ANIMAL STUDIES

Cannabinoid Administration Attenuates the Progression of Simian Immunodeficiency Virus

Patricia E. Molina,[1] Peter Winsauer,[2] Ping Zhang,[3] Edith Walker,[1] Leslie Birke,[1] Angela Amedee,[4] Curtis Vande Stouwe,[1] Dana Troxclair,[5] Robin McGoey,[5] Kurt Varner,[2] Lauri Byerley,[1] and Lynn LaMotte[6]

Abstract

Δ^9-Tetrahydrocannabinol (Δ^9-THC), the primary psychoactive component in marijuana, is FDA approved to ameliorate AIDS-associated wasting. Because cannabinoid receptors are expressed on cells of the immune system, chronic Δ^9-THC use may impact HIV disease progression. We examined the impact of chronic Δ^9-THC administration (0.32 mg/kg im, 2×daily), starting 28 days prior to inoculation with simian immunodeficiency virus (SIV_{mac251}; 100 $TCID_{50}$/ml, iv), on immune and metabolic indicators of disease during the initial 6 month asymptomatic phase of infection in rhesus macaques. SIV_{mac251} inoculation resulted in measurable viral load, decreased lymphocyte $CD4^+/CD8^+$ ratio, and increased $CD8^+$ proliferation. Δ^9-THC treatment of SIV-infected animals produced minor to no effects in these parameters. However, chronic Δ^9-THC administration decreased early mortality from SIV infection ($p = 0.039$), and this was associated with attenuation of plasma and CSF viral load and retention of body mass ($p = NS$). In vitro, Δ^9-THC (10 μm) decreased SIV (10 $TCID_{50}$) viral replication in MT4-R5 cells. These results indicate that chronic Δ^9-THC does not increase viral load or aggravate morbidity and may actually ameliorate SIV disease progression. We speculate that reduced levels of SIV, retention of body mass, and attenuation of inflammation are likely mechanisms for Δ^9-THC-mediated modulation of disease progression that warrant further study.

THE CANNABINOIDS including cannabidiol, cannabinol, and Δ^9-tetrahydrocannabinol (Δ^9-THC) exert their effects by binding to two major subtypes of cannabinoid receptor, CB1 and CB2.[1] The CB1 receptor is preferentially expressed in the brain where it mediates neurobehavioral effects. The CB2 receptor is expressed primarily in peripheral tissues, particularly in immune cells where they have been shown to affect cytokine production, lymphocyte phenotype, function and survival, cell-mediated immunity, and balance of Th1/Th2 cells.[2] With the advent of highly active antiretroviral therapy (HAART), human immunodeficiency virus (HIV) infection has become a chronic disease frequently coexisting with chronic use of drugs of abuse, including marijuana.[3] In addition, Dronabinol (Δ^9-THC; Marinol) is approved by the Food and Drug Administration for treatment of HIV-associated anorexia.[4] Although this approval has gained strong support from the lay public, little scientific evidence exists to support the efficacy of such an intervention. To date, no clinical studies have rigorously addressed the impact of chronic Δ^9-THC use on the course and progression of HIV infection. Only one study has examined the impact of short-term (21 day) Δ^9-THC administration (3 daily 0.9 g marijuana cigarettes; 3.95% Δ^9-THC) on HIV viral load. The results from that study did not show substantial elevation in viral load in HIV-infected individuals receiving stable antiretroviral regimens containing nelfinavir or indinavir,[5] and, thus, were considered to reflect the relative safety of short-term Δ^9-THC use in this patient population. The long-term effects of cannabinoid administration on progression of HIV infection had not been previously examined.

Using a well-established nonhuman primate model of HIV disease, we examined the impact of chronic intramuscular Δ^9-THC (provided by the National Institute on Drug Abuse, Research Technical Branch, Rockville, MD) administration on the early phase of simian immunodeficiency virus (SIV) infection in age-matched (4–6 years old) and body weight-matched healthy male Indian-derived rhesus macaques. Chronic administration of Δ^9-THC [or 0.05 ml/kg vehicle (VEH)] was initiated prior to SIV with 0.18 mg/kg, a dose that eliminated responding in a complex operant behavioral task in almost all of the subjects. The dose was subsequently increased for each subject to 0.32 mg/kg, over

Departments of [1]Physiology, [2]Pharmacology, [3]Medicine, [4]Microbiology, [5]Pathology, and [6]School of Public Health, Alcohol Research Center, and Alcohol and Drug Abuse Center of Excellence, LSUHSC, New Orleans, Louisiana.

a period of approximately 2 weeks, and maintained for the duration of the study. Almost all of the animals demonstrated tolerance to the behavioral effects of this dose prior to SIV inoculation (reported elsewhere).[6] Approximately 1 month after initiating chronic Δ^9-THC administration, eight animals were inoculated intravenously with 100 times the $TCID_{50}$ (50% tissue culture infective dose) of SIV_{MAC251}. The pathogenicity of this SIV isolate is similar to HIV.[7] The progression of SIV disease was monitored through clinical and biochemical parameters, and viral load in plasma and cerebrospinal fluid (CSF).

Contrary to what we expected, chronic cannabinoid administration did not significantly increase viral load or exacerbate immune dysfunction. Mean viral load in VEH/SIV$^+$ animals was 6.56 ± 0.16 log copies at 7 days and 6.04 ± 0.6 log copies/ml at 2 months postinfection (Fig. 1A). Viral load remained elevated (6.35 ± 0.76 and 5.8 ± 0.06 log copies/ml at 3 and 6 months, respectively) throughout the duration of the study. Viral load in THC/SIV$^+$ was lower (4.83 ± 0.56 log copies/ml) as compared to VEH/SIV$^+$ beginning at 2 months post-SIV infection ($p =$ NS). Viral mRNA in CSF peaked at day 14 postinfection and remained elevated up to 2 months postinfection in the VEH/SIV$^+$ and THC/SIV$^+$ animals (Fig. 1B). Thereafter, CSF viral load fluctuated between levels below the limit of detection and low counts in both SIV-infected groups. Across all time points, 60% of VEH/SIV$^+$
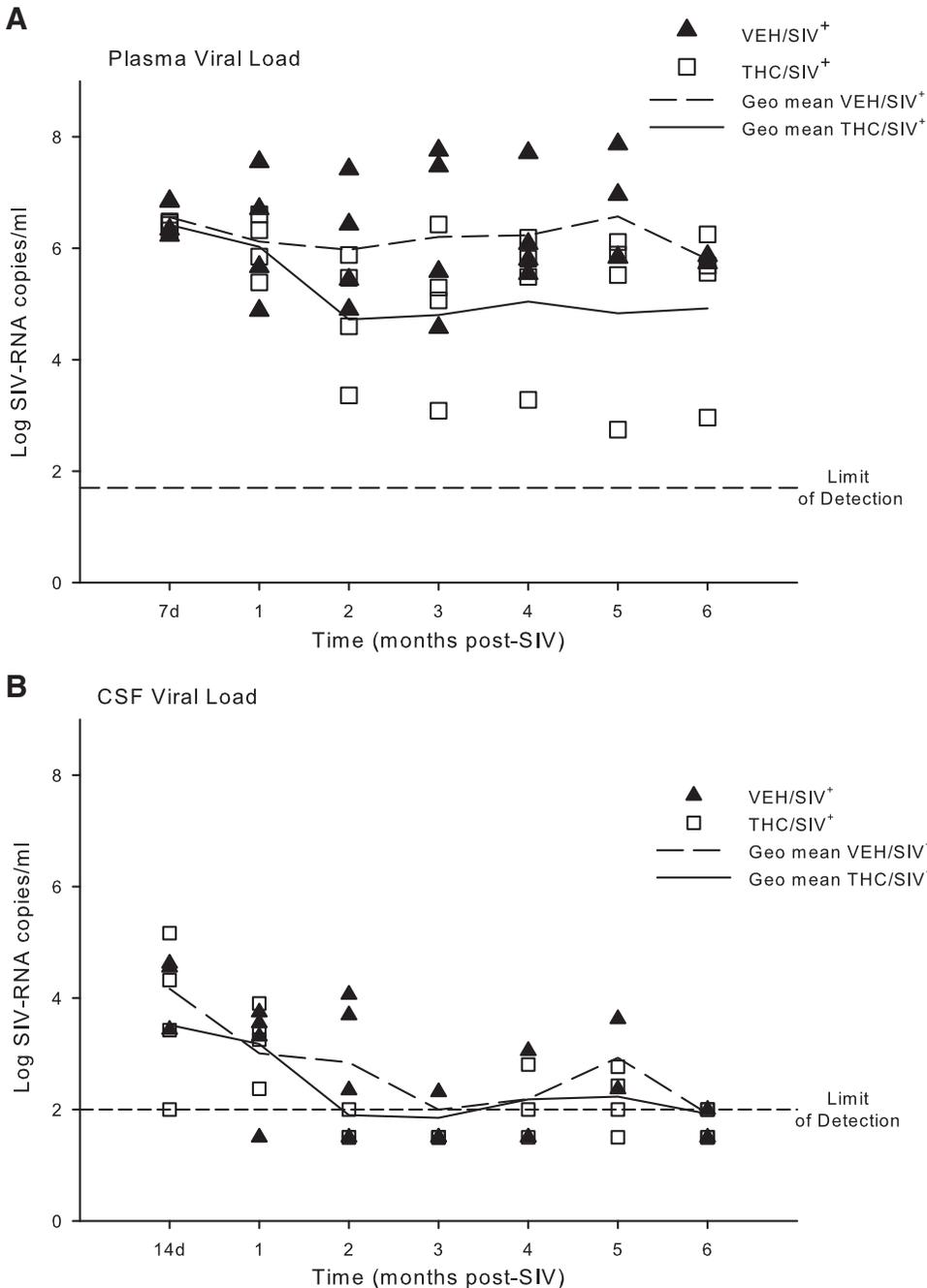

FIG. 1. Viral load detected in **(A)** plasma and **(B)** CSF (log SIV RNA copies/ml) over time in relation to SIV infection. Shown are individual viral counts for each infected animal in the vehicle-treated (VEH/SIV$^+$; solid triangles) and THC-treated (THC/SIV$^+$; open squares) groups as well as geometric means (lines). SIV copy number in plasma and CSF was measured by a real-time RT-PCR assay using gag primers and probe as previously described. Virus was isolated from $500 \mu l$ of plasma or $100 \mu l$ of CSF by high-speed centrifugation ($20,000 \times g$ for 60 min.) at $4°C$. The limit of detection for this assay (50 copies/ml plasma and 100 copies/ml CSF) is shown in the dotted lines. The contribution of the values below the limit of detection in the CSF assay was assessed as limit of detection divided by the square root of two.[23]

CSF samples were above the limit of detection for the assay. In contrast, only 40% of CSF samples from THC/SIV$^+$ animals had viral loads above the limit of detection.

Complete and differential blood counts were performed using a Beckman Coulter LH755 for total leukocyte counts and Wright–Giemsa staining of blood smears for leukocyte differentials. Blood lymphocyte subsets were determined by flow cytometry as previously described.[8] The CD4$^+$ to CD8$^+$ ratio decreased significantly from preinfection values ($p = 0.0001$) in both VEH- and THC-treated animals (Fig. 2B). The marked decrease in CD4$^+$ lymphocyte counts reached statistical significance ($p = 0.023$) at 0.5 and 1 months post-SIV infection in VEH/SIV$^+$ animals, and beginning at 2 months in THC/SIV$^+$ ($p = 0.037$). In contrast, CD8$^+$ counts

showed a short-lived increase at 2 weeks postinfection, which reached statistical significance only in THC/SIV$^+$ animals ($p = 0.029$) (Fig. 2D). CD4$^+$ and CD8$^+$ lymphocyte expressions of Ki67 and caspase 3 (Cas3) were measured as indices of proliferation and apoptosis. No significant changes were noted in the percent of either Ki67$^+$ or Cas3$^+$ on CD4$^+$ lymphocytes in either of the experimental groups (data not shown). In contrast, both markers were increased significantly in CD8$^+$ lymphocytes at 2 weeks postinfection, suggesting increased activation of these cells during the acute response to infection (Fig. 3A). The CD8$^+$ Ki67 expression was increased 10-fold at this time point, and was significantly higher in THC/SIV$^+$ animals when compared to the VEH/SIV$^+$-infected animals ($p = 0.049$). This rise in
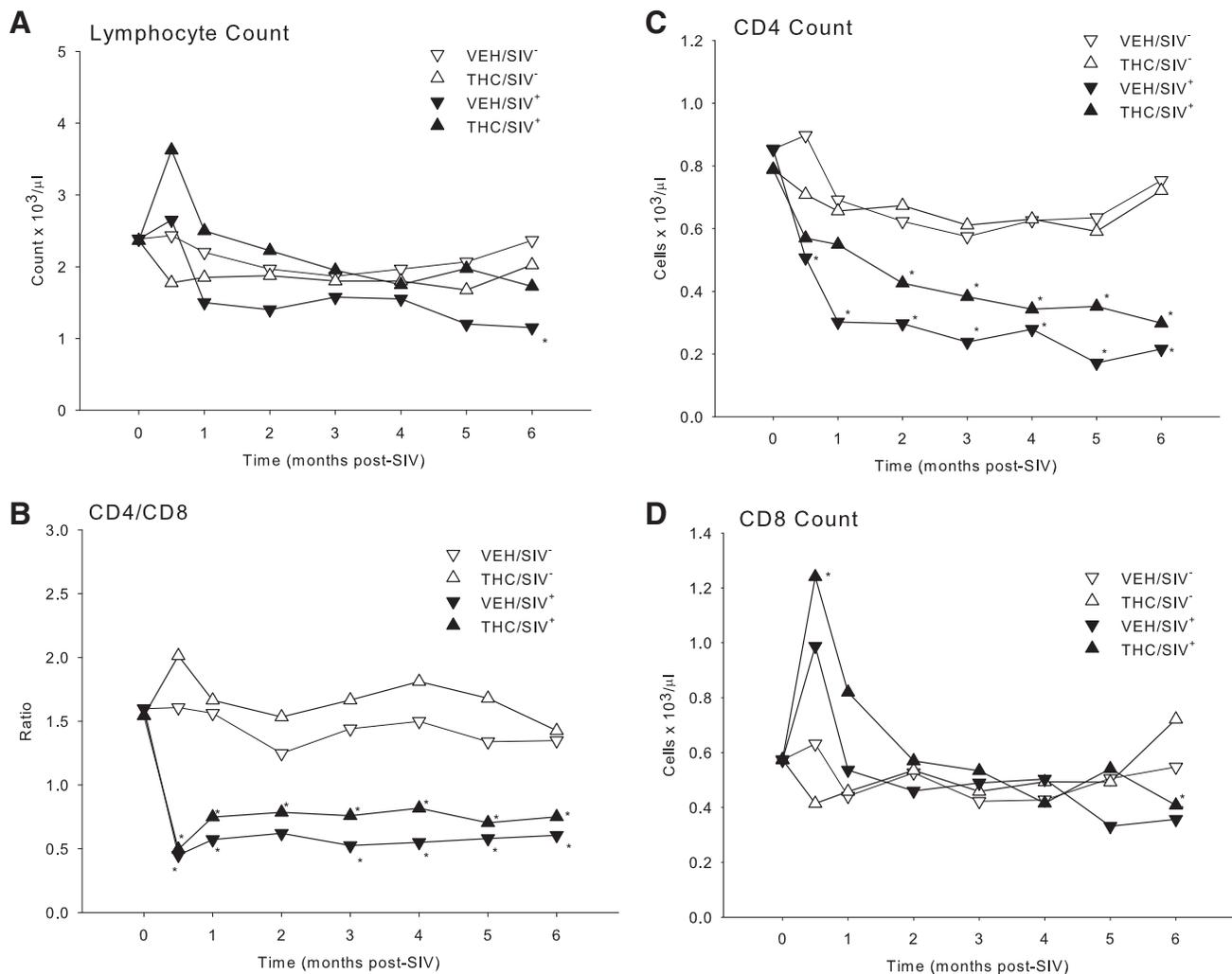

FIG. 2. (A) Lymphocyte count (cells$\times 10^3/\mu$l), (B) CD4$^+$/CD8$^+$ lymphocyte ratio, and (C) CD4$^+$ and (D) CD8$^+$ counts determined by flow cytometry in vehicle-treated uninfected (VEH/SIV$^-$), THC-treated uninfected (THC/SIV$^-$), vehicle-treated infected (VEH/SIV$^+$), and THC-treated infected (THC/SIV$^+$) rhesus macaques expressed as means over time post - SIV infection. Change from baseline was analyzed by a model that included baseline value, as a covariate, and factor effects for Study Period (SPno), THC (+/−), SIV (+/−), and all SPno, THC, and SIV interaction effects. The PROC MIXED procedure in SAS (version 9.1) was selected to perform the analyses. As these are repeated measures on the same subjects over the eight study periods, the within-subjects covariance structure was modeled as compound symmetry; the Kenward-Roger approximation was used to compute p-values for tests of significance. Values for experimental groups $N = 3$ in VEH/SIV$^-$ and $N = 4$ in all others. *$p < 0.05$ vs. time- and treatment-matched uninfected controls.
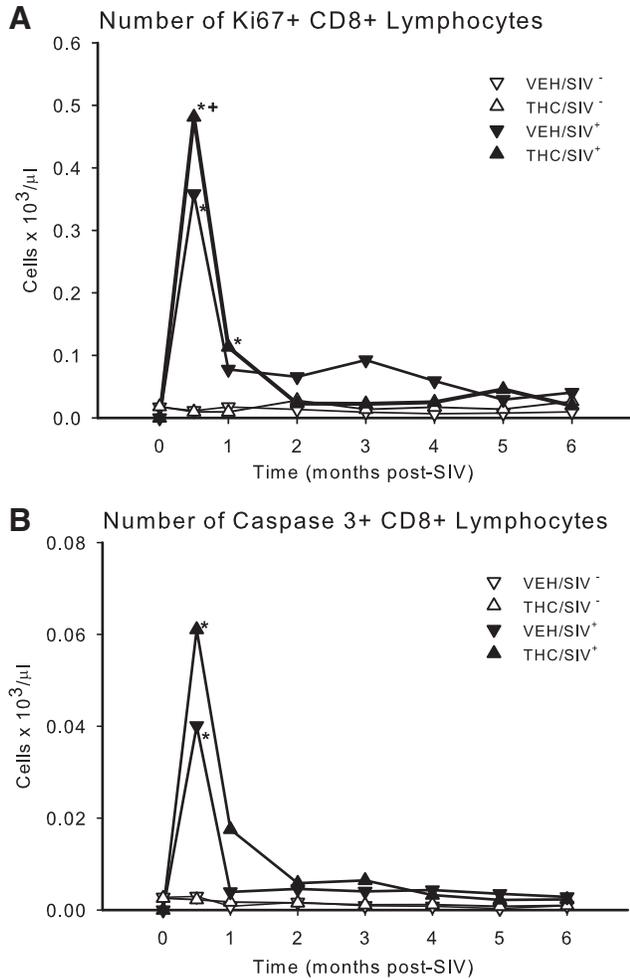
A Number of Ki67+ CD8+ Lymphocytes

B Number of Caspase 3+ CD8+ Lymphocytes

FIG. 3. Numbers of **(A)** Ki67$^+$ and **(B)** caspase 3$^+$ CD8$^+$ lymphocytes as determined by flow cytometry in vehicle-treated uninfected (VEH/SIV$^-$), THC-treated uninfected (THC/SIV$^-$), vehicle-treated infected (VEH/SIV$^+$), and THC-treated infected (THC/SIV$^+$) rhesus macaques expressed as means over time post-SIV infection. Values for experimental groups $N = 3$ in VEH/SIV$^-$ and $N = 4$ in all others. *$p < 0.05$ vs. time- and treatment-matched uninfected control. $^+$Versus time-matched VEH/SIV$^+$ values.

CD8$^+$ lymphocyte proliferation was transient in both groups with only values for THC/SIV$^+$ animals remaining higher ($p = 0.05$) than controls at 1 month post-SIV infection. Values for the VEH/SIV$^+$ and THC/SIV$^+$ groups were not different from control beyond 1 month postinfection. The changes in the number of Ki67$^+$ CD8$^+$ lymphocytes were paralleled by those in number of Cas3$^+$ CD8$^+$ lymphocytes. Cas3$^+$ CD8$^+$ lymphocytes showed a transient and significant ($p = 0.001$) 7- to 8-fold increase that peaked at 2 weeks post-SIV infection in both VEH/SIV$^+$ and THC/SIV$^+$ animals (Fig. 3B). Although a similar pattern of higher levels of Cas3$^+$ CD8$^+$ lymphocytes was observed in the THC/SIV$^+$ animals, this difference failed to reach statistical significance in comparison to the VEH/SIV$^+$ animals ($p = 0.06$). This rise in CD8$^+$ lymphocyte apoptosis was short-lived, and values after 1 month post-SIV infection were not different from uninfected control values.
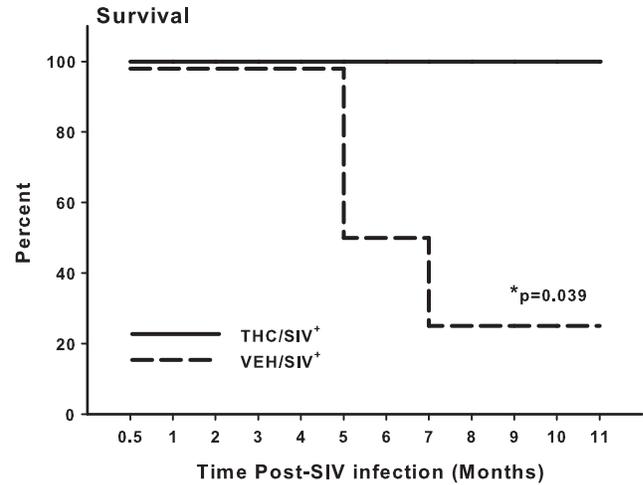
Survival

FIG. 4. Percent survival of vehicle-treated infected (VEH/SIV$^+$) and THC-treated infected (THC/SIV$^+$) rhesus macaques over the initial 11 months post-SIV infection, the timepoint when the first THC/SIV$^+$ animal reached end-stage criteria. Log rank statistic for the survival curve (Kaplan–Meier survival analysis) is greater than would be expected by chance ($p = 0.037$).

No deaths were noted during the first 5 months post-SIV infection in VEH/SIV$^+$ or THC/SIV$^+$ animals (Fig. 4). Two of the VEH/SIV$^+$ animals succumbed to SIV infection shortly after 5 months, and a third reached end stage at 7 months. Among the THC/SIV$^+$ animals, the first animal did not reach end stage until 11 months post-SIV inoculation. A summary of the clinical indications for euthanasia and the most salient necropsy findings is presented in Table 1.

Notably different patterns in weight gain were observed between the initial 3 month post-SIV infection period and the subsequent 3- to 6-month post-SIV period (Fig. 5). This was particularly true for the VEH/SIV$^+$ animals, which showed a tendency for greater ($p = $ NS) weight loss than the THC/SIV$^+$ animals. Echocardiography (Toshiba Aplio at 8.5 MHz) performed prior to (baseline) and 3 and/or 6 months after SIV infection in the two SIV-infected groups (VEH and THC) failed to show significant alterations in cardiac systolic or diastolic function (data not shown).

Cannabinoids, including Δ^9-THC, have been shown to have immunomodulatory effects[9,10] on cytokine production and lymphocyte phenotype, function, and survival[11,12,13] as well as cell-mediated immunity.[14] Similar immunosuppressant effects on lymphocyte[15] and alveolar macrophage[16] function have been reported in nonhuman primates. Furthermore, the potential of cannabinoids to regulate the activation and balance of human Th1/Th2 cells by a CB2 receptor-dependent pathway has been supported by findings from several studies.[17,18] More recent studies have provided evidence that the synthetic cannabinoid WIN 55,212-2 can potently inhibit HIV-1 expression in CD4$^+$ lymphocytes and microglial cell cultures in a time- and concentration-dependent manner.[19] Moreover, Rock et al.[20] demonstrated the involvement of CB2 receptors in cannabinoid antiviral activity in microglial cells. To examine the possibility that the improved survival of SIV-infected rhesus could have been

TABLE 1. CLINICAL INDICATIONS FOR EUTHANASIA AND NECROPSY FINDINGS[a]

Subject ID	Time days post-SIV	Clinical findings	Necropsy findings
VEH/SIV[+]			
A2L046	148	Head pressing, ataxia, inactivity, lack of a palpebral reflex and decreased papillary light reflex in the right eye, serum albumin <3 mg/dl, and dehydration, unresponsive to treatment	Cytomegalovirus meningitis with cerebral edema and uncal herniation. Acute bilateral bronchopneumonia and pulmonary edema
A1R047	166	Unilateral right facial nerve paralysis, lethargic, ventral recumbence, dyspnea	Giant cell pneumonia with *Mycobacterium* sp. *Pneumocystis jiroveci*, meningoencephalitis, and cerebral vasculitis
A1R058	220	Decreased platelet count, hematuria, hematochezia, pyuria; collapsed and did not respond to CPR	Pulmonary thromboembolism
A2R065	503	None	Pulmonary congestion, hepatic steatosis
THC/SIV[+]			
A1R044	343	Chronic progressive intermittent diarrhea, nonresponsive to treatment, chronic intermittent rectal prolapse, gradual body weight loss (>25%), serum albumin <3 mg/dl	*Mycobacterium* sp. involving lungs, liver, spleen, kidneys, gastrointestinal tract, and mesenteric lymph nodes with granulomatous inflammation
A1R022	351	None	Pulmonary edema, congestion, mild hepatic microsteatosis
A1R005	461	None	Steatohepatitis, pulmonary granulomatous inflammation, chronic pancreatitis
A2L094	503	None	Mild cerebral edema, mild acute steatohepatitis

[a]Animals were studied during the pretreatment period (prior to initiating the Δ^9-THC administration) and following SIV infection during the "asymptomatic phase of infection" prior to any of them reaching criteria for euthanasia. This period was defined as the period of time following SIV infection during which none of the animals showed clinical signs of disease including weight loss greater than 5% of basal, secondary infections that required antibiotic treatment, neurological manifestations of disease, severe diarrhea, and dehydration. Animals were sacrificed and necropsy performed when they met predefined clinical indications including the presence of three or more of the following: weight loss greater than 15%, hypoalbuminemia (<3 mg/dl) in the presence of edema, anemia and thrombocytopenia, 3 days of complete anorexia, major organ failure or medical conditions unresponsive to treatment (including respiratory distress, intractable diarrhea, or persistent vomiting, secondary infections that required antibiotic treatment), neurological manifestations of disease, severe diarrhea, and dehydration. Survival was tracked throughout the first year postinfection, at which time all animals still on study were euthanized and necropsy was performed.

due to direct suppression of viral replication, we examined the *in vitro* effects of 1 and 10 μM Δ^9-THC on viral replication in MT4-R5 cells (human T cell line)[21] infected with SIV$_{MAC251}$ (10 TCID$_{50}$). Pretreatment with 10 μM Δ^9-THC (3.2 μg/ml) resulted in a significant decrease in cell-associated viral load in cells collected at 3 and 6 days post-SIV inoculation (Fig. 6). Several possible mechanisms could be involved in this suppression of viral replication, including effects on cell cycle, interaction of cannabinoids with viral coreceptor, and viral integration into the host genome. Moreover, the contribution of the specific cannabinoid receptor subtypes to the overall effects also remains to be examined.

In summary, this study is the first to report *in vivo* experimental data demonstrating that chronic Δ^9-THC initiated prior to, and continued throughout the asymptomatic phase of SIV infection, does not impair the host's ability to control viral load, and does not increase morbidity and mortality from the infection. Although the small groups and natural variation in SIV disease are limitations of the study, the vehicle-treated group is representative of typical rhesus infections with SIV$_{mac251}$. Δ^9-THC treatment clearly did not increase disease progression, and indeed resulted in generalized attenuation of the classic markers of SIV disease (set

point viral load/viral level in general). The mechanisms underlying the decreased mortality in cannabinoid-treated SIV-infected animals remain to be elucidated. However, based on our results and reports in the literature, we speculate that retention of body mass, attenuation of viral replication, and an overall immunosuppressant effect of cannabinoids may contribute to the amelioration of SIV disease progression seen in our study. The cellular mechanisms, including the potential role of the recently identified interaction between the HIV coreceptor CXCR4 and the cannabinoid system[22] as potential sites of pharmacoimmunomodulation, remain to be determined.
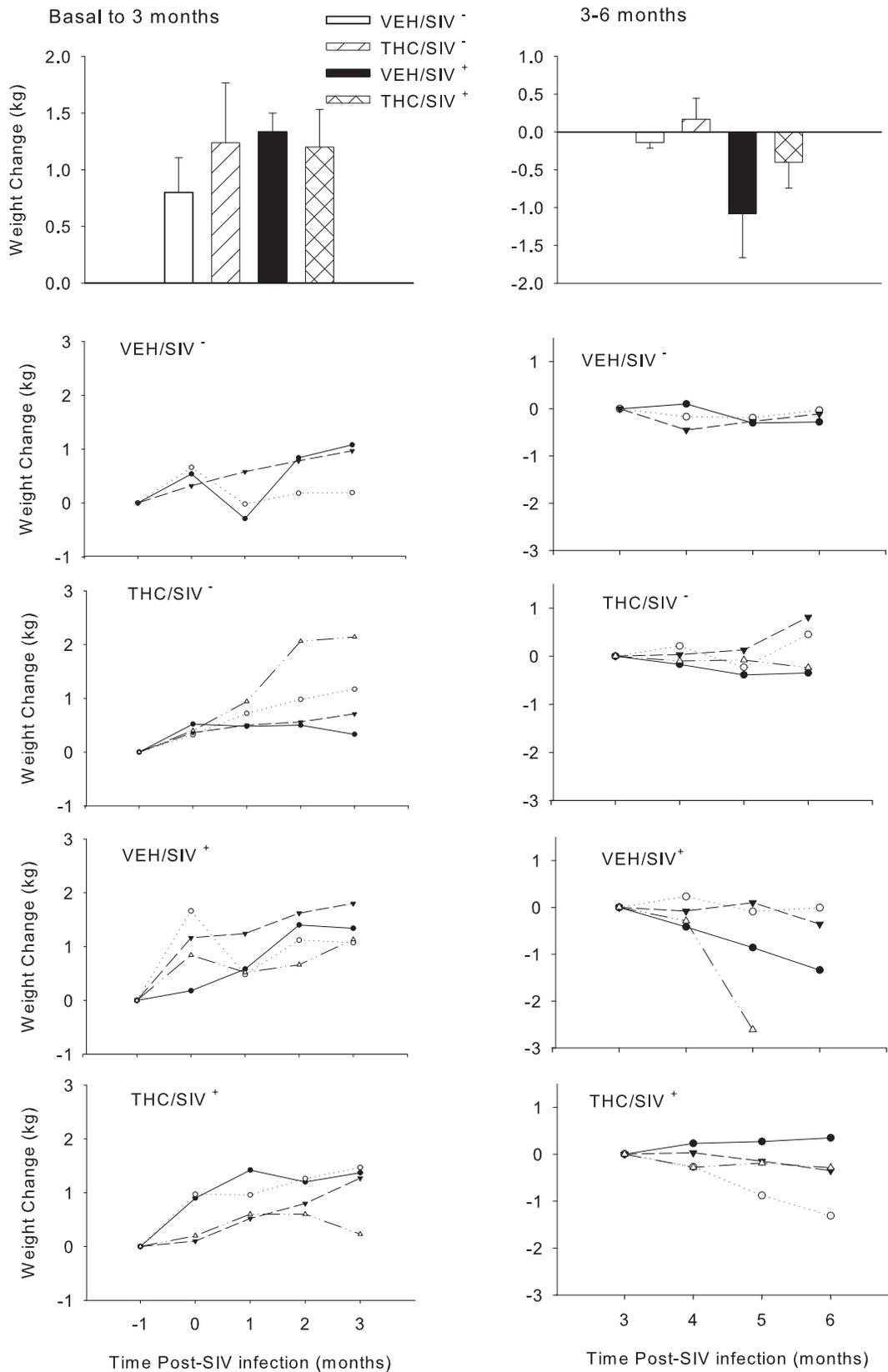
Acknowledgments

FIG. 5. Body weight change (kg) during the initial 3 months post-SIV infection (*left panels*) and during the subsequent 3- to 6-month period of infection. *Top panels* depict change in body weight in vehicle-treated uninfected (VEH/SIV⁻), THC-treated uninfected (THC/SIV⁻), vehicle-treated infected (VEH/SIV⁺), and THC-treated infected (THC/SIV⁺) rhesus macaques expressed as means ± SEM over time post-SIV infection. Because of the individual variability, data are shown for each animal during the initial 3 months post-SIV infection and during the later 3–6 months post-SIV infection in the lower panels, showing the trends in body weight changes. The symbols in the line graphs represent individual animals in the specified treatment group and carry over across time.
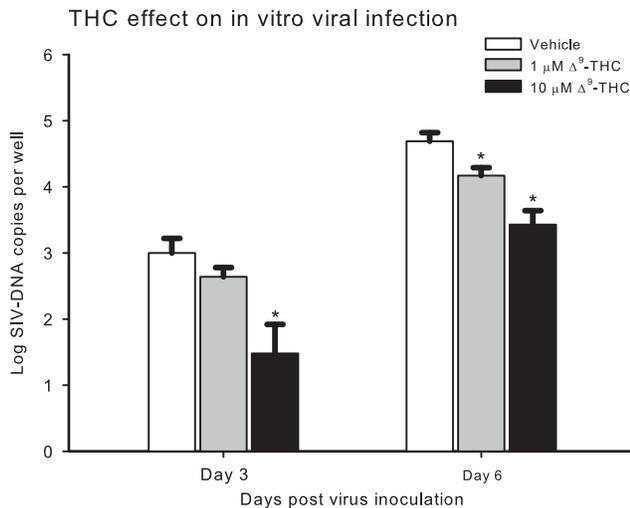
THC effect on in vitro viral infection

FIG. 6. MT4-R5 cells (human T cell line) were seeded at a cell density of 5×10^5/ml in RPMI 1640 containing 10% heat-inactivated fetal calf serum, 2 mM glutamine, 100 U/ml penicillin, 100 μg/ml streptomycin, and 1 μg/ml puromycin in T25 flasks and maintained at 37°C with 5% CO_2 in the presence of Δ^9-THC (1 or 10 μM) or vehicle for 11 days. Culture media was replaced at 3–4 day intervals. After 11 days, 1.5×10^6 MT4-R5 cells from each treatment group were inoculated with 10 $TCID_{50}$ SIV_{mac} in fresh media containing Δ^9-THC or vehicle, plated in 96-well dishes at a density of 1×10^5 cells/well, and maintained at 37°C with 5% CO_2. Uninfected cultures of Δ^9-THC- and vehicle-treated cells were maintained identically for use as controls. One-half of the replicate cultures were harvested 3 days post-SIV-infection, with the remainder harvested 6 days after infection. Supernatant and cell pellets were fractionated by centrifugation at $700\times g$ for 5 min at room temperature. Cell viability was monitored through cell counts using Trypan blue. DNA was prepared and the quantity of proviral SIV DNA in the cell pellets was determined by real-time PCR. DNA viral load (log SIV DNA copies/well) was quantified in cells harvested at 3 and 6 days postinoculation. Expression of CB1 and CB2 receptors was confirmed in these cells prior to using them in the study. Values are mean $\pm$ SEM of eight replicate wells. Results were analyzed with two-way ANOVA followed by pairwise multiple comparison procedures (Holm–Sidak method) *$p \leq 0.008$.

Author Disclosure Statement

No competing financial interests exist.

References

1. Pertwee RG: Pharmacology of cannabinoid CB1 and CB2 receptors. Pharmacol Ther 1997;74:129–180.
2. Klein TW, Newton C, Larsen K, et al.: The cannabinoid system and immune modulation. J Leukoc Biol 2003;74(4): 486–496.
3. Prestiss D, Power R, Balmas G, Tzuang G, and Israelski D: Patterns of marijuana use among patients with HIV/AIDS followed in a public health care setting. J Acquire Immune Defic Syndr 2004;35:38–45.
4. ElSohly M, deWit H, Wachtel SR, Feng S, and Murphy T: Delta9-tetrahydrocannabivarin as a marker for the ingestion of marijuana versus Marinol®: Results of a clinical study. J Anal Toxicol 2001;25:565–571.
5. Abrams D, Hilton J, Leiser R, et al.: Short-Term effects of cannabinoids in patients with HIV-1 infection. A randomized, placebo-controlled clinical trial. Ann Intern Med 2003; 39:258–266.
6. Winsauer PJ, Leonard ST, Birke LL, Howard JM, Lewis PB, and Molina PE: Effects of chronic delta-9-tetrahydrocannabinol (THC) administration on the acquisition and performance of response sequences during simian immunodeficiency virus (SIV) infection in rhesus macaques. FASEB J 2009;23:LB356.
7. Baskin GB, Murphey-Corb M, Martin LN, Soike KF, Hu FS, and Kuebler D: Lentivirus-induced pulmonary lesions in rhesus monkeys (Macaca mulatta) infected with simian immunodeficiency virus. Vet Pathol 1991;28:506–513.
8. Molina PE, McNurlan M, Rathmacher J, et al.: chronic alcohol accentuates nutritional, metabolic, and immune alterations during asymptomatic simian immunodeficiency virus infection. Alcohol Clin Exp Res 2006;30(12):2065–2078.
9. Friedman H, Newton C, and Klein T: Microbial infections, immunomodulation, and drugs of abuse. Clin Microbiol Rev 2003;16:209–219.
10. Klein T, Newton C, Larsen K, et al.: The cannabinoid system and immune modulation. J Leukoc Biol 2003;74:486–496.
11. Zhu W, Friedman H, and Klein T: Delta9-Tetrahydrocannabinol induces apoptosis in macrophages and lymphocytes: involvement of Bcl-2 and caspase-1. J Pharmacol Exp Ther 1998; 286:1103–1109.
12. Friedman H, Klein T, Newton C, and Daaka Y: Marijuana, receptors and immunomodulation. Adv Exp Med Biol 1995;373:103–113.
13. Nahas G, Suciu-Foca N, Armand J, and Morishima A: Inhibition of cellular mediated immunity in marihuana smokers. Science 1974;183:419–420.
14. Newton C, Klein T, and Friedman H: Secondary immunity to Legionella pneumophila and Th1 activity are suppressed by delta-9-tetrahydrocannabinol injection. Infect Immun 1994;62:4015–4020.
15. Daul C and Heath R: The effect of chronic marijuana usage on the immunological status of rhesus monkeys. Life Sci 1975;17:875–882.
16. Cabral G, Stinnett A, Bailey J, et al.: Chronic marijuana smoke alters alveolar macrophage morphology and protein expression. Pharmacol Biochem Behav 1991;40:643–649.
17. Pross S, Klein T, Newton C, Smith J, Widen R, and Friedman H: Differential suppression of T-cell subpopulations by THC (delta-9-tetrahydrocannabinol). Int J Immunopharmacol 1990;12:539–544.
18. Yuan M, Kiertscher S, Cheng Q, Zoumalan R, Tashkin D, and Roth M: Delta-9-tetrahydrocannabinol regulates Th1/Th2 cytokine balance in activated human T cells. J Neuroimmunol 2002;133:124–131.
19. Peterson P, Gekker G, Hu S, Cabral G, and Lokensgard J: Cannabinoids and morphine differentially affect HIV-1 expression in CD4(+) lymphocyte and microglial cell cultures. J Neuroimmunol 2004;147:123–126.
20. Rock R, Gekker G, Hu S, et al.: WIN55,212-2-mediated inhibition of HIV-1 expression in microglial cells: Involvement of cannabinoid receptors. J Neuroimmune Pharmacol 2007; 2:178–183.
21. Krowicka H, Robinson JE, Clark R, Hager S, Broyles S, and Pincus SH: Use of tissue culture cell lines to evaluate HIV

antiviral resistance. AIDS Res Hum Retroviruses 2008;24(7): 957–967.

22. Benamar K, Yondorf M, Geller EB, Eisenstein TK, and Adler MW: Physiological evidence for interaction between the HIV-1 co-receptor CXCR4 and the cannabinoid system in the brain. Br J Pharmacol 2009;157(7):1225–1231.

23. Hornung RW and Reed LD: Estimation of average concentration in the presence of nondetectable values. Appl Occup Environ Hyg 1990;5(1):46–51.

Address correspondence to:
Patricia E. Molina
LSUHSC Physiology
Medical Education Building
1901 Perdido Street
New Orleans, Louisiana 70112

E-mail: pmolin@lsuhsc.edu