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Cannabis Use Is Associated With Decreased Antiretroviral Therapy Adherence Among Older Adults With HIV

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Background. Conflicting evidence exists on the impact of cannabis use on antiretroviral therapy (ART) adherence among people with human immunodeficiency virus (PWH). We leveraged data collected among older PWH to characterize longitudinal associations between cannabis use and ART adherence.

Methods. AIDS Clinical Trials Group (ACTG) A5322 study participants were categorized as <100% (≥1 missed dose in past 7 days) or 100% (no missed doses) ART adherent. Participants self-reported current (past month), intermittent (past year but not past month), and no cannabis (in past year) use at each study visit. Generalized linear models using generalized estimating equations were fit and inverse probability weighting was used to adjust for time-varying confounders and loss to follow-up.

Results. Among 1011 participants (median age, 51 years), 18% reported current, 6% intermittent, and 76% no cannabis use at baseline; 88% reported 100% ART adherence. Current cannabis users were more likely to be <100% adherent than nonusers (adjusted risk ratio [aRR], 1.53 [95% CI, 1.11-2.10]). There was no association between ART adherence and current versus intermittent (aRR, 1.39 [95% CI, .85-2.28]) or intermittent versus no cannabis use (aRR, 1.04 [95% CI, .62-1.73]).

Conclusions. Among a cohort of older PWH, current cannabis users had a higher risk of <100% ART adherence compared to nonusers. These findings have important clinical implications as suboptimal ART adherence is associated with ART drug resistance, virologic failure, and elevated risk for mortality. Further research is needed to elucidate the mechanisms by which cannabis use decreases ART adherence in older PWH and to advance the development of more efficacious methods to mitigate nonadherence in this vulnerable population.

Keywords. adherence; aging; antiretroviral therapy; cannabis; HIV.

With consistent antiretroviral therapy (ART), people with human immunodeficiency virus (PWH) can successfully suppress plasma viral replication to nondetectable levels and experience improved health and quality of life. High ART adherence among PWH is critical, as significant health-related risks, such as development of ART resistance [1], virologic failure [2, 3], opportunistic infections [4], progression to AIDS [5],

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and mortality [6-8], have been associated with nonadherence. Moreover, less than perfect ART adherence has been associated with elevated inflammation, risk for viral rebound, and drug resistance mutations [9, 10]. Notably, with widespread ART use, more PWH are surviving into older age, and previous work has suggested that older PWH may be more likely to be adherent to their ART regimens as compared with younger PWH [11, 12]. However, given that factors particular to older PWH, such as severe menopausal symptoms [13] or greater neurocognitive impairment [14], are associated with ART nonadherence, an improved understanding of the challenges to adherence and development of methods by which to limit nonadherence is crucial, particularly among older PWH.

Multiple intersecting barriers likely underlie poor ART adherence among PWH, such as stigmatization, ART regimen complexities, negative side effects, neurocognitive impairment, and emotional factors, such as stress, depression, and anxiety [15-18]. Another salient factor that could drive ART nonadherence may be increased rates of substance use, which is

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highly prevalent among older PWH [19] and which may not only increase the risk for nonadherence to ART [20] but may also decrease the efficacy of ART treatment through drugdrug interactions [21]. Notably, the use of cannabis (Cannabis sativa) by PWH in the United States has been shown to be particularly high, ranging from 23% to 56% as compared to 13.3% in the general population [22]. Among participants in the AIDS Clinical Trials Group (ACTG) study A5322, a prospective observational study of PWH aged 40 years and older, 18% of participants were current cannabis users. Common reasons for cannabis use by PWH include reducing anxiety, depression, nausea, and pain and increasing appetite [23, 24]. However, cannabis use may have a detrimental impact on the medical care of PWH and may be associated with increased rates of missed clinic appointments [25]. Previous work has also shown that PWH with severe cannabis use disorder reported lower ART adherence [26] and more severe human immunodeficiency virus (HIV) symptoms and ART side effects as compared to cannabis-using and non-cannabis-using PWH without severe cannabis use disorder [27]. In contrast, conflicting evidence suggests that cannabis use has no impact on ART initiation, ART adherence, or plasma viral load suppression [28-30]. Moreover, although a prior study demonstrated that PWH who recently used cannabis had a significantly lower quality of life as compared to non-cannabis-using PWH, there was no difference in disease burden, physical function, CD4⁺ T-cell count, or HIV plasma viral load between the 2 groups [31]. Importantly, the association of regular, current cannabis use with ART adherence in older PWH has not been well defined.

Due to the high prevalence of cannabis use among PWH and the unfavorable impacts that elevated cannabis use may have on ART adherence, greater knowledge of how regular cannabis consumption affects the care of PWH is critical. This is particularly important among older PWH, who may be more negatively affected by the adverse health-related effects of ART nonadherence as compared to younger PWH. Therefore, the goal of this study was to longitudinally evaluate associations between self-reported cannabis use and ART adherence among a cohort of older PWH. We hypothesized that individuals who regularly used cannabis would have a greater incidence of ART nonadherence as compared to those who intermittently used cannabis or were non–cannabis users.

METHODS

Study Population

This analysis used data from participants in the ACTG study A5322, also known as HAILO (HIV Infection, Aging, and Immune Function Long-Term Observational Study). ACTG A5322 was a multicenter (32 clinical research sites in the United States and Puerto Rico) prospective observational study of 1035 PWH aged \geq 40 years enrolled between November 2013 and July 2014. Follow-up ended in December 2021. Semiannual evaluations included current medications and adherence; substance use questionnaires occurred annually. In the current analysis, A5322 participants with data on cannabis use and ART adherence available for at least 1 study visit from week 0 through week 288 of the study were considered for inclusion. We identified 1011 A5322 participants (98%) who fit these criteria and were included in the current analyses and excluded the 24 A5322 participants (2%) that did not fit these criteria. Among these participants, individual visits where an ART treatment gap lasted >21 days were excluded.

Patient Consent Statement

All A5322 participants provided written informed consent before enrollment. A5322 was approved by the local institutional review board at each site.

Cannabis

A5322 participants completed a yearly substance use questionnaire and self-reported cannabis use via a question that asked, "When was the last time you used marijuana (pot, hashish)?" by selecting 1 answer: (0) never used; (1) >1 year ago; (2) within the past year up until 1 month ago; or (3) within the past month. Participants were classified at each time point as nonusers if they answered (0) or (1), intermittent users if they answered (2), or current users if they answered (3).

ART Adherence

Antiretroviral therapy adherence was assessed every 6 months via self-reported questionnaires. Participants were categorized as 100% adherent if they reported no missed doses of any medication within the past 7 days, and as <100% adherent otherwise. We selected <100% as our cutoff given previous findings that imperfect (eg, <100%) ART adherence is associated with significant biological ramifications, such as inflammation, which has been linked to elevated morbidity and mortality among PWH regardless of apparent plasma HIV suppression [9, 32]. Since cannabis use was measured yearly, only adherence obtained at the concomitant annual visits was used in the current analyses.

Covariates

Based on epidemiological evidence from previous literature [26, 30], covariates considered as potential confounders included sex assigned at birth, age at baseline (A5322 study entry), race/ethnicity, educational level, health insurance, years on ART, nadir CD4, antidepressant use, physical activity level, alcohol use level, smoking status, other substance use, and comorbidities (Table 1). Potential confounders were refined by adding each separately to a univariable logistic regression model predicting ART adherence from cannabis use. Any variable

Table 1. Baseline Characteristics by Cannabis Use

	Cannabis Use							
Characteristic	Nonuser (n = 771)		Intermittent User (n = 63)		Current User (n = 177)		Total (n = 1011)	
Sex assigned at birth								
Male	605	(78)	58	(92)	154	(87)	817	(81)
Female	166	(22)	5	(8)	23	(13)	194	(19)
Age, y								
Median (Q1, Q3)	51	(46, 57)	50	(46, 58)	49	(44, 54)	51	(46, 56)
40–49	329	(43)	27	(43)	91	(51)	447	(44)
50–59	321	(42)	22	(35)	68	(38)	411	(41)
≥60	121	(16)	14	(22)	18	(10)	153	(15)
Race/ethnicity								
White, non-Hispanic	362	(47)	34	(54)	95	(54)	491	(49)
Black, non-Hispanic	225	(29)	22	(35)	57	(32)	304	(30)
Hispanic or other	184	(24)	7	(11)	25	(14)	216	(21)
Education								
High school graduate or less	271	(35)	18	(29)	74	(42)	363	(36)
Any education beyond high school	500	(65)	45	(71)	103	(58)	648	(64)
ART adherence								
<100%	76	(10)	12	(19)	37	(21)	125	(12)
100%	695	(90)	51	(81)	140	(79)	886	(88)
Time on ART, y								
Median (Q1, Q3)	8	(4.5, 12.1)	7	(4.1, 11.3)	7	(4.1, 11.8)	8	(4.4, 12.0)
Nadir CD4 count, cells/µL								
Median (Q1, Q3)	184	(56, 298)	228	(123, 323)	213	(78, 297)	191	(62, 300)
HIV-1 RNA, copies/mL								
≥50	60	(8)	5	(8)	11	(6)	76	(8)
<50	708	(92)	58	(92)	165	(94)	931	(92)
Comorbidities—any ^a								
Yes	132	(17)	11	(17)	26	(15)	169	(17)
No	639	(83)	52	(83)	151	(85)	842	(83)
Medical insurance								
None/unknown	159	(21)	11	(17)	29	(16)	199	(20)
Public	184	(24)	22	(35)	53	(30)	259	(26)
Private	343	(44)	21	(33)	69	(39)	433	(43)
Medicare	85	(11)	9	(14)	36	(15)	120	(12)
Antidepressant use—any ^b								
Yes	151	(20)	16	(25)	51	(29)	218	(22)
No	620	(80)	47	(75)	126	(71)	793	(78)
Physical activity								
<3 d/wk	360	(48)	28	(47)	77	(44)	465	(47)
≥3 d/wk	389	(52)	31	(53)	97	(56)	517	(53)
Alcohol use ^c								
Abstainer	342	(45)	15	(25)	27	(15)	384	(38)
Light drinker	279	(37)	22	(36)	75	(43)	376	(38)
Moderate drinker	41	(5)	2	(3)	21	(12)	64	(6)
Heavy drinker	100	(13)	22	(36)	53	(30)	175	(18)
Smoking status ^d								
Never	367	(48)	16	(25)	31	(18)	414	(41)
Prior	250	(32)	20	(32)	70	(40)	340	(34)
Current	154	(20)	27	(43)	76	(43)	257	(25)
Substance use—any ^e								
Never	561	(73)	22	(35)	74	(43)	657	(65)

		Cannabis Use							
Characteristic	Nonuser (n = 771)		Intern (I	Intermittent User (n = 63)		Current User (n = 177)		Total (n = 1011)	
Prior	182	(24)	30	(48)	69	(40)	281	(28)	
Current	27	(4)	11	(17)	31	(18)	69	(7)	

Data are presented as No. (%) unless otherwise indicated

Abbreviations: ART, antiretroviral therapy; HIV-1, human immunodeficiency virus type 1; Q1, quartile 1; Q3, quartile 3.

^aComorbidities (cardiovascular disease, hypertension, diabetes, cancer [incident or within 5 years], combined liver disease, kidney disease, or chronic hepatitis C) were tested individually and combined.

^bAntidepressant use was tested by class (selective serotonin reuptake inhibitors, aminoketone class, heterocyclics, tricyclics) and combined.

^cAlcohol use levels are defined for participants assigned male sex at birth (M) or female sex at birth (F) based on reported drinks per week: abstainer, zero drinks; light drinker, <7 (M) or <3 (F) drinks per week and no binging; moderate drinker, 7–14 (M) or 3–7 (F) drinks per week and no binging; heavy drinker, >14 (M) or >7 (F) drinks per week or binging. Binging is defined as ≥5 drinks on 1 occasion in the last 30 days.

^dSmoking status: never, no use; prior, if the participant has a history of smoking cigarettes; current, if the participant smokes cigarettes currently.

eSubstance use includes use of any of the following: cocaine, heroin, amphetamines, or other nonprescribed prescription drug. Substance use levels: never, no use; prior, use >1 month ago; or current, within the past month.

that changed the coefficient (log odds) for the effect of cannabis use on the outcome by $\geq 10\%$ was considered a confounder.

Statistical Analysis

Generalized linear models using generalized estimating equations (GEEs) were used to estimate the association between cannabis use and ART adherence at the same study visit. The models employed the logistic link and binomial distribution to estimate risk ratios (RRs). Time was modeled as study weeks, and the independence structure was used to reduce GEE bias from time-dependent confounding [33]. Sex assigned at birth and an interaction term for time-sex were included to assess whether the effect of cannabis use differed by sex assigned at birth. A separate model included age (<50 or \geq 50 years) and a time-age interaction term to assess whether the effect of cannabis use differed by age.

Inverse probability weighting (IPW) was used to control for time-varying confounders and loss to follow-up. A comprehensive description of the methodology for creating IPWs can be found elsewhere [34, 35]. For this analysis, stabilized inverse probability of treatment (cannabis use group) weights (IPTWs) were calculated as the probability of treatment given baseline covariates (sex assigned at birth, race/ethnicity, educational level, smoking status, time on ART, cannabis use history) divided by the probability of treatment given baseline and timevarying covariates (alcohol use, other substance use, ART adherence history). Probabilities were estimated with multinomial logistic regression models. Stabilized inverse probability of censoring weights (IPCWs) were calculated by fitting logistic regression models with the same predictors as for the IPTW models, but with only the most recent visit's cannabis use and previous visit's data (rather than the current visit) for timevarying exposures. The final stabilized IPWs were the product of the IPTW and IPCW. They were then truncated to the 1st and 99th percentiles and used in the generalized linear models.

Due to their cumulative nature, IPW creation requires full model data for each visit. Multiple imputation was used to impute missing covariates. For missed visits, data were imputed using the last observation carried forward, or for data missing from week 0, the next observation carried backwards. Only observed visits were used in the final generalized linear models. All data analysis was completed using SAS software version 9.4 (SAS Institute, Cary, North Carolina).

RESULTS

Study Population Characteristics

The 1011 (98%) participants who completed at least 1 substance use questionnaire while on ART and were included in the current analyses contributed 1–7 time points with a median (Q1, Q3) of 6 (4, 7). The majority of participants were assigned male sex at birth (81% [n = 817]) and the median age at baseline was 51 years (Table 1). Gender identity data were not collected from A5322 participants. Additionally, 49% (n = 491) of participants identified as White non-Hispanic, 30% (n = 304) identified as Black non-Hispanic, and 21% (n = 216) identified as Hispanic or as another race or ethnicity (Table 1).

Baseline Characteristics by Cannabis Use

At baseline there were 177 current cannabis users (18%), 63 intermittent cannabis users (6%), and 771 non-cannabis users (76%) (Table 1). A greater proportion of cannabis users reported using antidepressants as compared to intermittent and noncannabis users; more participants reported being light or heavy drinkers among intermittent and current cannabis users. A higher frequency of non-cannabis users reported abstaining from alcohol and other substances and being tobacco neversmokers as compared to intermittent and current cannabis users. Groups were similar in terms of educational level, time on ART, nadir CD4 count, percentage undetectable viral load, comorbid conditions, medical insurance coverage, and physical activity level. Among study participants, 12% (n = 125) were classified at baseline as being less than 100% adherent to their ART regimens (Table 1). A higher proportion of <100% ART adherence was observed among current cannabis users (21% [n = 37]) and intermittent cannabis users (19% [n = 12]) than non-cannabis users (10% [n = 76]).

Association Between Cannabis Use and Poor ART Adherence

In GEE models IP-weighted for study dropout only, current cannabis users were more likely to be <100% ART adherent than nonusers (RR, 1.78 [95% confidence interval {CI}, 1.42–2.23]; P < .01; Figure 1). There was no association between current versus intermittent cannabis use (RR, 1.29 [95% CI, .85–1.96]; P = .22) or intermittent versus non-cannabis use and ART adherence (RR, 1.38 [95% CI, .91–2.07]; P = .13). In multivariable analyses that were adjusted for baseline covariates and IP-weighted for time-varying exposures and study dropout, the association between cannabis use versus nonuse and <100% ART adherence remained (adjusted RR [aRR], 1.53 [95% CI, 1.11–2.10]; P < .01). There was no evidence for an interaction between age and current versus non-cannabis use.

Relationship Between Cannabis Use and ART Adherence by Sex Assigned at Birth

Among participants assigned male sex at birth, we observed that current cannabis users were more likely to be <100% ART adherent than nonusers in dropout-weighted (RR, 1.77 [95% CI, 1.38–2.27]; P < .01) and fully adjusted models (aRR, 1.67 [95% CI, 1.20–2.35]; P < .01) (Figure 2). An association between current cannabis use and <100% ART adherence among participants assigned female sex at birth as compared to

nonusers was also observed in the dropout-weighted model (RR, 2.27 [95% CI, 1.29–4.01]; P < .01), but not in the fully adjusted model (aRR, .89 [95% CI, .42–1.89]; P = .70) (Figure 2). This interaction was not statistically significant (P = .12).

DISCUSSION

Herein, we found that current cannabis users have a higher risk of being <100% adherent to their ART regimen when compared to nonusers, consistent with most previous work [26, 27]. Importantly, this association was maintained even when adjusted for demographic and behavioral characteristics. However, to our knowledge, our work is among the first to show this relationship specifically among older PWH, in which engagement in medical care and successful ART adherence is particularly important. Indeed, although ART adherence among older PWH is generally better as compared to younger PWH [11], factors particular to older PWH, such as severe menopausal symptoms [13] or enhanced neurocognitive impairment [14], are associated with ART nonadherence. Thus, a better understanding of how exogenous factors like cannabis use may interact with other determinants of ART nonadherence among older PWH is critical, given the unique risks and challenges that older PWH may experience.

Nonadherence to ART has historically been associated with poor outcomes, with early regimens requiring >95% adherence for successful virologic outcomes [4]. However, more modern ART regimens are associated with viral suppression when adherence is at \geq 85% [36], thought to be due to the pharmacologic forgiveness offered by these regimens [37]. Alternatively, previous work demonstrated that less than perfect adherence was associated with elevated inflammatory markers, including



Figure 1. Associations between cannabis use and antiretroviral therapy (ART) adherence among older people with human immunodeficiency virus. Generalized linear models using generalized estimating equations were used to estimate the association between cannabis use and ART adherence. Data are depicted as a forest plot of the nonadherence risk ratio (RR with 95% confidence interval [CI]). *Inverse probability (IP)—weighted for dropout. **Adjusted for baseline covariates (sex, race/ethnicity, educational level, smoking status, time on ART, cannabis use history) and IP-weighted for dropout and time-varying exposures (alcohol use, other substance use, ART adherence history).



Figure 2. Relationship between cannabis use and antiretroviral therapy (ART) adherence by sex assigned at birth. Models that included interaction terms for time × sex assigned at birth were used to evaluate whether the association between cannabis use and ART adherence varied among participants by sex assigned at birth. Data are depicted as a forest plot of the nonadherence risk ratio (RR with 95% confidence interval [CI]). *Inverse probability (IP)—weighted for dropout. **Adjusted for baseline co-variates (race/ethnicity, educational level, smoking status, time on ART, cannabis use history) and IP-weighted for dropout and time-varying exposures (alcohol use, other substance use, ART adherence history).

interleukin-2, interleukin-6, and interleukin-10, interferon- γ , tumor necrosis factor- α , and C-reactive protein, although this finding was largely driven by those with adherence <85% [9]. Moreover, in the setting of nondetectable viremia, less than perfect adherence, as measured by tenofovir-diphosphate or emtricitabine-triphosphate concentrations in dried blood spots, was a prognosticator of viral rebound, while intermittent adherence led to drug resistance mutations [10, 38, 39]. Combined, these data reinforce the need for high adherence to ART in PWH, as well as to understand factors such as the reasons for cannabis use that underlie nonadherence.

It is possible that sex-specific effects of cannabis exposure could constitute a potential mechanism underlying our observation that males but not females with current cannabis use were less likely to be ART adherent. Indeed, females and males differ in terms of cannabinoid receptor expression, cannabinoid metabolism, subjective effects of cannabis, and anxiety and depressive symptoms associated with cannabis use, among others [40, 41]. Notably, a prior study conducted among women enrolled in the Women's Interagency HIV Study (WIHS) demonstrated a significant effect of cannabis use on suboptimal ART adherence when restricted to single-tablet ART [26]. Although the women in A5322 and WIHS were similar in terms of race and ethnicity, other characteristics differed between these cohorts, including alcohol and substance use. These and other differences between male and female study participants, such as with sociodemographic characteristics, may impose distinct challenges and pressures that influence the specific reasons for and effects of cannabis use. A more precise understanding of the pharmacokinetic, physiological, behavioral, socioeconomic, and gender identity variations between participants by sex at birth will be critical to delineate

the mechanisms underlying differences in the associations between cannabis use and ART adherence across cohorts.

Although our findings suggest that current cannabis use is associated with less than complete ART adherence, additional literature suggests that cannabis use may be associated with beneficial immune effects, distinct from ART. For example, regular cannabis use by PWH has been associated with lower blood-brain barrier permeability as compared to PWH with less than daily use of cannabis [42]. Moreover, cannabis use was associated with faster decay of HIV DNA in PWH as compared to non-cannabis use [43] and lower plasma viremia following seroconversion [44]. Additionally, PWH with heavy cannabis use had lower peripheral inflammation and cellular immune activation as compared to non-cannabis-using PWH [45]. Similarly, recent cannabis use by PWH was associated with reduced levels of soluble inflammatory markers in blood and cerebrospinal fluid [46]. Data on the associations between cannabis use and levels of proinflammatory cytokines are mixed [47]. Thus, these findings underscore the importance of understanding how the potentially beneficial effects of cannabis use could be leveraged to offset inflammation due to HIV infection while minimizing any direct deleterious consequences on ART adherence or psychosocial or cognitive functioning.

A major strength of the current study was our ability to adjust for demographic and behavioral elements that are wellestablished risk factors for ART adherence. An additional strength was the use of data from a large cohort of older PWH who were followed longitudinally. A caveat of this may be that because all participants were enrolled in longitudinal clinical studies, our current study reflects a higher level of adherence to medication and clinical care than other study populations, which may limit the generalizability of our findings. Likewise, participation in a clinical study and access to clinical care may have led to a greater awareness among our study participants of the current ambiguity surrounding the benefits versus consequences of cannabis use, which may have contributed to the lower percentage of cannabis users in our study population as compared to what has been previously observed (18% vs 23%-56% [22], respectively). A limitation of our study is that because A5322 did not collect the number of days with imperfect ART adherence, we were unable to assess whether <85% adherence as compared to <100% adherence may be impacted by cannabis use. A further limitation of our study was the underrepresentation of women, which could explain the nonsignificant relationship between cannabis use and adherence among women, as well as the nonsignificant interaction by sex. Moreover, the small number of intermittent cannabis users precludes our ability to understand relationships between intermittent cannabis use and adherence. Our study was also limited in that our measurements of cannabis use were self-reported, and on an annual basis. Although selfreported cannabis use is a widely used measure, it is possible that inaccurate self-reporting could have influenced the outcomes. Additionally, controlling for other substance use specifically by each substance could have been more informative than a control for other substance use. Taken together, future studies that include both a greater number of women and participants that represent variable levels of cannabis use are needed. Moreover, studies that incorporate quantification of cannabis metabolites as objective measures of cannabis use could help to confirm self-reported cannabis usage, enable the measurement of the extent of cannabis use by each participant, allow for more precise classification of study participants into cannabis use categories, explore the differential effects of various types of cannabis products, and allow for evaluation of potential dose-response relationships [45, 48].

An additional limitation of our study is that since A5322 did not collect data on cannabis use indication, we were not able to distinguish between medical and recreational cannabis use. Common reasons for poor ART adherence among PWH include ART regimen complexities, negative side effects including nausea, and emotional factors such as anxiety and depression [15-17]. Notably, reduction of stress, anxiety, depression, physical pain, and nausea are among the most cited reasons for cannabis use among PWH [23, 24]. Conflicting evidence exists as to whether cannabis use for symptom management among PWH may provide a potential behavioral link with effective ART adherence, with some studies suggesting no association [30, 49] and others finding a significant impact [27, 50]. Additional work is needed to determine whether behavioral reasons, such as cannabis use for symptom management, may underlie our observed link between cannabis use and lower ART adherence among older PWH.

Taken together, our findings suggest that regular cannabis use by older PWH is associated with a greater risk of imperfect ART adherence compared to non–cannabis use. These findings have important clinical implications for the care of older PWH, as even a small reduction in ART adherence has been linked with greater inflammation and a higher risk for drug resistance, less effective viral suppression, and mortality. A better understanding of the relationship between cannabis use and ART adherence among older PWH can facilitate the development of more efficacious methods by which to mitigate nonadherence in this particularly vulnerable population. Finally, future work is needed to elucidate how the adverse effects of cannabis use on ART adherence could be balanced against the potential beneficial uses of cannabis to reduce inflammation and immune activation in older PWH.

Notes

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References

- Harrigan PR, Hogg RS, Dong WW, et al. Predictors of HIV drug-resistance mutations in a large antiretroviral-naive cohort initiating triple antiretroviral therapy. J Infect Dis 2005; 191:339–47.
- Bezabhe WM, Chalmers L, Bereznicki LR, Peterson GM. Adherence to antiretroviral therapy and virologic failure: a meta-analysis. Medicine (Baltimore) 2016; 95:e3361.
- Rosenblum M, Deeks SG, van der Laan M, Bangsberg DR. The risk of virologic failure decreases with duration of HIV suppression, at greater than 50% adherence to antiretroviral therapy. PLoS One 2009; 4:e7196.
- Paterson DL, Swindells S, Mohr J, et al. Adherence to protease inhibitor therapy and outcomes in patients with HIV infection. Ann Intern Med 2000; 133:21–30.
- Bangsberg DR, Perry S, Charlebois ED, et al. Non-adherence to highly active antiretroviral therapy predicts progression to AIDS. AIDS 2001; 15:1181–3.
- Hogg RS, Heath K, Bangsberg D, et al. Intermittent use of triple-combination therapy is predictive of mortality at baseline and after 1 year of follow-up. AIDS 2002; 16:1051–8.
- Lima VD, Harrigan R, Bangsberg DR, et al. The combined effect of modern highly active antiretroviral therapy regimens and adherence on mortality over time. J Acquir Immune Defic Syndr 2009; 50:529–36.
- 8. Wood E, Hogg RS, Yip B, et al. Effect of medication adherence on survival of HIV-infected adults who start highly active antiretroviral therapy when the CD4⁺ cell count is 0.200 to $0.350 \times 10(9)$ cells/L. Ann Intern Med **2003**; 139: 810–6.

- Castillo-Mancilla JR, Brown TT, Erlandson KM, et al. Suboptimal adherence to combination antiretroviral therapy is associated with higher levels of inflammation despite HIV suppression. Clin Infect Dis 2016; 63:1661–7.
- Castillo-Mancilla JR, Edwards JA, Brijkumar J, et al. Tenofovir diphosphate levels in dried blood spots are associated with virologic failure and resistance to first-line therapy in South Africa: a case-control cohort study. J Int AIDS Soc 2021; 24: e25849.
- Ghidei L, Simone MJ, Salow MJ, et al. Aging, antiretrovirals, and adherence: a meta analysis of adherence among older HIV-infected individuals. Drugs Aging 2013; 30:809–19.
- Mann SC, Castillo-Mancilla JR. HIV, aging, and adherence: an update and future directions. Curr Opin HIV AIDS 2020; 15:134–41.
- Duff PK, Money DM, Ogilvie GS, et al. Severe menopausal symptoms associated with reduced adherence to antiretroviral therapy among perimenopausal and menopausal women living with HIV in metro Vancouver. Menopause 2018; 25:531–7.
- Hinkin CH, Hardy DJ, Mason KI, et al. Medication adherence in HIV-infected adults: effect of patient age, cognitive status, and substance abuse. AIDS 2004; 18-(Suppl 1):S19–25.
- Gellad WF, Grenard JL, Marcum ZA. A systematic review of barriers to medication adherence in the elderly: looking beyond cost and regimen complexity. Am J Geriatr Pharmacother 2011; 9:11–23.
- Hendricks L, Eshun-Wilson I, Rohwer A. A mega-aggregation framework synthesis of the barriers and facilitators to linkage, adherence to ART and retention in care among people living with HIV. Syst Rev 2021; 10:54.
- Beusterien KM, Davis EA, Flood R, Howard K, Jordan J. HIV patient insight on adhering to medication: a qualitative analysis. AIDS Care 2008; 20:244–52.
- Moraes RP, Casseb J. Depression and adherence to antiretroviral treatment in HIV-positive men in São Paulo, the largest city in South America: social and psychological implications. Clinics (Sao Paulo) 2017; 72:743–9.
- Deren S, Cortes T, Dickson VV, et al. Substance use among older people living with HIV: challenges for health care providers. Front Public Health 2019; 7:94.
- Parsons JT, Starks TJ, Millar BM, Boonrai K, Marcotte D. Patterns of substance use among HIV-positive adults over 50: implications for treatment and medication adherence. Drug Alcohol Depend 2014; 139:33–40.
- Kumar S, Rao PS, Earla R, Kumar A. Drug-drug interactions between antiretroviral therapies and drugs of abuse in HIV systems. Expert Opin Drug Metab Toxicol 2015; 11:343–55.
- Pacek LR, Towe SL, Hobkirk AL, Nash D, Goodwin RD. Frequency of cannabis use and medical cannabis use among persons living with HIV in the United States: findings from a nationally representative sample. AIDS Educ Prev 2018; 30:169–81.
- Harris GE, Dupuis L, Mugford GJ, et al. Patterns and correlates of cannabis use among individuals with HIV/AIDS in maritime Canada. Can J Infect Dis Med Microbiol 2014; 25:e1–7.
- Costiniuk CT, Saneei Z, Salahuddin S, et al. Cannabis consumption in people living with HIV: reasons for use, secondary effects, and opportunities for health education. Cannabis Cannabinoid Res 2019; 4:204–13.
- Kipp AM, Rebeiro PF, Shepherd BE, et al. Daily marijuana use is associated with missed clinic appointments among HIV-infected persons engaged in HIV care. AIDS Behav 2017; 21:1996–2004.
- Zhang Y, Wilson TE, Adedimeji A, et al. The impact of substance use on adherence to antiretroviral therapy among HIV-infected women in the United States. AIDS Behav 2018; 22:896–908.
- Bonn-Miller MO, Oser ML, Bucossi MM, Trafton JA. Cannabis use and HIV antiretroviral therapy adherence and HIV-related symptoms. J Behav Med 2014; 37: 1–10.
- Lake S, Kerr T, Capler R, Shoveller J, Montaner J, Milloy MJ. High-intensity cannabis use and HIV clinical outcomes among HIV-positive people who use illicit drugs in Vancouver, Canada. Int J Drug Policy 2017; 42:63–70.
- Okafor CN, Zhou Z, Burrell LE, 2nd, et al. Marijuana use and viral suppression in persons receiving medical care for HIV-infection. Am J Drug Alcohol Abuse 2017; 43:103–10.

- Slawson G, Milloy MJ, Balneaves L, et al. High-intensity cannabis use and adherence to antiretroviral therapy among people who use illicit drugs in a Canadian setting. AIDS Behav 2015; 19:120–7.
- Allshouse AA, MaWhinney S, Jankowski CM, Kohrt WM, Campbell TB, Erlandson KM. The impact of marijuana use on the successful aging of HIV-infected adults. J Acquir Immune Defic Syndr 2015; 69:187–92.
- Tenorio AR, Zheng Y, Bosch RJ, et al. Soluble markers of inflammation and coagulation but not T-cell activation predict non–AIDS-defining morbid events during suppressive antiretroviral treatment. J Infect Dis 2014; 210:1248–59.
- 33. Keogh RH, Daniel RM, VanderWeele TJ, Vansteelandt S. Analysis of longitudinal studies with repeated outcome measures: adjusting for time-dependent confounding using conventional methods. Am J Epidemiol 2018; 187:1085–92.
- Hernán MA, Brumback BA, Robins JM. Estimating the causal effect of zidovudine on CD4 count with a marginal structural model for repeated measures. Stat Med 2002; 21:1689–709.
- Keogh RH, Daniel RM, VanderWeele TJ, Vansteelandt S. Analysis of longitudinal studies with repeated outcome measures: adjusting for time-dependent confounding using conventional methods. Am J Epidemiol 2018; 187:1085–92.
- Viswanathan S, Justice AC, Alexander GC, et al. Adherence and HIV RNA suppression in the current era of highly active antiretroviral therapy. J Acquir Immune Defic Syndr 2015; 69:493–8.
- Castillo-Mancilla JR, Coyle RP, Coleman SS, et al. Short communication: cascade of antiretroviral therapy adherence in virologically suppressed persons living with HIV. AIDS Res Hum Retroviruses 2020; 36:173–5.
- Morrow M, MaWhinney S, Coyle RP, et al. Emtricitabine triphosphate in dried blood spots predicts future viremia in persons with HIV and identifies mismatch with self-reported adherence. AIDS 2021; 35:1949–56.
- Jennings L, Robbins RN, Nguyen N, et al. Tenofovir diphosphate in dried blood spots predicts future viremia in persons with HIV taking antiretroviral therapy in South Africa. AIDS 2022; 36:933–40.
- Calakos KC, Bhatt S, Foster DW, Cosgrove KP. Mechanisms underlying sex differences in cannabis use. Curr Addict Rep 2017; 4:439–53.
- Nia AB, Mann C, Kaur H, Ranganathan M. Cannabis use: neurobiological, behavioral, and sex/gender considerations. Curr Behav Neurosci Rep 2018; 5:271–80.
- Ellis RJ, Peterson S, Cherner M, et al. Beneficial effects of cannabis on blood-brain barrier function in human immunodeficiency virus. Clin Infect Dis 2021; 73: 124–9.
- Chaillon A, Nakazawa M, Anderson C, et al. Effect of cannabis use on HIV DNA during suppressive ART. Clin Infect Dis 2019; 70:140–3.
- 44. Milloy MJ, Marshall B, Kerr T, et al. High-intensity cannabis use associated with lower plasma human immunodeficiency virus-1 RNA viral load among recently infected people who use injection drugs. Drug Alcohol Rev 2015; 34:135–40.
- 45. Manuzak JA, Gott TM, Kirkwood JS, et al. Heavy cannabis use associated with reduction in activated and inflammatory immune cell frequencies in antiretroviral therapy-treated human immunodeficiency virus-infected individuals. Clin Infect Dis 2018; 66:1872–82.
- Ellis RJ, Peterson SN, Li Y, et al. Recent cannabis use in HIV is associated with reduced inflammatory markers in CSF and blood. Neurol Neuroimmunol Neuroinflamm 2020; 7:e809.
- Krsak M, Wada NI, Plankey MW, et al. Self-reported cannabis use and markers of inflammation in men who have sex with men with and without HIV. Cannabis Cannabinoid Res 2021; 6:165–73.
- Huang W, Czuba LC, Manuzak JA, et al. Objective identification of cannabis use levels in clinical populations is critical for detecting pharmacological outcomes. Cannabis Cannabinoid Res 2021; 7:852–64.
- de Jong BC, Prentiss D, McFarland W, Machekano R, Israelski DM. Marijuana use and its association with adherence to antiretroviral therapy among HIV-infected persons with moderate to severe nausea. J Acquir Immune Defic Syndr 2005; 38:43–6.
- Corless IB, Lindgren T, Holzemer W, et al. Marijuana effectiveness as an HIV selfcare strategy. Clin Nurs Res 2009; 18:172–93.