Original Article

Prevalence of and Factors Associated with Sarcopenic Obesity in People Living with HIV

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Abstract

OBJECTIVES: To determine the prevalence of sarcopenic obesity (SO) and explore factors potentially associated with SO among people living with HIV (PLWH).

MATERIALS AND METHODS: A cross-sectional study was conducted between September 2024 and May 2025 among 312 PLWH aged 20–79 years attending Siriraj Hospital. All participants had been diagnosed with HIV for at least 12 months. SO was defined as having BMI ≥25 kg/m², high body fat according to ESPEN/EASO, and sarcopenia by hand grip and five-times chair stand test. Body composition was evaluated using bioelectrical impedance analysis.

RESULTS: The prevalence of SO was 7.33% (95% CI: 4.87–10.81%). No statistically significant associations were identified in the primary multivariable analyses. However, exploratory dose–response analyses suggested potential relationships between cumulative exposure to certain antiretroviral therapy (ART) agents and SO. A significant trend was observed for protease inhibitor exposure. Higher cumulative exposure to stavudine (d4T) was associated with SO in the highest quartile, while abacavir (ABC) showed an association at intermediate exposure levels, with a significant dose–response trend.

CONCLUSION: This study suggests exploratory associations between cumulative exposure to specific ART regimens and sarcopenic obesity among PLWH. Given the exploratory nature of the dose–response analyses and the limited number of SO cases, these findings should be interpreted with caution. Further longitudinal studies are warranted to clarify the long-term metabolic and functional effects of ART.

Keywords: sarcopenic obesity, HIV, antiretroviral therapy

Sarcopenic obesity (SO) is an emerging metabolic condition of growing concern, particularly among older adults.[1] It is characterized by the coexistence of excess adiposity and impaired skeletal muscle mass and function. A meta-analysis of 50 studies estimated its prevalence in the general older population at approximately 11%.[2] SO has been linked to increased mortality and morbidity. Individuals with this condition have a 1.21- to 3.25-fold higher risk of all-cause mortality compared with those without it.[3] Morbidity risks include type 2 diabetes mellitus (T2DM), cognitive decline, osteoporosis, knee osteoarthritis, and depression.[4,5] The development of SO is considered multifactorial. Proposed mechanisms include chronic low-grade inflammation, age-related hormonal changes, inadequate protein intake relative to energy consumption, micronutrient deficiencies, particularly vitamin D and physical inactivity.[3,6,7]

Human immunodeficiency virus (HIV) infection is a chronic condition in which the widespread use of antiretroviral therapy (ART) has substantially improved survival among people living with HIV (PLWH). However, persistent HIV-related immune activation and long-term ART exposure may contribute to metabolic and musculoskeletal alterations, potentially increasing the risk of sarcopenia, obesity, or coexistence. A meta-analysis found that PLWH have a 6.1-fold higher risk of sarcopenia than HIV-negative

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individuals.[8] In addition, a study from Japan found that 29.9% of PLWH were classified as obese, while 46% had so-called "hidden obesity," defined as increased body fat percentage despite a normal body mass index (BMI).[9] Although the prevalence of sarcopenia alone was comparable to that observed in the general population, more than half of individuals with sarcopenia also exhibited hidden obesity, suggesting concurrent alterations in muscle and adipose tissue compartments.[9]

Emerging evidence has also suggested that specific ART regimens may be associated with changes in body composition. For example, tenofovir alafenamide (TAF) has been associated with weight gain in some populations,[9] and randomized clinical trials have demonstrated greater weight gain with integrase strand transfer inhibitor (INSTI)-based regimens, including dolutegravir (DTG) and bictegravir (BIC), compared with other ART classes [10]. However, the extent to which ART exposure is associated with sarcopenic obesity, rather than obesity alone, remains unclear.

In summary, PLWH may be at increased risk of developing sarcopenic obesity compared with the general population. Despite growing recognition of these mechanisms, existing evidence on factors associated with sarcopenic obesity in PLWH remains fragmented, with most studies focusing on either sarcopenia or obesity alone. Moreover, the potential dose–response relationship between cumulative ART exposure and sarcopenic obesity has not been well characterized, particularly in Asian populations. Therefore, this study aimed to determine the prevalence of sarcopenic obesity and to explore factors potentially associated with SO among PLWH, with particular emphasis on age, ART exposure, and HIV-related characteristics.

Material and Methods

This observational study was conducted primarily using a cross-sectional design, with an exploratory analytic component resembling a case–control approach. The study took place at the Infectious and Immunodeficiency Clinic of the Department of Preventive and Social Medicine, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand. Participants were people living with HIV attending routine follow-up visits, including viral load monitoring, ART management, and general health promotion services.

The cross-sectional component was designed to estimate the prevalence of sarcopenic obesity, while the analytic component aimed to explore potential associations between sarcopenic obesity and demographic, clinical, and HIV-related factors, including cumulative ART exposure.

The study was conducted in accordance with the Declaration of Helsinki and received approval from the Siriraj Institutional Review Board (SIRB 669/2567; COA no. Si 693/2024 [IRB4]). Participants were recruited between September 2024 and May 2025 through a full census of eligible patients attending the clinic and poster invitations. Written informed consent was obtained from all participants prior to enrollment.

Participants and Data Collection

Eligible participants were adults aged 20–79 years, diagnosed with HIV for at least 12 months, and receiving care at the study clinic. Exclusion criteria included contraindications to body composition assessment (e.g., presence of a pacemaker), pregnancy, or severe physical limitations that precluded functional assessment.

Baseline demographic and clinical data were collected using structured questionnaires and medical record review. Anthropometric measurements and body composition, including body fat percentage and skeletal muscle mass, were assessed using a validated bioelectrical impedance analyzer (InBody770; InBody Thailand Co., Ltd., Bangkok, Thailand).

Definition of Sarcopenic Obesity

SO was conceptualized as a condition characterized by the coexistence of excess adiposity and impaired muscle function proposed by the European Society for Clinical Nutrition and Metabolism and the European Association for the Study of Obesity (ESPEN/EASO). In this study, obesity was defined as a body mass index (BMI) ≥25 kg/m², in accordance with World Health Organization (WHO) criteria for Asian populations, together with a high body fat percentage based on age- and sex-specific cut-off values. Sarcopenia was defined based on functional impairment.

Assessment of Sarcopenic Obesity

Obesity and overweight were determined based on body mass index (BMI) and body fat percentage using cut-off values from ESPEN/EASO and NIH/WHO criteria for Asian populations.[11] Sarcopenia was evaluated using handgrip strength and the five-time chair stand test. Low muscle strength indicating sarcopenia was defined as handgrip strength < 28 kg in males and <18 kg in females, or a chair stand time ≥12 seconds.

Participants were categorized into six groups based on BMI, body fat, and sarcopenia status, with SO defined as BMI ≥25 kg/m², high body fat, and sarcopenia. For the exploratory analytic component, participants with sarcopenic obesity were classified as cases, while those with obesity without sarcopenia served as the comparison group.

Covariates

General risk factors included age, sex, socioeconomic indicators, smoking status, alcohol consumption, physical activity (IPAQ),[12] nutritional status (MNA),[13] comorbidities, and non-HIV medication use. HIV-related variables encompassed initial CD4 cell count, current viral suppression

(<40 copies/mL), duration since HIV diagnosis, detailed ART history including type and duration, history of drug resistance, prior opportunistic infections (e.g., *Pneumocystis jirovecii* pneumonia, tuberculosis, cytomegalovirus, cryptococcal meningitis), and co-infections (hepatitis B, hepatitis C, and syphilis). ART regimen variables were defined as cumulative ever exposure; therefore, participants could be included in more than one ART category.

Statistical analysis

Sample size estimation was based on the primary objective of estimating the prevalence of sarcopenic obesity (SO). Using a cross-sectional formula with a 95% confidence level, a 5% margin of error, and an expected prevalence of 28.4% [14], the required sample size was 313 participants.

Descriptive statistics were used to summarize baseline characteristics, with categorical variables reported as frequencies and percentages, and continuous variables reported as means ± standard deviations or medians and interquartile ranges (IQR), depending on normality. For the analysis of factors associated with sarcopenic obesity, participants with SO were compared with those who had obesity alone. Group comparisons were performed using the chi-square test for categorical variables and the Mann–Whitney U test for continuous variables. Given the limited number of sarcopenic obesity cases, multivariable models were restricted to a small number of predictors selected based on biological plausibility and univariable screening, to minimize overfitting and imprecision. Variables with a p-value < 0.20 in univariable analysis were entered into a multivariable logistic regression model to estimate adjusted odds ratios (aORs) and 95% confidence intervals (CIs).

All statistical analyses were conducted using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). A two-sided p-value <0.05 was considered statistically significant.

Results

Between September 2024 and May 2025, 373 individuals were screened, and 300 eligible participants were enrolled, all completing questionnaires, body composition, and sarcopenic assessments. An additional 12 participants with SO were recruited to enhance analytic power for exploratory analyses of associated factors and were excluded from prevalence estimation. Additional SO cases were identified using the same recruitment approach and assessment protocols as the main study population. No alternative sampling strategies were applied. The flow of participant recruitment and enrollment is illustrated in the CONSORT diagram (Figure 1).

Participants had a median age of 53 years (IQR 44–60), 54.3% were male, 52.3% held a bachelor's degree or higher, and 35% reported a monthly income ≥30,000 Baht. Common comorbidities included dyslipidemia (54.6%), hypertension

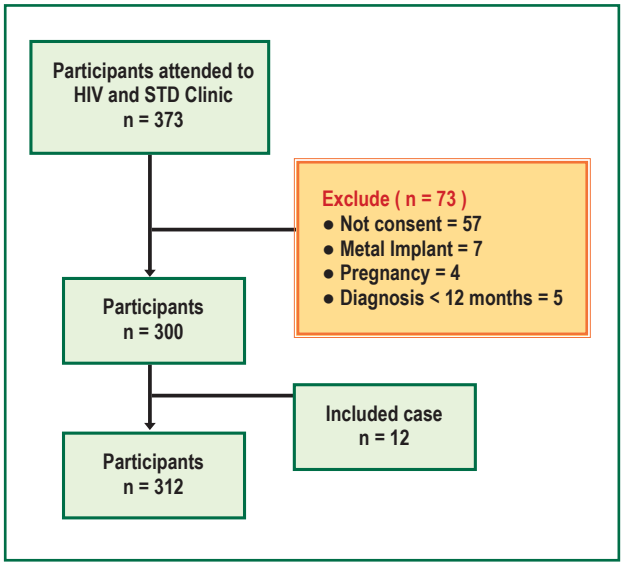


Figure 1: CONSORT diagram.

(28.3%), and diabetes (12.6%). Most were non-smokers (67.3%), 40% reported recent alcohol use, and 46.7% had low physical activity. Regarding HIV parameters, 55.7% had initial CD4 <200 cells/mm³, 98.7% achieved viral suppression, and median HIV duration was 18 years. The most commonly used ARTs were 3TC/FTC (99%), DTG (72%), and TDF (55.3%). History of drug resistance was reported in 12.7%, and 49% had prior opportunistic infections. Co-infections included syphilis (10.7%), hepatitis B (7.3%), and hepatitis C (5.7%).

Based on body composition and functional assessments, participants were classified into six phenotypic groups, with sarcopenic obesity accounting for 7.3% of the cohort. Including additional recruited cases, a total of 34 participants were included in analyses of factors associated with sarcopenic obesity.

Among SO participants, 55.9% were aged ≥50 years, a majority were female, and dyslipidemia (73.5%), hypertension (44.1%), and diabetes (26.5%) were common. Median BMI was 27.5 kg/m², body fat percentage 38.2%, skeletal muscle mass 7.5 kg/m², handgrip strength 23.0 kg, and chair stand time 12.51 seconds. Comparisons of demographic, clinical, lifestyle, and HIV-related characteristics between SO and non-SO groups are presented in Table 1. Additional group-specific characteristics and detailed phenotypic data are provided in Supplementary 1 and Supplementary 2.

The prevalence of SO among PLWH was 7.33% (22/300; 95% CI: 4.87–10.81%). In univariable logistic regression analyses, no demographic, lifestyle, or HIV-related factors were significantly associated with sarcopenic obesity at the conventional statistical threshold. However, cumulative exposure to NNRTI and protease inhibitor exposure demonstrated borderline associations ($p < 0.1$) and were therefore considered for multivariable analysis.

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Table 1: Comparison of baseline characteristics between SO and obesity alone.

Characteristic	Participants		*p*-value
	Obesity alone n = 70 , n(%)	Sarcopenic obesity n = 34, n(%)	
General risk factors			
Age in years (median and IQR)	50 (41–56)	52 (43–62)	0.160
Age ≥ 50 years	36 (51.4)	19 (55.9)	0.682
Male	36 (51.4)	17 (50.0)	1.000
Education level			
Primary or below	12 (17.1)	8 (23.5)	0.134
Secondary	22 (31.4)	9 (26.5)	
Bachelor or higher	36 (51.4)	17 (50.0)	
Monthly individual income (Bath)			
<15000	18 (25.7)	12 (35.2)	0.552
15000-29999	24 (34.3)	9 (26.5)	
≥ 30000	28 (40)	13 (38.2)	
Underlying disease			
HT	27(38.6)	15 (44.1)	0.672
T2DM	13 (18.6)	9 (26.5)	0.444
DLP	39 (55.7)	25 (73.5)	0.090
CKD	6 (8.6)	5 (14.7)	0.340
Non-HIV medication			
Anti-diabetes drug	13 (18.6)	9 (26.5)	0.444
Anti-hypertensive drug	25 (35.7)	16 (47.1)	0.291
Lowering lipid drug	34 (48.6)	23 (67.6)	0.093
Smoking			
Recent	8 (11.4)	3 (8.8)	0.184
Ex-drinker	10 (14.3)	10 (29.4)	
None (reference)	52 (74.3)	21 (61.8)	
Alcohol consumption			
Recent	35 (50.0)	9 (26.5)	0.022
Ex-drinker	17 (24.3)	17 (50.0)	
None (reference)	18 (25.7)	8 (23.5)	
Physical activity			
<600 MET-min/week	40 (57.1)	22 (64.7)	0.597
600-1500 MET-min/week	9 (12.9)	5 (14.7)	
>1500 MET-min/week (reference)	21 (30.0)	7 (20.6)	
Nutrition			
Malnutrition	0 (0)	0 (0)	0.785
Risk of malnutrition	11 (15.7)	6 (17.6)	
Normal nutrition status (reference)	59 (84.3)	28 (82.4)	
HIV-associated risk factors			
Initial CD4 cell count			1.000
< 200 cell/mm^3	40 (57.1)	19 (55.9)	
≥ 200 cell/mm^3 (reference)	30 (42.9)	15 (44.1)	
Current viral suppression			
Suppressed	70 (100)	34 (100)	-
Potential ART regimen			
d4T	16 (22.9)	14 (41.2)	0.066
ABC	7 (10.0)	8 (23.5)	0.079
Total PIs	17 (24.3)	4 (11.8)	0.136
Have history of drug resistance	7 (10.0)	2 (5.9)	0.484
Have history of OIs	35 (50.0)	16 (47.1)	0.836
Period of HIV diagnosis (median and IQR)	16 (9–21)	16 (11–22)	0.750
Total year of intake ART (median and IQR)	12.5 (8.00-18.00)	14.67 (9.41-19.33)	0.562
Co-infection, n(%)			
Hepatitis B	8 (11.4)	4 (11.8)	0.960
Hepatitis C	3 (4.3)	3 (8.8)	0.352
Syphilis	8 (11.4)	7 (20.6)	0.242

HT: Hypertension, T2DM: Type2 Diabetes Mellitus, DLP: Dyslipidemia, CKD: Chronic Kidney Disease, ART: Antiretroviral therapy, d4T: Stavudine, ABC: Abacavir, PIs: protease inhibitor drug group, OIs: opportunistic infections

Table 2: Univariable logistic regression analysis of factors associated with sarcopenic obesity among PLWH.

Risk factor	Crude odd ratio (95% CI)	*p*-value
Age (years)		
Age ≥ 50	1.196 (0.525-2.725)	0.670
Alcohol consumption		
Recent	0.579 (0.191-1.754)	0.334
Ex-drinker	2.250 (0.772-6.562)	0.138
None (reference)	1	
HIV-associated risk factors		
Initial CD4 cell count		
< 200 cell/mm^3	0.950 (0.416-2.170)	0.903
ART regimen		
d4T	1.134 (0.919-1.398)	0.241
ABC	1.145 (0.962-1.363)	0.128
DTG	1.171 (0.811-1.692)	0.400
BIC	1.183 (0.719-1.945)	0.508
Total NRTIs	1.019 (0.984-1.055)	0.302
Total NNRTIs	1.060 (0.993-1.131)	0.083
Total INSTIs	0.971 (0.794-1.189)	0.779
Total PIs	0.880 (0.761-1.017)	0.084
Period since HIV diagnosis		
Any year of diagnosis	1.006 (0.951-1.064)	0.846
Period of diagnosis ≥ 16 years	1.267 (0.556-2.885)	0.574
Period of taking ART	1.019 (0.954-1.089)	0.577
History of drug resistant or opportunistic infections		
Have history of drug resistant	0.563 (0.110-2.865)	0.489
Have history of opportunistic infections	0.889 (0.391-2.019)	0.778
Co-infection		
Hepatitis B	1.033 (0.288-3.705)	0.960
Hepatitis C	2.161 (0.413-11.321)	0.362
Syphilis	2.009 (0.662-6.100)	0.218

ART: Antiretroviral therapy, d4T: Stavudine, ABC: Abacavir, DTG: Dolutegravir, BIC: Bictegravir, NRTIs: Nucleoside Reverse Transcriptase Inhibitor drug group, NNRITs: Non-Nucleoside Reverse Transcriptase Inhibitor drug group, INSTIs: Integrase Strand Transfer Inhibitors drug group, PIs: protease inhibitor drug group

In multivariable analysis, neither cumulative NNRTI exposure (adjusted OR 1.038; 95% CI: 0.966–1.115; $p = 0.310$) nor cumulative PI exposure (adjusted OR 0.872; 95% CI: 0.747–1.019; $p = 0.085$) was independently associated with SO. Similarly, alcohol consumption showed no significant association, both among recent drinkers (aOR 0.460; 95% CI: 0.143–1.480) and ex-drinkers (aOR 2.129; 95% CI: 0.684–6.630). Detailed multivariable results are provided in Supplementary 3.

Secondary dose–response analyses were conducted by stratifying cumulative antiretroviral drug exposure into quartiles. A statistically significant trend across quartiles was observed for PIs (p for trend = 0.043). Among individual agents, stavudine (d4T) exposure in the highest quartile (Q4) was significantly associated with sarcopenic obesity (OR 6.30; 95% CI 1.75–22.74), while abacavir (ABC) exposure in Q3 showed a significant association (OR 9.63; 95% CI 1.03–90.16), with an overall significant trend across quartiles (p for trend = 0.047). These findings are summarized in Table 3.

Discussion

This study reported a SO prevalence of 7.33% (95% CI: 4.87%–10.81%) among PLWH. While no HIV-related factors were independently associated with SO in multivariable analyses, exploratory dose–response analyses suggested potential associations between cumulative exposure to certain antiretroviral therapy (ART) classes and sarcopenic obesity. Specifically, a significant trend was observed across quartiles of cumulative PIs exposure (p for trend = 0.043). In addition, exposure to d4T in the highest quartile was strongly associated with SO (OR 6.300, 95% CI: 1.745–22.743; $p = 0.005$), suggesting a possible threshold effect. while ABC demonstrated a significant dose–response relationship with increased risk at the third quartile (OR 9.630, 95% CI: 1.028–90.164; p for trend = 0.047).

The observed prevalence of SO in this cohort was lower than that reported in a previous study conducted in Mexico, which found nearly a threefold higher prevalence.[14] This discrepancy may be partly explained by differences in national obesity rates, as Mexico reported an obesity prevalence of 36.1% in 2022 compared with 14.5% in Thailand.[15]

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Table 3. Dose–response relationship between cumulative ART (by quartiles) and SO.

	Quantitative ART use							
	Q1 (reference)	Q2		Q3		Q4		*p* for trend
	OR (95%CI)	OR (95%CI)	*p* -value	OR (95%CI)	*p* -value	OR (95%CI)	*p* -value	
NRTIs		2.224 (0.627-7.890)	0.216	2.224 (0.627-7.890)	0.216	3.080 (0.885-10.725)	0.077	0.352
NNRTIs		3.143 (0.887-11.141)	0.076	2.588 (0.744-9.000)	0.135	2.329 (0.659-8.239)	0.190	0.081
INSTIs		1.429 (0.521-3.920)	0.489	1.210 (0.435-3.367)	0.715	0.457 (0.049-4.281)	0.493	0.455
PIs	1.00	N/A*	0.999	0.292 (0.034-2.532)	0.264	0.583 (0.058-5.844)	0.144	0.043
d4T		2.100 (0.432-10.212)	0.358	0.933 (0.174-5.007)	0.936	6.300 (1.745-22.743)	0.005	0.191
ABC		2.407 (0.322-17.979)	0.392	9.630 (1.028-90.164)	0.047	1.204 (0.105-13.838)	0.882	0.047
BIC		2.310 (0.140-38.215)	0.559	1.155 (0.101-13.249)	0.908	N/A**	0.999	0.237

To further explore potential dose–response relationships, a post-hoc analysis was conducted by stratifying antiretroviral drug exposure into quartiles. This post-hoc exploratory analysis was not pre-specified in the original study protocol and should therefore be interpreted cautiously.

ART: antiviral therapy; Q: quartiles; OR: odd ratio; CI: confident interval; NRTIs: Nucleoside Reverse Transcriptase Inhibitor drug group; NNRITs: Non-Nucleoside Reverse Transcriptase Inhibitor drug group; INSTIs-integrase strand transfer inhibitor drug group; PIs: protease inhibitors drug group; d4T: stavudine; ABC: abacavir; BIC: bictegravir, *Due to no number of participants in case group of Q2 ; **Due to no number of participants in control group of Q4

Additionally, differences in assessment methodology may have contributed to the variation. The Mexican study utilized dual-energy X-ray absorptiometry (DXA) without sex-specific cutoff points, whereas the present study employed bioelectrical impedance analysis (BIA) with sex-specific thresholds for body fat percentage and skeletal muscle mass.

A notable challenge in this study relates to the definition of SO as per the ESPEN and EASO Consensus and the 2025 *The Asia-Oceania consensus: Definitions and diagnostic criteria for sarcopenic obesity* (AWGS) criteria.[1,16] Only 3 participants met the criteria for definite SO, with muscle mass thresholds met by just 1 male and 2 female participants. Although muscle mass in the SO group ranged from 5.4 to 9.8 kg/m², clinically meaningful impairments in muscle strength and physical performance were evident, as reflected by reduced handgrip strength and prolonged chair stand time when compared with participants with obesity alone. These findings suggest that, in this cohort, functional decline may precede or be more prominent than reductions in muscle mass, supporting the concept that functional measures may capture early or "possible" SO more sensitively than body composition indices alone. Consequently, the majority of SO cases (91.2%) may be better classified as having possible SO rather than definite SO. This classification may partly explain the absence of strong associations in the main regression analyses. Future studies enrolling a larger number of participants meeting definite SO criteria may yield clearer associations and further inform the applicability of international diagnostic criteria within PLWH population.

The biological mechanisms linking ART exposure to sarcopenic obesity remain incompletely understood. Prior studies suggest that NRTIs and PIs may promote systemic inflammation, mitochondrial dysfunction, and muscle protein degradation, thereby promoting sarcopenia in PLWH.[17] Further, d4T has been implicated in central fat accumulation and wasting syndrome, primarily due to mitochondrial toxicity.[18] Although direct evidence linking ABC to sarcopenia is limited, findings from the REPRIEVE trial demonstrated an increased risk of major adverse cardiovascular events (MACE) associated with prior ABC exposure, suggesting potential metabolic consequences of cumulative exposure.[19] The absence of association with INSTI exposure may reflect relatively shorter cumulative exposure durations in this cohort. It is important to note that ART exposures in this study were not mutually exclusive, and the observed associations likely reflect cumulative or overlapping treatment histories rather than effects of individual regimens alone.

The wide confidence intervals observed in several analyses indicate imprecision and warrant cautious interpretation of these findings. The dose–response analyses were conducted post hoc and were not pre-specified in the original study protocol; therefore, these results should be considered exploratory and hypothesis-generating rather than confirmatory. Future studies with prospective designs and adequate sample sizes are needed to improve estimate precision and to better clarify the long-term metabolic effects of ART. Although d4T is no longer routinely used in Thailand, ABC remains commonly prescribed, including in provincial hospitals, underscoring the importance of continued evaluation of its long-term metabolic impact.

This study has the strength of a prevalence survey focused on SO among PLWH, a population at elevated metabolic risk. It also explores potential HIV-related contributing factors, with some ART drugs implicated in SO development. However, several limitations should be acknowledged. Inflammatory biomarkers were not directly measured. Although inflammation and nutritional status are recognized mechanisms contributing to sarcopenic obesity in PLWH, these factors were not directly assessed in the present study. Therefore, the proposed mechanistic links should be interpreted as conceptual rather than causal. In addition, the relatively small sample size and recruitment from a single tertiary care center may limit the generalizability of the findings to the wider Thai population. Future multi-center studies with larger, nationally

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representative cohorts are warranted to better define the epidemiology of sarcopenic obesity and to clarify its associations with cumulative antiretroviral therapy exposure in PLWH.

Conclusion

This study observed a relatively lower prevalence of sarcopenic obesity among PLWH compared to previous reports. Although conventional analyses did not identify statistically significant risk factors, dose–response analyses suggested potential associations between cumulative exposure to certain ART drugs, particularly PIs, d4T, and ABC. The apparent threshold effect of d4T and the dose–response relationship observed with ABC highlight the potential long-term metabolic consequences of ART exposure, even with historical or cumulative use. These findings emphasize the need for further large-scale and multicenter studies to better inform ART selection and metabolic risk management among PLWH.

Conflict of Interest

The authors declare no **conflict of interest** related to this study

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Supplementary

Supplementary 1. Baseline Characteristic from Initial Sample (n = 300).

Characteristic	Participants ; n(%)						
	Low-normal 135 (45)	Large body 34 (11.3)	Overweight 33 (11)	Overweight with sarcopenia 6 (2)	Obesity 70 (23.3)	Sarcopenic obesity 22 (7.3)	All 300 (100)
General risk factors							
Median and IQR of age	54 (47-60)	53 (45-62)	49 (38-56)	61 (50-66)	50 (41-56)	55 (46-65)	53 (44 - 60)
Age ≥ 50 years	91(67.4)	21(61.7)	16(48.4)	5(83.3)	36(51.4)	15(68.1)	184 (61.3)
Male	73 (54.1)	20 (58.8)	21 (63.6)	4 (66.7)	36 (51.4)	9 (40.9)	163 (54.3)
Education level							
Primary or below	25 (18.5)	8 (23.5)	3 (9.1)	4 (66.7)	12 (17.1)	8 (36.4)	60 (20%)
Secondary	39 (28.9)	6 (17.6)	9 (27.3)	1 (16.7)	22 (31.4)	6 (27.3)	83 (27.7)
Bachelor or higher	71 (52.6)	20 (58.8)	21 (63.6)	1 (16.7)	36 (51.4)	8 (36.4)	157 (52.3)
Monthly individual income (Baths)							
<15000	55 (40.7)	10 (29.4)	7 (21.2)	3 (50.0)	18 (25.7)	10 (45.6)	103 (34.3)
15000-29999	40 (29.6)	10 (29.4)	9 (27.2)	3 (50.0)	24 (34.2)	6 (27.3)	92 (30.7)
≥ 30000	40 (29.6)	14 (41.2)	17 (51.5)	0 (0)	28 (40.0)	6 (27.3)	105 (35)
Underlying disease							
HT	29 (21.5)	8 (23.5)	6 (18.2)	4 (66.7)	27 (38.6%)	11 (50.0)	85 (28.3)
T2DM	12 (8.9)	2 (5.9)	4 (12.1)	0 (0)	13 (18.6%)	7 (31.8)	38 (12.6)
DLP	70 (51.9)	19 (55.9)	16 (48.5)	3 (50.0)	39 (55.7%)	17 (77.3)	164 (54.6)
CKD	6 (4.4)	1 (2.9)	3 (9.1)	0 (0)	6 (8.6%)	3 (13.6)	20 (6.6)
Stroke	1 (0.7)	1 (2.9)	0 (0)	0 (0)	1 (1.4%)	2 (4.5)	4 (1.3)
MI	2 (1.4)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.3)
CHF	1 (0.7)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.3)
Non-HIV medication							
Anti-diabetes drug	10 (7.4)	2 (5.9)	4 (12.1)	0 (0)	13 (18.6)	7 (31.8)	36 (12.0)
Anti-hypertensive drug	32 (23.7)	9 (26.5)	7 (21.2)	4 (66.7)	25 (35.7)	12 (54.5)	89 (29.7)
Lowering lipid drug	61 (45.2)	18 (52.9)	13 (39.4)	4 (66.7)	34 (48.6)	15 (68.2)	145 (48.3)
Antiplatelet drug	6 (4.5)	1 (2.9)	0 (0)	0 (0)	0 (0)	0 (0)	7 (2.3)
Diuretic drug	1 (0.7)	0 (0)	0 (0)	0 (0)	2 (2.8)	0 (0)	3 (1)
Vit D	38 (28.1)	12 (35.3)	7 (21.2)	3 (50.0)	14 (20.0)	9 (40.9)	83 (27.7)
Others	20 (14.8)	5 (14.7)	4 (12.1)	1 (16.7)	9 (12.6)	3 (13.6)	42 (14)
Smoking							
Recent	20 (14.8)	3 (8.8)	4 (12.1)	1 (16.7)	8 (11.4)	1 (4.5)	37 (12.3)
Ex-drinker	30 (22.2)	7 (20.6)	8 (24.2)	1 (16.7)	10 (14.3)	5 (22.7)	61 (20.3)
None	85 (63.0)	24 (70.6)	21 (63.6)	4 (66.7)	52 (74.3)	16 (72.7)	202 (67.3)
Alcohol consumption							
Recent	54 (40.0)	14 (41.2)	13 (39.4)	0 (0)	35 (50.0)	4 (18.2)	120 (40)
Ex-drinker	45 (33.3)	11 (32.4)	13 (39.4)	3 (50.0)	17 (24.3)	12 (54.5)	101 (33.7)
None	36 (26.7)	9 (26.5)	7 (21.2)	3 (50.0)	18 (25.7)	6 (27.3)	79 (26.3)
Physical activity							
<600 MET-min/week	60 (44.4)	9 (26.5)	16 (48.5)	4 (66.7)	40 (57.1)	11 (50.0)	140 (46.7)
600-1500 MET-min/week	27 (20.0)	8 (23.5)	7 (21.2)	0 (0)	9 (12.9)	4 (18.2)	55 (18.)
>1500 MET-min/week	48 (35.6)	17 (50.0)	10 (30.3)	2 (33.)	21 (30.0)	7 (31.8)	105 (35%)
Nutrition							
Malnutrition	3 (2.2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3 (1.0)
Risk of malnutrition	45 (33.3)	3 (8.8)	10 (30.3)	0 (0)	11 (15.7)	5 (22.7)	74 (24.7)
Normal nutrition status	87 (64.4)	31 (91.2)	23 (69.7)	6 (100)	59 (84.3)	17 (77.3)	223 (74.3)
HIV-associated risk factors							
Initial CD4 cell count							
< 200 cell/mm^3	73 (54.1)	19 (55.9)	18 (54.5)	6 (100)	40 (57.1)	11 (50.0)	167 (55.7)
≥ 200 cell/mm^3	62 (45.9)	15 (44.1)	15 (45.5)	0 (0)	30 (42.9)	11 (50.0)	133 (44.3)
Current viral suppression							
Suppressed	133 (98.5)	34 (100)	31 (93.9)	6 (100)	70 (100)	22 (100)	296 (98.7)
Non-suppressed	2 (1.5)	0 (0)	2 (6.06)	0 (0)	0 (0)	0 (0)	4 (1.3)

Supplementary 1. Baseline Characteristic from Initial Sample (n = 300).

Characteristic	Participants ; n(%)						
	Low-normal 135 (45)	Large body 34 (11.3)	Overweight 33 (11)	Overweight with sarcopenia 6 (2)	Obesity 70 (23.3)	Sarcopenic obesity 22 (7.3)	All 300 (100)
Current ART regimen							
TDF	76 (56.3)	17 (50.0)	18 (54.5)	3 (50.0)	42 (60.)	10 (45.5)	166 (55.3)
TAF	22 (16.3)	8 (23.5)	8 (24.2)	0 (0)	14 (20.0)	7 (31.8)	59 (19.6)
ABC	20 (14.8)	6 (17.6)	6 (18.2)	3 (50.0)	6 (8.6%)	3 (13.6)	44 (14.6)
DTG	98 (72.6)	25 (73.5)	19 (57.6)	6 (100)	53 (75.7)	15 (68.2)	216 (72.0)
BIC	7 (5.2)	1 (2.9)	4 (12.1)	0 (0)	2 (2.9)	4 (18.2)	18 (6.0)
EFV	7 (5.2)	2 (5.9)	1 (3.0)	0 (0)	6 (8.6)	0 (0)	16 (5.3)
RPV	24 (17.8)	7 (20.6)	9 (27.3)	0 (0)	10 (14.3)	4 (18.2)	54 (18.0)
Any PI	9 (6.7)	1 (2.9)	2 (6.1)	0 (0)	3 (4.3)	1 (4.5)	16 (5.3)
Time since HIV diagnosis (Median and IQR)	18 (11-22)	19 (10-22)	19 (10-21)	18 (13-24)	16 (9-21)	20 (15-23)	18 (11 - 22)
Total year intake ART (Median and IQR)	N/A	N/A	N/A	N/A	13 (8-18)	15 (11-20)	N/A
Prior drug resistance							
Yes	20 (14.8)	5 (14.7)	4 (12.1)	0 (0)	7 (10.0)	2 (9.1)	38 (12.7)
Prior opportunistic infections							
Yes	64 (47.4)	20 (58.8)	15 (45.5)	3 (50.0)	35 (50.0)	10 (45.5)	147 (49)
Co-infection, n(%)							
Hepatitis B	6 (4.4)	2 (5.9)	2 (6.1)	0 (0)	8 (11.4)	4 (18.2%)	22 (7.3)
Hepatitis C	8 (5.9)	2 (5.9)	3 (9.1)	0 (0)	3 (4.3)	1 (4.5)	17 (5.7)
Syphilis	14 (10.4)	3 (8.8)	3 (9.1)	1 (16.7)	8 (11.)	3 (13.6)	32 (10.7)
Median and IQR of body analysis							
Body weight (kg)	55.8 (50.4-60.9)	67.5 (61.3-72.0)	64.1 (59.8-67.9)	62.6 (53.1-71.1)	77.1 (68.1-87.9)	73.7 (61.4-77.1)	62.5 (55.6 - 71.58)
Height (cm)	165 (158-170)	166 (156-170)	164 (158-168)	161 (148-171)	164 (156-170)	160 (152-165)	165 (156 - 170)
BMI (kg/m^2)	21.0 (19.6-22.1)	24.4 (23.5-25.5)	24 (23.3-24.6)	24.4 (24.2-24.6)	28.5 (26.8-30.3)	27.0 (26.2-28.5)	23.35 (21.2 - 26.28)
Body fat mass (kg)	12.4 (8.9-16.1)	15.6 (14.0-19.8)	19 (15.9-21.5)	17.9 (17.1-19.9)	26.6 (23.2-31.9)	25.2 (22.5-29.5)	17.45 (12.5 - 22.86)
Percentage body fat mass	22.9 (16.4-29.3)	22.3 (19.2-32.1)	27.7 (24.3-36.1)	29.4 (25.7-34.1)	37.0 (30.9-41.2)	38.4 (33.8-43.9)	28.85 (20.85 - 35.1)
Skeleton muscle mass (kg/m^2)	6.4 (5.7-7.3)	7.8 (6.8-8.3)	7.2 (6.2-7.4)	7.3 (5.7-7.8)	7.8 (6.7-8.4)	7.2 (6.1-7.9)	7.00 (6.1 – 7.76)
Hand grip strength test (kg)	28.2 (21.4-33.6)	32.1 (23.4-36.9)	32.0 (26.6-37.0)	24.1 (17.0-26.4)	28.9 (23.3-37.4)	22.7 (15.8-25.1)	28.25 (22.1 - 34.9)
5-time chair stand test (sec)	8.04 (7.05-9.23)	6.97 (6.28-8.75)	7.27 (6.18-8.67)	8.95 (8.44-13.41)	8.05 (6.67-9.15)	12.31 (9.54-13.74)	8.05 (6.71-9.35)

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Supplementary 2. Detail of comparison of baseline characteristics between SO and obesity alone.

Characteristic	Participants		
	Obesity n = 70	Sarcopenic obesity n = 34	*p*-value
General risk factors			
Age in years (median and IQR)	50 (41-56)	52 (43-62)	0.160*
Age ≥ 50 years	36 (51.4)	19 (55.9)	0.682
Male	36 (51.4)	17 (40.9)	1.000
Education level			
Primary or below	12 (17.1)	8 (23.5)	0.134
Secondary	22 (31.4)	9 (26.5)	
Bachelor or higher	36 (51.4)	17 (50.0)	
Monthly individual income (Baths)			
<15000	18 (25.7)	12 (35.2)	0.552
15000-29999	24 (34.3)	9 (26.5)	
≥ 30000	28 (40.0)	13 (38.2)	
Underlying disease			
HT	27 (38.6)	15 (44.1)	0.672
T2DM	13 (18.6)	9 (26.5)	0.444
DLP	39 (55.7)	25 (73.5)	0.090
CKD	6 (8.6)	5 (14.7)	0.340
Non-HIV medication, n(%)			
Anti-diabetes drug	13 (18.6)	9 (26.5)	0.444
Anti-hypertensive drug	25 (35.7)	16 (47.1)	0.291
Lowering lipid drug	34 (48.6)	23 (67.6)	0.093
Smoking, n(%)			
Recent	8 (11.4)	3 (8.8)	0.184
Ex-drinker	10 (14.3)	10 (29.4)	
None (reference)	52 (74.3)	21 (61.8)	
Alcohol consumption, n(%)			
Recent	35 (50.0)	9 (26.5)	0.022
Ex-drinker	17 (24.3)	17 (50.0)	
None (reference)	18 (25.7)	8 (23.5)	
Physical activity, n(%)			
< 600 MET-min/week	40 (57.1)	22 (64.7)	0.597
600-1500 MET-min/week	9 (12.9)	5 (14.7)	
>1500 MET-min/week (reference)	21 (30.0)	7 (20.6)	
Nutrition, n(%)			
Malnutrition	0 (0)	0 (0)	0.785
Risk of malnutrition	11 (15.7)	6 (17.6)	
Normal nutrition status (reference)	59 (84.3)	28 (82.4)	
HIV-associated risk factors			
Initial CD4 cell count			
< 200 cell/mm^3	40 (57.1)	19 (55.9)	1.000
≥ 200 cell/mm^3 (reference)	30 (42.9)	15 (44.1)	
Current viral suppression			
Suppressed	70 (100)	34 (100)	-
Receive ART regimen, mean of total person year, median and IQR			
AZT	14 (20.0)	4 (11.8)	0.298
	5.5, 2.5 (1.00-11.08)	5.00, 2.5 (1.00-9.00)	0.915
d4T	16 (22.9)	14 (41.2)	0.066
	3.24, 3.00 (1.00-5.50)	2.93, 1.5 (1.00-5.00)	0.797
TDF	67 (95.7)	32 (94.1)	0.721
	10.15, 10.25 (6.00-14.00)	10.92, 11.4 (7.00-14.33)	0.468
TAF	18 (25.7)	10 (29.4)	0.814
	1.48, 1.00 (0.75-2.00)	1.50, 1.00 (0.41-2.00)	0.961
ABC	7 (10.0)	8 (23.5)	0.079
	5.03, 3.67 (0.08-10.00)	5.50, 5.00 (3.50-8.00)	0.523
3TC	62 (88.6)	29 (85.3)	0.635
	7.66, 6.00 (2.00-12.08)	8.74, 8.80 (3.00-12.00)	0.258
FTC	59 (84.3)	27 (79.4)	0.586
	6.77, 7.00 (3.00-10.00)	7.68, 7.08 (6.00-9.41)	0.236
DTG	54 (77.1)	26 (76.5)	1.000
	1.76, 2.00 (1.00-2.00)	2.04, 2.00 (1.00-3.00)	0.318
RAL	4 (5.7)	0 (0.0)	0.155
	7.56, 7.13 (3.13-12.00)	-	-

Supplementary 2. Detail of comparison of baseline characteristics between SO and obesity alone.

Characteristic	Participants		
	Obesity n = 70	Sarcopenic obesity n = 34	*p*-value
BIC	4 (5.7)	5 (14.7)	0.126
	2.69, 2.00 (1.38-4.00)	1.80, 1.00 (1.00-2.00)	0.612
EFV	51 (72.9)	25 (73.5)	1.000
	8.04, 8.00 (3.00-12.00)	9.16, 8.00 (6.00-13.00)	0.409
NVP	12 (17.1)	9 (26.5)	0.303
	9.10, 5.00 (3.00-15.69)	11.00, 15.00 (1.00-20.00)	1.000
RPV	24 (34.3)	14 (41.2)	0.521
	4.25, 4.00 (2.00-6.50)	4.40, 4.17 (2.00-6.00)	0.891
ETR	1 (1.4)	1 (2.9)	0.598
	15.00, 15.00 (15.00-15.00)	2.00, 2.00 (2.00-2.00)	0.317
DOR	1 (1.4)	0 (0.0)	0.484
	7.00, 7.00 (7.00-7.00)	-	-
DDI	8 (11.4)	3 (8.8)	0.685
	2.79, 2.75 (0.36-5.00)	6.33, 6.00 (1.00-12.00)	0.215
DDC	1 (1.4)	0 (0.0)	0.484
	2.40, 2.40 (2.40-2.40)	-	-
SQV/r	1 (1.4%)	0 (0.0)	0.484
	6.00, 6.00 (6.00-6.00)	-	-
ATV/r	10 (14.3)	1 (2.9)	0.078
	7.27, 5.50 (3.33-10.00)	0.08, 0.08 (0.08-0.08)	0.114
LPV/r	15 (21.4)	4 (11.8)	0.232
	3.76, 1.00 (0.49-8.00)	3.12, 0.71 (0.25-6.00)	0.579
DRV/r	3 (4.3)	1 (2.9)	0.738
	2.53, 1.00 (0.58-6.00)	6.00, 6.00 (6.00-6.00)	0.346
IDV/r	5 (7.1)	1 (2.9)	0.389
	4.40, 3.00 (1.00-7.00)	2.00, 2.00 (2.00-2.00)	0.766
Total NRTIs	69 (98.6)	34 (100)	0.484
	25.15, 24.96 (16.00-35.00)	27.36, 26.83 (18.00-38.66)	0.311
Total NNRTIs	65 (92.9)	32 (94.1)	0.810
	9.89, 9.00 (5.00-15.00)	12.24, 11.50 (7.00-17.54)	0.052
Total INSTIs	58 (82.9)	31 (91.2)	0.257
	2.35, 2.00 (1.00-2.25)	2.00, 2.00 (1.00-3.00)	0.764
Total PIs	17 (24.3)	4 (11.8)	0.136
	9.69, 11.00 (5.00-14.00)	5.14, 3.58 (0.71-9.58)	0.209
period of HIV diagnosis (median and IQR)	16 (9-21)	16 (11-22)	0.750
Total year of intake ART (median and IQR)	12.5 (8.00-18.00)	14.67 (9.41-19.33)	0.562
Have history of drug resistance	7 (10.0)	2 (5.9)	0.484
Have history of OIs	35 (50.0)	16 (47.1)	0.836
Co-infection			
Hepatitis B	8 (11.4)	4 (11.8)	0.960
Hepatitis C	3 (4.3)	3 (8.8)	0.352
Syphilis	8 (11.4)	7 (20.6)	0.242
Median and IQR of body analysis			
Body weight (kg)	77.1 (68.1-87.9)	74.9 (67.3-82.7)	0.517
Height (cm)	164 (156-170)	162 (155-169)	0.700
BMI (kg/m²)	28.5 (26.8-30.3)	27.5 (26.3-30.0)	0.377
Body fat mass (kg)	26.6 (23.2-31.9)	25.9 (22.6-31.4)	0.652
Percentage body fat mass	37.0 (30.9-41.2)	38.2 (30.3-43.7)	0.531
Skeleton muscle mass (kg/m²)	7.8 (6.7-8.4)	7.5 (6.6-8.4)	0.613
Hand grip strength test (kg)	28.9 (23.3-37.4)	23.0 (17.5-27.1)	<0.0001
5-time chair stand test (sec)	8.05 (6.67-9.15)	12.51 (9.55-14.99)	<0.0001

HT: Hypertension, T2DM: Type2 Diabetes Mellitus, DLP: Dyslipidemia, CKD: Chronic Kidney Disease, ART: Antiretroviral therapy, AZT: Zidovudine, d4T: Stavudine, TDF: Tenofovir disoproxil fumarate, TAF: Tenofovir alafenamide, ABC: Abacavir, 3TC: Lamivudine, FTC: Emtricitabine, DTG: Dolutegravir, RAL: Raltegravir, BIC: Bictegravir, EFV: Efavirenz, NVP: Nevirapine, RPV: Rilpivirine, ETR: Etravirine, DOR: Doravirine, DDI: Didanosine, DDC: Zalcitabine, SQV/r: Saquinavir/ritonavir, ATV/r: Atazanavir/ ritonavir, LPV/r: Lopinavir/ritonavir, DRV/r: Darunavir/ ritonavir, IDV/r: Indinavir/ritonavir, NRTIs: Nucleoside Reverse Transcriptase Inhibitor drug group, NNRITs: Non-Nucleoside Reverse Transcriptase Inhibitor drug group, INSTIs: Integrase Strand Transfer Inhibitors drug group, PIs: protease inhibitor drug group, OIs: opportunistic infections, BMI: body mass index

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Supplementary 3: Multivariable analysis of risk factors associated with SO

Risk factor	Crude OR (95% CI)	Adjusted OR (95% CI)	p-value (adjusted model)
NNRTIs	1.060 (0.993-1.131)	Model 1: 1.043 (0.975-1.116)	0.223
		Model 2: 1.038 (0.966-1.115)	0.310
PIs	0.880 (0.761-1.017)	Model 1: 0.897 (0.774-1.039)	0.148
		Model 2: 0.872 (0.747-1.019)	0.085
Alcohol consumption			
Recent	0.579 (0.191-1.754)	Model 2: 0.460 (0.143-1.480)	0.193
Ex-drinker	2.250 (0.772-6.562)	Model 2: 2.129 (0.684-6.630)	0.192

Model 1 : adjusted by NNRTIs, PIs
Model 2 : adjusted by NNRTIs, PIs, Alcohol consumption
OR: odd ratio; CI: confident interval; NNRITs: Non-Nucleoside Reverse Transcriptase Inhibitor drug group; PIs: protease inhibitors drug group