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Sexual behaviour changes and HIV infection among men who have sex with men: evidence from an open cohort in China

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ABSTRACT

Background The HIV epidemic in key populations such as men who have sex with men (MSM) is a public health issue of worldwide concern. China has seen an increase in newly diagnosed HIV infections through male–male sexual contact in the past decade. In a long-term cohort, how the complex behaviour pattern of MSM changed and the association with the HIV risk are unclear at present.

Methods This study was conducted from October 2011 to December 2019 in Tianjin. MSM were recruited by snowball sampling through online and offline ways. Demographic and sexual behavioural data were collected for analysis. Three indicators (condom use in last anal sex, frequency of condom use during anal sex and the number of sexual partners) were used to define the behaviour change. Participants with zero, one, and two or three risk indicators were categorised into behaviour types of 'protective', 'moderate', and 'fragile', respectively. Change in behaviour type between baseline and each visit was considered. Time-varying Cox models were performed to evaluate HIV infection risk.

Results Of 2029 MSM included in the study, 127 were new HIV diagnoses. The overall incidence rate was 3.36 per 100 person-years. The percentage of 'protective' and 'moderate' behaviour types had a conspicuous growth trend as the follow-up. Furthermore, the HIV incidence rate in each visit among different behaviour transition types showed a general downward trend as the number of total follow-up times increased. Individuals who remained in 'fragile' (adjusted HR (aHR): 25.86, 95% CI: 6.92 to 96.57) or changed from 'protective' to 'moderate' (aHR: 4.79, 95% CI: 1.18 to 19.47), 'protective' to 'fragile' (aHR: 23.03, 95% CI: 6.02 to 88.13), and 'moderate' to 'fragile' (aHR: 25.48, 95% CI: 6.79 to 95.40) between baseline and the last follow-up had a higher HIV risk. Gained risk indicators were associated with the increase of HIV risk (gained one indicator, aHR: 2.67, 95% CI: 1.68 to 4.24; gained two or three indicators, aHR: 4.99, 95% CI: 3.00 to 8.31) while losing just one risk indicator could halve the risk (aHR: 0.43, 95% CI: 0.21 to 0.90).

Conclusions Among MSM in Tianjin, it is necessary to get timely behaviour change for those with high-incidence behaviour patterns while sustaining for those with low-incidence patterns.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This study was based on an open cohort of men who have sex with men in China with a long time span (2011–2019).
⇒ Three indicators related to participants' sexual behaviours (condom use in last anal sex, frequency of condom use during anal sex and the number of sexual partners) were used to define the behaviour change jointly.
⇒ Associations between behaviour change and risk of HIV infection were estimated through Cox models.
⇒ Sexual behaviours were self-reported and measured retrospectively, and may have been misremembered or otherwise misreported.

Trial registration number Chinese Clinical Trials Registry (ChiCTR2000039500).

INTRODUCTION

The HIV epidemic is a significant public health issue of worldwide concern.[1–4] The prevalence of HIV has been low among the general population over the past three decades. However, the burden of HIV is disproportionately concentrated among men who have sex with men (MSM).[5–7] China's HIV epidemic began in the early 1990s among injecting drug users.[8 9] The main route of transmission was needle-sharing.[10 11] Due to China's effective legal control and intensive regulations on drugs,[12 13] the main spread route of HIV inevitably turned into sexual contact since the 21st century, especially male-to-male sexual contact.[7 14 15] Corresponding studies aimed to ascertain the pattern of sexual behaviours among MSM had important practical significance though sexual behaviours between men that were taboo both politically and culturally in China.[16 17]

Effective interventions and behaviour changes had been responsible for the HIV prevention successes to date.[18 19] HIV interventions typically concentrate on unprotected anal intercourse (UAI),[20] multiple sex partners,[21] alcohol and drug use,[13 22] pre-exposure prophylaxis (PrEP)[23 24] or post-exposure prophylaxis (PEP)[25 26] utilisation and adherence to antiretroviral therapy (ART).[27] It was well established from a variety of studies that timely behaviour changes and biomedical interventions can reduce HIV transmission.[28–30] However, most studies used a single measurement to describe behaviour changes. In a long-term cohort, how the complex behaviour pattern changed and the association with the HIV risk were largely unknown at present.

This study was based on an open cohort among MSM in Tianjin, China (2011–2019). The study collected each MSM's sexual behaviour and HIV infection status at each visit. The aims of the present study were the following: (1) to describe the HIV incidence rate within the cohort; (2) to quantify the behaviour changes over the follow-up and to address the association between behaviour change and the risk of HIV infection; and (3) to explore influencing factors for progression to behaviour changes.

METHODS

Study design

The Men who have Sex with Men Health Encouragement Longitudinal Project was a longitudinal cohort study among MSM launched in Tianjin, China. The main objectives of the project include the following: (1) establish community-based HIV prevention service stations aimed at the key population, (2) improve the accessibility and utilisation of HIV testing and prevention services, and (3) provide ART support services for people living with HIV. The organisations involved in the project included the US Centers for Disease Control and Prevention (CDC); National Center for AIDS/STD Control and Prevention, Chinese CDC; Tianjin City CDC and Tianjin Shenlan Community-Based Organization (CBO). This study was registered with the Chinese Clinical Trials Registry (ChiCTR2000039500).

Data collection and participants

Tianjin Shenlan CBO was a formal community-based organisation that provided community-based HIV voluntary counselling and testing (VCT) support services (including HIV testing, counselling and psychological support) for MSM. Participants were mobilised to get tested for HIV in Shenlan's public health advisory service centre. When participants came to the centre for testing or counselling, experienced MSM investigators would conduct a face-to-face interview with participants in a private room. During this period, a structured questionnaire (including demographics and sexual behaviour information) was completed by the participants under the guidance of the investigators. The investigators of the organisation mostly were also MSM. All investigators had undergone training before entering work, which would be a benefit for smooth unhindered communication with participants and could ensure the reliability of the results. After the interview, every participant would get several condoms and lubricant for free. Information collection adopted a real-name registration system (ID card number, mobile phone number and fingerprint information were collected). Prior to the interviews, all participants signed a written informed consent, including the objective, procedures, confidentiality and participants' rights. Enrolled participants were encouraged to conduct routine HIV test every 3 months (90 days). The entire research process was supervised and coordinated by Tianjin City CDC.

The snowball sampling method was used to recruit participants. Participants were recruited from gay bars, gay bathhouses, social network sites (WeChat, QQ, gay chat website), gay apps and peer referrals. The initial enrolment took place on 1 October 2011, and follow-up ended on 31 December 2019. Inclusion criteria were the following: (1) had at least two visits during the cohort period and HIV serological test was negative when they first registered, (2) ≥16 years old, (3) biologically male, (4) reported anal intercourse with another man in the past 6 months. If the participants of the cohort changed dynamically, the original participants could drop out continuously, and the new participants could join at any time. Of 6565 MSM captured in this study, 4096 were excluded for having only one visit, 432 for having HIV seropositive result at baseline and 8 for lack of behavioural information. A total of 2029 MSM met the eligibility criteria and were included in the study eventually. The flow diagram of the study was listed in online supplemental figure 1. The comparison of baseline characteristics between included and excluded MSM was listed in online supplemental table 1.

Definitions of behaviour changes

In this study, behaviour changes include the change in the number of risk indicators and change in sexual behaviour type. Sexual behaviour type was used to represent different patterns of sexual behaviour characteristics. It was collectively defined by three indicators related to participants' sexual behaviour in the past 6 months. The three indicators included variables of condom use in last anal sex,[31] frequency of condom use during anal sex[21] and the number of sexual partners.[32] These three variables were related to the HIV infection (online supplemental table 2). Participants had the information of the three variables in each follow-up. Each indicator was divided into two levels: 'ideal level' and 'risk level' (online supplemental table 3). Among the three variables mentioned above, if one participant had one variable of 'risk level', then it meant the participant had one risk indicator, and so on. The number of risk indicators was in the range of zero to three.

Behaviour type was defined based on the risk indicators. Behaviour type was categorised as 'protective' if the

Table 1 Characteristics and sexual behaviours at baseline for MSM with HIV infection or negative HIV test

Variables at baseline	Total N (%)	HIV infection N (%)	HIV negative N (%)
Age			
<45	1504 (74.13)	96 (75.59)	1408 (74.03)
45–60	464 (22.87)	27 (21.16)	437 (22.98)
>60	61 (3.01)	4 (3.15)	57 (3.00)
Marital status			
Married	947 (46.67)	70 (55.12)	877 (46.11)
Unmarried	1082 (53.33)	57 (44.88)	1025 (53.89)
Education			
Below high school	56 (2.76)	5 (3.94)	51 (2.68)
High school	1172 (57.76)	90 (70.87)	1082 (56.89)
College or more	801 (39.48)	32 (25.20)	769 (40.43)
Residence time in Tianjin			
<3 months	405 (19.96)	41 (32.28)	364 (19.14)
3–7 months	39 (1.92)	2 (1.57)	37 (1.74)
7–12 months	41 (2.02)	5 (3.94)	36 (1.89)
1–2 years	86 (4.24)	2 (1.57)	84 (72.61)
>2 years	1458 (71.86)	77 (60.63)	1381 (72.61)
Condom use in last anal sex			
Yes	1550 (76.39)	78 (61.42)	1472 (77.39)
No	479 (23.61)	49 (38.58)	430 (22.61)
Frequency of condom use during anal sex*†			
Consistent use	785 (38.69)	43 (33.86)	742 (39.01)
Inconsistent use	1244 (61.31)	84 (66.14)	1160 (60.99)
Number of sexual partners†			
<10	1709 (84.23)	116 (91.34)	1593 (83.75)
More than 10	320 (15.77)	11 (8.66)	309 (16.25)
STI†			
Yes	68 (3.35)	2 (1.57)	66 (3.47)
No	1961 (96.65)	125 (98.43)	1836 (96.53)
Inject drugs†			
Yes	22 (1.08)	2 (1.57)	20 (1.05)
No	2007 (98.92)	125 (98.43)	1882 (98.94)
Accept health service‡			
Yes	938 (46.23)	53 (41.73)	885 (46.50)
No	1091 (53.77)	74 (58.27)	1017 (53.50)
MSW§†			
Yes	102 (5.03)	5 (3.94)	97 (5.10)
No	1927 (94.97)	122 (96.06)	1805 (94.90)

*The frequency of condom use during anal sex in the past 6 months was divided into two categories: consistent use (when engaging in anal intercourse, condoms were used in more than 80% of cases and condoms were used throughout the sex) and inconsistent use (other cases).
†In the past 6 months.
‡Health service represented whether participants had accepted any HIV-related health service (HIV testing, condom distribution, HIV risk-reducing consult, peer education or HIV infection risk assessment) in the past 12 months.
§MSW represented the participants who have been obtaining money or goods through sexual activity.
MSM, men who have sex with men; MSW, male sex worker; STI, sexually transmitted infection.

participant had no risk indicator; as 'moderate' if the participant had one risk indicator; as 'fragile' if the participant had more than two risk indicators (two or three risk indicators). The behaviour type and the number of risk indicators could change as time varies (during the follow-up period).

Change in the number of risk indicators was defined as the difference of risk indicators between any two

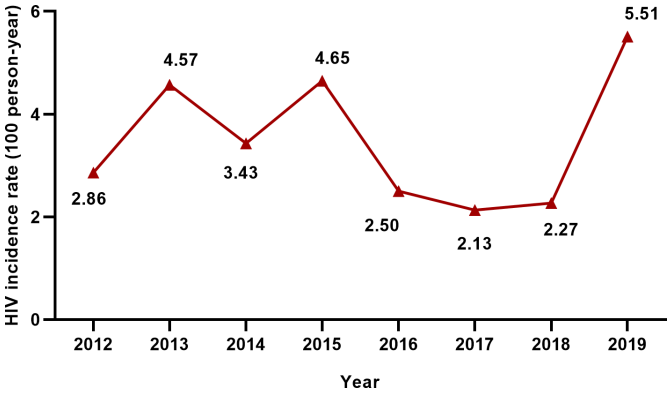

Figure 1 HIV incidence rates by year. When calculating the incidence rate, the numerator was the number of HIV infections in each year and the denominator was the sum of the total actual survival time of each participant in this year. The first people newly diagnosed with HIV occurred in 2012, though the study started in 2011.

follow-ups. Behaviour transition type was defined as the change of behaviour type between any two visits. Then the behaviour transition type yielded nine possible combinations of behaviour types: consistently protective, protective to moderate, protective to fragile, moderate to protective, consistently moderate, moderate to fragile, fragile to protective, fragile to moderate and consistently fragile.

HIV laboratory test

Before testing, MSM would choose to collect blood or saliva. Patrons' oral mucosal exudate test (Mano Bio-Pharmaceutical Co, Beijing, China) was used for the former and a blood rapid detection reagent (Wan Fu Biotechnology Co, Guangzhou, China) for the latter. In addition, 5 mL of blood sample was collected from those who get any positive tests above. Then, the blood sample was sent to Tianjin CDC to perform ELISA (Wan Tai Biological Pharmaceutical Co, Beijing, China). HIV infection was confirmed by Western blot assay (MP Biomedical Asia Pacific, Singapore). As the exact infection time was hard to affirm, for the chronic infections (infection time over 6 months), the infection time was defined as the midpoint between the last negative test date and first positive test time, while the acute and early infection (<6 months) was the time diagnosed as HIV infection.[33]

Statistical methods

Categorical variables were described by frequencies and percentages. For the general demographic characteristics, differences were calculated using Pearson's X^2 test or Fisher's exact test.

HIV incidence rates were estimated within each year and among subgroups of different behaviour transition types in each visit, with person-year (PY) over the follow-up time as the denominator.

Change in behaviour type was calculated in each visit (according to baseline behaviour type). Considering that the total number of each participant was unequal, the proportion of each behaviour type at each visit and the proportion of behaviour transition type from baseline to each visit were calculated.

Univariate and multivariable time-varying Cox models were performed to evaluate (1) risk of HIV infection among different behaviour type subgroups over each follow-up (all records of the participants were included in the model in counting process format); and (2) behaviour changes and association with the risk of HIV infection (two time points were opted to define the behaviour change, baseline and the last follow-up). HRs, adjusted HRs (aHRs) and 95% CI of the variables were estimated. The logistic regression model was applied to investigate the influencing factors for progression to behaviour type of 'fragile' or 'moderate' in the last follow-up among baseline behaviour type subgroups. ORs, adjusted ORs (aORs) and 95% CI were estimated. In addition, all models were adjusted for baseline covariates. All the data analyses were performed in SAS V.9.4 (SAS Institute).

Patient and public involvement

This study was mainly completed by Tianjin CDC, with Tianjin Shenlan CBO as the specific implementor of the study. Patients or the public were not directly involved in the design and implementation of the study. However, the findings could influence the design of other subsequent studies, such as specific studies targeting drug users or male sex workers in the MSM population.

RESULTS

Characteristics of the participants

A total of 2029 MSM met the eligibility criteria and were included in the study eventually. The total follow-up person time was 3772.03 PY. The median total follow-up time was 1.28 years (IQR: 0.57–2.72; range: 8 days–8.13 years) starting from baseline. Confirmed by the laboratory test, 127 participants were new HIV diagnoses. Sixty-three were classified as acute and early HIV infected and 64 were chronically infected.

The characteristics of the participants when they first registered (baseline) were shown in table 1. Among all the participants, the median age was 34 years old (P_{25}: 25; P_{75}: 45); 53.33% were unmarried; 57.76% had a high school degree; 39.48% had a college degree or above; 71.87% had been living in Tianjin for more than 2 years while 19.96% had been living in Tianjin for less than 3 months; 76.39% used condom in the last anal sex; 38.69% had been consistently using condoms during anal sex over the past 6 months; 84.23% had less than 10 sexual partners over the past 6 months; 3.35% had sexually transmitted infection (STI) over the past 6 months; 46.23% had received HIV health service over the past 1 year; 5.03% had been working as male sex workers.

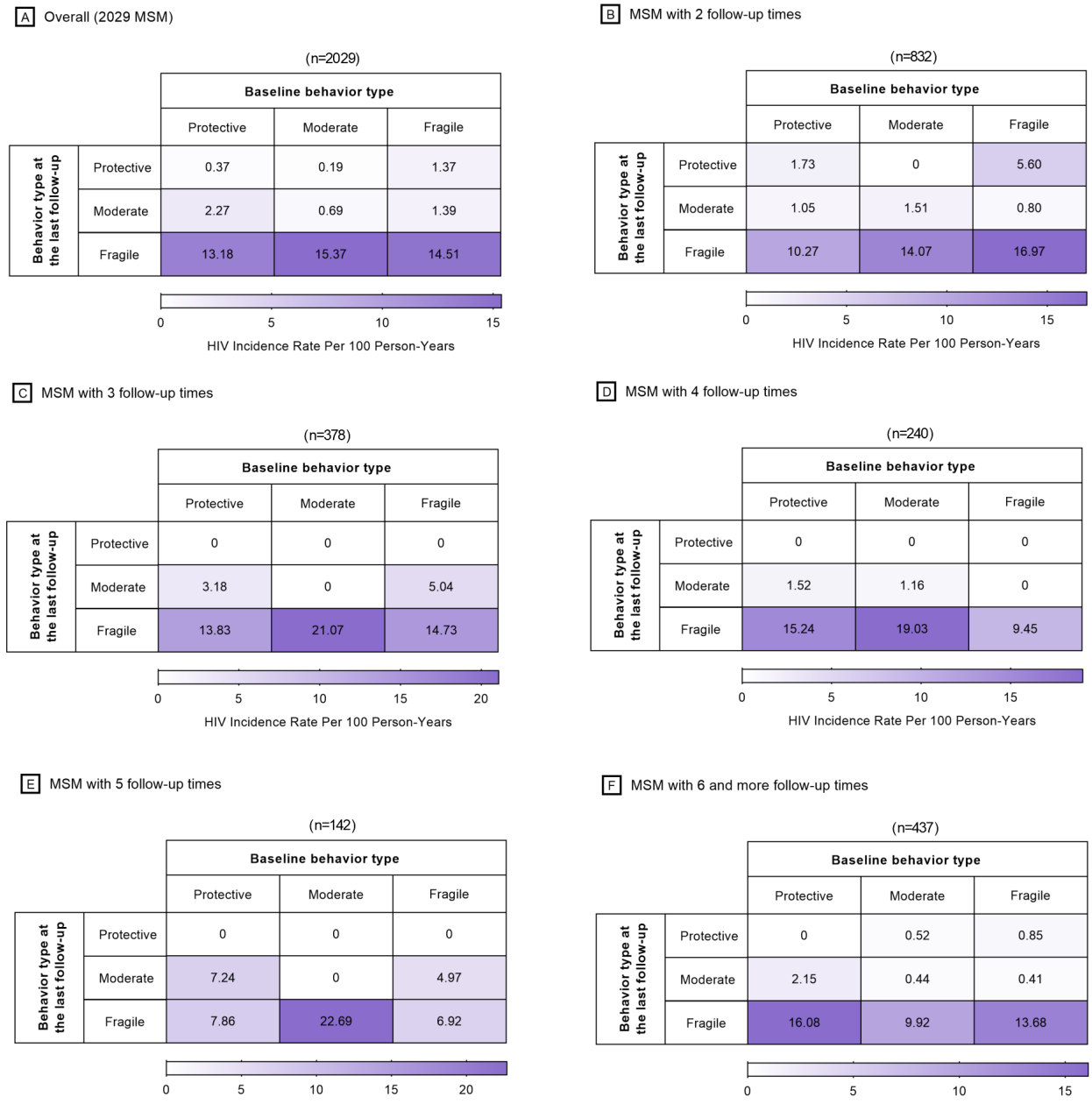

Figure 2 Heatmap of HIV incidence rates among MSM with different follow-up times. MSM with two follow-up times represented the participants whose number of total follow-up times was 2, and so on. Participants were divided into subgroups according to the number of their total follow-up times. The calculation of HIV incidence rate was done within each subgroup. Values and colours indicated HIV incidence rate per 100 PY (for example, in (A), 0.37 that represented the HIV incidence rate in 'protective' to 'protective' group was 0.37 per 100 PY). The lighter colour indicates that the HIV incidence rate was lower for MSM in that subgroup, whereas the darker colour indicates a higher incidence rate in that subgroup. MSM, men who have sex with men; PY, person-year.

The total number of follow-up times of each participant was listed in online supplemental table 4. The median follow-up times were 3 times (range from 2 to 34, P_{25}: 2; P_{75}: 5). A total of 41.01% of participants had two follow-up times; 78.46% had follow-up times no more than five times. The percentage of participants with a total number of follow-up times more than 10 times was 7.15%.

HIV incidence rate

Among the whole study population, the overall HIV incidence rate was 3.36 per 100 PY (95% CI: 2.83 to 3.99).

Figure 1 and online supplemental table 5 showed the HIV incidence rates by years. The rates were relatively higher in 2013 (4.57 per 100 PY (95% CI: 3.31 to 6.31)), 2015 (4.65 per 100 PY (95% CI: 3.53 to 6.12)) and 2019 (5.51 per 100 PY (95% CI: 3.97 to 7.66)), though the rates did not show a linear trend significance during 2011–2019. Among age subgroups, incidence rates were as follows: <45 years, 3.83 per 100 PY (95% CI: 3.24 to 4.52); 45–60 years, 2.81 per 100 PY (95% CI: 2.14 to 3.69); >60 years, 2.08 per 100 PY (95% CI: 0.95 to 4.55) (online supplemental table 6).

Table 2 Univariate and multivariable Cox proportional hazards model with time-varying covariates for HIV infection

HIV infection risk models*	Per 1-risk indicator increase†	Sexual behaviour type		
		Protective	Moderate	Fragile
HR (95% CI)	3.68 (3.03 to 4.46)	Reference	2.38 (1.12 to 5.02)	19.74 (10.28 to 37.91)
Adjusted HR (95% CI)‡	3.37 (2.76 to 4.11)	Reference	2.22 (1.05 to 4.71)	16.53 (8.57 to 31.88)

*All follow-up records of each participant were included into the model in counting process format.
†The number of risk indicators was in the range of 0–3. Per 1-risk indicator increase meant that the number of indicators was included into the model as a continuous variable.
‡Multivariable Cox regression analysis was adjusted for age, education, marital status, residence time in Tianjin and MSW.
MSW, male sex worker.

To compare the HIV incidence rate among different behaviour transition types, participants were divided into subgroups according to the number of their total follow-up times. The calculation of the HIV incidence rate was done within each subgroup. Stratified by the behaviour type categories at baseline, the overall HIV incidence rates were as follows: 'protective', 3.14 per 100 PY (95% CI: 2.30 to 4.29); 'moderate', 2.92 per 100 PY (95% CI: 2.13 to 3.99); 'fragile', 4.02 per 100 PY (95% CI: 3.07 to 5.26) (online supplementary table 7). Overall, the HIV incidence rate has shown a general downward trend as the number of total follow-up times increased (two times: 4.88 (95% CI: 3.65 to 6.53); three times: 4.49 (95% CI: 3.06 to 6.59); four times: 2.89 (95% CI: 1.72 to 4.84); five times: 3.21 (95% CI: 1.74 to 5.91); six times and more: 2.27 (95% CI: 1.64 to 3.15)). MSM who had more visits showed a low risk of infection in comparison with those who had fewer visits. Within each subgroup, the HIV incidence rate tended to concentrate towards the lower right corner of the heatmap (ie, concentrated towards the behaviour type of 'fragile') (figure 2).

Time-varying behaviour type and risk of HIV infection

The risk of HIV infection was evaluated through Cox models with time-varying behaviour types. Compared with 'protective' behaviour type, 'moderate' behaviour type (aHR: 2.22, 95% CI: 1.05 to 4.71) and 'fragile' behaviour type (aHR: 16.53, 95% CI: 8.57 to 31.88) were associated with a greater risk of HIV infection. Likewise, there was a significant and linear increase in the risk of HIV infection for each additional time-varying risk indicator (aHR: 3.37, 95% CI: 2.76 to 4.11) (table 2).

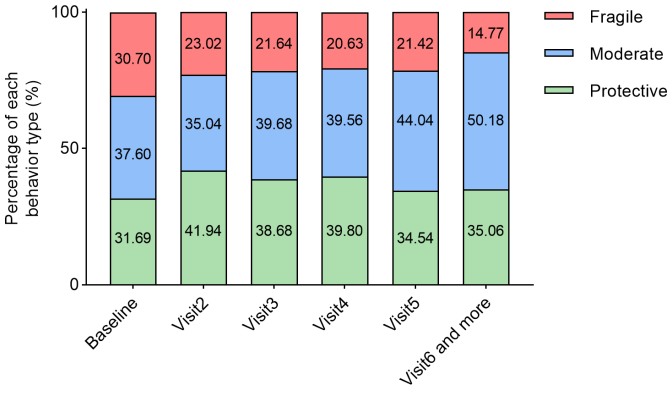

Figure 3 Percentage of behaviour type in each visit. Values and area of the rectangles indicated percentage of behaviour type in each visit (for example, 31.69, which represented the percentage of 'protective' behaviour type, was 31.69% at baseline).

Behaviour types in each visit

The percentage of each behaviour type ('protective', 'moderate' and 'fragile') at baseline was: 31.69% (643 of 2029), 37.60% (763 of 2029) and 30.70% (623 of 2029), respectively. As the number of follow-up visits increased, the percentage of 'protective' and 'moderate' behaviour types had a growth trend (35.06% and 50.18% at six and more visits, respectively), while the percentage of 'fragile' behaviour type declined (14.77% at six and more visits) (figure 3).

Behaviour changes and association with the risk of HIV infection from baseline to the last follow-up

The behaviour types at baseline and the last follow-up were selected to evaluate the behaviour changes (change in risk indicators: difference in risk indicators between baseline and the last follow-up; change in behaviour type: 'behaviour types at baseline' to 'behaviour type in the last follow-up') and the association with the risk of HIV infection. The choice of two time points was based on a main argument: the pattern of behaviour changes from baseline to each follow-up was relatively stable (details in online supplemental table 8 and online supplemental figure 2). The first and the last visits were good proxies for behaviour changes during follow-up.

In multivariable analysis, as 'no change in indicators' as the reference level, losing one risk indicator could decline the risk at 0.43 (95% CI: 0.21 to 0.90), while gained indicators were related to the increasing risk of HIV infection (gained one risk indicator: aHR: 2.67, 95% CI: 1.68 to 4.24); gained two or three risk indicators: aHR: 4.99, 95% CI: 3.00 to 8.31).

As for the different behaviour transition types, the risk of HIV infection was not statistically different from that of the consistently protective group (reference level) in the moderate to protective group (aHR: 0.65, 95% CI: 0.08 to 5.16), the consistently moderate group (aHR: 1.52, 95%

Table 3 Behaviour changes and association with the risk of HIV infection between baseline and the last follow-up

	HIV infection status (N, %)		Univariate Cox regression analysis			Multivariable Cox regression analysis†		
Behaviour changes*	Negative	HIV	HR	95% CI	P value	aHR	95% CI	P value
Change in risk indicators								
Lost 2–3 indicators	236 (12.4)	7 (5.5)	0.56	0.25 to 1.27	0.1680	0.57	0.25 to 1.29	0.1822
Lost 1 indicator	525 (27.6)	9 (7.1)	0.41	0.19 to 0.86	0.0182	0.43	0.21 to 0.90	0.0251
No change in indicators	725 (38.1)	30 (23.6)	Reference			Reference		
Gained 1 indicator	325 (17.1)	48 (37.8)	2.82	1.78 to 4.46	0.0001	2.67	1.68 to 4.24	0.0001
Gained 2–3 indicators	91 (4.8)	33 (26.0)	6.13	3.73 to 10.08	0.0001	4.99	3.00 to 8.31	0.0001
Behaviour transition type								
Consistently protective	318 (16.7)	2 (1.6)	Reference			Reference		
Protective to moderate	210 (11.0)	11 (8.7)	4.78	1.18 to 19.26	0.0275	4.79	1.18 to 19.47	0.0283
Protective to fragile	77 (4.0)	25 (19.7)	28.76	7.66 to 108.05	0.0001	23.03	6.02 to 88.13	0.0001
Moderate to protective	301 (16.0)	1 (0.8)	0.64	0.08 to 5.03	0.6703	0.65	0.08 to 5.16	0.6912
Consistently moderate	315 (16.6)	4 (3.1)	1.62	0.33 to 7.84	0.5449	1.52	0.31 to 7.41	0.6019
Moderate to fragile	109 (5.7)	33 (26.0)	34.32	9.27 to 127.06	0.0001	25.48	6.79 to 95.40	0.0001
Fragile to protective	219 (11.5)	7 (5.5)	2.95	0.68 to 12.67	0.1457	2.87	0.66 to 12.46	0.1590
Fragile to moderate	237 (12.5)	7 (5.5)	3.06	0.71 to 13.17	0.1316	2.66	0.61 to 11.53	0.1906
Consistently fragile	116 (6.1)	37 (29.1)	31.43	8.53 to 115.75	0.0001	25.86	6.92 to 96.57	0.0001
Total	1902	127						

*Two time points (baseline and the last follow-up) were opted to evaluate behaviour changes.
†Multivariable Cox regression analysis was adjusted for age, education, marital status, residence time in Tianjin and MSW.
aHR, adjusted HR; MSW, male sex worker.

CI: 0.31 to 7.41), the fragile to protective group (aHR: 2.87, 95% CI: 0.66 to 12.46) and the fragile to moderate group (aHR: 2.66, 95% CI: 0.61 to 11.53). Instead, the risk of HIV infection was distinctly greater in the protective to moderate group (aHR: 4.79, 95% CI: 1.18 to 19.47), the protective to fragile group (aHR: 23.03, 95% CI: 6.02 to 88.13), the moderate to fragile group (aHR: 25.48, 95% CI: 6.79 to 95.40) and the consistently fragile group (aHR: 25.86, 95% CI: 6.92 to 96.57) (table 3 and online supplemental figure3).

Influencing factors for progression to behaviour type of 'fragile' or 'moderate' in the last follow-up

We also investigated which influencing factors were related to the progression of behaviour transition type of 'fragile' or 'moderate' by the end of follow-up among baseline behaviour type subgroups.

Within age subgroups, the younger participants had a higher likelihood of progression to behaviour type of 'fragile' or 'moderate' by the end of follow-up.

Notably, the likelihood of progression to behaviour type of 'fragile' or 'moderate' was weakened as the number of total follow-up times increased (per 1-time increase in the total follow-up times: aOR=0.95, 95% CI: 0.91 to 0.99) among participants 'fragile' at baseline.

Compared with participants who lived in Tianjin for less than 3 months, participants who lived in Tianjin for more than 2 years had a lower likelihood of progression to behaviour type of 'fragile' or 'moderate' by the end of follow-up (aOR: 0.65, 95% CI: 0.37 to 0.87) (online supplemental table 9).

DISCUSSION

The characteristics of MSM are mainly high mobility and concealment. It was a challenge to ensure long-term cohort retention and sustain routine HIV test programmes among this population. Therefore, we conducted an open cohort study among MSM in Tianjin, China. A total of 2029 MSM were included in the study eventually from 2011 to 2019. Among the whole study population, the overall HIV incidence rate was 3.36 per 100 PY (95% CI: 2.83 to 3.99). The incidence rate was at a lower level. Previous studies conducted in other cities in China had shown a pretty high HIV incidence rate among MSM: 6.6 per 100 PY in Hangzhou,[34] 6.78 per 100 PY in Yangzhou, 5.77 per 100 PY in Guangzhou,[35] 5.3 per 100 PY in Shenyang,[36] 5.12 per 100 PY in Nanjing,[37] 3.5 per 100 PY in Yunnan[38] and 7.1 per 100 PY in Beijing.[39] The incidence is also at a low level compared with related studies in other regions (sub-Saharan Africa,[40] Latin America[41] and the USA[42–44]). In this study, the percentage of 'protective' and 'moderate' behaviour types had a conspicuous growth trend as the follow-up. Furthermore, the HIV incidence rate in each visit among different behaviour transition types showed a general downward trend as the number of total follow-up times increased. The evidence mentioned above indicated the effectiveness of the community-based

VCT project in reducing HIV incidence. However, challenges still exist and need to be addressed. The incidence rate in 2019 was much higher than in other years (5.51 per 100 PY (95% CI: 3.97 to 7.66)). We speculated that the reason might be the publicity and promotion of PrEP/PEP started in 2018 among the MSM population in Tianjin. PrEP/PEP were effective biomedical strategies to prevent the further transmission of HIV.[23 24] Although the utilisation of PrEP/PEP was not widespread among MSM in Tianjin, this might promote the cognitive concepts of 'treatment optimism' about HIV.[45] MSM might rationalise their risk behaviour before (or after) engaging in sexual behaviours,[46] which promoted the generation of risk behaviours.[47 48]

Previous studies concentrate on using one standalone indicator to describe the behaviour change. For example, one study in China[49] used the percentage of UAI occurrences to describe the behaviour change. However, this study evaluated behaviour change with greater precision (behaviour changes were collectively defined by three indicators and divided into two patterns: change in the number of risk indicators and behaviour transition type) among a great sample size (N=2029) in a long-term follow-up (2011–2019). What is more, this study quantified the behaviour changes and association with the risk of HIV infection from baseline to the last follow-up. The results of this study showed that individuals who remained 'fragile' or changed from 'protective' to 'moderate', 'protective' to 'fragile' and 'moderate' to 'fragile' between baseline and the last follow-up had a higher HIV risk as compared with individuals with persistently 'protective' behaviour type. When this analysis was conducted in risk indicators, similar results were found. Gained risk indicators were associated with the increase of HIV risk while losing just one risk indicator could halve the risk (aHR: 0.43). This study demonstrated the importance of maintaining protective sexual practices and timely behaviour changes in high-incidence population that could help reduce the risk of HIV infection.

The cohort had a high rate of loss to follow-up (for 4096 MSM only one visit record), which may have biased the results. Indeed, the complexity of the MSM population made maintaining a long-term follow-up cohort difficult. This study was based on an open cohort whose main purpose was to cover as many MSM as possible. Whether or not a participant will proceed to the next visit is entirely driven by their personal endogenous motivation, although messages were sent to MSM 90 days after their testing to remind them to perform another HIV testing. In the future, plans of following research including recruiting more staff are under consideration. Special staff will conduct regular return visits and urge MSM to carry out routine HIV testing.

LIMITATIONS

This research has several limitations. First, in our study, the snowball sampling method was used to recruit participants, which may have selection bias. However, we recruited participants in a variety of ways (gay bars, gay bathhouses, social network sites, gay apps and peer referrals) to increase the representativeness. Second, our data lacked information on the use of alcohol, recreational drugs and PrEP usage. The presence of these substances might affect the sexual behaviour of participants, which should be addressed in future research. Further, our data collection adopted a real-name registration system (ID card number, mobile phone number and fingerprint information were involved). Due to the privacy of some questions (such as whether you had ever had STI), the participants might have concealed the actual situation, which may result in social expectation bias. We conducted an interview-style questionnaire collection to avoid this. Besides, all MSM investigators had received professional training to ensure the authenticity of the data.

CONCLUSION

In this study, sexual behaviour changes are collectively defined by three indicators (condom use in last anal sex, frequency of condom use during anal sex and the number of sexual partners) related to participants' sexual behaviour in the past 6 months. Behaviour changes from 2011 to 2019 and ensuing HIV infection risk are calculated. Long-term sexual behaviour patterns of MSM keep changing and gradually have a tendency to be less risky during the study period. The proportion of high-risk behaviours is 30.70% at baseline. This number declined to 14.77% at six and more visits. This result may provide clues for the effectiveness of community-based HIV/AIDS interventions.

Transition from low-incidence to high-incidence population is associated with a similar risk of HIV infection than continuing high incidence. Further strategies are needed to promote the low incidence change.

MSM should sustain low-incidence behaviour patterns otherwise would undergo higher HIV infection risk. Future HIV interventions should be prioritised not only to those MSM who were part of the high-incidence population, but also to those MSM who have been in the temporarily low-incidence population but are at risk of being in the high-incidence population.

Contributors ZY, CL, ZC, YL and JM contributed to the conception of the study. HH, T-TZ and DS contributed to the framework of the study. MY and JY collected the data. QC and XW cleaned the raw data. HH and HZ helped perform the analysis with constructive discussions. T-TZ and ZY analysed the data and wrote the manuscript. ZC revised the manuscript and was responsible for the overall content as guarantor.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not required.

Ethics approval This study involves human participants and was approved by the Institutional Review Board (IRB) of the National Center for AIDS/STD Control and Prevention, China CDC (IRB approval number: X130205267). Participants gave informed consent to participate in the study before taking part.

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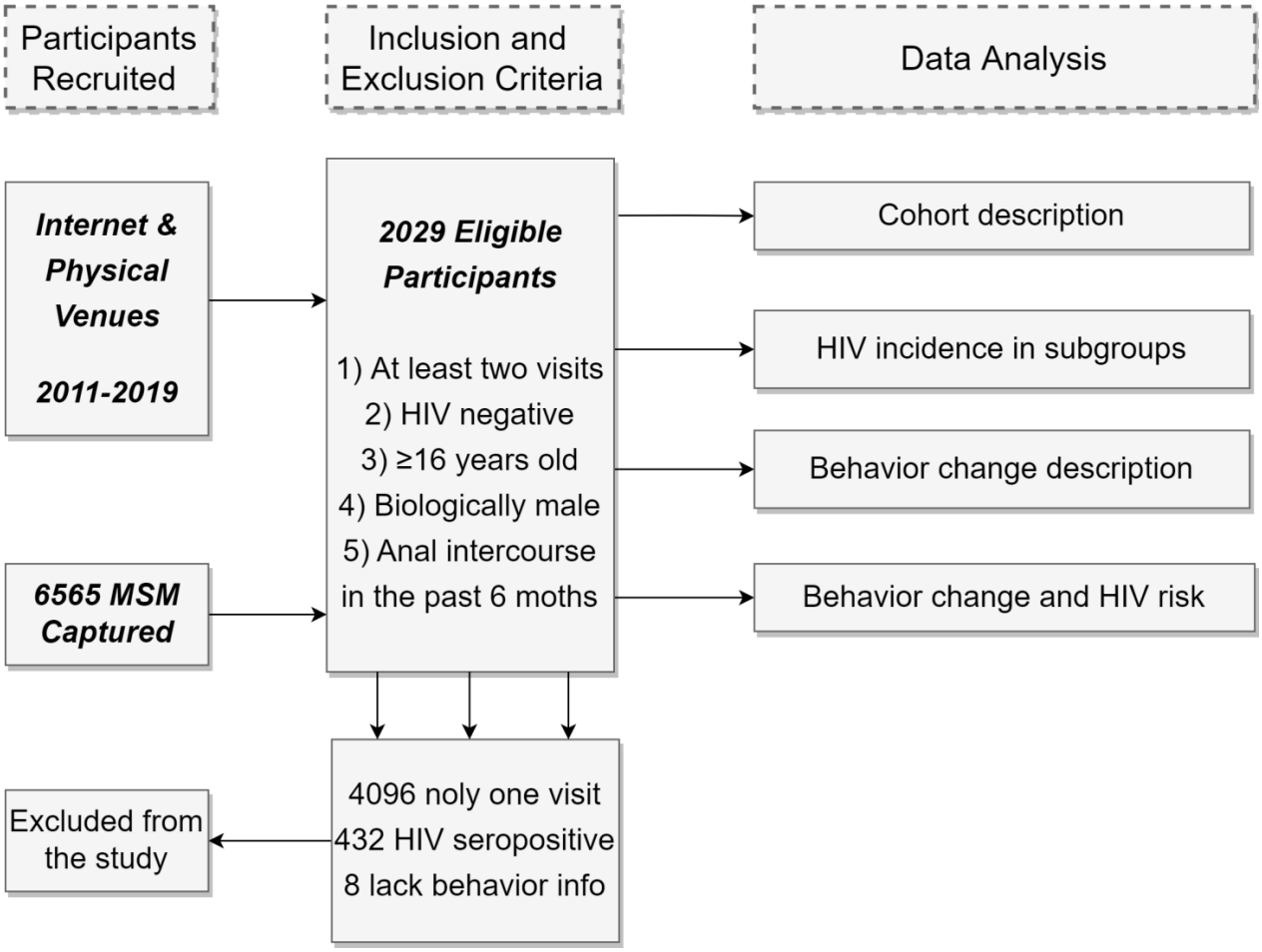
REFERENCES

1 Faria NR, Rambaut A, Suchard MA, *et al*. HIV epidemiology. the early spread and epidemic ignition of HIV-1 in human populations. *Science* 2014;346:56–61.
2 The Lancet. The global HIV/AIDS epidemic-progress and challenges. *Lancet* 2017;390:333.
3 Maxmen A. Older men and young women drive South African HIV epidemic. *Nature* 2016;535:335.
4 Beyrer C, Baral SD, Collins C, *et al*. The global response to HIV in men who have sex with men. *Lancet* 2016;388:198–206.
5 Suguimoto SP, Techasrivichien T, Musumari PM, *et al*. Changing patterns of HIV epidemic in 30 years in East Asia. *Curr HIV/AIDS Rep* 2014;11:134–45.
6 Zhang K-L, Detels R, Liao S, *et al*. China's HIV/AIDS epidemic: continuing challenges. *Lancet* 2008;372:1791–3.
7 Kaufman J, Jing J, China JJ. China and AIDS--the time to act is now. *Science* 2002;296:2339–40.
8 Beyrer C, Razak MH, Lisam K, *et al*. Overland heroin trafficking routes and HIV-1 spread in South and south-east Asia. *AIDS* 2000;14:75–83.
9 Lu L, Jia M-H, Zhang X-B, *et al*. [Analysis for epidemic trend of acquired immunodeficiency syndrome in yunnan province of China]. *Zhonghua Yu Fang Yi Xue Za Zhi* 2004;38:309–12.
10 Wang L, Guo W, Li D, *et al*. HIV epidemic among drug users in China: 1995-2011. *Addiction* 2015;110 Suppl 1:20–8.
11 Qian HZ, Qian ZH, Vermund SH, *et al*. Risk of HIV/AIDS in China: subpopulations of special importance. *Sex Transm Infect* 2005;81:442–7.
12 Sullivan SG, Wu Z. Rapid scale up of harm reduction in China. *Int J Drug Policy* 2007;18:118–28.
13 Duan C, Wei L, Cai Y, *et al*. Recreational drug use and risk of HIV infection among men who have sex with men: a cross-sectional study in Shenzhen, China. *Drug Alcohol Depend* 2017;181:30–6.
14 Zhang L, Chow EPF, Jing J, *et al*. HIV prevalence in China: integration of surveillance data and a systematic review. *Lancet Infect Dis* 2013;13:955–63.
15 Dong M-J, Peng B, Liu Z-F, *et al*. The prevalence of HIV among MSM in China: a large-scale systematic analysis. *BMC Infect Dis* 2019;19:1000.
16 Choi K-H, Hudes ES, Steward WT. Social discrimination, concurrent sexual partnerships, and HIV risk among men who have sex with men in Shanghai, China. *AIDS Behav* 2008;12:71–7.
17 Neilands TB, Steward WT, Choi K-H. Assessment of stigma towards homosexuality in China: a study of men who have sex with men. *Arch Sex Behav* 2008;37:838–44.
18 Koblin B, Chesney M, Coates T, *et al*. Effects of a behavioural intervention to reduce acquisition of HIV infection among men who have sex with men: the explore randomised controlled study. *Lancet* 2004;364:41–50.
19 Coates TJ, Richter L, Caceres C. Behavioural strategies to reduce HIV transmission: how to make them work better. *Lancet* 2008;372:669–84.
20 Carballo-Diéguez A, Dolezal C, Leu CS, *et al*. A randomized controlled trial to test an HIV-prevention intervention for latino gay and bisexual men: lessons learned. *AIDS Care* 2005;17:314–28.
21 Parazzini F, Cavalieri D'oro L, Naldi L, *et al*. Number of sexual partners, condom use and risk of human immunodeficiency virus infection. *Int J Epidemiol* 1995;24:1197–203.
22 Scribner R, Theall KP, Simonsen N, *et al*. HIV risk and the alcohol environment: advancing an ecological epidemiology for HIV/AIDS. *Alcohol Res Health* 2010;33:179–83.
23 Grant RM, Lama JR, Anderson PL, *et al*. Preexposure chemoprophylaxis for HIV prevention in men who have sex with men. *N Engl J Med* 2010;363:2587–99.
24 Elliott T, Sanders EJ, Doherty M, *et al*. Challenges of HIV diagnosis and management in the context of pre-exposure prophylaxis (PreP), post-exposure prophylaxis (PEP), test and start and acute HIV infection: a scoping review. *J Int AIDS Soc* 2019;22:e25419.
25 Schechter M, do Lago RF, Mendelsohn AB, *et al*. Behavioral impact, acceptability, and HIV incidence among homosexual men with access to postexposure chemoprophylaxis for HIV. *J Acquir Immune Defic Syndr* 2004;35:519–25.
26 Kahn JO, Martin JN, Roland ME, *et al*. Feasibility of postexposure prophylaxis (PEP) against human immunodeficiency virus infection after sexual or injection drug use exposure: the San Francisco PEP study. *J Infect Dis* 2001;183:707–14.
27 He L, Yang J, Ma Q, *et al*. Reduction in HIV community viral loads following the implementation of a "treatment as prevention" strategy over 2 years at a population-level among men who have sex with men in Hangzhou, China. *BMC Infect Dis* 2018;18:62.
28 Johnson WD, Diaz RM, Flanders WD, *et al*. Behavioral interventions to reduce risk for sexual transmission of HIV among men who have sex with men. *Cochrane Database Syst Rev* 2008;15:Cd001230.
29 Asiimwe-Okiror G, Opio AA, Musinguzi J, *et al*. Change in sexual behaviour and decline in HIV infection among young pregnant women in urban Uganda. *AIDS* 1997;11:1757–63.
30 Maheu-Giroux M, Vesga JF, Diabaté S, *et al*. Changing dynamics of HIV transmission in Côte d'Ivoire: modeling who acquired and transmitted infections and estimating the impact of past HIV interventions (1976-2015). *J Acquir Immune Defic Syndr* 2017;75:517–27.
31 Hendriksen ES, Pettifor A, Lee S-J, *et al*. Predictors of condom use among young adults in South Africa: the reproductive health and HIV research unit national youth survey. *Am J Public Health* 2007;97:1241–8.
32 Hoenigl M, Weibel N, Mehta SR, *et al*. Development and validation of the san diego early test score to predict acute and early HIV infection risk in men who have sex with men. *Clin Infect Dis* 2015;61:468–75.
33 Williamson JM, Satten GA, Hanson JA, *et al*. Analysis of dynamic cohort data. *Am J Epidemiol* 2001;154:366–72.
34 Li Q, Li X, Luo Y, *et al*. HIV incidence and cohort retention among men who have sex with men in Hangzhou, China: a prospective cohort study. *Medicine* 2019;98:e17419.
35 Wang Q-Q, Chen X-S, Yin Y-P, *et al*. HIV prevalence, incidence and risk behaviours among men who have sex with men in Yangzhou and Guangzhou, China: a cohort study. *J Int AIDS Soc* 2014;17:18849.
36 Wang H-Y, Wang N, Chu Z-X, *et al*. Intimate partner violence correlates with a higher HIV incidence among MSM: a 12-month prospective cohort study in Shenyang, China. *Sci Rep* 2018;8:2879.
37 Yang H, Hao C, Huan X, *et al*. HIV incidence and associated factors in a cohort of men who have sex with men in Nanjing, China. *Sex Transm Dis* 2010;37:208–13.
38 Xu J, An M, Han X, *et al*. Prospective cohort study of HIV incidence and molecular characteristics of HIV among men who have sex with men(MSM) in Yunnan Province, China. *BMC Infect Dis* 2013;13:3.
39 Jia Z, Huang X, Wu H, *et al*. HIV burden in men who have sex with men: a prospective cohort study 2007-2012. *Sci Rep* 2015;5:11205.
40 Joshi K, Lessler J, Olawore O, *et al*. Declining HIV incidence in sub-Saharan Africa: a systematic review and meta-analysis of empiric data. *J Int AIDS Soc* 2021;24:e25818.
41 Soto RJ, Ghee AE, Nunez CA, *et al*. Sentinel surveillance of sexually transmitted infections/HIV and risk behaviors in vulnerable populations in 5 central American countries. *J Acquir Immune Defic Syndr* 2007;46:101–11.
42 Friedman MR, Feliz NB, Netto J, *et al*. High HIV incidence among young black men who have sex with men: constructing a

retrospective cohort from a community health programme. *Sex Transm Infect* 2018;94:284–6.
43 Mena L, Crosby RA. Portrait of an epidemic: extremely high human immunodeficiency virus prevalence and incidence among young black men having sex with men and residing in a southern City. *Sex Transm Dis* 2017;44:401–2.
44 Balaji AB, An Q, Smith JC, *et al*. High human immunodeficiency virus incidence and prevalence and associated factors among adolescent sexual minority Males-3 cities, 2015. *Clin Infect Dis* 2018;66:936–44.
45 Macapagal K, Birkett M, Janulis P, *et al*. HIV prevention fatigue and HIV treatment optimism among young men who have sex with men. *AIDS Educ Prev* 2017;29:289–301.
46 Huebner DM, Rebchook GM, Kegeles SM. A longitudinal study of the association between treatment optimism and sexual risk behavior in young adult gay and bisexual men. *J Acquir Immune Defic Syndr* 2004;37:1514–9.
47 Oldenburg CE, Nunn AS, Montgomery M, *et al*. Behavioral changes following uptake of HIV pre-exposure prophylaxis among men who have sex with men in a clinical setting. *AIDS Behav* 2018;22:1075–9.
48 Montaño MA, Dombrowski JC, Dasgupta S, *et al*. Changes in sexual behavior and STI diagnoses among MSM initiating PreP in a clinic setting. *AIDS Behav* 2019;23:548–55.
49 Huan X, Tang W, Babu GR, *et al*. HIV risk-reduction counseling and testing on behavior change of MSM. *PLoS One* 2013;8:e69740.

Contents



sFigure1. Flow diagram of the study

sTable1. Characteristics of excluded and included study participants at baseline

Variables at Baseline	Included (N=2029) N (%)	Excluded (N=4096) N (%)	*P*
Age			0.1555
<45	1504(74.13)	3098(75.63)	
45-60	464(22.87)	856(20.90)	
>60	61(3.01)	142(3.47)	
Marital status			0.0198
Married	947(46.67)	1783(43.53)	
Unmarried	1082(53.33)	2313(56.47)	
Education			0.6467
Below high school	56(2.76)	125(3.05)	
High school	1172(57.76)	2322(56.69)	
College or more	801(39.48)	1649(40.26)	
Residence time in Tianjin			0.0001
<3 months	405(19.96)	1154(28.17)	
3-7 months	39(1.92)	125(3.05)	
7-12 months	41(2.02)	85(2.08)	
1-2 years	86(4.24)	166(4.05)	
>2 years	1458(71.86)	2566(62.65)	
Condom use in last anal sex			0.1283
Yes	1550(76.39)	3056(74.61)	
No	479(23.61)	1040(23.39)	
Frequency of condom use during anal sex[ab]			0.6946
Consistent use	785(38.69)	1606(39.21)	
Inconsistent use	1244(61.31)	2490(60.79)	
Number of Sexual partners[b]			0.4535
<10	1709(84.23)	3480(84.96)	
More than 10	320(15.77)	616(15.04)	
STI[b]			0.7909
Yes	68(3.35)	132(3.22)	
No	1961(96.65)	3963(96.78)	
Inject drugs[b]			0.7625
Yes	22(1.08)	41(1.00)	
No	2007(98.92)	4053(99.00)	
Accept health service[c]			0.0001
Yes	938(46.23)	1681(41.04)	
No	1091(53.77)	2415(58.96)	
MSW[db]			0.0369
Yes	102(5.03)	159(3.88)	
No	1927(94.97)	3936(96.12)	

Abbreviations: STI, sexually transmitted infections; MSW, male sex workers.

[a] The frequency of condom use during anal sex in the past 6 months was divided into two categories, consistent use (When engaging in anal intercourse, condoms were used in more than 80% of cases and condoms were used throughout the sex) and inconsistent use (other cases).

[b] In the past 6 months.

[c] Health service represented whether participants had accepted any HIV related health service (HIV testing, condom distribution, HIV risk reducing consult, peer education or HIV infection risk assessment) in the past 12 months.

[d] MSW stands for male sex workers. It represented if the participants have been obtained money or goods through sexual activity.

sTable2. Univariate and multivariate cox proportional hazard model with time-varying covariates for HIV infection risk

Variables	Univariate cox regression analysis			Multivariate cox regression analysis[e]		
	HR	95%CI	*P* value	HR	95%CI	*P* value
Age						
<45	REF					
45-60	1.14	0.78-1.69	0.4819			
>60	0.94	0.38-2.32	0.8956			
Marital status						
Married	REF			REF		
Unmarried	4.73	2.90-7.71	0.0001	4.72	2.86-7.78	0.0001
Education						
Below high school	REF			REF		
High school	0.51	0.24-1.06	0.0719	0.93	0.43-2.01	0.7619
College or more	0.29	0.13-0.63	0.0018	0.47	0.20-1.07	0.0574
Residence time in Tianjin						
<3 months	REF			REF		
3-7 months	0.52	0.12-2.19	0.3804	0.66	0.16-2.83	0.5718
7-12 months	1.71	0.72-4.05	0.2195	1.14	0.48-2.78	0.7572
1-2 years	0.27	0.06-1.14	0.0770	0.27	0.06-1.13	0.0727
>2 years	0.50	0.34-0.74	0.0005	0.68	0.46-1.07	0.0748
Condom use in last anal sex						
Yes	REF			REF		
No	12.39	8.53-17.99	0.0001	5.10	3.19-8.13	0.0001
Frequency of condom use during anal sex[ab]						
Consistent use	REF			REF		
Inconsistent use	10.13	6.14-16.69	0.0001	3.66	1.97-6.82	0.0001
Number of Sexual partners[b]						
<10	REF			REF		
More than 10	1.33	0.93-1.92	0.1173	1.53	1.05-2.24	0.0266
STI[b]						
Yes	REF					
No	0.88	0.36-2.15	0.7831			
Inject drugs[b]						
Yes	REF					
No	1.81	0.25-13.01	0.5512			
Accept health service[c]						
Yes	REF			REF		
No	1.55	0.96-2.49	0.0687	1.20	0.74-1.94	0.4501
MSW[db]						
Yes	REF			REF		
No	0.66	0.34-1.27	0.2183	1.39	0.71-2.72	0.3340

Abbreviation: STI, sexually transmitted infections; MSW, male sex workers; HR, hazard ratio; CI: confidence interval; REF, reference level.

[a] The frequency of condom use during anal sex in the past 6 months was divided into two categories, consistent use (When engaging in anal intercourse, condoms were used in more than 80% of cases and condoms were used throughout the sex) and inconsistent use (other cases).

[b] In the past 6 months.

[c] Health service represented whether participants had accepted any HIV related health service (HIV testing, condom distribution, HIV risk reducing consult, peer education or HIV infection risk assessment) in the past 12 months.

[d] MSW stands for male sex workers. It represented if the participants have been obtained money or goods through sexual activity.

[e] Multivariate cox regression analysis included marital status, education, residence time in Tianjin, condom use during last sex, condom use during

anal sex, number of sexual partners, health service utilization, MSW.

sTable3. Definition of sexual behavior indicator levels

Variables	Ideal level	Risky level
Condom use in last anal sex	Yes	No
Frequency of condom use during anal sex	Consistent use	Inconsistent use
Number of sexual partners	<10	More than 10

sTable4. Total number of follow-up times among MSM in Tianjin from 2011-2019

Number of Follow-Up Times[a]	**Number of MSM** (%)	**Cumulative Percentage** (%)
2	832 (41.01)	41.01
3	378 (18.63)	59.64
4	240 (11.83)	71.46
5	142 (7.00)	78.46
6	111 (5.47)	83.93
7	67 (3.30)	87.24
8	56 (2.76)	90.00
9	25 (1.23)	91.23
10	33 (1.63)	92.85
>10	145 (7.15)	100.00
Total	2029 (100.00)	

[a] Represented the total number of follow-ups for each participant within the period from first enrollment to the last follow-up. Mean: 4.39 times; Standard Deviation: 3.96; Median: 3 times; P_{25}: 2 times; P_{75}: 5 times.

sTable5. HIV Incidence rates by year

Year	Number of MSM	HIV seroconversion	Incidence Rate (95%CI)[a]
2012[b]	454	8	2.86 (1.59-5.14)
2013	589	20	4.57 (3.31-6.31)
2014	702	18	3.43 (2.35-4.98)
2015	794	27	4.65 (3.53-6.12)
2016	860	16	2.50 (1.63-3.83)
2017	823	12	2.13 (1.29-3.53)
2018	776	10	2.27 (1.32-3.93)
2019	518	16	5.51 (3.97-7.66)

[a] When calculating the incidence rate, numerator was the number of HIV infection in each year and denominator was the sum of total actual survival time of each participant in this year.

[b] The first case of HIV seroconversion occurred in 2012, though the study started in 2011.

sTable6. HIV incidence rate among age subgroups

Age subgroup	Number of MSM	HIV seroconversion	Incidence Rate (95%CI)
<45	1504	85	3.83 (3.24-4.52)
45-60	464	37	2.81 (2.14-3.69)
>60	61	5	2.08 (0.95-4.55)

sTable7. Incidence rates for HIV infection among MSM with different follow-up times

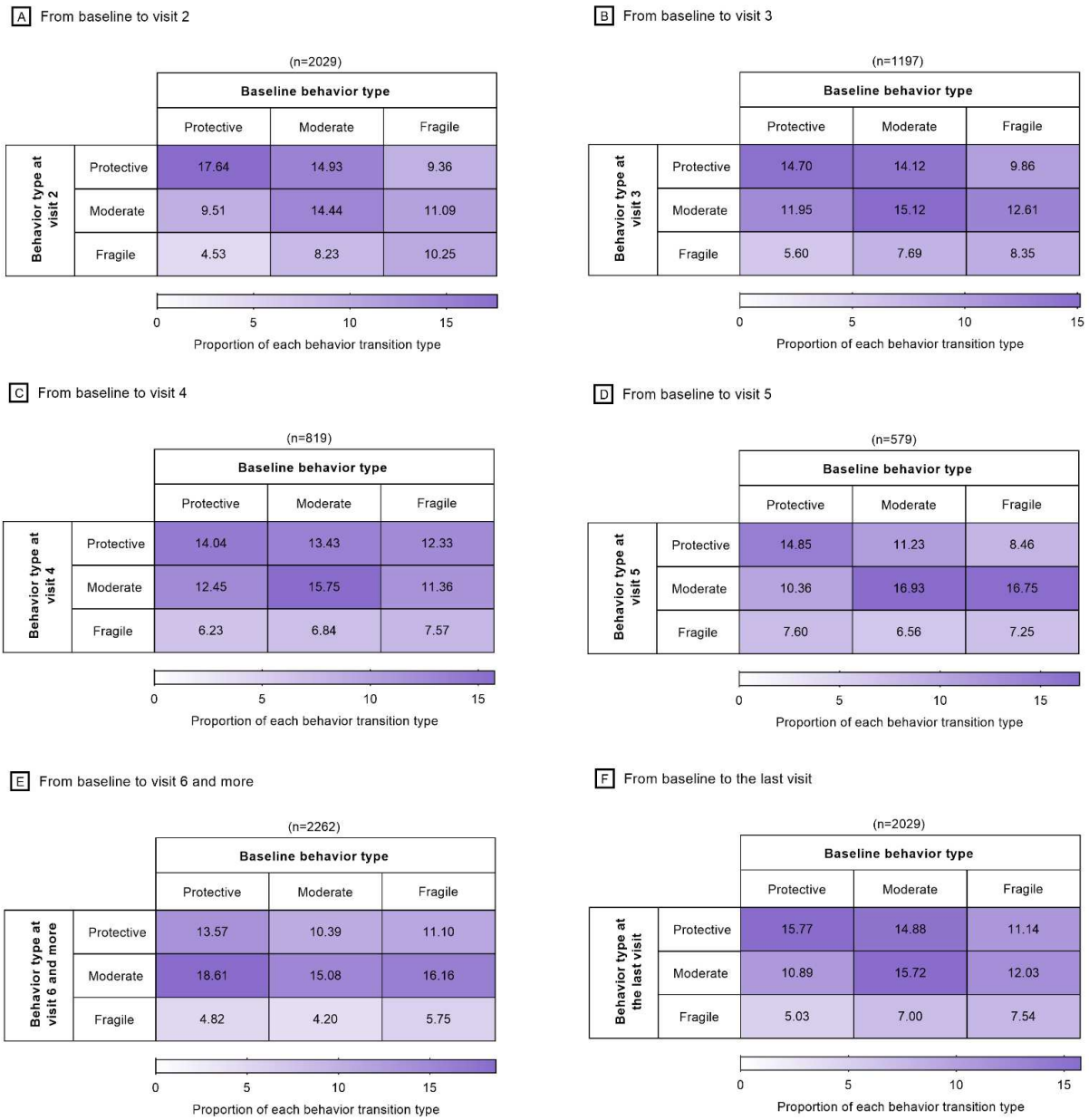
Behavior transition type		Incidence Rate Per 100 Person-Years (95%CI)			Total
		Baseline			
		Protective	Moderate	Fragile	
2 Times[a]	Protective	1.73 (0.44-6.83)	0 (0.00-0.00)	5.6 (2.39-13.12)	4.88 (3.65-6.53)
	Moderate	1.05 (0.15-7.38)	1.51 (0.38-5.97)	0.8 (0.11-5.63)	
	Fragile	10.27 (4.06-25.99)	14.07 (7.92-24.99)	16.97 (11.14-25.85)	
3 Times	Protective	0 (0.00-0.00)	0 (0.00-0.00)	0 (0.00-0.00)	4.49 (3.06-6.59)
	Moderate	3.18 (0.81-12.44)	0 (0.00-0.00)	5.04 (1.67-15.18)	
	Fragile	13.83 (6.58-29.07)	21.07 (10.91-40.69)	14.73 (7.43-29.19)	
4 Times	Protective	0 (0.00-0.00)	0 (0.00-0.00)	0 (0.00-0.00)	2.89 (1.72-4.84)
	Moderate	1.52 (0.22-10.63)	1.16 (0.17-8.14)	0 (0.00-0.00)	
	Fragile	15.24 (5.38-43.19)	19.03 (9.77-37.06)	9.45 (2.53-35.33)	
5 Times	Protective	0 (0.00-0.00)	0 (0.00-0.00)	0 (0.00-0.00)	3.21 (1.74-5.91)
	Moderate	7.24 (1.91-27.51)	0 (0.00-0.00)	4.97 (1.29-19.19)	
	Fragile	7.86 (2.08-29.73)	22.69 (8.39-61.37)	6.92 (1.04-45.85)	
6 times And more	Protective	0 (0.00-0.00)	0.52 (0.07-3.67)	0.85 (0.21-3.38)	2.27 (1.64-3.15)
	Moderate	2.15 (0.90-5.12)	0.44 (0.06-3.11)	0.41 (0.06-2.9)	
	Fragile	16.08 (9.11-28.37)	9.92 (4.64-21.2)	13.68 (7.46-25.1)	
Overall	Protective	0.37 (0.09-1.48)	0.19 (0.03-1.35)	1.37 (0.66-2.86)	3.36 (2.83-3.99)
	Moderate	2.27 (1.27-4.07)	0.69 (0.26-1.83)	1.39 (0.67-2.9)	
	Fragile	13.18 (9.15-18.99)	15.37 (11.23-21.04)	14.51 (10.77-19.55)	
Total		3.14 (2.30-4.29)	2.92 (2.13-3.99)	4.02 (3.07-5.26)	

[a] 2 times represented the participants whose number of total follow-up times was 2, and so on. Participants were divided into subgroups according to their number of total follow-up times. The calculation of HIV incidence rate was done within each subgroup.

sTable8. Behavior transition type from baseline to each visit

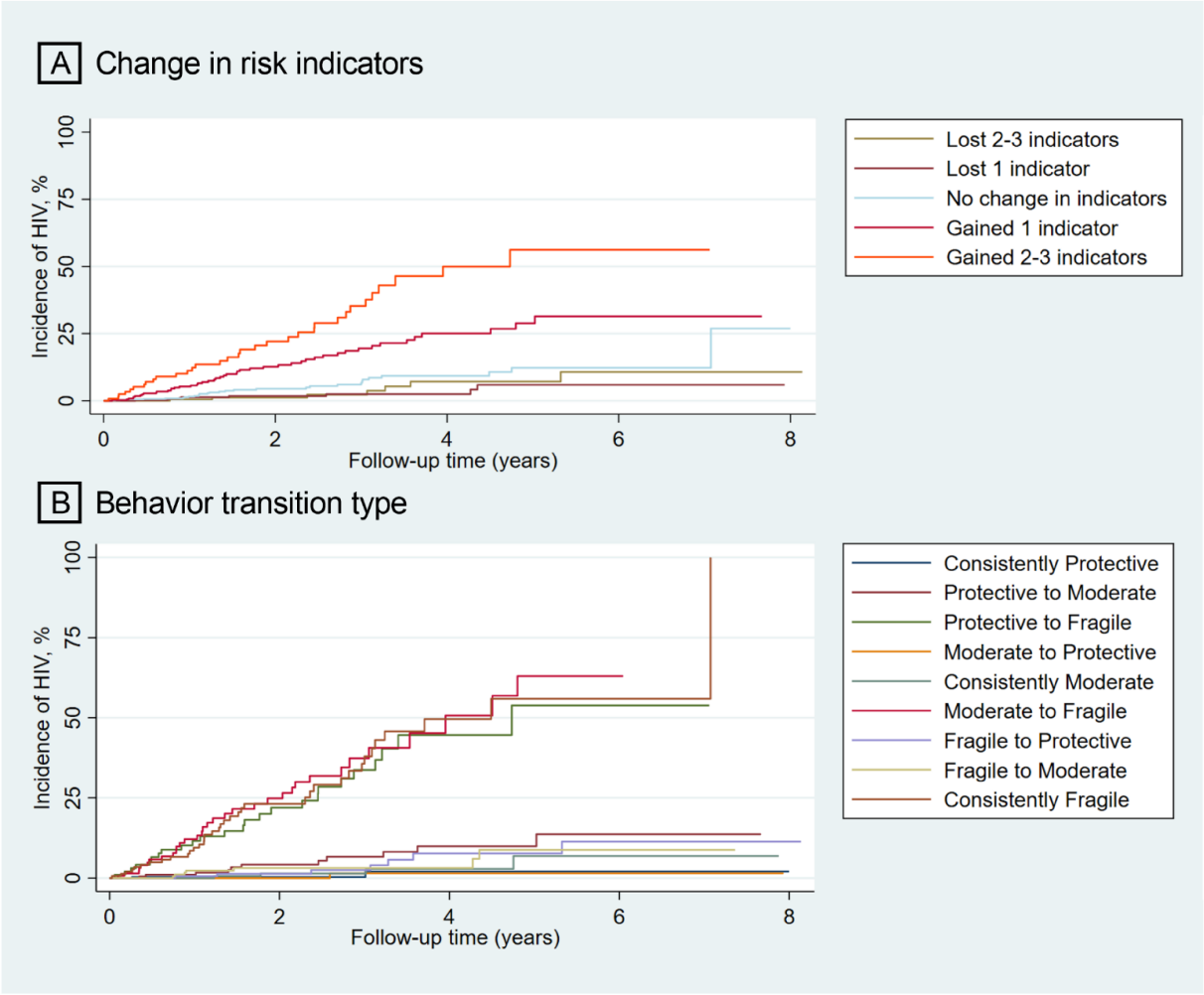
Behavior transition type in each visit[a] **N (%)**		**Baseline**			Total
		Protective	Moderate	Fragile	
2nd	Protective	358 (17.64)	303 (14.93)	190 (9.36)	851 (41.94)
	Moderate	193 (9.51)	293 (14.44)	225 (11.09)	711 (35.04)
	Fragile	92 (4.53)	167 (8.23)	208 (10.25)	467 (23.02)
3rd	Protective	176 (14.70)	169 (14.12)	118 (9.86)	463 (38.68)
	Moderate	143 (11.95)	181 (15.12)	151 (12.61)	475 (39.68)
	Fragile	67 (5.60)	92 (7.69)	100 (8.35)	259 (21.64)
4th	Protective	115 (14.04)	110 (13.43)	101 (12.33)	326 (39.80)
	Moderate	102 (12.45)	129 (15.75)	93 (11.36)	324 (39.56)
	Fragile	51 (6.23)	56 (6.84)	62 (7.57)	169 (20.63)
5th	Protective	86 (14.85)	65 (11.23)	49 (8.46)	200 (34.54)
	Moderate	60 (10.36)	98 (16.93)	97 (16.75)	255 (44.04)
	Fragile	44 (7.60)	38 (6.56)	42 (7.25)	124 (21.42)
6th And More	Protective	307 (13.57)	235 (10.39)	251 (11.10)	793 (35.06)
	Moderate	421 (18.61)	341 (15.08)	373 (16.16)	1135 (50.18)
	Fragile	109 (4.82)	92 (4.20)	130 (5.75)	334 (14.77)
Total		643 (31.69)	763 (37.60)	623 (30.70)	8915 (100.00)

[a] listed the number (proportion) of each behavior type in each visit.



sFigure2. Heatmap of percentage of each behavior transition type in each visit

Figure legends 1: Values and colors indicated the percentage of each behavior transition type in each visit (for example, in Figure 1A, 17.64 represented the percentage of “protective” to “protective” was 17.64% from baseline to visit2). A lighter color indicates that the percentage was lower for MSM in that subgroup, whereas a darker color indicated a higher percentage in that subgroup.



sFigure3. Kaplan-Meier curves of incident HIV among different Behavior changes

sTable9. OR and 95% CI for behavior transition-type of “fragile” or “moderate” in the last follow-up stratified by the behavior type categories at baseline

Behavior changes	“Fragile” or “Moderate” at the last follow-up as the dependent variable, OR (95% CI)[a]		
	Protective at baseline	Moderate at baseline	Fragile at baseline
Per 1-time increase in the total follow-up times	1.02 (0.98-1.06)	0.99 (0.95-1.03)	0.95 (0.91-0.99)
Age			
<45	REF	REF	REF
45-60	0.57 (0.37-0.87)	0.45 (0.29-0.68)	0.52 (0.35-0.78)
>60	0.48 (0.16-1.39)	0.23 (0.10-0.54)	0.71 (0.25-2.05)
Residence time in Tianjin			
<3 months	REF	REF	REF
3-7 months	0.51 (0.11-2.32)	1.31 (0.40-4.30)	3.54 (0.75-16.63)
7-12 months	1.06 (0.36-3.12)	1.53 (0.30-7.78)	1.76 (0.53-5.86)
1-2 years	1.93 (0.75-4.97)	0.89 (0.40-1.96)	1.88 (0.72-4.85)
>2 years	0.92 (0.59-1.43)	0.65 (0.45-0.99)	1.10 (0.73-1.66)

Abbreviation: OR, odds ratio; CI: confidence interval; REF, reference level.

[a] Multivariate logistic regression analysis included total follow-up times, age, marital status, education, residence time in Tianjin, health service utilization