Association of HIV infection with metabolic syndrome among normal or underweight young adults: evidence from the CHART cohort

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1. Introduction

Benefited tremendously from antiretroviral therapy (ART) with long life (1), people living with HIV (PLWH) increasingly face non-HIV health problems such as metabolic complications including lipodystrophy, dyslipidemia, and insulin resistance (2). This cluster of metabolic conditions, combined with elevated blood pressure, is known as metabolic syndrome (MS). Individuals with MS are thought to be more susceptible to cardiovascular disease (CVD) and diabetes mellitus (DM), as well as stroke and cancers (3-5).

Many studies have suggested that MS is largely an inflammatory disease. Both adipose tissue (AT) and chemokines or cytokines derived from monocytes contribute to the MS via inflammatory pathways (6). Among the general population, excessive fat tissue is the main cause of MS development (7), and metabolic health often declines as body mass index (BMI) increases. However, the development of MS in PLWH is probably more complex with the coexistence of HIV infection and obesity. Research in developed countries shows that HIV-infected individuals had a high prevalence of being overweight or obesity prior to ART initiation, and 20% progressed to a higher unhealthy weight after ART initiation (8). Weight gain after receiving ART, along with HIV infection may accelerate metabolic dysfunction because excessive adipose accumulation and HIV

SUMMARY

Metabolic syndrome (MS) is common among obese people. Little is known about the magnitude and characteristics of MS in people living with HIV (PLWH) in Asian countries in general and China in particular. Using baseline data collected between February 2017 through January 2020 from the Comparative HIV and Aging Research in Taizhou (CHART) cohort in China, we examined MS among 2,227 PLWH and 5,264 matched people without HIV, respectively. MS was defined using the criteria set forth by the International Diabetes Federation (IDF). Approximately 76.7% of PLWH had body mass index (BMI) < 24.0 kg/m², significantly higher than people without HIV (50.3%). Among participants with BMI < 24.0 kg/m², PLWH had a significantly higher prevalence of MS than people without HIV (20.6% vs. 14.5%; aOR: 1.41, 95% CI: 1.19-1.68) overall, and at an age of 18-29 (10.4% vs. 3.4%, aOR: 3.49, 95% CI: 1.99-6.11) and 30-44 years (17.3% vs. 8.5%, aOR: 2.03, 95% CI: 1.47-2.81), respectively. Among participants with BMI ≥ 24.0 kg/m², MS prevalence was not significantly different between PLWH and people without HIV overall, but significantly lower in PLWH than people without HIV for those aged over 60 years (65.9% vs. 77.8%, aOR: 0.53, 95% CI: 0.32-0.88). Among PLWH, MS was significantly associated with older age and higher CD4 cell count, and with stavudine (d4T) use only in the group of BMI < 24.0 kg/m². Our finding is indicative of a relatively higher risk for early onset of MS among HIV-infected young adults with lower BMI. Research is needed to elucidate the pathogenic mechanism for MS among PLWH.

Keywords metabolic syndrome, body mass index, young adults, HIV infection, China
infection are chronic inflammatory states (9,10). Of note, overweight and obesity are not common in all PLWH especially in some Asian countries, where PLWH usually have a relatively low weight compared to the general population ever after ART initiation (11). For PLWH with low BMI, the effect of HIV-infection on development of MS is probably not overshadowed by that of excessive adipose tissue.

The global literature has revealed diverse estimates of prevalence of MS among PLWH (12). However, there is no definitive conclusion about the association between HIV infection and MS (13-16). Meanwhile, data on prevalence and risk factors for MS among PLWH with relatively lower or normal weight are very limited. Therefore, we conducted a cross-sectional study to:

1. estimate the prevalence of MS and its association with different categories of BMI;
2. examine correlates of MS among PLWH in mainland China.

2. Materials and Methods

2.1. Study design and participants

Using baseline data collected between February 2017 through January 2020 from an ongoing cohort known as the "Comparative HIV and Aging Research in Taizhou" (CHART) in Taizhou prefecture, Zhejiang province, east China, we examined MS among 2,227 PLWH and 5,264 individuals without HIV, respectively. The CHART is an ongoing prospective cohort study of HIV and age-related co-morbidities among PLWH and people without HIV; details of baseline characteristics of CHART have been described previously (17,18).

According to China treatment guidelines, the first-line of HIV treatment regimen for ART-naive patients consists of two nucleotide reverse-transcriptase inhibitors (NRTIs) including lamivudine (3TC), along with zidovudine (AZT) or stavudine (d4T), replaced with tenofovir disoproxil fumarate [TDF] since 2010), and one non-nucleotide reverse-transcriptase inhibitor (NNRTIs) namely nevirapine (NVP) or efavirenz (EFV). Patients who experience side effects or drug resistance from NRTIs may receive the two NRTIs mentioned above plus lopinavir (LPV) – a protease inhibitor (PI).

The study was approved by the Institutional Review Board of Fudan University School of Public Health, Shanghai, China. All participants have subscribed to the informed consent.

2.2. Data collection

Basic demographic and lifestyle characteristics of all participants were collected using a structured questionnaire, including sex, age, physical activity, smoking status, and alcohol use. Age groups were categorized by cut-offs of 18-29, 30-44, 45-59, and 60 and above according to the previous paper (17).

2.3. Definition of metabolic syndrome (MS)

According to the "International Diabetes Federation" (IDF) (20), MS is defined as the presence of at least three of the following five components: i) an increased waist circumference (Asian males > 90 cm; Asian females > 80 cm); ii) blood pressure ≥ 130/85 mmHg or hypertension based on self-report and/or local hospital records; iii) raised triglycerides (TG) levels ≥ 150 mg/dL (1.7 mmol/L); iv) reduced high density lipoprotein (HDL) < 40 mg/dL (1.03 mmol/L) in males or HDL < 50 mg/dL (1.29 mmol/L) in females; and v) elevated level of HbA1c > 5.7 % (21) or diabetes based on self-report and/or local hospital records.

2.4. Statistical analysis

All analyses were carried out using Stata 15.0 (Stata Corp., College Station, TX, USA). Descriptive data were expressed as mean with standard deviation, median (IQR) or tabulated as the number and percentage. Differences between groups were assessed by χ² test for categorical variables and by t-test or Kruskal-Wallis test for continuous variables, where appropriate. Logistic regressions were performed to evaluate the association of HIV-infection and MS within different BMI (< 24.0 or ≥ 24.0 kg/m²) and age groups. HIV-specific correlates (e.g., CD4) of MS were also examined among PLWH. Variables with p < 0.200 in univariate analysis and a priori were included in final multivariate analysis.

3. Results and Discussion

A total of 7,491 participants aged 18 to 75 years were
MS is higher among PLWH than in the general population (15,16,22). In our study, the overall MS prevalence is lower among PLWH (29.0%, 95% CI: 27.1-30.9) than people without HIV (37.5%, 95% CI: 36.2-38.9), partially due to lower weight and BMI of HIV cases. Nevertheless, a significantly higher risk for MS was observed among PWLH with BMI < 24.0 kg/m² than their HIV-negative counterparts (20.6% vs. 14.5%; AOR: 1.41, 95% CI: 1.19-1.68, p < 0.001 (Table 2), a finding similar to previous research (23).

MS is an age-related morbidity where incidence tends to go up with increased age (24). The prevalence of MS increased with age for both PLWH and people without HIV, from 16.0% at 18-29 years to 39.2% at 60-72 years among PLWH, and from 16.7% to 60.1% correspondingly among people without HIV. Similar patterns were observed among participants within both BMI strata, i.e., BMI < 24.0 kg/m² or BMI ≥ 24.0 kg/m² (Table 2). Given the effect of BMI (as a moderator) on HIV infection with MS, we statistically contrasted the BMI- and age-specific prevalence of MS among participants with BMI < 24.0 kg/m² and BMI ≥ 24.0 kg/m², respectively (Figure 1 and Table 2). A higher prevalence of MS was observed among PLWH than people without HIV, ranging from 24.1% in the younger age group to 37.7% in the older age group. The prevalence differences between HIV and non-HIV groups were statistically significant (p < 0.001). The prevalence of MS increased with BMI, from 16.7% in the lower BMI category (< 24.0 kg/m²) to 38.0% in the higher BMI category (≥ 24.0 kg/m²), and this difference was also statistically significant (p < 0.001).

### Table 1. Characteristics of PLWH and people without HIV stratified by BMI category

| Variables          | Total (n = 5,264) | BMI < 24.0 kg/m² (n = 2,645) | BMI ≥ 24.0 kg/m² (n = 2,619) |
|--------------------|------------------|------------------------------|------------------------------|
|                    | HIV+ (n = 2,227) | HIV- (n = 2,037)             | HIV+ (n = 1,707)             | HIV- (n = 1,931)             |
| Male               | 1,737 (78.0)     | 3,782 (71.9)                 | 1,332 (78.0)                 | 1,751 (66.2)                 |
| Age, yrs           | 44.1 ± 14.0      | 44.2 ± 14.4                  | 43.7 ± 14.3                  | 41.8 ± 14.6                  |
| 18-29              | 438 (19.7)       | 1,001 (19.0)                 | 367 (21.5)                   | 651 (24.6)                   |
| 30-44              | 767 (34.4)       | 1,808 (34.4)                 | 571 (33.5)                   | 948 (35.8)                   |
| 45-59              | 657 (29.3)       | 1,567 (29.8)                 | 487 (28.5)                   | 672 (25.4)                   |
| 60-75              | 370 (16.6)       | 888 (16.9)                   | 282 (16.5)                   | 374 (14.1)                   |
| Smoking status     |                 |                              |                              |                              |
| Never              | 1,349 (60.6)     | 2,979 (56.6)                 | 1,025 (60.1)                 | 1,608 (60.8)                 |
| Previous           | 269 (12.1)       | 498 (9.5)                    | 198 (11.6)                   | 193 (7.3)                    |
| Current            | 609 (27.4)       | 1,787 (34.0)                 | 484 (28.3)                   | 844 (31.9)                   |
| Regular exercise   | 801 (36.0)       | 1,650 (31.3)                 | 624 (36.6)                   | 812 (30.7)                   |
| Regular alcohol use| 207 (9.3)        | 1,043 (19.8)                 | 159 (9.3)                    | 451 (17.1)                   |
| SBP, mmHg          | 124.4 ± 15.4     | 126.8 ± 17.8                 | 123.0 ± 14.6                 | 121.0 ± 16.2                 |
| DBP, mmHg          | 76.8 ± 10.2      | 78.1 ± 17.5                  | 75.8 ± 9.8                   | 74.8 ± 16.7                  |
| TG, mmol/L         | 2.16 ± 1.8       | 2.23 ± 1.76                  | 1.95 ± 1.40                  | 1.71 ± 1.14                  |
| HDL, mmol/L        | 1.10 ± 0.34      | 1.18 ± 0.30                  | 1.12 ± 0.36                  | 1.26 ± 0.32                  |
| HbA1c, %           | 5.28 ± 0.80      | 5.71 ± 0.86                  | 5.25 ± 0.77                  | 5.54 ± 0.67                  |
| WC, cm             | 82.1 ± 7.8       | 85.2 ± 10.7                  | 79.8 ± 6.6                   | 75.3 ± 7.4                   |
| BMI, kg/m²         | 22.0 ± 3.06      | 24.2 ± 3.7                   | 20.8 ± 1.9                   | 21.2 ± 1.9                   |
| Metabolic syndrome | 646 (29.0)       | 1,976 (37.5)                 | 351 (20.6)                   | 383 (14.5)                   |
| Years since HIV diagnosis/ | 2.3 (0.6-5.1) | 2.3 (0.6-5.3) | 2.2 (0.6-4.8) | 2.2 (0.6-4.8) |
| Duration on ART, yrs/ | 1.7 (0.4-4.0) | 1.7 (0.4-4.2) | 1.7 (0.5-3.6) | 1.7 (0.5-3.6) |
| < 1                | 913 (41.0)       | 701 (41.1)                   | 212 (40.8)                   | 140 (28.5)                   |
| 1–5                | 567 (25.5)       | 419 (24.6)                   | 148 (28.5)                   | 160 (30.6)                   |
| ≥ 6                | 747 (33.5)       | 587 (34.4)                   | 160 (30.6)                   | 160 (30.6)                   |
| Ever using d4T     | 139 (6.2)        | 116 (6.8)                    | 23 (4.4)                     | 0.050                        |
| Ever using Protease Inhibitors | 640 (28.7) | 485 (28.4) | 155 (29.8) | 0.538                        |

**ART**, antiretroviral therapy; **SBP**, systolic blood pressure; **DBP**, diastolic blood pressure; **TG**, triglyceride; **HDL**, high density lipoprotein; **HbA1c**, glycated hemoglobin; **WC**, waist circumference; **BMI**, body mass index; **d4T**, stavudine; **Pls**, Protease Inhibitors. p-value for chi-square test or Kruskal-Wallis test, where it is appropriate. 1 Median (interquartile range); 16 observations were missing.
people without HIV within the age group of 18-29 years (10.4% vs. 3.4%, aOR: 3.49, 95% CI: 1.99-6.11); 30-44 years (17.3% vs. 8.5%, aOR: 2.03, 95% CI: 1.47-2.81); and 45-59 years (26.1% vs. 21.7%, aOR: 1.25, 95% CI: 0.94-1.66). The positive association of HIV infection with MS is evident at younger ages, possibly because the influence of aging itself surrenders to the impact of HIV infection on MS at a younger age. Besides aging itself, the effect of HIV infection might also be overshadowed by the effect of prevalent traditional risk factors on MS, which therefore render the insignificant association of HIV infection and MS in older age groups.

However, no significant difference in the presence of MS was observed among PLWH and their negative counterparts with BMI ≥ 24.0 kg/m² within age groups 18-29 and 30-44, which might correlate with the role of fat tissue in the development of MS. Excessive fat is a major cause of MS for both the general population and PLWH. However, adipose tissue not only acts as a storage and secretion organ involved in energy regulation and metabolism, but also functions as an immune regulator involved in many biological processes (25,26). Accordingly, the harmful nature of the HIV virus itself and/or use of ART may somehow be covered by the impact of excessive adipose tissue (27), which might lead to a similar prevalence of MS in PLWH comparable to the general population among the overweight or obese group. Nonetheless, we observed a lower prevalence of MS among overweight or obese PLWH within the 60-75 age group. As the development of MS in PLWH is the result of the interplay between traditional risk factors, viral load, and type of ART usage (28), it is possible that diverse factors are involved in this complex biological process that then lead to this phenomenon. The reasons remain to be investigated.

In PLWH (Table 3), factors significantly associated with MS in individuals with BMI < 24.0 kg/m² included all older age groups, current CD4 ≥ 500 count/µL and ever using d4T. In individuals with BMI ≥ 24.0 kg/m², a significantly increased risk was only observed in 45-59 and 60-75 age groups, as well as in current CD4 ≥ 500 count/µL. The overall findings on MS among PLWH are consistent with those often observed in the general population where MS risks increase with age (24), although no sex difference was observed in our study.

Similar to previous studies (29), no significant association of duration of HIV infection and duration on ART with MS was observed in this study. Considering some ART regimens have a hyperlipidemic effect, the combination of antiretroviral drugs (ARVs) rather than the duration on ART and HIV infection may exert more effects on MS. Given that stavudine (d4T) could induce lipodystrophy and central fat gain (30), it is not surprising that ever using d4T is associated with MS. It is noted that such association was only significant among the overweight or normal weight PLWH after adjustment for other covariates, which suggests the potential impact of fat accumulation itself on MS among overweight or obese patients. While the use of PIs for treatment might increase risks for MS (31), higher prevalence of MS was only observed among underweight or normal weight people in this study.

Table 2. Association of HIV Infection with Metabolic Syndrome by BMI Category and Age groups

| Age Groups | BMI < 24.0 kg/m² | BMI ≥ 24.0 kg/m² |
|------------|------------------|-----------------|
|            | MS Prevalence (%) | aOR (95% CI)   | p   | MS Prevalence (%) | aOR (95% CI)   | p   |
| 18-29      | 5.9 (60/1,018)   | 3.49 (1.99-6.11)| < 0.001 | 42.0 (177/421) | 1.25 (0.74-2.10)| 0.405 |
| 30-44      | 11.9 (180/1,519) | 2.03 (1.47-2.81)| < 0.001 | 53.8 (568/1,056) | 1.01 (0.73-1.38)| 0.964 |
| 45-59      | 23.6 (273/1,159) | 1.25 (0.94-1.66)| 0.122 | 64.6 (685/1,060) | 0.78 (0.55-1.10)| 0.155 |
| 60-75      | 33.7 (221/656)   | 0.80 (0.57-1.13)| 0.207 | 76.1 (458/602)   | 0.53 (0.32-0.88)| 0.014 |
| Total      | 16.9 (734/4,352) | 1.41 (1.19-1.68)| < 0.001 | 60.1 (1888/3,139)| 0.88 (0.72-1.07)| 0.189 |

BMI, Body Mass Index; MS, metabolic syndrome; aOR, adjusted Odds Ratio. *Adjusted for age, gender, smoking status, exercise and alcohol use for the total sample. **Adjusted for age, gender, smoking status, exercise and alcohol use for each age-specific subgroup.
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Table 3. Logistic Regression Analysis of Factors Associated with Metabolic Syndrome among PLWH

| Variables                  | BMI < 24.0 kg/m² | cOR (95% CI) | p   | aOR (95% CI) | p   | BMI ≥ 24.0 kg/m² | cOR (95% CI) | p   | aOR (95% CI) | p   |
|----------------------------|------------------|--------------|-----|--------------|-----|-----------------|--------------|-----|--------------|-----|
| Male                       |                  | 1.13 (0.85-1.49) | 0.394 | 0.97 (0.71-1.32) | 0.834 |                  | 1.37 (0.89-2.09) | 0.150 | 1.33 (0.83-2.12) | 0.232 |
| Age, yrs                   |                  |              |      |              |      |                  |              |      |              |      |
| 18-29                      |                  | 1            |      |              |      |                  | 1            |      |              |      |
| 30-44                      |                  | 1.82 (1.22-2.71) | 0.003 | 1.80 (1.19-2.71) | 0.005 |                  | 1.41 (0.82-2.43) | 0.220 | 1.43 (0.81-2.51) | 0.214 |
| 45-59                      |                  | 3.05 (2.06-4.52) | < 0.001 | 3.10 (2.06-4.64) | < 0.001 |                  | 1.88 (1.07-3.29) | 0.028 | 1.97 (1.09-3.54) | 0.024 |
| 60-75                      |                  | 3.86 (2.54-5.88) | < 0.001 | 4.07 (2.63-6.31) | < 0.001 |                  | 2.36 (1.24-4.48) | 0.009 | 2.41 (1.24-4.67) | 0.009 |
| Smoking status             |                  |              |      |              |      |                  |              |      |              |      |
| Never                      |                  |              |      |              |      |                  |              |      |              |      |
| Previous                   |                  | 1            |      |              |      |                  | 1            |      |              |      |
| Current                    |                  | 0.96 (0.73-1.26) | 0.314 | 0.86 (0.63-1.16) | 0.314 |                  | 1.03 (0.68-1.56) | 0.886 | 1.13 (0.72-1.77) | 0.590 |
| Regular exercise           |                  | 1.00 (0.78-1.27) | 0.969 |              |      |                  | 1.09 (0.76-1.58) | 0.629 |              |      |
| Regular alcohol use        |                  | 0.93 (0.62-1.40) | 0.727 |              |      |                  | 1.18 (0.64-2.17) | 0.589 |              |      |
| Current CD4, count/µL < 200 |                  |              |      |              |      |                  |              |      |              |      |
| 200-500                    |                  |              |      |              |      |                  |              |      |              |      |
| ≥ 500                      |                  | 0.85 (0.59-1.22) | 0.376 | 0.93 (0.64-1.35) | 0.705 |                  | 1.29 (0.75-2.21) | 0.361 | 1.50 (0.85-2.63) | 0.162 |
| Years since HIV diagnosis  |                  |              |      |              |      |                  |              |      |              |      |
| < 1                        |                  |              |      |              |      |                  |              |      |              |      |
| 1-< 3                      |                  | 0.74 (0.53-1.05) | 0.093 |              |      |                  | 0.95 (0.61-1.50) | 0.831 |              |      |
| ≥ 3                        |                  | 1.16 (0.89-1.51) | 0.262 |              |      |                  | 1.04 (0.69-1.55) | 0.861 |              |      |
| Duration on ART, yrs       |                  |              |      |              |      |                  |              |      |              |      |
| < 1                        |                  |              |      |              |      |                  |              |      |              |      |
| 1-< 3                      |                  | 0.91 (0.67-1.24) | 0.551 | 0.99 (0.71-1.38) | 0.947 |                  | 0.81 (0.53-1.24) | 0.336 | 0.81 (0.51-1.27) | 0.349 |
| ≥ 3                        |                  | 1.21 (0.92-1.55) | 0.167 | 0.97 (0.71-1.33) | 0.868 |                  | 0.96 (0.63-1.46) | 0.848 | 1.01 (0.63-1.61) | 0.979 |
| Ever using d4T             |                  | 2.45 (1.65-3.65) | < 0.001 | 2.31 (1.47-3.62) | < 0.001 |                  | 0.69 (0.30-1.59) | 0.380 | 0.60 (0.24-1.48) | 0.269 |
| Ever using PIs             |                  | 1.08 (0.83-1.39) | 0.571 | 1.19 (0.90-1.58) | 0.228 |                  | 1.21 (0.83-1.77) | 0.327 | 1.25 (0.82-1.90) | 0.298 |

Variables with p < 0.200 in univariate analysis were included in multivariate regression. All models were adjusted for gender and age. cOR, crude Odds Ratio; aOR, adjusted Odds Ratio; BMI, Body Mass Index; ART, Antiretroviral Therapy; d4T, Stavudine; PIs, Protease Inhibitors. "The variable 'years since diagnosis' was not included in multivariate regression for collinearity with duration on ART."
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