ISSN 2096-7071 (Print)
ISSN 2096-3101 (Online)
CN 10-1629/R1

CHINA CDC WEEKLY

Vol. 5 No. 41 Oct. 13, 2023

CCDC weekly

中国疾病预防控制中心周报

ISSN 2096-7071
9 772096 707231 4 1

Cover Image: adapted from the World Health Organization, https://www.who.int/campaigns/international-lead-poisoning-prevention-week/2023.

Preplanned Studies

Multiple Trajectories of Cereal Consumption and Their Associations with Type 2 Diabetes in Chinese Adults — China, 1997–2018

Mengran Liu[1]; Zhiru Wang[2]; Feifei Huang[2]; Weiyi Li[2]; Zhihong Wang[2]; Huijun Wang[2]; Gangqiang Ding[2,#]

Summary

What is already known about this topic?

Consuming refined grains, specifically white rice, elevates the risk of developing type 2 diabetes (T2D). Conversely, incorporating whole grains into the diet is linked to a reduced risk.

What is added by this report?

This study employed a novel multi-trajectory modeling technique to account for the intercorrelations among various cereal consumption patterns. Four distinct multi-trajectory groups of cereal intake, identified from 1997 to 2018 within the Chinese population, were associated with varying levels of T2D risk.

What are the implications for public health practice?

This research investigates the implications of evolving cereal consumption patterns on T2D in nondiabetic adults. This study delineates unique trajectories linked with cereal intake patterns, thereby providing a robust foundation for policymakers to craft initiatives to prevent T2D among adults in China.

An in-depth analysis of the correlation between cereal consumption and type 2 diabetes (T2D) risk has significant implications for public health, particularly in nations where staples include white rice and wheat products and where the incidence of T2D is rising. Dietary cereal intake in China is dynamic and changes over time. Thus far, no longitudinal study has been conducted to identify trajectories of cereal intake within the Chinese population or to investigate the secular trend of cereal consumption with T2D risk. This study incorporated data from 4,464 adults 18 years and above, sourced from seven distinct waves of the China Health and Nutrition Survey (CHNS) from 1997 to 2018. A group-centric multi-trajectory modeling approach was employed to discern cereal-intake trajectories (individual trajectories for rice, wheat, and other grains intake and multi-trajectories of overall cereal-intake patterns) across 21 years. To examine the correlation between cereal intake and T2D risk, multivariate Cox proportional hazard and restricted cubic spline (RCS) models were employed. Four distinct multi-trajectory groups of cereal intake, identified from 1997 to 2018 within the Chinese population, were associated with varying levels of T2D risk. Compared to the group with "balanced cereal intake", a higher subsequent risk of T2D was noted in the group with "high white rice intake without other grains". Notably, daily intakes of white rice exceeding 240 grams for men and 280 grams for women could potentially act as threshold points for T2D development.

T2D continues to pose a significant public health issue worldwide. In the past few decades, China has witnessed an incremental rise in T2D prevalence, with an adult ratio of 11.2% between 2015 and 2017, exemplifying a stark public health quandary (*1*). Previous epidemiological studies have suggested an increased risk of T2D linked with consuming refined grains, such as white rice. In contrast, whole grains pose a reduced risk (*2*–*5*). However, these studies primarily used single time point assessments for dietary exposure.

Moreover, dietary data were either partially available or absent in each follow-up round. Limited studies have explored the potential impact of long-term cereal intake trends and their subsequent changes while considering the heterogeneity of the population. Traditional Chinese grain classifications typically comprise rice, wheat, and other grain varieties. Understanding the long-term intake trajectories of these specific cereal subtypes is crucial for assessing the risk of T2D, especially in a nation like China where cereals contribute to nearly half of the total energy intake and T2D incidence is rapidly rising.

The present analysis uses data from seven waves (1997 to 2018) of the CHNS. An exploration of the long-term trajectories of cereal intake was conducted, designating the period from 1997 to 2018 as the "track identification period." A potential confounder, changes in diet following the development of T2D, was mitigated by using dietary information obtained prior to the diagnosis of T2D in prospective analyses. However, since fasting blood samples were only available from the waves of 2009, 2015, and 2018, our cohort analysis on the association between cereal intake and incident T2D is confined to these three waves, termed the "survival analysis period."

This study selected participants aged 18 years or over who were neither pregnant nor breastfeeding and had participated in the surveys conducted in 2009, 2015, and 2018 (n=24,372). Participants with insufficient dietary data, abnormal daily energy intake, incomplete blood samples, or missing demographic information were excluded from the selection. Out of the remaining participants (n=19,499), those who were involved in at least two follow-up waves from 2009 to 2018 and were not diagnosed with T2D upon initially entering the "survival analysis period" were chosen (n=8,886). From this group, participants with fewer than three waves of available dietary data before being diagnosed with T2D were discarded. The final analysis also excluded individuals who reported having diabetes in the survey from 1997 to 2006 to ensure that all participants were non-diabetic upon commencement of the "survival analysis period." Ultimately, 4,464 participants were included in the final analysis. Supplementary Figure S1 (available in https://weekly.chinacdc.cn/) provides a flow chart that depicts the participant selection process for the present study. The survey was approved by the institutional review committees of the National Institute for Nutrition and Health, Chinese Center for Disease Control and Prevention (No. 201524), and the informed consent forms were signed by all participants.

In this study, food consumption data was gathered via three consecutive 24-hour dietary recalls, which included two weekdays and one weekend day. The evaluation of cereal intake included the consumption of rice, wheat, and other grains. "Rice" was defined as white rice and its associated products, such as rice cakes and rice noodles. "Wheat" was categorized as refined wheat and its products, including white bread, noodles, and mantou (steamed buns). Lastly, "other grains" encompassed corn, barley, oats, millet, and similar grains. The average per capita daily intake of various foods and nutrients and total energy intake (TEI) were calculated, using the China Food Composition Table as a reference (*6*).

Fasting plasma glucose (FPG) and glycated hemoglobin A1c (HbA1c) were measured in surveys conducted in 2009, 2015, and 2018. T2D was defined, in accordance with the diagnosis criteria set by the World Health Organization and China's guidelines (*7–8*), by fulfilling at least one of the three following conditions: a) FPG ≥7.0 mmol/L; b) HbA1c ≥6.5%; c) administration of diabetes treatments, such as oral hypoglycemic medications or insulin injections.

A population-based multi-trajectory model was applied to identify multiple consumption trajectories of rice, wheat, and others, distinguishing between males and females (*9*). Multi-trajectory modeling was executed utilizing a STATA plug-in, employing a continuous norming distribution for continuous data, with follow-up years serving as the timescale for these trajectories. The selection of the most suitable model adhered to strict statistical criteria: a) Models with a smaller Bayesian information criterion were regarded as superior fits; b) Each trajectory class encompassed at least 2% of the sample population; c) Average posterior probability of membership within each group with values exceeding 0.7 served as an indicator of adequate internal reliability; d) The odds of correct classification within each group were ascertained, with a recommended minimum ratio of 5 to 1 per group (*10*).

The risk of T2D concerning the trajectories was evaluated using the multivariate Cox proportional hazards regression model. Hazard ratios (HRs) and 95% confidence intervals (*CI*s) were calculated accordingly. In the analysis, three models were created. Model 1 did not account for any covariates, whereas Model 2 included adjustments for lifestyle features and demographic characteristics. Model 3 was built upon Model 2 by adjusting for dietary factors such as initial rice/wheat/other grains intake, overall energy intake, waist circumference, and systolic blood pressure. In a supplemental analysis, potential dose-response relationships were scrutinized via an RCS. The relationship between continuous variable cereal intake and T2D risk was examined here. To accurately represent the participant's long-term cereal consumption, the cumulative average of cereal intake was computed as a continuous variable, considering the period from the participant's entry into the cohort to the point immediately before their T2D diagnosis. All analyses were conducted using SAS (version 9.4, SAS Institute, Inc., Cary, NC, USA), Stata 15SE (StataCorp, College Station, TX, USA), and R software (R Foundation for Statistical Computing, Vienna, Austria). Statistical significance was determined by a *P*-value of less than 0.05.

The analysis encompassed 4,464 participants, consisting of 2,044 males and 2,420 females, reflecting a fundamental gender balance. The mean age, with standard deviation (SD), was 42.23 (12.00) for males and 43.02 (11.31) for females. The baseline characteristics of the participants are delineated in Supplementary Table S1 (available in https://weekly.chinacdc.cn/).

Cereal consumption was analyzed by gender. Figure 1 illustrates individual trajectories of rice, wheat, and other grain intake, with separate plots for males (Figure 1A, C, E) and females (Figure 1B, D, F). Four intake trajectories were identified in terms of rice and wheat consumption for both genders, namely: “low stability” (Group 1), “normal stability” (Group 2), “median decrease” (Group 3), and “high-level decline” (Group 4). In regards to other grains, three intake trajectories were noted in both genders: “no intake” (Group 1), “low increase” (Group 2), and “moderate fluctuation” (Group 3). Among the 4,464 participants, 422 (9.45%) developed T2D during follow-up, with the total person-years amounting to 33,659. In males, lower T2D risk was associated with other grain intake trajectories in Groups 2 and 3 as compared to Group 1, with a HR (95% *CI*) of 0.60 (0.45–0.81) for Group 2 and 0.52 (0.33–0.84) for Group 3. Similarly, in females, lower T2D risk was associated with Group 3’s other grain intake trajectory compared to Group 1 [HR=0.56 (0.34–0.90)]. See Supplymentary Table S2 (available in https://weekly.chinacdc.cn/) for the Cox proportional hazards analysis results exploring the association between cereal intake trajectories and T2D risk in males and females.

Four distinct gender-specific multi-trajectory patterns of cereal consumption (rice, wheat, and other grains) were identified (Figure 2): Group 1 (both genders) exhibited a decrease in very high rice intake, maintained low stable wheat intake, and exhibited deficient intake of other grains. Group 2 (both genders) showcased a decrease in high rice intake, moderate stable wheat intake, and deficient intake of other grains. Group 3 (men) and Group 4 (women) had a balanced cereal intake. In contrast, Group 4 (men) and Group 3 (women) displayed very low rice intake, a decrease in high wheat intake, and moderate intake of other grains.

In female Groups 1 and 2, characterized by a high white rice intake without other grains, the HRs (95% *CIs*) for T2D were 1.70 (1.01–2.85) and 1.56 (1.01–2.40), respectively, when compared with Group 4 (the “balanced cereal intake” group). Supplementary Table S3 (available in https://weekly.chinacdc.cn/) indicates the average rice, wheat, and other grain intake among the different multi-trajectory groups for both males and females at follow-up. Our findings suggest that group-based multi-trajectory modeling is an effective tool for identifying cereal-intake trajectory groups.

The RCS analysis (Figure 3) indicated a statistically significant correlation and nonlinear relationship between cereal consumption and T2D risk ($P<0.05$). For men, a negative correlation was observed between rice intake (ranging from 100 to 280 grams/day) and T2D risk; however, risk increased when consumption exceeded 280 grams/day. A significant increase in T2D risk was noted for women when rice intake rose above 240 grams/day. Consumption of other grains, ranging between 20 and 100 grams/day, demonstrated a protective effect (HR<1) among women.

DISCUSSION

This cohort study involving Chinese adults examined the link between different consumption patterns of rice, wheat, and other grains and the risk of developing T2D. The research discovered that a balanced intake of cereals, particularly one characterized by a high consumption of white rice without the inclusion of other grains, corresponds to a heightened risk of developing T2D. On the contrary, a moderate intake of coarse grains is inversely related to this risk. However, the correlation between cereal consumption and T2D risk might diverge based on gender. Our study suggests that daily intake above 240 grams and 280 grams of white rice may be a threshold for T2D development in men and women, respectively. To the best of our knowledge, this is the first report detailing the evolution of cereal consumption in Chinese adults over a continuous 21-year period (1997–2018). This research is unique due to using a group-based trajectory model for partitioning cereal consumption into groups with similar changing features, enabling an investigation of the health outcomes associated with different cereal consumption patterns.

In China, the term “coarse grains” is typically used to refer to grains excluding refined rice and wheat products. Western diets more commonly incorporate whole grains, defined by a fiber-to-carbohydrate ratio

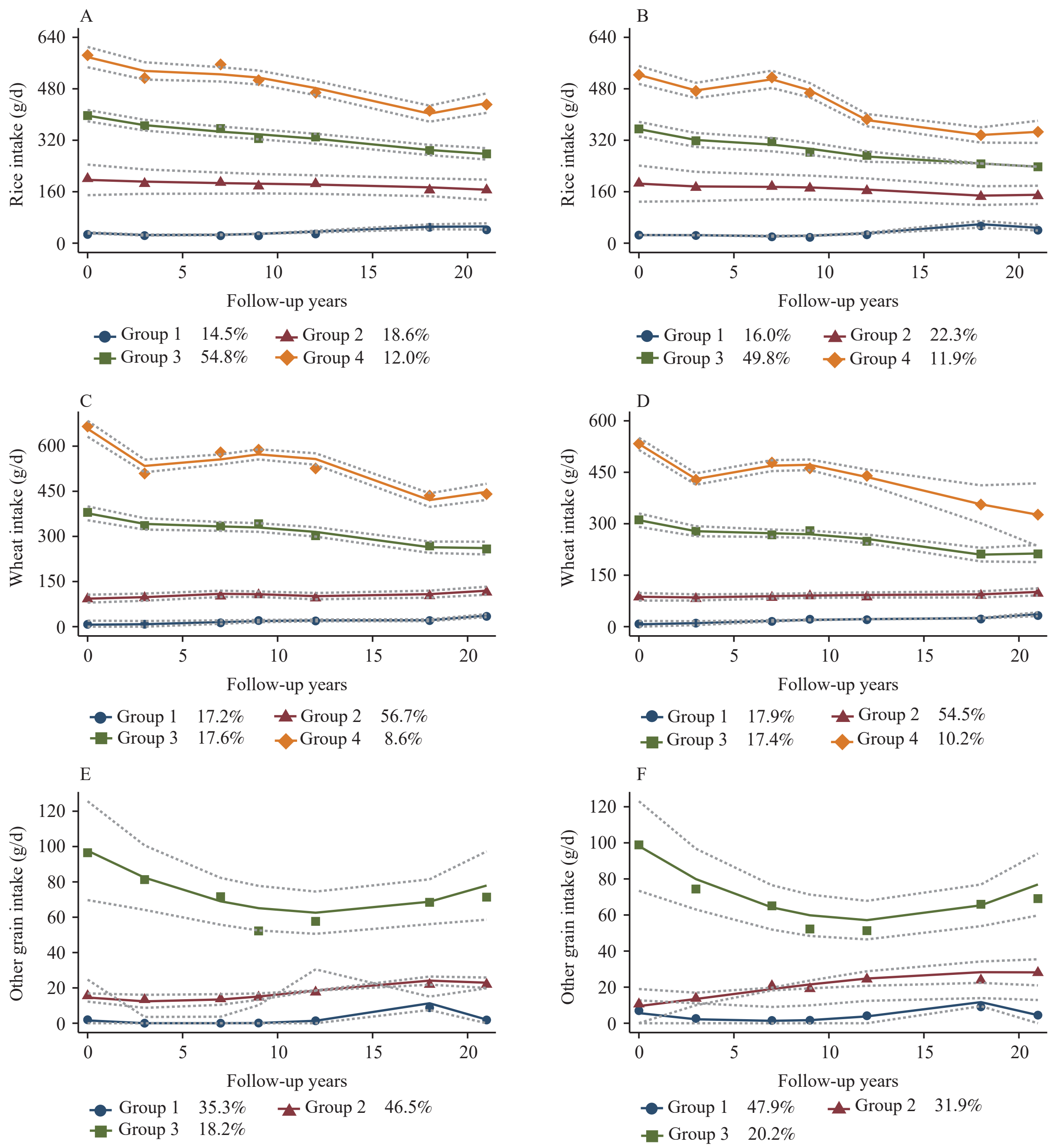


FIGURE 1. Trajectory of rice, wheat, and other grain intake in China from 1997 to 2018 among male and female participants. (A) Rice among males; (B) Rice among females; (C) Wheat among males; (D) Wheat among females; (E) Other grain among males; (F) Other grain among females.

Note: The solid lines depict the average estimated intake of rice, wheat, and other grains over time, while the dashed lines represent 95% confidence intervals. The data points represented by dots are weighted based on each individual's responses and the posterior probabilities of group membership. Cereal intake, measured in grams per average day, is shown on the vertical axis. The horizontal axis represents the follow-up time in years. The different colored lines correspond to distinct trajectory groups identified within the study population, with the legend indicating the groups and the proportion of people represented by each color.

equal to or greater than 0.1. Notably, an inverse correlation was identified for other grains, confirming an association across singular and multiple trajectories. Consistently aligning with prior studies on whole grain consumption, it was determined that trajectory groups consuming a specific volume of other grains exhibited a reduced risk of T2D compared to the "no/deficient intake group." This conclusion is supported by a

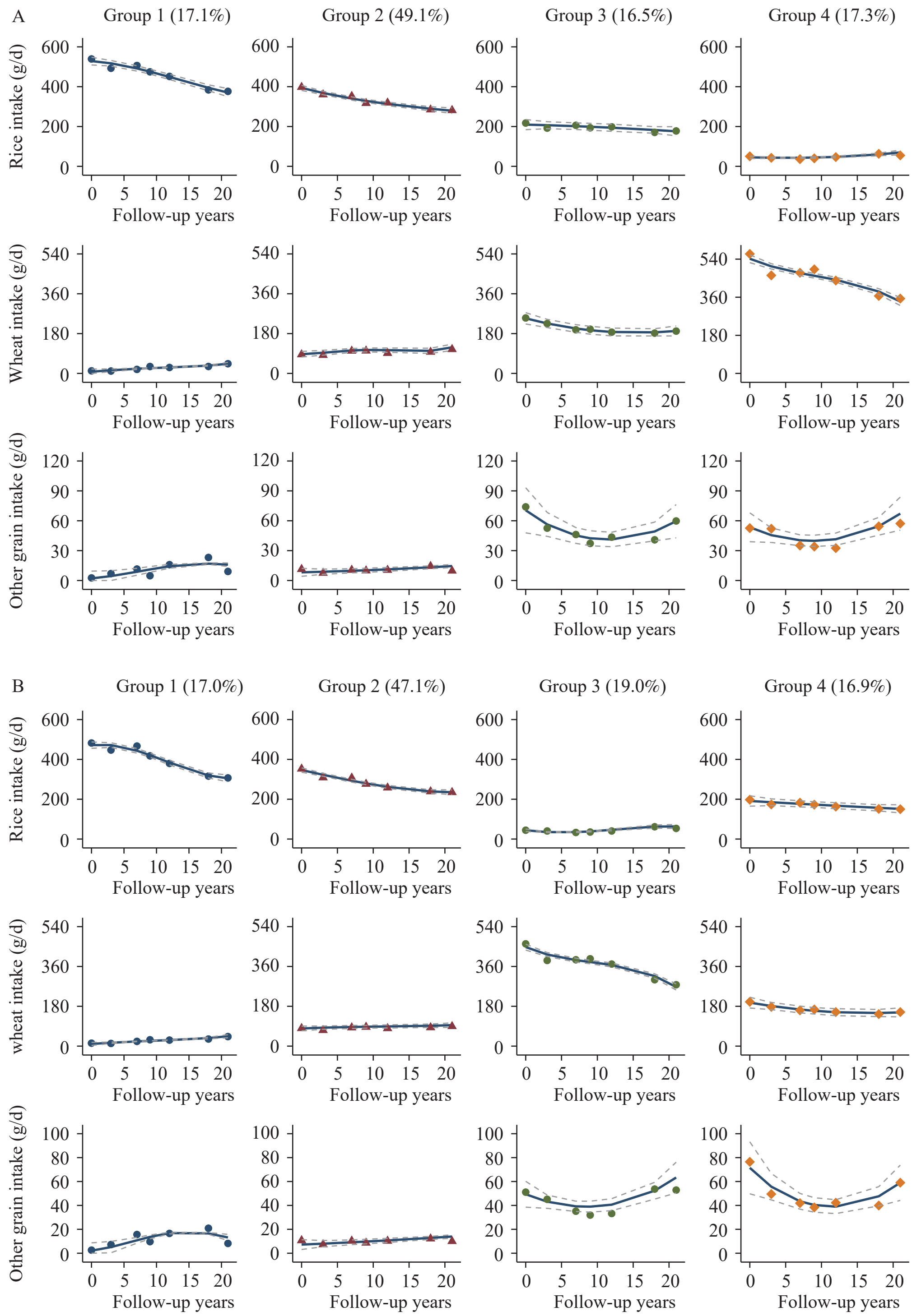


FIGURE 2. Multivariate trajectories of rice, wheat, and other grain consumption among (A) males and (B) females in the Chinese population, 1997–2018.

Note: The solid lines within the graph depict the average estimated intake of rice, wheat, and other grains over time. The dashed lines, on the other hand, represent the 95% confidence intervals. The individual data points, represented by dots, are individually weighted based on the posterior probabilities associated with each group membership. On the vertical axis, cereal intake measurements (including intake of rice, wheat and other grains) are represented in grams per average day. The horizontal axis, however, denotes follow-up time measured in years. Various trajectory groups identified within the study population are represented with distinctive color lines. Each color set of lines illustrates the intake trajectory of rice, wheat, and other grains for the identified population. The legend provides corresponding group associations and the percentage of individuals within each group.

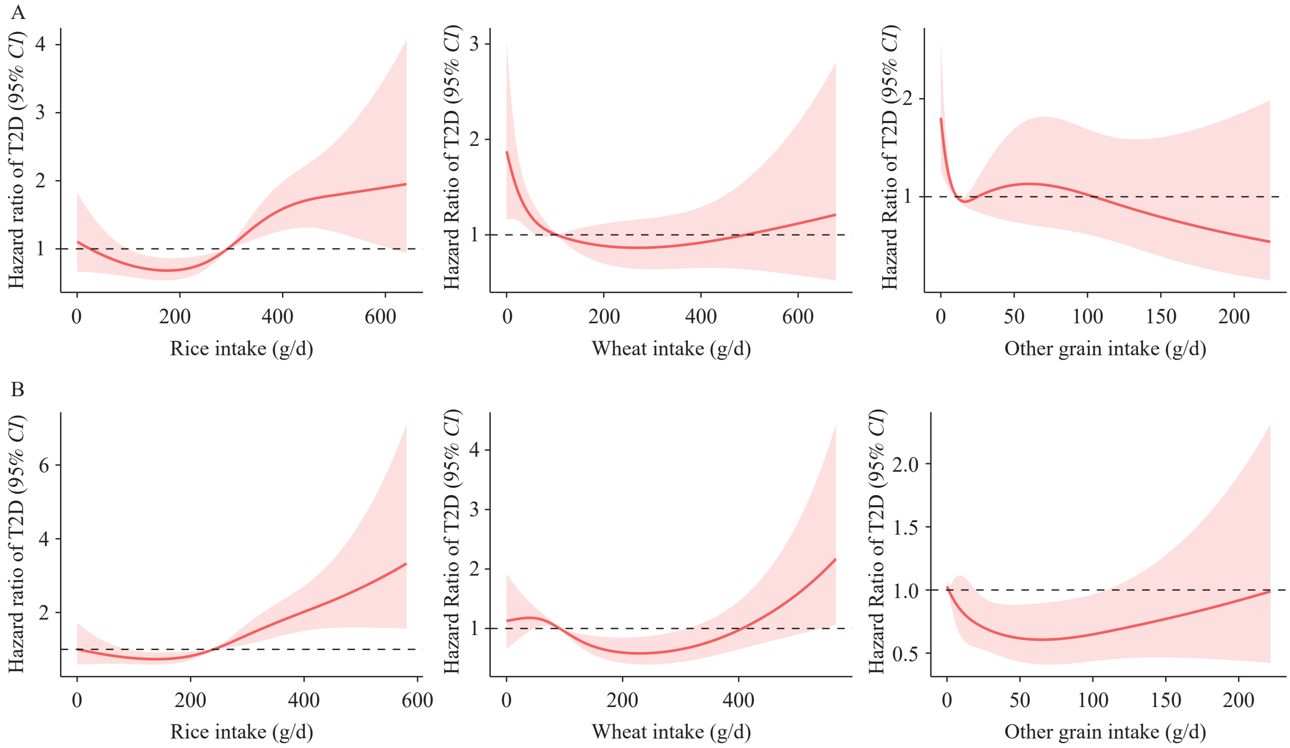


FIGURE 3. Exposure-response relationships between intake of rice, wheat, or other grains and risk of type 2 diabetes as determined by adjusted Cox proportional hazards analyses with restricted cubic splines among (A) male and (B) female participants.

Note: The y-axis represents the logarithm of the hazard ratios obtained from the multi-variable Cox model. The adjusted hazard ratio pertaining to the risk of T2D is illustrated by the red line. The shaded area depicts the 95% *CI* of these adjusted hazard ratios.

Abbreviation: T2D=type 2 diabetes; RCS=restricted cubic spline; *CI*=confidence interval.

significant body of scholarly research.

No statistically significant associations were found between various trajectories of rice intake and the risk of T2D. Interestingly, however, the group that did not supplement their diet with rice but had a high white rice consumption, exhibited a higher T2D risk in the multi-trajectory analysis. A parallel observation was noted in a Japanese study, where a similar association between T2D risk and white rice consumption was discerned. Although participants with a higher rice intake tended to have a lower body mass index, according to this study, they nonetheless displayed a heightened risk of T2D. This suggests that other mechanisms besides obesity might increase T2D risk due to high rice intake (*1*). The underlying mechanism for high white rice consumption and increased T2D risk remains uncertain. One plausible explanation for this could be the higher glycemic index (GI) of white rice, a dietary staple in Asian populations, significantly contributing to the glycemic load (GL). Moreover, the processing of polished rice strips away beneficial nutrients such as dietary fiber and magnesium, which have been proven to mitigate diabetes risk.

Differences in basal metabolism, physical activity, and lifestyle exist between genders. From this study's standpoint, we posit that cereals, serving as the primary source of carbohydrates and a significant contributor to GL, have a more pronounced influence on women than men. Our research findings support the view that cereal ingestion, encompassing rice and other grain consumption, has a more significant impact on T2D risk among women than their male counterparts. In our dose-RCS analysis, substantial distinctions were observed between men and women, with women's intake of coarse grains in the quantity of 20–80 grams inversely correlated with T2D risk. Accordingly, we advocate for a more intensive investigation of women's consumption behaviors and cereal intake patterns.

Products made from refined wheat, such as bread, white noodles, and steamed buns, vary considerably between Western and Asian countries. Although several studies have explored the relationship between the consumption of refined bread and the risk of T2D, the conclusions drawn from these studies are inconsistent. Compared to the extensive research on wheat consumption and the risk of obesity or being overweight, studies focusing on T2D risk are quite limited. In this study, no significant correlation was found between wheat intake and T2D risk in either gender. According to research on Geographic Variations in Dietary Patterns in China (*11*), wheat products are often consumed with other grains such as corn, rye, and millet, resulting in a mixed coarse and fine grain consumption pattern. On the other hand, white rice is generally accompanied by cooked vegetables and meat and rarely combined with other grains.

Our study contains numerous limitations worth noting. First, employing three consecutive 24-hour dietary recalls may lead to an underestimation of sporadic coarse grain intake. Second, identifying trajectories necessitates a minimum of three rounds of data. To fulfill the trajectory model fitting requirements, we imposed stringent inclusion criteria on our study design, potentially diminishing the representativeness of the samples analyzed and limiting the generalizability of our findings. Third, due to the inherent characteristics of observational studies, there is a potential for residual confounding, even after adjusting for various potential covariates.

This study was conducted to identify long-term trends in cereal consumption among Chinese adults and assess their corresponding risk of developing T2D. The objective was to provide fresh insights into T2D prevention by modifying risk factors. Findings suggest that the association between cereal intake patterns and diabetes onset has the potential to inform future dietary guidelines aimed at chronic disease prevention.

Conflicts of interest: The authors declare no conflict of interest.

Funding: This research was funded by the National Key R&D Program of Ministry of Science and Technology [Research project on dietary nutrition Assessment and intervention techniques (No. 2020YFC2006300)].

doi: 10.46234/ccdcw2023.172

Corresponding author: Gangqiang Ding, dinggq@chinacdc.cn.

[1] Department of Education and Training, Chinese Center for Disease Control and Prevention, Beijing, China; [2] Key Laboratory of Trace Element Nutrition of National Health Commission of China, National Institute for Nutrition and Health, Chinese Center for Disease Control and Prevention, Beijing, China.

Submitted: August 20, 2023; Accepted: October 10, 2023

REFERENCES

1. Li YZ, Teng D, Shi XG, Qin GJ, Qin YF, Quan HB, et al. Prevalence of diabetes recorded in mainland China using 2018 diagnostic criteria from the American Diabetes Association: national cross sectional study. BMJ 2020;369:m997. http://dx.doi.org/10.1136/bmj.m997.
2. Hu Y, Ding M, Sampson L, Willett WC, Manson JE, Wang ML, et al. Intake of whole grain foods and risk of type 2 diabetes: results from three prospective cohort studies. BMJ 2020;370:m2206. http://dx.doi.org/10.1136/bmj.m2206.
3. Yu JY, Balaji B, Tinajero M, Jarvis S, Khan T, Vasudevan S, et al. White rice, brown rice and the risk of type 2 diabetes: a systematic review and meta-analysis. BMJ Open 2022;12(9):e065426. http://dx.doi.org/10.1136/bmjopen-2022-065426.
4. Sun Q, Spiegelman D, van Dam RM, Holmes MD, Malik VS, Willett WC, et al. White rice, brown rice, and risk of type 2 diabetes in US men and women. Arch Intern Med 2010;170(11):961 – 9. http://dx.doi.org/10.1001/archinternmed.2010.109.
5. Akiko N, Tetsuya M, Mitsuhiko N, Yoshihiko T, Masayuki K, Manami I, et al. Rice intake and type 2 diabetes in Japanese men and women: the Japan Public Health Center–based prospective study. Am J Clin Nutr 2010;92(6):1468 – 77. http://dx.doi.org/10.3945/ajcn.2010.29512.
6. Chinese Diabetes Society. Guideline for the prevention and treatment of type 2 diabetes mellitus in China (2020 edition). Chin J Diabetes Mellitus 2021;13(4):315 – 409. http://dx.doi.org/10.3760/cma.j.cn311282-20210304-00142. (In Chinese).
7. . Yang YX, Wang GY, Pan XC. Chinese food composition. 2nd ed. Beijing: Peking University Medical Press. 2009. http://mbook.kongfz.com/180607/740627079/. (In Chinese).
8. Alberti KG, Zimmet PZ. Definition, diagnosis and classification of diabetes mellitus and its complications Part 1: diagnosis and classification of diabetes mellitus provisional report of a WHO consultation. Diabet Med 1998;15(7):539 – 53. http://dx.doi.org/10.1002/(SICI)1096-9136(199807)15:7<539::AID-DIA668>3.0.CO;2-S.
9. Nagin DS, Jones BL, Passos VL, Tremblay RE. Group-based multi-trajectory modeling. Stat Methods Med Res 2018;27(7):2015 – 23. http://dx.doi.org/10.1177/0962280216673085.
10. van der Nest G, Lima Passos V, Candel MJJM, van Breukelen GJP. An overview of mixture modelling for latent evolutions in longitudinal data: Modelling approaches, fit statistics and software. Adv Life Course Res 2020;43:100323. http://dx.doi.org/10.1016/j.alcr.2019.100323.
11. Zhao RP, Zhao LY, Gao X, Yang F, Yang YX, Fang HY, et al. Geographic variations in dietary patterns and their associations with overweight/obesity and hypertension in China: findings from china nutrition and health surveillance (2015–2017). Nutrients 2022;14(19):3949. http://dx.doi.org/10.3390/NU14193949.

SUPPLEMENTARY MATERIALS

SUPPLEMENTARY TABLE S1. Baseline characteristics of the participants (*n*=4,464).

Baseline characteristics	Male (*n*=2,044)	Female (*n*=2,420)	Overall (*n*=4,464)
Age, years (mean±SD)	42.23±12.00	42.02±11.31	42.12±11.63
Geographic region, *n* (%)			
Urban	544 (12.19)	636 (14.25)	1,180 (26.43)
Rural	1,500 (33.60)	1,784 (39.64)	3,284 (73.57)
Distribution of education level, *n* (%)			
Primary school	747 (16.73)	1,329 (29.77)	2,076 (46.51)
Middle school	796 (17.84)	716 (16.04)	1,512 (33.87)
High school and above	501 (11.22)	375 (8.40)	876 (19.62)
Per capita annual household income, CNY/year [median (IQR)]	9,656.92 (5,475.88–16,317.86)	9,820.00 (5,498.84–16,388.04)	9,700.63 (5,490.01–16,370.44)
Urban score (mean±SD)	56.36 (12.89)	56.02 (13.07)	56.17 (12.99)
Smoking, *n* (%)			
Nonsmoker	773 (17.32)	2,323 (52.04)	3,096 (69.35)
Current smoker	1,271 (28.47)	97 (2.17)	1,368 (30.65)
Alcohol drinking, *n* (%)			
Nondrinker	708 (15.86)	2,126 (47.62)	2,834 (63.49)
Current drinker	1,336 (29.93)	294 (6.59)	1,630 (36.51)
METs/week [median (IQR)]	245.69 (107.65–437.00)	269.39 (130.13–484.65)	258.39 (119.01–462.94)
Average daily energy intake, measured in kilocalories (mean±SD)	2,660.13±710.35	2,282.9±666.83	2,455.63±712.27
BMI, kg/m^2 (mean±SD)	22.48±2.90	22.67±3.14	22.58±3.03
WC, cm (mean±SD)	79.89±9.35	77.06±9.12	78.36±9.33
SBP, mmHg (mean±SD)	119.93±14.77	115.71±16.54	117.64±15.89
DBP, mmHg (mean±SD)	78.49±10.32	75.42±10.68	76.83±10.63

Note: Characteristics are described using either the median IQR or mean SD for continuous variables, and counts (proportions) for discrete variables.
Abbreviation: IQR=interquartile range; SD=standard deviation; CNY=Chinese Yuan; BMI=body mass index; WC=waist circumference; SBP=systolic blood pressure; DBP=diastolic blood pressure; MET=metabolic equivalent.

SUPPLEMENTARY TABLE S2. Associations between trajectory groups and T2D risk by sex.

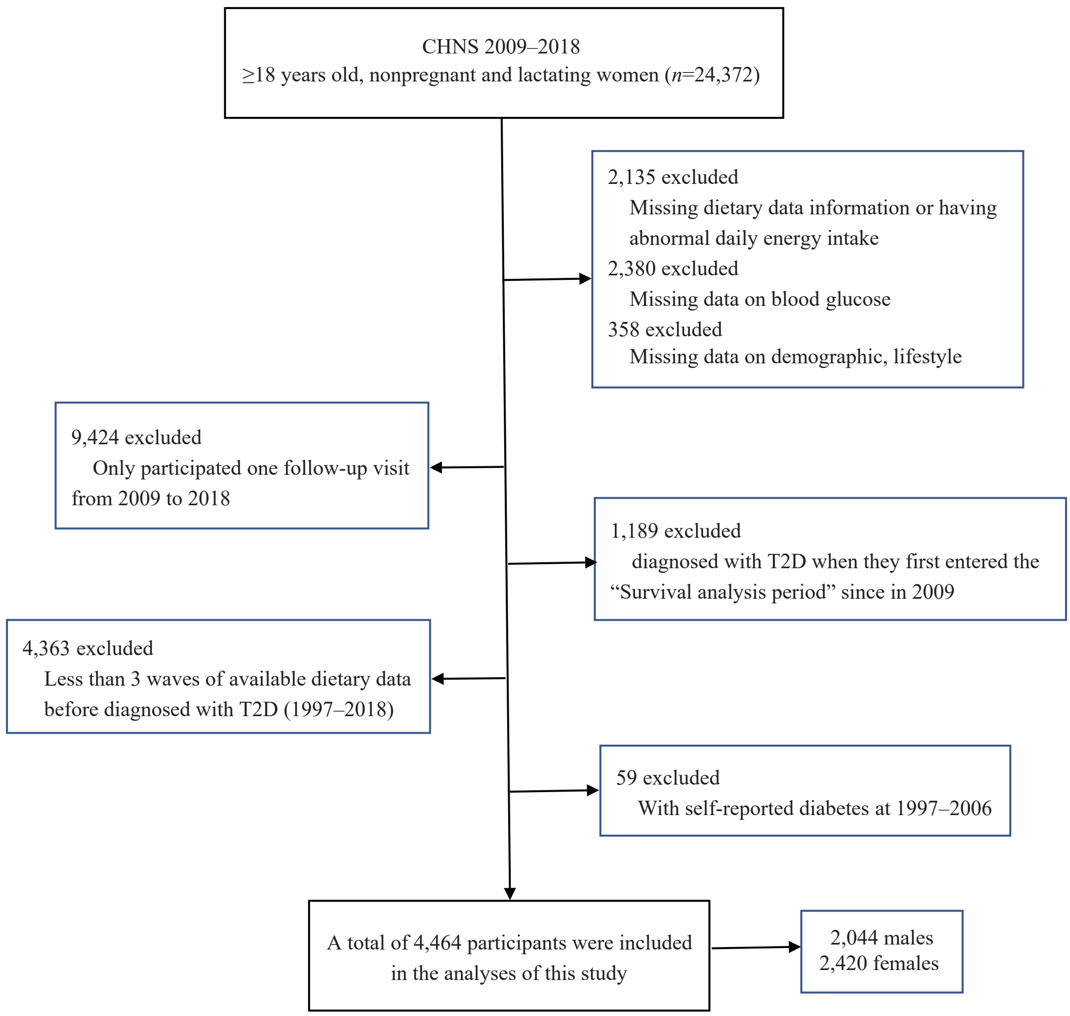
Gender	Food group	Trajectory group	*n*	Model 1 HRs (95% *CI*)	Model 2 HRs (95% *CI*)	Model 3 HRs (95% *CI*)
Male (*n*=2,044)	Rice	Group 2	381	1	1	1
		Group 1	296	0.95 (0.58–1.53)	1.18 (0.72–1.94)	1.20 (0.70–2.03)
		Group 3	1,121	1.06 (0.75–1.52)	1.25 (0.87–1.80)	1.16 (0.76–1.77)
		Group 4	246	1.01 (0.62–1.63)	1.38 (0.83–2.28)	1.13 (0.58–2.22)
	Wheat	Group 2	1,158	1	1	1
		Group 1	351	1.13 (0.80– 1.60)	1.19 (0.83–1.68)	1.19 (0.82–1.73)
		Group 3	359	1.05 (0.73–1.51)	1.09 (0.76–1.57)	1.19 (0.72–1.98)
		Group 4	176	0.72 (0.41– 1.27)	0.84 (0.46–1.53)	1.22 (0.48– 3,09)
	Other grains	Group 1	722	1	1	1
		Group 2	950	0.72 (0.54–0.96)*	0.66 (0.49–0.89)*	0.60 (0.45–0.81)*
		Group 3	372	0.66 (0.45–0.98)*	0.63 (0.42–0.94)*	0.52 (0.33–0.84)*
	Multiple trajectories	Group 3	338	1	1	1
		Group 1	349	1.07 (0.68–1.71)	1.28 (0.80–2.06)	1.51 (0.93–2.45)
		Group 2	1,004	1.16 (0.79–1.71)	1.22 (0.82–1.80)	1.34 (0.91–2.00)
		Group 4	353	0.98 (0.61–1.60)	1.14 (0.70–1.86)	1.06 (0.65–1.73)
Female (*n*=2,420)	Rice	Group 2	540	1	1	1
		Group 1	387	1.07 (0.65– 1.74)	1.07 (0.65–1.77)	1.30 (0.77–2.22)
		Group 3	1,205	1.35 (0.93–1.97)	1.42 (0.97–2.07)	1.39 (0.90–2.14)
		Group 4	288	1.22 (0.73–2.04)	1.29 (0.76–2.21)	1.06 (0.54–2.08)
	Wheat	Group 2	1,319	1	1	1
		Group 1	433	0.94 (0.65– 1.35)	0.90 (0.62–1.31)	0.92 (0.62–1.39)
		Group 3	422	0.72 (0.47–1.09)	0.69 (0.45–1.04)	0.73 (0.43– 1.25)
		Group 4	246	0.99 (0.62–1.56)	1.01 (0.62–1.65)	1.39 (0.62–3.13)
	Other grains	Group 1	1,159	1	1	1
		Group 2	771	1.10 (0.81–1.49)	1.10 (0.81–1.50)	0.97 (0.71–1.33)
		Group 3	490	0.72 (0.48–1.08)	0.69 (0.46–1.04)	0.56 (0.34–0.90)*
	Multiple trajectories	Group 4	410	1	1	1
		Group 1	411	1.24 (0.75–2.04)	1.27 (0.76–2.11)	1.70 (1.01–2.85)*
		Group 2	1,140	1.27 (0.83–1.94)	1.31 (0.86–2.02)	1.56 (1.01–2.40)*
		Group 3	459	1.21 (0.74–1.97)	1.22 (0.74–2.01)	1.27 (0.77–2.10)

Note: Model 1 does not include any covariate adjustments. Model 2 incorporates adjustments for factors such as age, education level, geographic locality (urban or rural), urbanization index, annual household income per capita, levels of physical activity, current status of smoking and drinking, sleep duration, and medical history. Additionally, Model 3 includes adjustments for baseline intake of rice, wheat, and other grains, total energy intake, waist circumference, and systolic blood pressure.
Abbreviation: HR=hazard ratio; *CI*=confidence interval.
* $P<0.05$.

SUPPLEMENTARY TABLE S3. Mean consumption of rice, wheat, and other grains among different multi-trajectory groups of males and females at follow-up.

Gender	Multiple trajectory groups	Cereal classification	1997 (mean, g/d)	2000 (mean, g/d)	2004 (mean, g/d)	2006 (mean, g/d)	2009 (mean, g/d)	2015 (mean, g/d)	2018 (mean, g/d)
Male	Group 1	Rice	545.39	496.19	509.82	488.37	456.84	390.93	381.42
		Wheat	9.95	8.65	15.94	29.12	24.62	30.20	39.20
		Other grains	2.71	6.77	13.23	4.96	18.71	26.59	9.48
	Group 2	Rice	398.09	361.54	351.89	315.66	319.15	283.79	280.72
		Wheat	83.12	82.38	101.55	102.86	90.45	95.92	109.76
		Other grains	13.38	8.16	11.27	10.07	11.05	14.24	9.83
	Group 3	Rice	215.02	186.16	205.23	191.45	196.02	167.47	176.34
		Wheat	257.21	229.13	197.24	196.62	193.43	184.80	194.02
		Other grains	102.28	61.68	64.73	43.72	50.36	45.95	73.84
	Group 4	Rice	49.45	43.55	36.52	39.57	46.30	62.05	53.96
		Wheat	565.21	462.55	476.14	492.98	436.12	366.58	353.83
		Other grains	56.99	54.56	41.06	38.91	36.45	68.68	65.95
Female	Group 1	Rice	484.38	452.08	474.38	426.10	385.30	320.54	313.62
		Wheat	12.34	10.97	19.54	27.16	26.37	29.60	42.17
		Other grains	2.09	9.31	16.57	11.15	17.09	23.21	8.64
	Group 2	Rice	352.92	306.99	306.46	275.61	257.36	238.75	233.26
		Wheat	81.37	72.44	83.62	86.09	79.74	84.69	88.82
		Other grains	12.26	7.12	11.27	8.72	10.93	12.17	9.82
	Group 3	Rice	46.60	41.01	33.26	35.21	39.81	60.92	53.18
		Wheat	460.78	385.89	389.30	395.07	370.94	300.36	277.36
		Other grains	53.44	46.37	39.99	34.68	36.16	66.66	59.92
	Group 4	Rice	192.79	171.88	179.27	169.52	159.62	148.62	146.94
		Wheat	195.72	178.24	163.80	166.36	156.99	145.67	156.91
		Other grains	125.43	59.38	56.28	46.62	47.13	43.88	75.98

Note: We found that group-based multi-trajectory modeling do effectively identify cereal-intake muti-trajectory groups.



SUPPLEMENTARY FIGURE S1. Flow chart outlining the inclusion of participants in the current study.
Abbreviation: CHNS=the China Health and Nutrition Survey; T2D=type 2 diabetes.

Vital Surveillances

Genetic Features of 84 Genomes of Monkeypox Virus in Recent Circulation — Beijing Municipality, China, 2023

Daitao Zhang[1]; Haoyuan Jin[1]; Yulan Sun[1]; Yang Yang[1]; Renqing Li[1]; Weihong Li[1]; Xin Zhang[1]; Shuang Li[1]; Yanwei Chen[1]; Quanyi Wang[1]; Yang Pan[1,#]

ABSTRACT

The first indigenous incidence of Mpox (previously known as monkeypox) within Chinese mainland was documented in May 2023, with subsequent local and imported cases identified. A comprehensive understanding of the Mpox virus's (MPXV) characteristics within Beijing remains incomplete. In this study, 84 MPXV genomes from 82 local incidents and two imported instances, detected between May and July 2023, were analyzed. All MPXV strains fell within lineage C.1 of the West African clade, displaying limited genetic heterogeneity, encompassing 76–87 nucleotide substitutions and holding nucleotide identities between 99.996% and 100%. Phylogenetic exploration indicated that all genomes exhibited high homology to those presently prevalent in neighboring East Asian and Southeast Asian regions. Forty-six distinct haplotypes were identified among the strains, with 36.90% of genomes corresponding to four common haplotypes, suggesting repeated cross-regional introductions and restrained distribution via recurrent local transmission. These findings elucidate the genetic diversity and phylogenesis of MPXVs during their nascent transmission within Beijing and provide vital information to enhance future Mpox containment strategies.

INTRODUCTION

Monkeypox (Mpox), an *Orthopoxvirus*-induced zoonotic illness, was first reported as having infected a human in the Democratic Republic of Congo in 1970 (*1*). Over the ensuing decades, instances of endemic circulation have been reported only infrequently in both West and Central Africa (*2*). In May of 2022, a case of Mpox was imported into the United Kingdom by a traveler visiting from Nigeria (*3*). Subsequently, a hitherto unseen outbreak has unfolded across multiple countries that hitherto had not reported cases, including nations in Europe and North America. This led to a declaration by the World Health Organization (WHO) in July 2022 that an international public health emergency was in effect (*3–5*). As reported in August 2023, this worldwide outbreak incurred 89,000 confirmed cases across 114 countries, resulting in 157 fatalities (*6*).

Prior to 2023, the Chinese mainland reported only one imported case of Mpox, likely due to stringent border control, quarantine, and isolation policies implemented during the coronavirus disease 2019 (COVID-19) pandemic (*7–8*). In late May 2023, the first recorded local Mpox infection occurred in Beijing (*9*). Since that time, diagnoses have increased, spreading across Beijing and other provinces throughout China. Despite this, the genetic characteristics of MPXV in China remain largely unexplored. This study aims to detail the genetic diversity of MPXV in recent Beijing infections.

MATERIALS AND METHODS

Participants and Sample Collection

This study enrolled all individuals in Beijing who received a positive result for MPXV via nucleic acid testing from May 31, 2023 to July 31, 2023. Samples of vesicular or pustular fluid, skin lesion swabs, and oropharyngeal swabs were acquired from confirmed symptomatic cases of Mpox. For asymptomatic individuals, rectal or perianal swabs and oropharyngeal swabs were obtained. The protocols for sample collection adhered to the Technical Guidelines for Mpox Prevention and Control (2022 edition), as issued by the National Health Commission of China.

Polymerase Chain Reaction Testing for MPXV

Viral DNA was extracted using the QIAamp MinElute Virus Kit (Qiagen, Dusseldorf, Germany) and detected using the MPXV polymerase chain reaction (PCR) kit (Kinghawk Co. Ltd., Beijing, China), which targets F3L, using the ABI 7500 system (Applied Biosystems, Carlsbad, CA, US) following the manufacturers' protocols.

Next-Generation Sequencing

The amplicon sequencing method was used to generate MPXV genomes. Viral DNA was amplified by multiplex PCR. PCR products were purified using AMpure XP Beads (Beckman, Brea, CA, US) and quantified by Qubit 3.0 fluorometry (Thermo Fisher Scientific, Waltham, MA, US). Next-generation sequencing libraries were prepared with the Nextera DNA Library Prep Kit and sequenced using the Illumina Nextseq 2000 system (Illumina, San Diego, CA, US).

Analysis of Phylogenetics and Haplotypes

The sequence processes, including reads trimming, mapping, consensus sequence extraction, and variant calling for each sample were conducted using CLC Genomics Workbench (version 22.0, Qiagen, Hilden, Germany). Our study employed the complete MPXV genome of the current outbreak (NC_063383), which has a genome size of 197,209 bp, as a reference genome. The alignment was accomplished via the MAFFT server, while a phylogenetic tree was constructed using the neighbor-joining method with a bootstrap value of 500 (*10*). MEGA (version 11) was used to calculate the nucleotide identity, and the phylogenetic tree was visualized through the ChiPlot server. For the phylogenetic analysis, 141 representative MPXV genomes from the public domain were chosen and compared with the genomes acquired in our study. The clade was determined by Nextclade (*11*). Haplotypes were determined by using DnaSP 6, and the haplotype frequencies in populations were calculated using Arlequin 3.5.2.2 with default parameters (*12*). The network was visualized using the PopART (version 1.7) (*13*).

RESULTS

We conducted a comprehensive investigation on the transmission pathways of MPXV in Beijing by employing next-generation sequencing techniques on samples gathered from all identifiable Mpox incidences throughout the study duration. An aggregate of 84 high-grade MPXV genome sequences derived from 84 instances were incorporated into the analysis. The enrolled cases were exclusively male, presenting a median age bracket of 32 years (interquartile range extending from 28 to 35 years). A minimal fraction of the cases (2.38%) contracted the infection abroad, juxtaposed against the significant majority (97.62%) who were recognized as locally-infected individuals.

A phylogenetic tree, based on the neighbor-joining method, was utilized to evaluate the relatedness of the MPXV genomes in Beijing to those globally circulating. This analysis incorporated the 84 locally sequenced genomes from this study and 141 other publicly available genomes. The 84 Beijing genomes were all found to belong to the MPXV C.1 lineage (Figure 1), with nucleotide identities ranging from 99.996% to 100%. These genomes formed a cluster in the phylogenetic tree, signifying a few related MPXV introductions. Upon closer inspection, it was clear that the Beijing case genomes were markedly homologous to those identified in other regions of China and neighboring East Asia and Southeast Asia.

Phylogenetic analysis reveals constrained diversity within the MPXV genome in Beijing. However, epidemiological investigations suggest multiple unique inflection events rather than a single source, and not all cases appear directly linked. The analysis of haplotypes identifies a high variation with 46 distinct haplotypes found within the non-ITR variable and central regions (*14*) (Figure 2). Notably, a substantial proportion of genomes, 36.90% or 31 genomes coalesced around four key haplotypes: Hap 12, Hap 13, Hap 16, and Hap 7. Despite this, no intermediate forms between these four haplotypes have been detected. Interestingly, another distinct cluster, Hap 11, was identified with six individual genomes. These findings hint at frequent trans-regional importation and proliferated dissemination through multiple local transmission chains.

Of the 84 MPXV genomes examined in this study, only two were identified as cases of imported infections. The first imported case was detected in Beijing upon a patient's return from Thailand in the latter part of April and confirmed positive on June 2; this case is thought to be the first local instance in Beijing (*9*). Interestingly, the haplotype network revealed that the first imported case and subsequent local case were identified as Hap 1, which was not the source of later cases, which derived from other related yet independent infections. Similarly, another imported infection identified on June 16 as Hap 39 possessed a notably distinct genome compared to the others. This particular imported MPXV exhibited 76 nucleotide substitutions and 34 amino acid substitutions relative to the reference genome (accession number NC_063383.1), including changes such as C33332T (OPG050:R26Q), G37974A

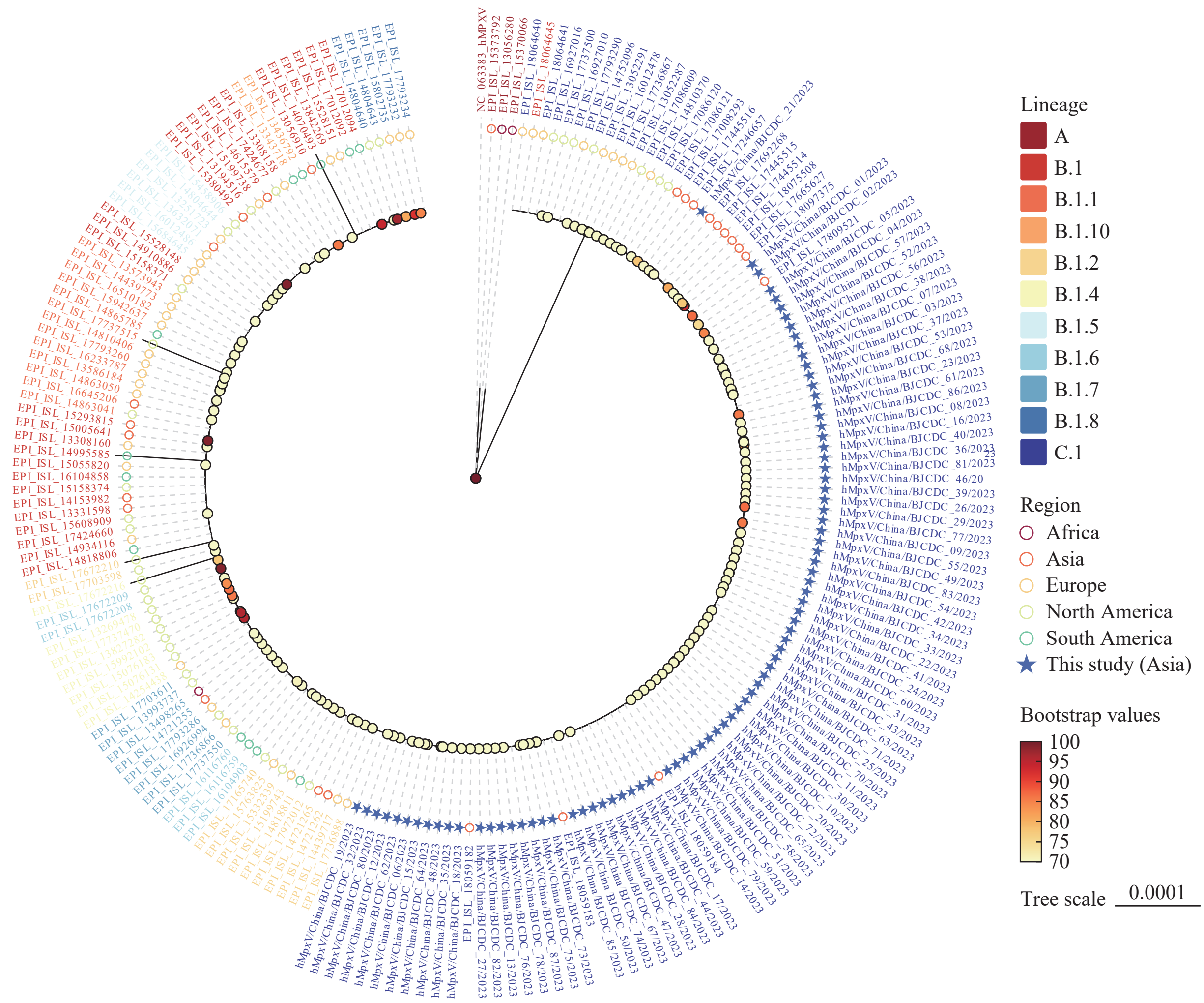


FIGURE 1. Phylogenetic tree derived from the complete Mpox virus genomes.

Note: The phylogenetic analysis of 84 strains in Beijing, conducted from May 31 to July 31, 2023, is presented. Distinct lineages are represented by strain names in varying colors. Bootstrap values are indicated by circles filled with gradient colors. Strains sequenced within the current study are marked with asterisks.

(OPG056:S354L), and C149963T (OPG0176:S52L), which were not present in the previous Beijing case. Overall, our data suggested that the genetic diversity of local MPXVs in Beijing was lower than that of the imported instances.

To date, two separate clades of MPXV have been identified, Clade I (CA-MPXVs/Clade I, previously referred to as the Congo Basin or Central African clade), and Clade II or III (WA-MPXVs/Clade II or III, formerly known as the West African clade) (*15*–*16*). The ongoing Mpox outbreak, beginning in 2022, can be traced back to lineage B.1, Clade II, which shares a genetic connection with a significant outbreak in Nigeria between 2017 and 2018 (*17*). A noteworthy number of single-nucleotide polymorphisms (SNPs) – over 50 – were identified in the viral genome during this outbreak, a figure considerably higher than the average estimate based on the *Orthopoxviruses* substitution rate (*18*). A similar phenomenon is noted in the present study, with 76–87 SNPs discovered in the MPXV genomes of the Beijing cases. It is proposed that an abundance of mutations within viral genomes could be attributed to the interaction between the host's apolipoprotein B editing complex (APOBEC3), cytosine deaminase, and host adaptation (*18*–*19*). APOBEC3's significant impact results in a strong tendency towards G>A and C>T substitutions in the A∶T-rich framework of the MPXV (*18*). A total of 61 (52.14%) G>A substitutions and 45 (38.46%) C>T substitutions were observed among the 117 SNPs in all MPXV genomes from the Beijing cases. This codon bias aids the virus's immune evasion through deaminase-dependent or independent processes (*19*).

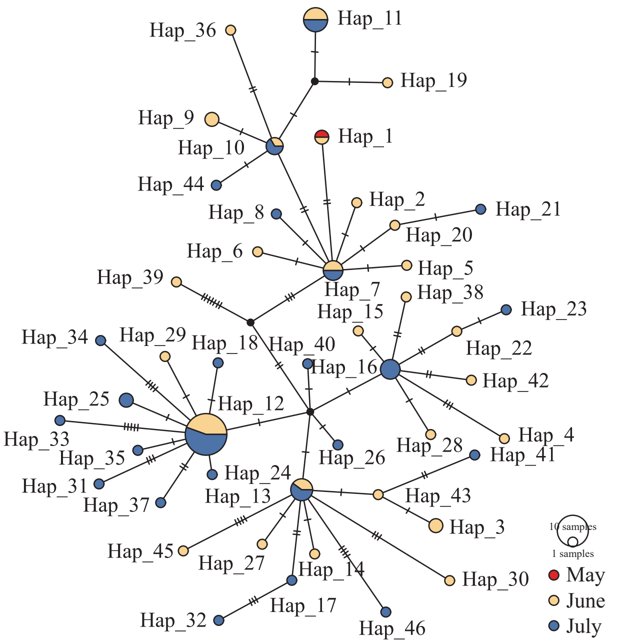


FIGURE 2. Network of Mpox viruses haplotypes observed in Beijing from May to July, 2023.

Note: The size of each plot corresponds to the number of cases reported. The collected samples from May, June, and July of 2023, are represented in red, yellow, and blue, respectively.

CONCLUSIONS

In conclusion, this paper presents the genetic characteristics of the MPXVs currently circulating in Beijing. Our research illustrates that over the past two months since the discovery of the first imported case, local transmission has been significantly restrained. Nevertheless, the extensive genetic diversity displayed in the imported cases underscores the necessity of continuous surveillance for both foreign introductions and local transmission of MPXVs.

Conflicts of interest: No conflicts of interest.

Funding: The present study received support from the National Key Research and Development Program of China (2021ZD0114103). Additional support was also provided by the High-Level Public Health Technical Talent Training Plan (Reference: lingjunrencai-01-02).

doi: 10.46234/ccdcw2023.173

[#] Corresponding author: Yang Pan, panyang10@gmail.com.

[1] Institute for Infectious Disease and Endemic Disease Control, Beijing Center for Disease Prevention and Control, Beijing, China.

Submitted: September 11, 2023; Accepted: October 07, 2023

REFERENCES

1. Ladnyj ID, Ziegler P, Kima E. A human infection caused by monkeypox virus in Basankusu territory, Democratic Republic of the Congo. Bull World Health Organ 1972;46(5):593-7. https://pubmed.ncbi.nlm.nih.gov/4340218/.
2. Di Giulio DB, Eckburg PB. Human monkeypox: an emerging zoonosis. Lancet Infect Dis 2004;4(1):15 – 25. http://dx.doi.org/10.1016/S1473-3099(03)00856-9.
3. Vivancos R, Anderson C, Blomquist P, Balasegaram S, Bell A, Bishop L, et al. Community transmission of monkeypox in the United Kingdom, April to May 2022. Euro Surveill 2022;27(22):2200422. http://dx.doi.org/10.2807/1560-7917.ES.2022.27.22.2200422.
4. Patel A, Bilinska J, Tam JCH, Da Silva Fontoura D, Mason CY, Daunt A, et al. Clinical features and novel presentations of human monkeypox in a central London Centre during the 2022 outbreak: descriptive case series. BMJ 2022;378:e072410. http://dx.doi.org/10.1136/BMJ-2022-072410.
5. Ren SY, Li J, Gao RD. 2022 Monkeypox outbreak: why is it a public health emergency of international concern? What can we do to control it? World J Clin Cases 2022;10(30):10873-81. http://dx.doi.org/10.12998/wjcc.v10.i30.10873.
6. WHO. 2022-23 Mpox (Monkeypox) outbreak: global trends. Geneva: World Health Organization; 2023 Aug. https://worldhealthorg.shinyapps.io/mpx_global/.
7. Zhao H, Wang WL, Zhao L, Ye S, Song JD, Lu RJ, et al. The first imported case of Monkeypox in the mainland of China - Chongqing municipality, China, September 16, 2022. China CDC Wkly 2022;4(38):853 – 4. http://dx.doi.org/10.46234/ccdcw2022.175.
8. Luo Q, Han J. Preparedness for a monkeypox outbreak. Infect Med 2022;1(2):124 – 34. http://dx.doi.org/10.1016/j.imj.2022.07.001.
9. Zhang DT, Qi X, Li F, Chu YH, Wu K, Li J, et al. The first local case of mpox caused by an imported case in the Chinese mainland. Biosaf Health 2023;5(4):187 – 90. http://dx.doi.org/10.1016/j.bsheal.2023.07.003.
10. Katoh K, Rozewicki J, Yamada KD. MAFFT online service: multiple sequence alignment, interactive sequence choice and visualization. Brief Bioinform 2019;20(4):1160 – 6. http://dx.doi.org/10.1093/bib/bbx108.
11. Aksamentov I, Roemer C, Hodcroft EB, Neher RA. Nextclade: clade assignment, mutation calling and quality control for viral genomes. J Open Source Software 2021;6(67):3773. http://dx.doi.org/10.21105/joss.03773.
12. Excoffier L, Lischer HEL. Arlequin suite ver 3. 5: a new series of programs to perform population genetics analyses under Linux and Windows. Mol Ecol Resour 2010;10(3):564 – 7. http://dx.doi.org/10.1111/j.1755-0998.2010.02847.x.
13. Leigh JW, Bryant D. POPART: full-feature software for haplotype network construction. Methods Ecol Evol 2015;6(9):1110 – 6. http://dx.doi.org/10.1111/2041-210X.12410.
14. Karagoz A, Tombuloglu H, Alsaeed M, Tombuloglu G, AlRubaish AA, Mahmoud A, et al. Monkeypox (mpox) virus: classification, origin, transmission, genome organization, antiviral drugs, and molecular diagnosis. J Infect Public Health 2023;16(4):531 – 41. http://dx.doi.org/10.1016/j.jiph.2023.02.003.
15. Brown K, Leggat PA. Human Monkeypox: current state of knowledge and implications for the future. Trop Med Infect Dis 2016;1(1):8. http://dx.doi.org/10.3390/tropicalmed1010008.
16. Reynolds MG, Damon IK. Outbreaks of human monkeypox after cessation of smallpox vaccination. Trends Microbiol 2012;20(2):80 – 7. http://dx.doi.org/10.1016/j.tim.2011.12.001.
17. Yinka-Ogunleye A, Aruna O, Dalhat M, Ogoina D, McCollum A, Disu Y, et al. Outbreak of human monkeypox in Nigeria in 2017-18: a clinical and epidemiological report. Lancet Infect Dis 2019;19(8):872 – 9. http://dx.doi.org/10.1016/S1473-3099(19)30294-4.
18. Isidro J, Borges V, Pinto M, Sobral D, Santos JD, Nunes A, et al. Phylogenomic characterization and signs of microevolution in the 2022 multi-country outbreak of monkeypox virus. Nat Med 2022;28(8):1569 – 72. http://dx.doi.org/10.1038/s41591-022-01907-y.
19. Pecori R, Di Giorgio S, Paulo Lorenzo J, Nina Papavasiliou F. Functions and consequences of AID/APOBEC-mediated DNA and RNA deamination. Nat Rev Genet 2022;23(8):505 – 18. http://dx.doi.org/10.1038/s41576-022-00459-8.

Methods and Applications

Measuring the Capability of Biological Incident Rescue Teams in China: A Fuzzy Analytic Hierarchy Process Based Model — Tianjin Municipality, China, 2022–2023

Zichen Zhou[1,&]; Lulu Yao[2,&]; Shike Hou[2]; Yan Zhou[3]; Chao Zhao[4]; Song Bai[2]; Nan Li[1]; Tiantian Li[2]; Yongzhong Zhang[2,#]

ABSTRACT

Introduction: The swift advancement of biotechnology has presented both opportunities and challenges to our society, thrusting biosafety to the forefront of concern. Consequently, the evaluation of rescue capabilities in the event of a bioterrorism incident becomes of paramount importance. Currently, there is a notable absence of specific measurement criteria and a comprehensive evaluation system. This paper aims to establish a systematic approach towards assessing emergency response capabilities in the context of bioterrorism incidents.

Methods: We employed an enhanced Delphi methodology to establish an index evaluation framework. Subsequently, the weight of the judgment matrix was ascertained via the application of the fuzzy comprehensive evaluation approach. This led to the creation of a fuzzy comprehensive evaluation model for bioterrorism rescue capability.

Results: A modified Delphi study was conducted involving 11 experts across two rounds, achieving a response rate of 100%. The Kendall coordination coefficients recorded in the first and second rounds were 0.303 and 0.632, respectively ($P<0.05$). Upon comprehensive analysis involving score, coefficient of variation, and full score ratio, we distinguished five primary indicators and 25 secondary indicators. Subsequently, an evaluation model was developed based on the Analytic Hierarchy Process (AHP) tailored to assess the response to a rescue from bioterrorism.

Discussion: The expert panel confirmed consensus on all aspects of the model, validating its comprehensive content. The succeeding course of action involves converting the assessment model to a measurable scale, affirming its functionality, and implementing it in practical evaluation tasks to further enhance the capabilities of the biological incident rescue team.

Recent years have seen a rapid increase in both population density and personnel flow, with parallel advancements in biotechnology and information technology. This has resulted in an increasingly complex international biosafety situation, amplified by the potential misuse of biotechnology in bioterrorism activities, posing significant threats to public security and international order (*1*).

According to the Global Terrorist Database, there have been approximately 200,000 terrorist attacks worldwide from 1981 to 2021, 41 of which involved bioterrorism. These attacks led to 11 fatalities and 813 disease-related cases (*2*). Given this context of prevailing biosecurity concerns, current rescue capabilities are proving insufficient to meet the actual requirements.

Emergency rescue teams and disaster emergency management operations pertaining to biological events are faced with challenges such as inadequate training experience, response capabilities, and a lack of uniform criteria for ability evaluation. Challenges also include an inconsistency in the quality of rescue teams, as well as sluggish team construction. With bioterrorism presenting as a low-probability, high-risk event, there is a scarcity of research literature on the subject. The prevalent assessment system for rescue capability concentrates more on tsunamis, earthquakes, and similar events (*3*).

Additionally, the prevailing research relies heavily on the Delphi method. In this method, due to the subjectivity of experts and the ambiguity of indicators, the weights assigned to each indicator are unclear. Consequently, it is challenging to represent the significance of key indices with precise values, leading to less accurate evaluation outcomes (*4*).

Therefore, the urgent need for a rigorous evaluation system for the response and rescue in bioterrorism events cannot be overstated.

METHODS

We utilized the Delphi method to construct the indicator system in this research study and deployed the boundary value method for indicator selection. Once identified, we calculated the weight of each index via the analytic hierarchy process and utilized these calculations to construct a fuzzy comprehensive evaluation model. Microsoft Excel (Version 2016; Microsoft, New York, USA) and SPSS software (Version 22.0; IBM, New York, USA) were employed for all statistical analyses. Further details regarding these methodologies are furnished in the Supplementary Material (available in https://weekly.chinacdc.cn/).

Semi-Structured Interview

We elicited insights from experts affiliated with the Chinese Academy of Military Medical Sciences, the Chinese Center for Disease Control and Prevention, and various academic institutions, through comprehensive semi-structured interviews prior to formal correspondence. This approach facilitated dynamic and adaptable dialogues, allowed for customized inquiries according to unique needs, and helped to foster rapport with the interviewees.

Questions were drafted in accordance with the Guidelines for Capacity Building and Grading Evaluation of National Urban Rescue Teams (draft), exploring their perceptions of bioterrorism events, the core responsibilities of rescue teams, and interdepartmental collaboration, among other relevant topics.

After assimilating the study's background, objectives, and methods, the experts offered extensive inputs and recommendations through the provisional indicator framework. Consequently, we refined and improved the draft indicator framework by integrating these expert opinions to guide the subsequent development of the questionnaire.

Expert Selection

Considering the suitability of the Delphi method and the field-specific requirements of the study, we selected 11 senior professionals as expert participants. These experts were pulled from various domains such as public health, emergency management, or epidemiology. They were drawn from several organizations, including the Chinese Center for Disease Control and Prevention, People's Liberation Army, People's Armed Police Force, hospitals, and universities, as well as aggregated from experts at the national and provincial levels, utilizing purposive sampling.

All chosen expert participants had accumulated over five years of experience in emergency management, disaster-related occupations, or on the subject of research. Each held an associate senior professional title or superior, obtained a minimum of a bachelor's degree, and was acknowledged for conducting relevant research in their fields. All expert participants voluntarily contributed to the study with good compliance and gave the assurance of their dedication until the study consultations were concluded.

Questionnaire Design

Based on the framework derived from literary analysis and expert interviews, the initial draft of the expert consultation questionnaire was developed. This draft showcased the underlying context, explanations pertinent to the index system, assessment of index importance and familiarity, and expert-specific data. Following the first round of expert consultation, the questionnaire was revised to reflect the outcome. The second version incorporated comprehensive scoring averages, coefficients of variance, full score ratios, and each index's expert opinion from the initial consultation round for reference. Experts assigned weights to every index using a 5-point scale.

RESULTS

The Delphi survey was carried out between August 19 and September 20, 2022. We invited a total of 15 specialists from national, provincial, and municipal disease control and prevention centers, health administrative departments, scientific research institutions, and allied domains. After reaching out via email, 11 experts expressed their interest and confirmed their availability to participate. Subsequently, we communicated with these experts through emails soliciting their feedback on the indicator content. This process was repeated for the second round of consultation. Ultimately, all 11 invited experts successfully participated in the full Delphi survey, achieving a response rate of 100%. Information detailing the participant's demographic characteristics can be found in Table 1.

Through a combination of literature review, semi-structured expert interviews, and consideration of China's unique national conditions, the tasks of emergency rescue teams in bioterrorism incidents were

TABLE 1. The characteristics of experts in the panel.

Characteristics	Demographics	Count (n=11)
Gender	Male	9
	Female	2
Age (years)	35–40	1
	41–45	5
	46–50	2
	Over 50	3
Specialty	University academic	5
	Physician	4
	Disaster management	2
Title of the job	Professor	9
	Associate professor	2
Education level	Master	3
	Doctoral/PhD	8
Work area	Public health	4
	Disaster rescue	1
	Emergency management	5
	Rescue technology	1
Working experience (years)	5–10	2
	11–15	2
	16–20	4
	Over 20	3

distilled into four main responsibilities. These include: controlling exposure within the population and halting transmission to prevent further infection; rapidly curbing the situation through establishing isolation areas, conducting epidemiological investigations, and decontaminating affected regions; identifying biological pathogens and incident types to provide an essential basis for medical services; and mitigating harmful consequences while ensuring thorough on-site recovery. The expert interview questionnaire is presented in Supplementary Table S1 (available in https://weekly.chinacdc.cn/).

In two iterations of expert consultation, our team computed and scrutinized the expert authority coefficient as well as the consistency degree. The given experts' judgment basis (Ca) values were 0.895 and 0.877 respectively, while the familiarity degree (Cs) values stood at 0.836 and 0.855 in respective order. The expert authority coefficient (CR), on the other hand, was consistently at 0.866, thereby satisfying the Cr≥0.7 criterion. This implies a high level of expert authority and, by extension, the reliability of the expert consultation process (Supplementary Table S2, available in https://weekly.chinacdc.cn/).

The Kendall coordination coefficient demonstrated a shift from 0.303 (P<0.05) to 0.632 (P<0.05). This increase, falling within the 0.6 to 0.8 range, signifies a high degree of consistency and a low level of significance, thereby indicating a high level of independence among the indicators. Coefficients of variation for the two evaluations were observed to be 0.106 and 0.063 respectively, both under the threshold of 0.25. This detail suggests that expert opinions were notably aligned, yielding consistent evaluation results and validating the credibility of the index system. The results of the Kendall coordination coefficient test can be found in Supplementary Table S3 (available in https://weekly.chinacdc.cn/).

Based on expert feedback and scoring, the boundary value for each index was computed (Supplementary Table S4, available in https://weekly.chinacdc.cn/). The chosen indexes were then consolidated and accordingly adjusted, following expert recommendations. This process eventually yielded five primary indicators and twenty-five secondary indicators for assessing a bioterrorism rescue team's capability. The significance of these level indexes within the developed evaluation system was gauged in two rounds of expert consultations and group discussions (Supplementary Table S5, available in https://weekly.chinacdc.cn/). Importance was ascertained based on the influence of certain factors on bioterrorism rescue capabilities, thereby determining the final weight of each index (Table 2).

DISCUSSION

To the best of our knowledge, this represents the first study conducted in China that employs the Delphi survey and the Analytic Hierarchy Process (AHP) to explore expert perspectives, with the aim of establishing a capability evaluation model for biological rescue teams. The derived evaluation model from our study can serve as a useful reference instrumental in the development and enhancement of rescue team capabilities. Furthermore, it provides a robust tool for evaluating the efficacy of rescue teams in the context of bioterrorism incidents.

The formation of expert panels is integral to the Delphi method. Currently, a well-defined standard for the evaluation of bioterrorism response capabilities does not exist, hence the necessity to establish one through the guidance of an expert panel (*5*). In the current study, we assembled the panel from a cross-section of professionals in China, including university

TABLE 2. First and second-level index weight distribution and testing.

Indicators	Weights	Consistency check
First Level Indicator		
Capacity building of rescue team A	0.13200	CI=0.056 RI=1.120 CR=0.050 Maximum characteristic value =5.225
Emergency response factors of rescue team B	0.23053	
Rescue team emergency rescue factors C	0.48353	
Rescue team evacuation D	0.06378	
Recovery evaluation factors of rescue team E	0.09016	
Second Level Indicator		
Emergency response mechanism A1	0.16734	CI=0.071 RI=1.120 CR=0.064 Maximum characteristic value =5.285
Team building A2	0.09408	
Material and equipment A3	0.46158	
Training and exercises A4	0.20207	
Team composition A5	0.07493	
Organize, direct and coordinate B1	0.19634	CI=0.067 RI=0.890 CR=0.075 Maximum characteristic value =4.201
Emergency response mechanism B2	0.35045	
Information acquisition and analysis B3	0.33875	
Risk communication B4	0.11447	
Control of exposed population C1	0.06259	CI=0.088 RI=1.410 CR=0.062 Maximum characteristic value =8.615
Isolation and quarantine C2	0.06963	
Field survey and sampling C3	0.23293	
On-site decontamination C4	0.16486	
Real-time monitoring C5	0.04847	
Emergency medical rescue C6	0.08167	
Epidemiological investigation C7	0.11844	
Detection and analysis C8	0.22141	
Research and evaluation D1	0.58126	CI=0.002 RI=0.520 CR=0.004 Maximum characteristic value =3.004
On-site inspection D2	0.30915	
Withdraw the team D3	0.10959	
Physical examination E1	0.15667	CI=0.084 RI=1.120 CR=0.075 Maximum characteristic value =5.336
Psychological intervention E2	0.21289	
Recovery of equipment E3	0.30692	
Mitigation evaluation E4	0.06353	
Evaluation of effectiveness E5	0.26000	

Abbreviation: CR=expert authority coefficient; CI=coincidence indicator; RI=random consistency index.

academicians, hospital executives, and researchers from the CDC. These individuals have established careers in public health, emergency management, and disaster relief and possess a vast array of knowledge in terms of managerial and technical roles. Equipped with a deep understanding and distinctive perspectives on rescue operations, they have generated an evaluative model in this study which can therefore be effectively deployed in critically assessing the management, personal quality, and operational competence of bioterrorism response teams.

Biological incidents, such as disease epidemics or biohazard spills, pose substantial threats to public health and safety. Consequently, the effective execution of on-site mitigation activities is vital to lessen these events' impact and safeguard lives. These activities extend beyond routine crowd management and decontamination to include critical aspects such as sampling and detection. The quality of the on-site sampling process is paramount as it influences detection accuracy. Given the novelty and diversity of biological warfare agents, their identification relies on both prompt on-site detection and meticulous laboratory monitoring. Optimal outcomes necessitate rapid field detection balanced with rigorous laboratory scrutiny. The nexus between these two aspects deserves due consideration as the detection outcomes significantly influence on-site management strategies and decision-making processes.

Since the severe acute respiratory syndrome (SARS) outbreak in 2003, China has primarily directed its emergency response capability evaluation system towards public health emergencies (*6*). The country's experience with events like the H1N1 influenza pandemic and the coronavirus disease 2019 (COVID-19) pandemic further accentuates the necessity of a robust and efficient emergency response capability evaluation framework.

Presently, there appears to be an absence of rescue quality assessment. This includes evaluations of comprehensive procedures, the health and equipment deterioration of team personnel, the anticipatory control of the incident, as well as on-site and ultimate controls. To enhance impartiality, third-party evaluations should be contemplated. This approach will not only expedite the incident's resolution but will also bolster capacity building within rescue teams.

Team building encompasses the entire cycle of entry, operation, management, and departure of team members. Strategic investment in talent can produce the most enduring contribution to the quality of rescue efforts (*7*). As such, it is critical to augment funding towards talent development, and to implement regular, capability-focused training and upskilling that align with practical needs, thus fostering sustainable human development. Notably, in the context of China, the role of cross-sectoral collaboration in team building demands acknowledgement, and needs to be incorporated in the initial stages of team design.

This study, like any other, has limitations that must be recognized. First, due to the infrequency of bioterrorism events and a shortage of related research, we attempted to compose an expert panel for the Delphi investigation by selecting individuals with significant research relevance. Nevertheless, the number of experts chosen was limited, and none were from outside the domestic scope. Secondly, there is a lack of research evaluating the capabilities of rescue teams, which suggests a potential avenue for future research expansion.

In summary, consensus was achieved on all indicators of the model by the panel of experts, demonstrating good content validity for the overall scale. The subsequent phase involves transforming this evaluation model into a scalable format for distribution via a questionnaire. Moreover, we plan to examine the feasibility of applying this method in other medical capacity assessments, particularly within the realm of emergency medical rescue teams for emerging infectious diseases. Prior to its utilization in actual assessment work, the practicality and implementability of this model must be analyzed in the context of evaluating the capability of a biological event rescue team.

Conflicts of interest: No conflicts of interest.

Acknowledgements: All the individuals who participated in this study for their support.

Funding: Supported by the National Key Research and Development Program of China (2021YFC2600504); relying on the China National Key Research and Development Program-Research on Bioterrorism Prevention and Control Technology in Important Public Places.

doi: 10.46234/ccdcw2023.174

[#] Corresponding author: Yongzhong Zhang, zyzzjx@tju.edu.cn.

[1] College of Management and Economy, Tianjin University, Tianjin, China; [2] Institute of Disaster and Emergency Medicine, Tianjin University, Tianjin, China; [3] School of Pharmaceutical Science and Technology, Tianjin University, Tianjin, China; [4] Center for Biosafety Research and Strategy, Tianjin University, Tianjin, China.
[&] Joint first authors.

Submitted: September 19, 2023; Accepted: October 08, 2023

REFERENCES

1. Katz R, Graeden E, Abe K, Attal-Juncqua A, Boyce MR, Eaneff S. Mapping stakeholders and policies in response to deliberate biological events. Heliyon 2018;4(12):e01091. http://dx.doi.org/10.1016/j.heliyon.2018.e01091.
2. GTD. Global Terrorism Database results. 2022. https://www.start.umd.edu/gtd/search/Results.aspx?chart=overtime&searchbiological&count100. [2023-8-19].
3. Zhang LL, Liu X, Li YP, Liu Y, Liu ZP, Lin JC, et al. Emergency medical rescue efforts after a major earthquake: lessons from the 2008 Wenchuan earthquake. Lancet 2012;379(9818):853 – 61. http://dx.doi.org/10.1016/S0140-6736(11)61876-X.
4. Calamai F, Derkenne C, Jost D, Travers S, Klein I, Bertho K, et al. The chemical, biological, radiological and nuclear (CBRN) chain of survival: a new pragmatic and didactic tool used by Paris Fire Brigade. Crit Care 2019;23(1):66. http://dx.doi.org/10.1186/s13054-019-2364-2.
5. Shaw KL, Brook L, Cuddeford L, Fitzmaurice N, Thomas C, Thompson A, et al. Prognostic indicators for children and young people at the end of life: a Delphi study. Palliat Med 2014;28(6):501 – 12. http://dx.doi.org/10.1177/0269216314521852.
6. Zhang H, Huang JS, He X, Lv P, Qiu DL. An analysis of the current status of hospital emergency preparedness for infectious disease outbreaks in Beijing, China. Am J Infect Control 2007;35(1):62 – 7. http://dx.doi.org/10.1016/j.ajic.2006.03.014.
7. Brown GV, Sorrell TC. Building quality in health — the need for clinical researchers. Med J Aust 2009;190(11):627 – 9. http://dx.doi.org/10.5694/j.1326-5377.2009.tb02591.x.

SUPPLEMENTARY MATERIALS

Detailed Methods of the Study

In light of the applicability of the Delphi method in this study, 11 prominent experts were purposefully selected from numerous fields including public health, emergency management, epidemiology, and others. These specialists were drawn from various institutions such as the Chinese Center for Disease Control and Prevention, the People's Liberation Army, the People's Armed Police Force, hospitals, and universities. Additionally, seasoned experts at national, provincial, and municipal levels were included. All involved had no less than five years of experience in fields related to emergency management, rescue work, or relevant research. Moreover, the experts held at least an associate senior professional title, possessed a bachelor's degree or higher, and had respectable recognition in their research fields. Participation was voluntary with all participants demonstrating strong compliance and commitment to remain involved until the conclusion of the study.

Using the analytic hierarchy process to determine weight: This study employed the analytic hierarchy process (AHP), using scales of 1–9 judgment matrices (Supplementary Table S5) to conduct pairwise comparisons of same-level elements. These comparisons were then used to construct the judgment matrix, calculate the maximum eigenvalue, and perform a consistency test on the judgment matrix of the equivalent level. The primary formula for pathogenicity testing and ranking was as follows:

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} & \cdots & a_{1n} \\ a_{21} & 1 & a_{23} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & a_{n3} & \cdots & 1 \end{bmatrix} A =$$

$$CI = (\lambda max - n)/(n - 1) \quad (1)$$

A is the judgment comparison matrix, while λ *max* is the maximum eigenvalue of the judgment matrix. *n* is the order of the judgment matrix, whereas confidence interval (*CI*) is the consistency of the matrix. The closer the value that *CI* is to 0, the stronger the consistency of the judgment matrix, and the weight value of the index being allocated reasonably. RI is the random consistency index, which is used to measure the size of *CI*. The standard value of RI is obtained according to the order of the matrix. expert authority coefficient (CR) is the test coefficient, and when CR<0.1, *A* is judged to have satisfactory consistency.

Establishing a comprehensive fuzzy evaluation model: According to the established evaluation index system, on the basis of AHP, the fuzzy comprehensive evaluation method was used to establish the corresponding comprehensive evaluation factor set. To determine the evaluation index and comment set: U = {A, B, C, D, E}, A = {A1, A2, A3, A4, A5}…

The evaluation set and corresponding score set V for comprehensive evaluation were established. The evaluation level is *n* kinds of decisions on the state of each index, V = {V1, V2, V3, ... Vn}, where Vi represents the ith

SUPPLEMENTARY TABLE S1. Semi-structured interview questions.

Number	Question
1	What are the main hazards of a bioterrorist attack? What is the difference between nuclear and chemical events?
2	What rescue teams for bioterrorism are there? Who is it made up of? What institutions are they based on?
3	How are rescue teams and other departments such as police/emergency departments divided? What is the main job of the rescue team against bioterrorism? What's the difference from other rescue teams?
4	What is the main direction in the capacity building of the rescue team? What is the most important of these?
5	What are the specific tasks in the prevention and preparation phases of the rescue team?
6	What do rescue teams need to accomplish during the response and disposal phases? Which step is the most important?
7	What equipment do rescue teams use to transport people to hospitals? How is the target or designated hospital selected?
8	Is there a standard for rescue team personnel to classify the dead at the scene? What are the criteria?
9	Is there any understanding of the construction of the evaluation index system for the work quality of rescue teams? What are the indexes?
10	What is the research direction of the work quality evaluation and capacity building of the rescue team?

SUPPLEMENTARY TABLE S2. Expert authority coefficient.

Rounds	Ca	Cs	CR
Round 1	0.895	0.836	0.866
Round 2	0.877	0.855	0.866

Abbreviation: Ca=experts' judgment basis; Cs=familiarity degree; CR=authority coefficient.

evaluation result, i = 1, 2, 3, ... , n, and n is the total number of evaluation results. In this paper, the evaluation levels were divided into five grades: very important, relatively important, general, less important and very little important.

V = {V1, V2, V3, V4, V5}

= {very important, relatively important, general, less important, very little important}

= {5, 4, 3, 2, 1}

The degree of membership of each index relative to the evaluation set was computed, and the membership degree of the ith influence factor in the set U to the jth element in the evaluation set V was designated as rij, with a range from 0 to 1. Given m influencing factors and n evaluation elements, the fuzzy relationship matrix R can be defined as follows:

$$R = (rij)mn = \begin{bmatrix} r_{i11} & r_{i12} & \cdots & r_{i1k} \\ r_{i21} & r_{i22} & \cdots & r_{i2k} \\ \vdots & \vdots & \ddots & \vdots \\ r_{imi1} & r_{imi2} & \cdots & r_{imik} \end{bmatrix} \quad (2)$$

We established a comprehensive evaluation model to calculate the overall score of the system, taking into account the weight value wij for each hierarchical factor as determined by AHP. A comprehensive assessment was performed on the single index, resulting in the computation of the fuzzy relation evaluation vector Bi.

$$Bi = wiR = (wi1, wi2, wimi)\begin{bmatrix} r_{i11} & r_{i12} & \cdots & r_{i1k} \\ r_{i21} & r_{i22} & \cdots & r_{i2k} \\ \vdots & \vdots & \ddots & \vdots \\ r_{imi1} & r_{imi2} & \cdots & r_{imik} \end{bmatrix}$$

$$= (bi1, bi2, \ldots bik), i = (1, 2, \ldots m)$$

Progressively, the evaluation model was developed. Subsequently, both the fuzzy evaluation matrix B and the equivalent score F were computed as follows:

$$B = wR$$

$$F = BVT$$

Statistical analysis: Data were organized using Microsoft Excel (Version 2016; Microsoft, New York, USA), while SPSS software (Version 22.0; IBM, New York, USA) was utilized for computing the expert positive coefficient (questionnaire recovery rate) and the coordination coefficient W of expert opinions. A non-parametric test was conducted on K relevant samples of W value, with $P<0.05$ suggesting a tendency towards consistent expert scores. The Cr was computed based on the experts' judgment basis (Ca) and familiarity degree (Cs) using the Formula Cr = (Ca + Cs)/2. An authority coefficient >0.70 indicated high predictive accuracy and dependable consultation results. We also calculated the mean ± standard deviation and coefficient of variation on the concentration degree of indicators at all levels (comprehensive scores) of expert opinions. Indicators were deemed highly acceptable if the standard deviation of the importance score of indicators was less than 1 and the coefficient of variation was less than 0.2.

The results of the Kendall Coordination Coefficient test are displayed in Supplementary Table S3. In the initial phase, a Kendall Coordination Coefficient of 0.303 ($P<0.05$) was observed, suggesting a generalized yet relevant evaluation consistency among the 11 reviewers, as the coefficient fell between 0.2 and 0.4. In the subsequent round, the Kendall Coordination Coefficient increased to 0.632 ($P<0.05$), reflecting a strong degree of consistency as the value lay between 0.6 and 0.8. This implied a low level of significance and, consequently, a high degree of independence among the indicators. Further, the variation coefficients in these two rounds were 0.106 and 0.063, respectively, remaining below the threshold value of 0.25, thereby denoting a significant concentration in expert opinions. This convergence of expert perspectives indicated consistent evaluation outcomes and affirmed the reliability of the index system.

SUPPLEMENTARY TABLE S3. Kendall coefficient test.

Rounds	Kendall coordination coefficent	Statistics value	Significance	Coefficient of variation
Round 1	0.303	93.457	0	0.106
Round 2	0.632	201.497	0	0.063

Based on expert feedback and scores, we calculated the boundary value for each index (Supplementary Table S4). Indices failing to meet the screening conditions were assessed and subsequently eliminated. In accordance with expert guidance, we suitably consolidated and adjusted the selected indices. Ultimately, we established five primary indicators and 25 secondary indicators as evaluation criteria for assessing the capability of a bioterrorism response team.

SUPPLEMENTARY TABLE S4. Index screening of critical value indicators.

Scale		Composite score			Coefficient of variation			Full score ratio		
		Mean value	Standard deviation	Eligibility criteria	Mean value	Standard deviation	Eligibility criteria	Mean value	Standard deviation	Eligibility criteria
Round 1	First-level indicators	4.56	0.44	≥4.12	0.10	0.06	≤0.16	0.91	0.09	≥0.82
	Second-level indicators	4.59	0.15	≥4.44	0.11	0.04	≤0.15	0.92	0.05	≥0.87
Round 2	First-level indicators	4.53	0.17	≥4.35	0.07	0.04	≤0.11	0.91	0.11	≥0.79
	Second-level indicators	4.83	0.18	≥4.65	0.06	0.04	≤0.10	0.97	0.06	≥0.91

SUPPLEMENTARY TABLE S5. Scaling the judgment matrix.

Scale	Definition	Meaning
1	The same importance	The two indicators are of the same importance.
3	Slightly important	Index i is slightly more important than index j.
5	Obviously important	Index i is obviously more important than the index j.
7	Strongly important	Index i is strongly more important than index j.
9	Absolutely important	Index i is absolutely more important than index j.
2,4,6,8	The median value of the above adjacent judgment.	
	If the ratio of the importance of the index i and the index j is a_{ij}, then the ratio of the factor to the importance of the $a_{ij} = 1/a_{ji}$. Factor is $a_{ij}=1/a_{ji}$.	

Commentary

Prevention and Treatment of Pneumoconiosis in the Context of Healthy China 2030

Huanqiang Wang[1,&]; Qiao Ye[2,&,#]; Huadong Zhang[3,#]; Xin Sun[1,#]; Tao Li[1]

Since the onset of reform and opening-up policies, China has risen to become the world's second-largest economy. This transformative period has witnessed considerable advancements in medical services provision, resulting in significant improvements in the overall healthcare landscape. A noteworthy accomplishment is the creation of the world's largest and most comprehensive social security system. Adhering to principles of inclusivity, multi-tiered coverage, and long-term sustainability, this system guarantees the fulfillment of basic life necessities. By the end of 2022, over 1 billion individuals were covered by basic old-age insurance, 238 million by unemployment insurance, 291 million by work-related injury insurance, and more than 1.3 billion by basic medical insurance (*1*). Despite extraordinary progress, noticeable gaps remain in healthcare and support services. This is especially true for migrant workers suffering from pneumoconiosis, a condition induced by prolonged exposure to dust in the workplace.

Advancements in the Prevention and Treatment of Pneumoconiosis in China

Current situation As of the end of 2021, China reported approximately 951,000 pneumoconiosis cases, constituting a significant portion-90%-of all occupational disease cases. There are approximately 450,000 active cases of occupational pneumoconiosis, primarily from coal workers' pneumoconiosis (CWP) and silicosis (*2*). Unfortunately, there are scarce effective pharmaceutical interventions and technologies to halt the progression of pneumoconiosis, which often coincides with other conditions such as pulmonary tuberculosis (PTB), chronic obstructive pulmonary disease (COPD), pulmonary arterial hypertension (PAH), lung cancer, and mesothelioma; these comorbidities further degrade patients' quality of life. Alarmingly, statistical data indicate that approximately 7.5% of pneumoconiosis patients in China also suffer from PTB (*3*). Pneumoconiosis remains the most prevalent and severe occupational disease nationwide.

Efforts and achievements The Chinese government has shown a consistent commitment toward the prevention and management of pneumoconiosis. In the 1960s, a robust set of dust prevention measures, known as the Eight-Figure Policy, was established. This strategy included technological innovation, wet dust removal, sealing, ventilation, personal protection, administration systems, health education, and audits, whereby it adopted a comprehensive approach that resulted in significant outcomes. Later, in the 1980s, the People's Republic of China promulgated the Regulations on Prevention and Control of Pneumoconiosis, which was further bolstered by the introduction of the Law on Prevention and Control of Occupational Diseases in 2002, coupled with relevant regulations. This series of legislative measures has formed a strong legislative framework for the prevention of pneumoconiosis.

A handful of nations worldwide, namely China, the United States, the United Kingdom, New Zealand, Germany, and Finland, have established robust data collection systems relating to occupational disease (*4*). Over the prior decade, remarkable progress has been made in legislation, standardization systems, regulatory frameworks, prevention of occupational diseases, and dust control, all of which have been realized through the collaborative efforts of relevant institutions, departments, and governments at various levels. An administrative body has been established specifically to address occupational health hazards, thereby bolstering technical service capabilities and providing support within the occupational health field. Surveillance of occupational diseases and harmful agents has been expanded, with comprehensive measures being implemented to secure occupational health conditions (*5*). The results of these endeavors are undeniable — there has been a significant decrease in newly reported occupational diseases in China, from 26,393 cases in 2013 to 11,108 in 2022, representing a 58% reduction.

The continuing challenges Pneumoconiosis is universally acknowledged as the most common occupational disease, representing a substantial public health concern globally. Numerous industries worldwide are associated with exposure to respirable crystalline silica (RCS) dust, the chief cause of silicosis. These industries encompass quarrying, mining, mineral processing, foundry operations, brick and tile production, refractory processing, and construction actions involving materials such as stone, brick, concrete, and insulation boards (*6*). Moreover, the risks posed by dust exposure pervade an array of sectors beyond conventional industries such as construction and building, extending to evolving sectors. These include stone cutting, kitchen benchtop fabrication with artificial stone, dental prosthetic creation, and even stone-washed jeans manufacturing (*7*).

Once controlled in developed countries, pneumoconiosis among coal miners has emerged anew in the 21st century, particularly in nations such as the United States and Australia (*8*). The rapid urbanization and industrialization process in China has exposed many secondary industry workers to dust, a leading contributor to pneumoconiosis. The coal mining workforce in China numbered six million prior to 1995, which has now dwindled to approximately 2.9 million. The high levels of pneumoconiosis incidence and prevalence rates among these miners nonetheless remains troubling (*9*).

The 2020 National Occupational Hazard Survey unveiled startling results regarding the state of China's leading industries — mining, manufacturing, and electricity, gas, and water production and supply. The survey indicates that an estimated 69.3% of businesses in these sectors are exposed to dust hazards. Moreover, approximately 47.4% of the workforce exposed to work-related hazards are at risk from dust-related dangers (*10*). Given the long latency period of pneumoconiosis, which typically spans 10 to 20 years or more, it is plausible to anticipate a significant surge in new pneumoconiosis cases in upcoming years. It is of equal concern that employment injury insurance covers less than 30% of migrant workers, who primarily constitute the workforce in dust-exposed environments. The absence of sufficient insurance coverage amplifies the difficulties in diagnosing, treating, and providing medical support to those affected by pneumoconiosis. Therefore, these challenges emerge as crucial present and prospective public health concerns in China.

Present Features and Challenges

Legal, regulatory, and governance frameworks Substantial revision is needed in the existing regulations and technical standards aimed at pneumoconiosis prevention and control. Their outmoded state impedes accommodation of both individual and private organizations thriving in the present market economy. This lack of alignment extends to workers involved in labor dispatching, outsourcing, platform-based engagements, and part-time employments. Furthermore, there is a dearth of early warning systems and prompt control strategies for managing emerging hazards.

Second, the approach to occupational disease management in numerous small to medium-sized enterprises confronted with dust-related risks is deficient. These workplaces often exhibit dust concentrations that fail to align with national health standards, lacking essential dust-control facilities, and display inconsistent implementation of compulsory occupational health surveillance. This raises the implication that official reports may underrepresent the true extent of occupational diseases in China.

Third, the efficacy of occupational health supervision, particularly at the county level, is impeded by a lack of dedicated professionals with expertise in occupational health. This personnel deficit hampers the capacity of such supervisory entities to appropriately execute their regulatory functions.

Diagnosis and management of diseases Currentdiagnostic methods for occupational pneumoconiosislack cohesion, and the onus of managing laborrelations and work-related injury compensation doesnot fall on the health department. This fragmentedsystem hampers medical and health institutions fromefficiently collecting employment histories andoccupational disease data. Furthermore, there is anoticeable deficit of scientific criteria for diagnosingpneumoconiosis in the clinical field. Presently, theprocess of diagnosing occupational pneumoconiosisheavily relies on comparing patients' chest X-rayimages to a standardized reference film. However, thiscomparison method fails to optimally assist with earlydiagnoses, disease assessments, and prognosis guidance.Furthermore, a common issue is that patients oftenfind this diagnostic process difficult to comprehend,which further complicates the situation.

Technical assistance and scientific proficiency The dearth of robust, thorough research on the hazards associated with dust has hindered significant progress in fundamental theoretical explorations. This scarcity of dedicated inquiry into such critical scientific issues impairs the progression of innovative technologies. Additionally, the unavailability of extensive and transferable pneumoconiosis reporting systems makes it difficult to ascertain reliable morbidity and mortality rates. This uncertainty prevents both researchers and the general population from acquiring a comprehensive understanding of pneumoconiosis, thereby obstructing the development of region-specific and departmental policy measures for preventing and managing this disease. A lack of cross-disciplinary expertise for preventing and treating of pneumoconiosis has led to inferior professional and technical standards for diagnosing and treating occupational health ailments compared with non-occupational respiratory diseases. The sporadic accessibility of national clinical resources and pertinent biometric information related to pneumoconiosis hampers the feasibility of conducting in-depth research in this area.

Approaches to the management of pneumoconiosis A holistic approach is deemed most effective for the management of pneumoconiosis, incorporating elements such as smoking cessation, oxygen therapy, rehabilitation, pharmaceutical interventions, and the consideration of innovative lung transplantation techniques for end-stage disease. The primary goals are to retard the degradation of lung function, deter disease progression, enhance patients' quality of life, prevent complications, and lower mortality rates. However, a substantial deficit remains in the inclusive theoretical and experiential research in this domain. An array of patients grapples with the long-term financial burden stemming from healthcare costs. Community-based medical insurance frequently falls short, leaving patients with restricted resources for self-management. This consequently results in a significant number of patients deficient in efficient management of complications, fostering rapid disease progression, and resulting in escalated disability and mortality rates.

Industrial injury insurance as a component of social security The existing industrial injury insurancesystem grapples with numerous challenges in its designand implementation. These encompass inadequatecoverage for migrant workers, limited access for mostindependent workers, and problems encountered whentrying to access industrial injury insurance benefitsfollowing a change of job. Given their high levels ofmobility and unclear labor relationships, migrantworkers often have difficulty documenting their historyof occupational dust exposure. Consequently,establishing a causal link between their illnesses andoccupational factors can be problematic. Individualswith Pneumoconiosis are inadequately protected, facing hurdles such as limited re-employmentopportunities, financial strains due to their healthconditions, and insufficient social support.

Recommendations and Future Directions

The endorsement of the Healthy China Initiative at the 19th National Congress of the Communist Party of China reflects a commitment to public health, population wellbeing, and the establishment of a healthy nation. To realize the goals set forth in the Healthy China 2030 Planning Outline, the General Office of the State Council advanced the Opinions on Implementing the Healthy China Action. Within this framework, the Occupational Health Protection Action was conceived to enhance prevention and management of occupational diseases, including pneumoconiosis. Adhering to the objectives outlined in the Action Plan for the Prevention and Control of Pneumoconiosis, it is anticipated that by 2022 and 2030, there will be a significant and continuing decline in the ratio of new pneumoconiosis cases reported from workers with less than five years of dust exposure to the total number of annual reports.

The evidence from our analysis suggests a significant influence of several social and risk factors on the rising prevalence of pneumoconiosis among coal miners in China. Factors such as societal coal demands, industrial strategies, coal industry workforce size, employment structures, coal productivity, enterprise characteristics, scale of operations, mining technologies, dust control strategies, occupational health evaluations, pneumoconiosis diagnosis and reporting systems, occupational health management and regulation, and social security provisions all contribute to the issue. Consequently, it underscores the need for a comprehensive, multidisciplinary initiative across scientific, engineering, medical, managerial, societal, political, economic, and legal sectors to effectively address and ultimately eradicate pneumoconiosis.

In accordance with the "Healthy China" initiative, there is a pressing need for proactive strategies. These should comprise legislative and regulatory improvements, progress in the categorization and diagnosis of pneumoconiosis, fortification of management procedures, bolstering of technical support and scientific capabilities, along with the broadening of industrial injury insurance and social security provisions.

Laws, regulations, and governance systems The mandates stipulated in the Law of the People's Republic of China on the Prevention and Control of Occupational Diseases and the Regulations on Work-Related Injury Insurance, along with its associated laws and standards, necessitate a thorough and systematic examination. With regards to both core health promotion guidelines and the distinct attributes of the primary stage of socialism, the establishment of a cost-effective occupational health service framework is recommended. Moreover, initiating supplementary liability insurance for employers at a heightened risk of pneumoconiosis could be considered beneficial. Appropriate interventions such as these could significantly improve the monitoring and control of dust-related hazards.

In the field of occupational health management, it is crucial to develop and apply novel strategies. An approach under consideration involves the fusion of on-site supervision, law enforcement, as well as hazard detection and assessment, piloted in certain industries or regions. This tactic intends to improve management of supervision information through network-based systems. Additionally, it is important to investigate the potential for developing a governance structure for registered occupational hygienists. An essential focus should be the cultivation of a collaborative linkage mechanism that includes grassroots governments, fostering cross-sectoral cooperation. This mechanism would necessitate the formulation of a tripartite coordination framework that involves workers, employers, and governmental entities. Furthermore, a paramount objective is to devise a rating and blacklisting system for occupational disease prevention and control. This system would establish and enforce accountability and deterrence, thereby facilitating rigorous actions against illegal activities.

Diagnosis and management strategies A proactive stance must be taken towards establishing a solid framework for the clinical identification and determination of pneumoconiosis. In light of the specific dynamics related to clinical identification and occupational attribution in patients suffering from pneumoconiosis, it is deemed necessary to reform the system for the diagnosis of occupational pneumoconiosis in two critical ways, drawing upon practices from developed countries dealing with occupational diseases. The revised system should fundamentally consist of two parts: the clinical identification of pneumoconiosis that is linked with the recognition of occupational exposure and causal connections; and second, the onus should fall on regulatory entities to confirm essential information required for the diagnosis of occupational diseases.

Additionally, the proposal recommends integrating pneumoconiosis into the basic social medical insurance framework. This action would facilitate parity between routine and occupational injury medical insurance. Patients diagnosed with occupational pneumoconiosis would hence have access to occupational injury medical insurance coverage. We encourage a more extensive application of existing policies — including basic medical insurance, critical illness insurance, medical aid, public welfare assistance funds, and life assistance programs — for those individuals not protected by occupational injury insurance or those whose employers have ceased operations.

Technical assistance and scientific proficiency The establishment of an integrated medical innovation system connecting scientific research, prevention, diagnosis, and management of pneumoconiosis is of critical importance. This warrants the strengthening of fundamental research facilities and platforms in medical institutions, in addition to enhancing the effective allocation of resources for public health and medical initiatives. A proposal for a nationwide, open pneumoconiosis information reporting system, bolstered by an expansive national database encompassing clinical resources and biometric information associated with pneumoconiosis cases, is tabled. It is worth underscoring the significance of enhancing the education and training structure, with the aim of integrating public health education and clinical medical perspectives. This effort calls for the reinforcement of educational and training institutions responsible for nurturing the requisite skills and competencies for pneumoconiosis prevention and management. Moreover, increasing investments in scientific research centered on dust prevention and control as well as the diagnosis and management of pneumoconiosis is advocated to widen and deepen our comprehension in these fields.

A comprehensive approach to healthcare management in patient care The inclusion of pneumoconiosis prevention and management within the foundational public health service system is advocated. Such a process necessitates an escalation in funding, reinforcement of the closed-loop dynamic management model, and a broadening of the multi-tier rehabilitation system. This expansive network incorporates representatives at the state, provincial, city, county, and town or community level, in addition to families and individuals. The proposition also extends to the establishment of a national occupational disease medical rehabilitation guidance center to augment the proficiency of primary medical rehabilitation.

Patients with pneumoconiosis should receive targeted treatment, medical interventions, and comprehensive health management based on their individual risk assessment. With the growth of China's economy, priority should be given to initiating occupational health exams and follow-up care for dust-exposed workers who have left their positions. This initiative should first be trialed in more developed provincial-level administrative divisions before gradually being implemented nationwide. The ultimate goal is to guarantee comprehensive, lifelong health management for all workers exposed to dust.

The call for a robust medical innovation system encompassing scientific research, prevention, diagnosis, and treatment of pneumoconiosis is both immediate and paramount. To achieve this, a significant strengthening of primary research facilities and platforms in medical institutions is necessary, in tandem with an increase in the efficiency of public health and medical resource allocation. We strongly advocate the inauguration of a nationwide pneumoconiosis information reporting system, coupled with developing a comprehensive database for national pneumoconiosis clinical resources and biometric information. There is also a need to enhance our education and training framework. This will require integrating public health education and clinical medicine to ensure a holistic learning experience. Subsequently, we propose the expansion and improvement of education and training centers dedicated to fostering expertise in pneumoconiosis prevention and management. Furthermore, we suggest prioritizing increased investments in scientific research pertaining to dust prevention and control, along with research into the diagnosis and management of pneumoconiosis. We anticipate that this strategy will significantly advance our understanding and expertise in these crucial fields.

Industrial injury insurance in relation to social security

The initial stage in this process necessitates a comprehensive review and enhancement of laws and regulations pertaining to industrial injury insurance. The focus will transition from a mere compensation approach, moving toward more active prevention procedures. This methodology is designed to strengthen health advocacy and secure employment for workers endangered by dust-related hazards. The program seeks to encompass a varied workforce, which includes migrant labor(s), dispatched workers, outsourced personnel, platform-based and part-time employees, as well as participants in the gig economy. Considering the gradual and hidden progression of pneumoconiosis, it is vital to formulate a sturdy, long-term protection strategy for industrial injuries. This system should safeguard the health and welfare rights of those workers affected by pneumoconiosis, even after their departure from the workforce or retirement. Additionally, the suggestion to incorporate pneumoconiosis into the social basic medical insurance directory has been proposed, thereby allowing the parallel existence of medical insurance and industrial injury insurance.

Enhancing the medical security system is a vital progression which can be achieved through the execution of specific policies aimed at civil aid, and solidifying the creation of a linkage mechanism incorporating societal resources. This cooperative endeavor ensures a proactive role in bolstering medical security.

Advocacy is encouraged at the state level for the establishment of distinct national and local funding streams targeting pneumoconiosis. This includes the implementation of a specialized security framework with provisions for patients suffering from occupational diseases. These provisions are particularly aimed at patients whose employers have gone out of business or whose labor relations are unverifiable, ensuring they receive medical assistance and livelihood protection.

Conflicts of interest: No conflicts of interest.

Funding: The Advisory Research Project of the Chinese Academy of Engineering in 2019 (No. 2019-XZ-70).

doi: 10.46234/ccdcw2023.162

[#] Corresponding authors: Xin Sun, sunxin@niohp.chinacdc.cn; Qiao Ye, yeqiao_chaoyang@sina.com; Huadong Zhang, 845403791 @qq.com.

[1] National Institute of Occupational Health and Poison Control, Chinese Center for Disease Control and Prevention, Beijing, China; [2] Department of Occupational Medicine and Toxicology, Clinical Center for Interstitial Lung Diseases, Beijing Institute of Respiratory Medicine, Beijing Chao-Yang Hospital Capital Medical University, Beijing, China; [3] Chongqing Center for Disease Control and Prevention, Chongqing, China.
[&] Joint first authors.

Submitted: August 23, 2023; Accepted: September 20, 2023

REFERENCES

1. The State Council Information Office of the People's Republic of China. China's epic journey from poverty to prosperity. 2021. http://english.www.gov.cn/archive/whitepaper/202109/28/content_WS61528550c6d0df57f98e0ffa.html. [2021-9-28].
2. National Health Commission of the People's Republic of China, National Health Commission, Occupational Health Division. Overview on the survey of occupational disease hazards in China. 2022. http://www.nhc.gov.cn/zyjks/s3586s/202205/e391a7a3bdce44259a51d2782b9b2c60.shtml. [2022-5-9]. (In Chinese).
3. Wang HQ, Dai HP, He JY, Lyu XP, Zhang XR, Li T. Epidemiological characteristics of pulmonary tuberculosis in patients with pneumoconiosis based on its social determinants and risk factors in China: a cross-sectional study from 27 provinces. Chin Med J 2022; 135(24):2984 – 97. http://dx.doi.org/10.1097/CM9.0000000000002486.
4. International Labour Organization. National system for recording and notification of occupational diseases: practical guide. Geneva: International Labour Office; 2013. http://search.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/publication/wcms_210950.pdf.
5. National Health Commission held a press conference on strengthening occupational health monitoring to protect workers' health (Full transcript). 2023. https://www.cn-healthcare.com/article/20230615/content-579435.html. [2022-5-9]. (In Chinese).
6. Leung CC, Yu ITS, Chen WH. Silicosis. Lancet 2012;379(9830): 2008 – 18. http://dx.doi.org/10.1016/S0140-6736(12)60235-9.
7. Wu N, Xue CJ, Yu SW, Ye Q. Artificial stone-associated silicosis in China: A prospective comparison with natural stone-associated silicosis. Respirology 2020;25(5):518 – 24. http://dx.doi.org/10.1111/resp.13744.
8. Hoy RF, Jeebhay MF, Cavalin C, Chen WH, Cohen RA, Fireman E, et al. Current global perspectives on silicosis-Convergence of old and newly emergent hazards. Respirology 2022;27(6):387 – 98. http://dx.doi.org/10.1111/resp.14242.
9. Wang HQ, Ye Q, Chen Y, Li T. Epidemiology of coal miners' pneumoconiosis and its social determinants: An ecological study from 1949 to 2021 in China. Chin Med J Pulm Crit Care Med 2023;1(1): 46 – 55. http://dx.doi.org/10.1016/j.pccm.2023.03.002.
10. Occupational Health Division of National Health Commission of PRC. Survey of occupational disease hazards in China. 2022. http://www.nhc.gov.cn/zyjks/s3586s/202205/e391a7a3bdce44259a51d2782b9b2c60.shtml. [2022-5-9]. (In Chinese).

Indexed by Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI), PubMed Central (PMC), Scopus, Chinese Scientific and Technical Papers and Citations, and Chinese Science Citation Database (CSCD)

The inauguration of *China CDC Weekly* is in part supported by Project for Enhancing International Impact of China STM Journals Category D (PIIJ2-D-04-(2018)) of China Association for Science and Technology (CAST).

CCDC weekly

Vol. 5 No. 41 Oct. 13, 2023

Published since November, 2019

Responsible Authority

National Health Commission of the People's Republic of China

Sponsor

Chinese Center for Disease Control and Prevention

Editing and Publishing

China CDC Weekly Editorial Office
No.155 Changbai Road, Changping District, Beijing, China
Tel: 86-10-63150501, 63150701
Email: weekly@chinacdc.cn

Printing

Beijing Kexin Printing Co., Ltd

CSSN

ISSN 2096-7071 (Print)
ISSN 2096-3101 (Online)
CN 10-1629/R1