) | 48.5 (16) |
| | Other | 66.1 (39) | 51.5 (17) |
| CDC stage ^b | Non C | 71.2 (42) | 82.4 (28) |
| | C | 28.8 (17) | 17.6 (6) |
| HIV-1 subtype | Non B | 21.1 (12) | 44.1 (15) |
| | B | 78.9 (45) | 55.9 (19) |
| HIV-1 coreceptor usage | R5 | 52.8 (28) | 66.7 (22) |
| | X4R5 | 47.2 (25) | 33.3 (11) |
| anti-CMV IgG | Negative | 50.8 (30) | 29.4 (10) |
| | Positive | 49.2 (29) | 70.6 (24) |
| | | Median (IQR) | Median (IQR) |
| Current status | | | |
| Age (years) | | 18 (15-19) | 16 (15-19) |
| HIV-RNA (log ₁₀ copies/ml) | | NA | 3.7 (3.0-4.4) |
| HIV-DNA (log ₁₀ copies/10 ⁶ PBMCs) | | 2.8 (2.4-3.0) | 3.1 (2.8-3.5) |
| CD4 T-cell count/μl | | 642 (522-944) | 423 (270-534) |
| CD4 T-cell percentage | | 31 (27-36) | 21 (14-27) |
| CD4/CD8 ratio | | 0.85 (0.68-1.17) | 0.38 (0.27-0.55) |
| HIV disease history | | | |
| Age at first HAART ^c (years) | | 7 (5-10) | 8 (6-10) |
| Cumulative duration of HAART over the last 10 years (months) | | 108 (88-118) | 83 (52-112) |
| Duration of last period of HIV RNA < 500 copies/ml (months) | | 47 (17-75) | NA |

| | | |
|--|------------------|--------------------|
| Cumulative viremia over the last 10 years ^d | 4489 (2161-6221) | 10415 (6139-12009) |
| Nadir CD4 T-cell % ^e | 8 (5-10) | 9 (4-13) |
| Age at nadir CD4 T-cell % (years) | 8 (2-14) | 9 (3-11) |
| Duration of CD4 T-cell % < 15 during lifetime (months) | 23 (5-50) | 28 (5-56) |

Abbreviations: IQR, interquartile range; CDC, Centers for Disease Control and Prevention; R5, virions using CCR5 as a coreceptor; X4R5, virions using CXCR4 as a coreceptor and dual-tropic viruses; CMV, cytomegalovirus; NA, not applicable; HAART, highly active antiretroviral therapy

^a patients whose mothers originated from Sub-Saharan Africa and the Caribbean were grouped together and compared with those born to mothers with other geographic origins (mainland France, North Africa and Asia)

^b according to the Centers for Disease Control and Prevention (CDC) classification [38-39]

^c HAART was defined as any combination of at least three drugs or any combination including at least one protease inhibitor or one non nucleoside reverse transcriptase inhibitor.

^d Cumulative viremia was defined as the area under the curve of HIV-RNA load over time and was estimated as previously described [40]. Results are expressed as days x log₁₀ HIV-RNA copies/ml of plasma.

^e nadir was defined as the lowest value reached during follow-up

Table 2: Univariate and multivariate analysis of factors associated with CD4_N, CD8_N and CD4_{RTE} percentages in aviremic patients

| Aviremic patients | | | | | | | | | |
|---|----------|--|-----------|----------------|----------|--------------------------------------|--------------|----------|--|
| Dependent variable: CD4_N | | Unadjusted analysis^a | | | | Adjusted analysis^b | | | |
| | | Median (IQR) | Estimate | [95% CI] | <i>P</i> | Estimate | [95% CI] | <i>P</i> | |
| | | Pearson's r | | | | | | | |
| Sociodemographic, clinical and virological variables | | | | | | | | | |
| Sex | Male | 53 (42-65) | Reference | | | | | | |
| | Female | 55 (43-63) | 0.28 | [-6.83;7.39] | 0.94 | | | | |
| Ethnicity | Black | 50 (39-67) | Reference | | | | | | |
| | Other | 55 (44-64) | 2.07 | [-5.21;9.35] | 0.57 | | | | |
| CDC stage | Non C | 53 (43-62) | Reference | | | Reference | | | |
| | C | 61 (49-68) | 5.59 | [-2.48;13.66] | 0.17 | -0,48 | [-9.24;8.27] | 0.91 | |
| HIV-1 subtype | Non B | 42 (37-59) | Reference | | | | | | |
| | B | 56 (44-64) | 6.26 | [-2.13 ;14.65] | 0.14 | | | | |
| HIV-1 coreceptor usage | R5 | 44 (37-58) | Reference | | | Reference | | | |
| | X4R5 | 61 (52-68) | 12.01 | [5.26;18.76] | 0.0008 | 10.38 | [2.86;17.89] | 0.008 | |
| anti-CMV IgG | Negative | 56 (44-64) | Reference | | | | | | |
| | Positive | 51 (37-64) | -4.37 | [-11.35;2.59] | 0.21 | | | | |

Current status

| | | | | | | | |
|--|--------|-------|---------------|-------|-------|--------------|------|
| Age ^c | -0.092 | -0.52 | [-2.09;1.05] | 0.51 | -0.36 | [-1.80;1.08] | 0.62 |
| HIV-DNA ^d | 0.239 | 6.26 | [-0.91;13.43] | 0.09 | | | |
| CD4 T-cell count/ μ l ^e | 0.431 | 2.21 | [0.91;3.51] | 0.001 | 1.64 | [0.33;2.94] | 0.02 |
| CD4 T-cell percentage | 0.292 | 0.54 | [0.04;1.03] | 0.03 | | | |
| CD4/CD8 ratio | 0.344 | 13.01 | [3.77;22.23] | 0.007 | | | |

HIV disease history

| | | | | | | | |
|--|--------|-------|---------------|------|------|---------------|------|
| Age at first HAART ^c | -0.069 | -0.23 | [-1.16;0.70] | 0.62 | | | |
| Cumulative duration of HAART over the last 10 years ^f | -0.114 | -0.56 | [-1.92;0.81] | 0.42 | | | |
| Duration of last period of HIV RNA < 500 copies/ml ^f | -0.221 | -0.80 | [-1.80;0.19] | 0.11 | | | |
| Cumulative viremia over the last 10 years ^g | 0.335 | 13.26 | [-2.70;23.80] | 0.01 | 9.73 | [-0.28;19.73] | 0.06 |
| Nadir CD4 T-cell % | 0.014 | 0.02 | [-0.49;0.54] | 0.92 | | | |
| Age at nadir CD4 T-cell % ^c | -0.013 | -0.05 | [-1.00;0.91] | 0.92 | | | |
| Duration of CD4 T-cell % < 15 during lifetime ^f | -0.164 | -0.61 | [-1.64;4.21] | 0.24 | | | |

Aviremic patients
Dependent variable: CD8_N

| | | Unadjusted analysis ^a | | | | Adjusted analysis ^b | | |
|---|----------|----------------------------------|-----------|----------------|----------|--------------------------------|---------------|----------|
| | | Median (IQR) | Estimate | [95% CI] | <i>P</i> | Estimate | [95% CI] | <i>P</i> |
| | | Pearson's r | | | | | | |
| Sociodemographic, clinical and virological variables | | | | | | | | |
| Sex | Male | 33 (22-42) | Reference | | | Reference | | |
| | Female | 45 (33-53) | 10.72 | [2.90;18.53] | 0.008 | 10.92 | [3.08;18.77] | 0.008 |
| Ethnicity | Black | 36 (27-52) | Reference | | | | | |
| | Other | 41 (30-50) | 1.35 | [-7.49;10.19] | 0.76 | | | |
| CDC stage | Non C | 36 (30-48) | Reference | | | | | |
| | C | 41 (28-56) | 5.18 | [-3.84;14.20] | 0.25 | | | |
| HIV-1 subtype | Non B | 30 (23-41) | Reference | | | | | |
| | B | 42 (31-50) | 7.65 | [-2.70;18.00] | 0.14 | | | |
| HIV-1 coreceptor usage | R5 | 35 (28-47) | Reference | | | Reference | | |
| | X4R5 | 45 (32-57) | 7.77 | [-0.98;16.53] | 0.08 | 10.25 | [2.58;17.92] | 0.01 |
| anti-CMV IgG | Negative | 45 (34-54) | Reference | | | Reference | | |
| | Positive | 31 (23-43) | -11.08 | [-18.83;-3.34] | 0.006 | -4.75 | [-12.49;2.98] | 0.22 |

Current status

| | | | | | | | |
|--|--------|-------|---------------|--------|-------|---------------|------|
| Age ^c | -0,045 | -0,31 | [-2.30;1.69] | 0.76 | -0.56 | [-2.24;1.12] | 0.51 |
| HIV-DNA ^d | 0.222 | 6.29 | [-1.73;14.30] | 0.12 | | | |
| CD4 T-cell count/ μ l ^e | 0.463 | 2.70 | [1.20;4.20] | 0.0007 | 1.47 | [-0.05; 2.99] | 0.06 |
| CD4 T-cell percentage | 0.358 | 0.74 | [0.18;1.30] | 0.01 | | | |
| CD4/CD8 ratio | 0.409 | 15.93 | [5.50;26.36] | 0.004 | | | |

HIV disease history

| | | | | | | | |
|--|--------|-------|---------------|------|-------|--------------|------|
| Age at first HAART ^c | 0.111 | 0.43 | [-0.68;1.54] | 0.44 | | | |
| Cumulative duration of HAART over the last 10 years ^f | -0.263 | -0.15 | [-0.30;0.10] | 0.07 | -0.96 | [-2.39;0.47] | 0.18 |
| Duration of last period of HIV RNA < 500 copies/ml ^f | -0.020 | -0.08 | [-1.28;1.10] | 0.89 | | | |
| Cumulative viremia over the last 10 years ^g | 0.185 | 8.57 | [-0.47;21.90] | 0.20 | | | |
| Nadir CD4 T-cell % | -0.075 | -0.16 | [-0.76;0.45] | 0.60 | | | |
| Age at nadir CD4 T-cell % ^c | 0.020 | 0.08 | [-1.11;1.27] | 0.89 | | | |
| Duration of CD4 T-cell % < 15 during lifetime ^f | -0.171 | -0.82 | [-2.20;0.55] | 0.23 | | | |

Aviremic patients
Dependent variable: CD4_{RTE}

| | | Unadjusted analysis ^a | | | | Adjusted analysis ⁱ | | |
|---|----------|----------------------------------|-----------|--------------|----------|--------------------------------|-------------|----------|
| | | Median (IQR) | Estimate | [95% CI] | <i>P</i> | Estimate | [95% CI] | <i>P</i> |
| | | Pearson's r | | | | | | |
| Sociodemographic, clinical and virological variables | | | | | | | | |
| Sex | Male | 73 (68-77) | Reference | | | Reference | | |
| | Female | 79 (76-84) | 6.77 | [2.85;10.69] | 0.001 | 4.85 | [1.16;8.54] | 0.01 |
| Ethnicity | Black | 74 (68-82) | Reference | | | | | |
| | Other | 78 (73-80) | 1.97 | [3.00;6.93] | 0.43 | | | |
| CDC stage | Non C | 77 (72-80) | Reference | | | | | |
| | C | 75 (72-82) | 0.70 | [-4.18;5.58] | 0.77 | | | |
| HIV-1 subtype | Non B | 78 (72-80) | Reference | | | | | |
| | B | 74 (69-81) | 2.41 | [-3.51;8.33] | 0.41 | | | |
| HIV-1 coreceptor usage | R5 | 79 (74-80) | Reference | | | | | |
| | X4R5 | 74 (72-80) | -0.42 | [-5.24;4.40] | 0.86 | | | |
| anti-CMV IgG | Negative | 79 (76-80) | Reference | | | Reference | | |
| | Positive | 74 (69-80) | -3.72 | [-8.07;0.62] | 0.09 | -0.12 | [-3.;3.65] | 0.99 |

Current status

| | | | | | | | |
|--|--------|-------|---------------|--------|-------|--------------|-------|
| Age ^c | -0.161 | -0.47 | [-1.42;0.48] | 0.33 | -0.41 | [-1.14;0.32] | 0.26 |
| HIV-DNA ^d | 0.197 | 2.75 | [-1.80;7.31] | 0.23 | | | |
| CD4 T-cell count/ μ l ^e | 0.520 | 1.46 | [0.66;2.26] | 0.0007 | 1.01 | [0.27;1.75] | 0.009 |
| CD4 T-cell percentage | 0.370 | 0.38 | [0.06;0.69] | 0.02 | | | |
| CD4/CD8 ratio | 0.288 | 5.21 | [-0.82;11.24] | 0.09 | | | |

HIV disease history

| | | | | | | | |
|--|--------|-------|---------------|-------|-------|---------------|------|
| Age at first HAART ^c | -0.131 | -0.28 | [-0.99;0.43] | 0.43 | | | |
| Cumulative duration of HAART over the last 10 years ^f | 0.041 | 0.14 | [-1.01;1.29] | 0.81 | | | |
| Duration of last period of HIV RNA < 500 copies/ml ^f | -0.058 | -0.11 | [-0.77;0.54] | 0.73 | | | |
| Cumulative viremia over the last 10 years ^g | -0.146 | -3.12 | [-10.15;3.91] | 0.37 | | | |
| Nadir CD4 T-cell % | 0.456 | 0.43 | [0.15;0.71] | 0.004 | | | |
| Age at nadir CD4 T-cell % ^c | -0.055 | -0.10 | [-0.71;0.51] | 0.74 | | | |
| Duration of CD4 T-cell % < 15 during lifetime ^f | -0.446 | -0.83 | [-1.38;-0.27] | 0.004 | -0.55 | [-1.03;-0.08] | 0.02 |

^a Median (IQR) or Pearson's r as well as results from linear regression are indicated for univariate analysis, *P* values are those from linear regression.

^b adjusted for the variables included in the model. The following variables with *P* values < 0.20 in univariate analysis were not included in the model, because of their associations with other independent variables: HIV-1 subtype was associated with CD4 T-cell count; HIV-DNA levels and duration of the last period of HIV RNA < 500 copies/ml were associated with cumulative viremia.

^c per year.

^d per log₁₀ HIV-DNA copies/10⁶ PBMCs.

^e per 100 cells/μl.

^f per 10 months.

^g per 10000 days x log₁₀ HIV-RNA copies/ml of plasma.

^h adjusted for variables included in the model. The following variables with *P* values < 0.20 in univariate analysis were not included in the model, because of their associations with other independent variables: HIV-1 subtype was associated with CD4 T-cell count; HIV-DNA levels were associated with cumulative duration of HAART over the last 10 years.

ⁱ adjusted for variables included in the model. The following variable with *P* values < 0.20 in univariate analysis was not included in the model, because of its associations with another independent variable: nadir CD4 T-cell % was associated with duration of CD4 T-cell % < 15 during lifetime.

Table 3: Univariate and multivariate analysis of factors associated with CD4_N, CD8_N and CD4_{RTE} percentages in viremic patients

| Viremic patients | | Unadjusted analysis^a | | | | Adjusted analysis^b | | |
|---|----------|--|-------------------------|---------------|----------|--------------------------------------|----------------|----------|
| Dependent variable: CD4_N | | Median (IQR) | Estimate Pearson's r | [95% CI] | <i>P</i> | Estimate | [95% CI] | <i>P</i> |
| Sociodemographic, clinical and virological variables | | | | | | | | |
| Sex | Male | 57 (49-63) | Reference | | | | | |
| | Female | 59 (54-65) | 2.61 | [-5.39;10.61] | 0.51 | | | |
| Ethnicity | Black | 58 (53-63) | Reference | | | | | |
| | Other | 60 (52-67) | 3.10 | [-5.07;11.26] | 0.44 | | | |
| CDC stage | Non C | 58 (52-63) | Reference | | | | | |
| | C | 63 (58-65) | 0.21 | [-9.60;10.02] | 0.97 | | | |
| HIV-1 subtype | Non B | 60 (49-66) | Reference | | | Reference | | |
| | B | 58 (54-63) | 1.03 | [-6.95;9.00] | 0.79 | -1.89 | [-10.32; 6.53] | 0.65 |
| HIV-1 coreceptor usage | R5 | 58 (52-62) | Reference | | | | | |
| | X4R5 | 64 (52-73) | 5.72 | [-3.12;14.56] | 0.19 | | | |
| anti-CMV IgG | Negative | 59 (49-75) | Reference | | | | | |
| | Positive | 58 (53-64) | -2.32 | [-11.56;6.92] | 0.61 | | | |

Current status

| | | | | | | | |
|--|--------|-------|---------------|-------|-------|---------------|------|
| Age ^c | -0.205 | -0.92 | [-2.65;0.81] | 0.29 | -0.81 | [-2.53; 0.92] | 0.34 |
| HIV-RNA ^d | 0.021 | 0.25 | [-4.39;4.90] | 0.91 | 1.62 | [-3.07; 6.32] | 0.71 |
| HIV-DNA ^e | -0.102 | -2.03 | [-10.17;6.11] | 0.61 | | | |
| CD4 T-cell count/ μ l ^f | 0.393 | 1.68 | [0.13;3.24] | 0.04 | 2.02 | [0.19; 3.84] | 0.03 |
| CD4 T-cell percentage | 0.475 | 0.48 | [0.13;0.83] | 0.009 | | | |
| CD4/CD8 ratio | 0.456 | 11.83 | [2.72;20.94] | 0.02 | | | |

HIV disease history

| | | | | | | | |
|--|--------|-------|---------------|------|--|--|--|
| Age at first HAART ^c | -0.262 | -0.85 | [-2.20;0.50] | 0.21 | | | |
| Cumulative duration of HAART over the last 10 years ^g | 0.003 | 0.01 | [-0.99;1.00] | 0.99 | | | |
| Cumulative viremia over the last 10 years ^h | -0.194 | -5.46 | [-16.34;5.42] | 0.31 | | | |
| Nadir CD4 T-cell % | 0.248 | 0.38 | [-0.21;0.97] | 0.20 | | | |
| Age at nadir CD4 T-cell % ^c | 0.118 | 0.22 | [-0.51;0.95] | 0.54 | | | |
| Duration of CD4 T-cell % < 15 during lifetime ^g | -0.300 | -0.82 | [-1.86;0.21] | 0.11 | | | |

Viremic patients

Dependent variable: CD8_N

| | | Unadjusted analysis ^a | | | | Adjusted analysis ⁱ | | |
|---|----------|----------------------------------|-----------|----------------|----------|--------------------------------|--------------|----------|
| | | Median (IQR) | Estimate | [95% CI] | <i>P</i> | Estimate | [95% CI] | <i>P</i> |
| Sociodemographic, clinical and virological variables | | | | | | | | |
| Sex | Male | 20 (14-25) | Reference | | | | | |
| | Female | 23 (18-29) | -0.01 | [-7.78;7.77] | 0.99 | | | |
| Ethnicity | Black | 21 (14-25) | Reference | | | | | |
| | Other | 24 (16-28) | 2.04 | [-5.47;9.55] | 0.58 | | | |
| CDC stage | Non C | 21 (14-27) | Reference | | | | | |
| | C | 25 (19-29) | 4.31 | [-4.84;13.47] | 0.34 | | | |
| HIV-1 subtype | Non B | 25 (18-29) | Reference | | | | | |
| | B | 20 (14-33) | 4.47 | [-2.91;11.86] | 0.22 | | | |
| HIV-1 coreceptor usage | R5 | 21 (15-25) | Reference | | | | | |
| | X4R5 | 26 (16-32) | 2.47 | [-5.62;10.57] | 0.54 | | | |
| anti-CMV IgG | Negative | 27 (22-36) | Reference | | | Reference | | |
| | Positive | 20 (14-25) | -9.24 | [-16.86;-1.63] | 0.02 | -2.74 | [-9.60;4.13] | 0.42 |

Current status

| | | | | | | | |
|--|--------|-------|----------------|---------|-------|--------------|--------|
| Age ^c | 0.121 | 0.51 | [-1.15;2.17] | 0.53 | 0.15 | [-1.09;1.38] | 0.81 |
| HIV-RNA ^d | -0.285 | -3.27 | [-7.63;1.08] | 0.13 | -1.43 | [-4.66;1.79] | 0.37 |
| HIV-DNA ^e | -0.397 | -7.78 | [-15.19;-0.37] | 0.04 | | | |
| CD4 T-cell count/ μ l ^f | 0.749 | 3.21 | [2.09;4.33] | <0.0001 | 2.85 | [1.51;4.18] | 0.0002 |
| CD4 T-cell percentage | 0.808 | 0.78 | [0.55;1.00] | <0.0001 | | | |
| CD4/CD8 ratio | 0.806 | 19.78 | [13.92;25.65] | <0.0001 | | | |

HIV disease history

| | | | | | | | |
|--|--------|--------|----------------|------|--|--|--|
| Age at first HAART ^c | -0.032 | -0.11 | [-1.63;1.41] | 0.88 | | | |
| Cumulative duration of HAART over the last 10 years ^g | 0.091 | 0.21 | [-0.73;1.16] | 0.64 | | | |
| Cumulative viremia over the last 10 years ^h | -0.382 | -10.76 | [-21.03;-0.49] | 0.04 | | | |
| Nadir CD4 T-cell % | 0.315 | 0.46 | [-0.09;1.01] | 0.10 | | | |
| Age at nadir CD4 T-cell % ^c | -0.368 | -0.62 | [-1.24;-0.02] | 0.05 | | | |
| Duration of CD4 T-cell % < 15 during lifetime ^g | -0.190 | -0.50 | [-1.52;0.52] | 0.32 | | | |

Viremic patients

Dependent variable: CD4_{RTE}

| | | Unadjusted analysis ^a | | | | Adjusted analysis ^j | | |
|---|----------|----------------------------------|-----------|---------------|----------|--------------------------------|-----------|----------|
| | | Median (IQR) | Estimate | [95% CI] | <i>P</i> | Estimate | [95% CI] | <i>P</i> |
| | | Pearson's r | | | | | | |
| Sociodemographic, clinical and virological variables | | | | | | | | |
| Sex | Male | 82 (80-84) | Reference | | | | | |
| | Female | 81 (78-90) | 0.24 | [-6.54;7.02] | 0.94 | | | |
| Ethnicity | Black | 80 (77-87) | Reference | | | | | |
| | Other | 83 (80-86) | 0.03 | [-7.17;7.23] | 0.99 | | | |
| CDC stage | Non C | 81 (79-84) | Reference | | | | | |
| | C | 84 (80-90) | 2.79 | [-6.14;11.71] | 0.52 | | | |
| HIV-1 subtype | Non B | 84 (81-86) | Reference | | | | | |
| | B | 80 (78-84) | 0.96 | [-5.77;7.68] | 0.77 | | | |
| HIV-1 coreceptor usage | R5 | 81 (78-90) | Reference | | | | | |
| | X4R5 | 81 (80-84) | -3.74 | [-10.98;3.50] | 0.29 | | | |
| anti-CMV IgG | Negative | 84 (81-90) | Reference | | | | | |
| | Positive | 80 (79-84) | -0.85 | [-7.99;6.28] | 0.80 | | | |

Current status

| | | | | |
|--|--------|-------|---------------|------|
| Age ^c | -0.301 | -0.76 | [-2.02;0.51] | 0.22 |
| HIV-RNA ^d | -0.165 | -1.31 | [-5.45;2.83] | 0.52 |
| HIV-DNA ^e | 0.068 | 0.84 | [-6.22;7.90] | 0.80 |
| CD4 T-cell count/ μ l ^f | -0.032 | -0.09 | [-1.65;1.46] | 0.90 |
| CD4 T-cell percentage | 0.093 | 0.06 | [-0.27;0.39] | 0.71 |
| CD4/CD8 ratio | 0.289 | 4.62 | [-3.80;13.05] | 0.26 |

HIV disease history

| | | | | |
|--|--------|-------|--------------|------|
| Age at first HAART ^c | -0.058 | -0.11 | [-1.22;1.01] | 0.84 |
| Cumulative duration of HAART over the last 10 years ^g | 0.158 | 0.23 | [-0.54;1.01] | 0.53 |
| Cumulative viremia over the last 10 years ^h | -0.064 | -0.98 | [-9.07;7.11] | 0.80 |
| Nadir CD4 T-cell % | 0.140 | 0.13 | [-0.36;0.63] | 0.58 |
| Age at nadir CD4 T-cell % ^c | 0.285 | 0.32 | [-0.25;0.90] | 0.25 |
| Duration of CD4 T-cell % < 15 during lifetime ^g | -0.042 | -0.08 | [-1.04;0.89] | 0.87 |

^a Median (IQR) or Pearson's r as well as results from linear regression are indicated for univariate analysis, P values are those from linear regression.

^b adjusted for the variables included in the model. The following variables with *P* values < 0.20 in univariate analysis were not included in the model, because of their associations with other independent variables: nadir CD4 T-cell % and duration of CD4 T-cell % < 15 during lifetime were correlated with current CD4 T-cell count

^c per year.

^d per log₁₀ HIV-RNA copies/ml.

^e per log₁₀ HIV-DNA copies/10⁶ PBMCs.

^f per 100 cells/μl.

^g per 10 months.

^h per 10000 days x log₁₀ HIV-RNA copies/ml of plasma.

ⁱ adjusted for the variables included in the model. The following variables with *P* values < 0.20 in univariate analysis were not included in the model, because of their associations with other independent variables: age at nadir CD4 T-cell % was associated with age at the time of the study; HIV-DNA levels and cumulative viremia over the last 10 years were associated with plasma HIV-RNA.

^j No multivariate model could be built for this dependent variable.

Figure legend

CD4_N, CD8_N, and CD4_{RTE} percentages, current plasma HIV RNA level and current CD4 T-cell counts. The percentages of CD4_N among CD4 T lymphocytes (A), of CD8_N among CD8 T lymphocytes (B) and of CD4_{RTE} among CD4_N T lymphocytes (C) are presented by current plasma HIV RNA detection status, as box-and-whisker plots, with the whiskers representing the minimum and maximum for all data. *P* values from the Wilcoxon test are shown. The associations between CD4_N and CD8_N percentages (D), CD4_N and CD4_{RTE} percentages (E) and CD8_N and CD4_{RTE} percentages (F) are shown for aviremic (open symbols) and viremic (closed symbols) patients. CD4_N (G), CD8_N (H) and CD4_{RTE} (I) percentages are presented as a function of CD4 T-cell counts for aviremic and viremic patients. Regression lines are shown on the graphs.