BMJ Open

Prevalence of metabolic syndrome among the adult population in western China and the association with socioeconomic and individual factors: four cross-sectional studies

Xinyin Xu ,[1] Jing Zeng,[1] Wei Yang,[2] Ting Dong,[1] Xin Zhang,[1] Shuwen Cheng,[1] Xiaobo Zhou,[3] Maigeng Zhou,[4] Ling Niu,[5] Guanghui Yi,[1] You Li,[1] Lishi Zhang,[6] Yin Deng,[1] Xianping Wu[7]

To cite: Xu X, Zeng J, Yang W, *et al*. Prevalence of metabolic syndrome among the adult population in western China and the association with socioeconomic and individual factors: four cross-sectional studies. *BMJ Open* 2022;**12**:e052457. doi:10.1136/bmjopen-2021-052457

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2021-052457).

Received 18 April 2021
Accepted 02 February 2022

For numbered affiliations see end of article.

Correspondence to
Xianping Wu;
wwwuxp@163.com and
Dr Yin Deng;
391115491@qq.com

ABSTRACT

Objectives This study explored the prevalence of and individual influencing factors for metabolic syndrome (MS) as well as associated socioeconomic factors and regional aggregation.

Design Four cross-sectional surveys were analysed for trends in MS and associations with socioeconomic and individual factors through multilevel logistic regression analyses. The risk associated with nutrient intake was also assessed through a dietary survey in 2015.

Setting From 2010 to 2018, 8–15 counties/districts of West China were included.

Participants A total of 28 274 adults were included in the prevalence analysis. A total of 23 708 adults were used to analyse the related factors.

Results The overall prevalence of MS ranged from 21.4% to 27.8% over the 8 years, remaining basically stable within the 95% CI. Our study found that the urbanisation rate and hospital beds per 1000 people were positively associated with MS, and the number of doctors in healthcare institutions per 1000 persons was negatively associated with MS. The ORs for females, people with college education and higher and unmarried or single people were 1.49, 0.67 and 0.51, respectively ($p<0.05$). The ORs of people who smoked at least 20 cigarettes/day, ate more than 100 g of red meat/day, consumed fruit or vegetable juice and drank carbonated soft drinks less than weekly were 1.10, 1.16, 1.19–1.27 and 0.81–0.84, respectively. The ORs rose with increasing sedentary time and decreased with higher physical activity.

Conclusion The high burden of MS, unreasonable proportions of energy and micronutrient intake and low percentage of high levels of physical activity were the major challenges to public health in western China. Improving the human resources component of medical services, such as the number of doctors, increasing the availability of public sports facilities and E-health tools and improving individual dietary quality and education might help prevent MS.

Strengths and limitations of this study

- Most previous studies on the factors affecting metabolic syndrome in China focused on the individual level (level 1) and were based on a single hospital or community, thereby lacking the ability to explore the effect of socioeconomic factors (level 2), which should not be ignored.
- In this study, a multilevel analysis based on socioeconomic as well as individual factors provides a reference for relevant metabolism research that avoids ignoring socioeconomic factors and more accurately assesses individual effects.
- This study compared the epidemiologic characteristics of metabolic syndrome using the latest cross-sectional data from four studies and integrated them in a multilevel model.
- The limitation of this study, which was based on cross-sectional surveys, was that the results reflected the association between disease and influencing factors but not necessarily causality.
- To reduce confounding, the objects whose treatment-related behavioural changed after being diagnosed with hypertension, diabetes and dyslipidaemia were not included in the model.

INTRODUCTION

In the global status report on chronic diseases,[1] the WHO recommends monitoring the diseases (hypertension, diabetes, dyslipidaemia and obesity) involved in diagnosing metabolic syndrome (MS) and the main related risk factors. Based on this, China has improved its national monitoring system for chronic diseases and their risk factors, which was launched in 2004. The number of deaths caused by cardiovascular diseases in the majority of China, including western China, has increased annually, and cardiovascular disease is now the leading cause of death, which means that it has a very high disease burden.[2–4] MS is an important risk factor for cardiovascular disease and diabetes.[5–7] This study first aimed to explore the prevalence of MS

using cross-sectional data from different counties/districts in western China. With rapid development and disparity between the economy and culture, changes in the traditional dietary structure and lifestyle have varied substantially in different places in China in the last 10 years,[8–12] with aggregated effects in certain areas.[13–17] As most previous studies on the factors affecting MS in China were based on small unrepresentative samples,[18] more analyses based on regionally or nationally representative data are needed. In addition, studies in China to date have not taken into account the effects of environmental factors, such as socioeconomic factors, on MS. Compared with the influence of individual behavioural factors, such as unhealthy dietary patterns,[19–27] the influence of socioeconomic factors on diseases often varies according to respondents' geographical locations, and the effects of location need to be taken into account in the analysis. Only a few studies have explored the aggregate effects at high levels (grouped by geographical location) while discussing the factors affecting MS to date.[28] Therefore, this study aimed to analyse whether regional aggregation effects exist among the counties/districts with multilevel analysis. Then, the effects of dietary and behavioural factors were studied after controlling for regional aggregation differences.

The results are also useful for regional governments seeking to formulate and implement prevention and control strategies of MS by improving public health, reducing inequality and promoting healthy life style.

METHODS

Objects

The study was analysed based on four continuous cross-sectional surveys using the multistage cluster random sampling method in 8–15 counties/districts of Sichuan Province in western China (figure 1). The surveys focused on non-communicable disease (NCD) and risk factor surveillance in 2010 and 2013 and on NCD and nutrition surveillance (a new name for the same surveillance) in 2015 and 2018, respectively. The counties/districts were selected from the China CDC's National Disease Surveillance Point System[29 30] (a total of 31 in Sichuan) and were based on economic status, population density, educational level and crude mortality so as to make them as provincially representative as possible. The flow diagram of the study sample in each county/district is shown in online supplemental figure 1. According to the sampling method, the sample size was estimated according to the following factors: confidence level (95%, u=1.96), MS prevalence rate (p), design efficiency (deff=2) and relative error (r=20%, d=r*p). According to the results of a previous survey (the National Diabetes and Metabolic Disorders Survey in China, male 25.8%, female 18.0%),[31] the MS prevalence rate (p) was set as 18.0%. The sample size was calculated to be 875 for each layer. If the number of layers was set to four considering sex and location type (urban and rural), a sample of 3500 was acceptable.

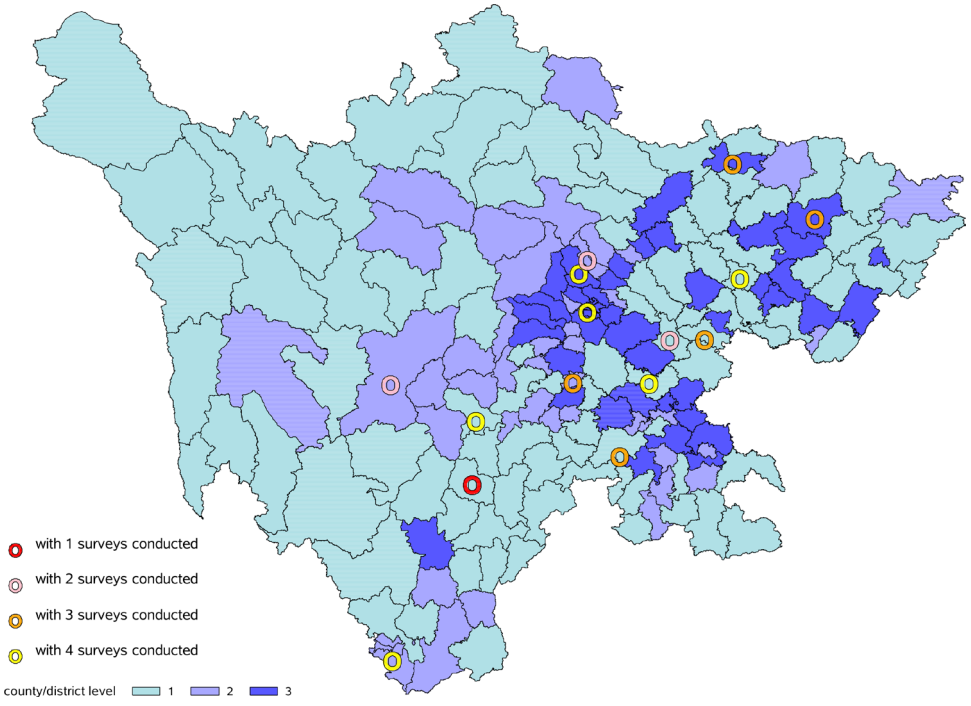

Figure 1 Geographical distribution of four surveys in Sichuan Province. The four continuous cross-sectional surveys were conducted in 8–15 cities of Sichuan Province in western China using the multistage cluster random sampling method and included non-communicable disease (NCD) and risk factor surveillance in 2010 and 2013 and NCD and nutrition surveillance (the new name for the same surveillance) in 2015 and 2018. According to the urbanisation rate, population number and mortality rate, all the counties/districts of Sichuan Province were divided into three levels. The survey points in this study were distributed at different levels so that the monitoring results better reflected the situation of the whole Sichuan Province.

$$N = deff\frac{u^2 p(1-p)}{d^2}$$

The surveys asked questions relating to NCDs and risk factors in 2010, 2013, 2015 and 2018. In the surveys, the prevalence of MS and related factors (intake of vegetables, fruits and red meat, smoking and physical activity) were examined. In 2015, food intake for 3 days was collected by weighing (oil, salt and seasoning) and 24-Hour Dietary Recall methods. The result for 3293 adults was reviewed, so this study was also able to assess nutrient intake in 2015. The three full-day meal review surveys covered two working days and one rest day of a week (online supplemental figure 2). We then built a model that explores the factors affecting MS. Respondents who self-reported treatment by changing diet and behaviour because of hypertension, diabetes and dyslipidaemia were not included in the model. The population information, urbanisation rate, beds in medical institutions per 1000 people and number of doctors in healthcare institutions per 1000 people were obtained from the China Statistical Yearbook.

Physical measures

The questionnaires asked questions about participants' basic characteristics, including smoking habits, alcohol consumption, diet, physical activity, blood pressure (BP), blood glucose level, blood lipid profile and other health conditions. The physical examination measured participants' height, weight, waist circumference (WC) and BP. The biochemical tests used fasting blood samples, typically drawn between 7 and 8 AM. Dietary information was collected using a food-frequency questionnaire. All participants were asked to avoid any food intake other than water for 10–12 hours before the examination. BP was measured based on the China Hypertension Prevention Guidelines (2010 Edition). WC was measured according to the WHO's recommended method.

Statistical analyses and dietary assessment

We first performed a descriptive analysis to assess the demographics of Sichuan Province in western China. Data from each cross-sectional survey were adjusted according to the sampling weight and no-response weight via SAS software (SAS studio https://welcome.oda.sas.com/). For the prevalence comparisons and combined analyses, the data of 2010, 2013 and 2015 were also adjusted by poststratification weight according to the sex and age ratios for Sichuan Province in 2018. Continuous variables are described as means (95% CIs). The nutrient intake of the subjects was calculated according to the China Food Composition (2002 and 2004 editions) guidelines. Three new indicators related to chronic diseases in the China Dietary Reference Intakes (DRIs, 2013 edition) were used to assess the dietary status of the adult participants without chronic disease (hypertension, dyslipidaemia and self-reported diabetes, cancer, asthma, chronic obstructive pulmonary disease, myocardial infarction and stroke). They were the acceptable macronutrient distribution range (AMDR), proposed intakes for preventing non-communicable chronic disease (PI-NCD) and specific proposed level (SPL). To explore MS risk factors, MS was specified as the dependent variable, and independent variables were selected through a number of single-factor analysis models (by the complex sampling logistic regression method, $p<0.2$), as well as by referring to the results of previous studies that used only 1 year of data.[32] Finally, the relationships between MS and individual risk factors, after eliminating the influence of socioeconomic factors, were explored by multilevel logistic regression via MLwiN software and are described as ORs and p values. In the model, the county/district level was defined as level 2, while the individual level was defined as level 1, and the second-order predictive quasi-likelihood method was used to fit the null model without any explanatory variable.

The Rao-Scott χ^2 test was used to compare the rates among multiple groups. The geographical distribution of survey points and the Venn diagram of five components of MS were drawn by SAS software and R software, respectively.

Definitions and components of MS

The diagnostic criteria for MS differ internationally, and a consensus definition was created.[33] In 2013, the cut-off point for Chinese people based on new studies of WC in the Chinese population was updated by the Chinese government in the Chinese Criteria of Weight for Adults (WS/T428-2013).[34] According to the consensus definition and the updated cut-off value, meeting any three of the following criteria constituted an MS diagnosis: (a) abdominal obesity, defined in the Chinese population as a WC≥90 cm for males and ≥85 cm for females;[34] (b) elevated triglycerides (TRIG)≥1.7 mmol/L or treatment for high TRIG; (c) reduced high-density lipoprotein cholesterol (HDL-CHO) (<1.03 mmol/L in males or <1.29 mmol/L in females) or the use of treatment specifically for dyslipidaemia; (d) elevated BP (systolic BP≥130 mm Hg or diastolic BP≥85 mm Hg) or the use of treatment specifically for high blood pressure and (e) elevated fasting blood glucose (FBG) (≥5.6 mmol/L) or a previous diagnosis of type 2 diabetes mellitus. According to this definition, abdominal obesity was considered a component of MS but not a precondition, and ethnicity-specific values were used.

Patients and public involvement

Patients and the public were not involved in this study, including the design, data collection, analysis and interpretation.

RESULTS

Prevalence of MS and the values of related components

In total, 28 274 samples (≥18 years old) were obtained from the four cross-sectional surveys (4847 from 2010, 7131 from 2013, 8301 from 2015 and 7995 from 2018). The age-standardised, sex-standardised, urban-standardised and rural-standardised MS prevalence rates for 2010, 2013, 2015 and 2018 were 27.8% (95% CI=22.8% to 32.8%), 24.4% (95% CI=21.5% to 27.3%), 21.4% (95% CI=17.8% to 24.5%) and 27.4% (95% CI=24.9% to 29.9%), respectively. The overall

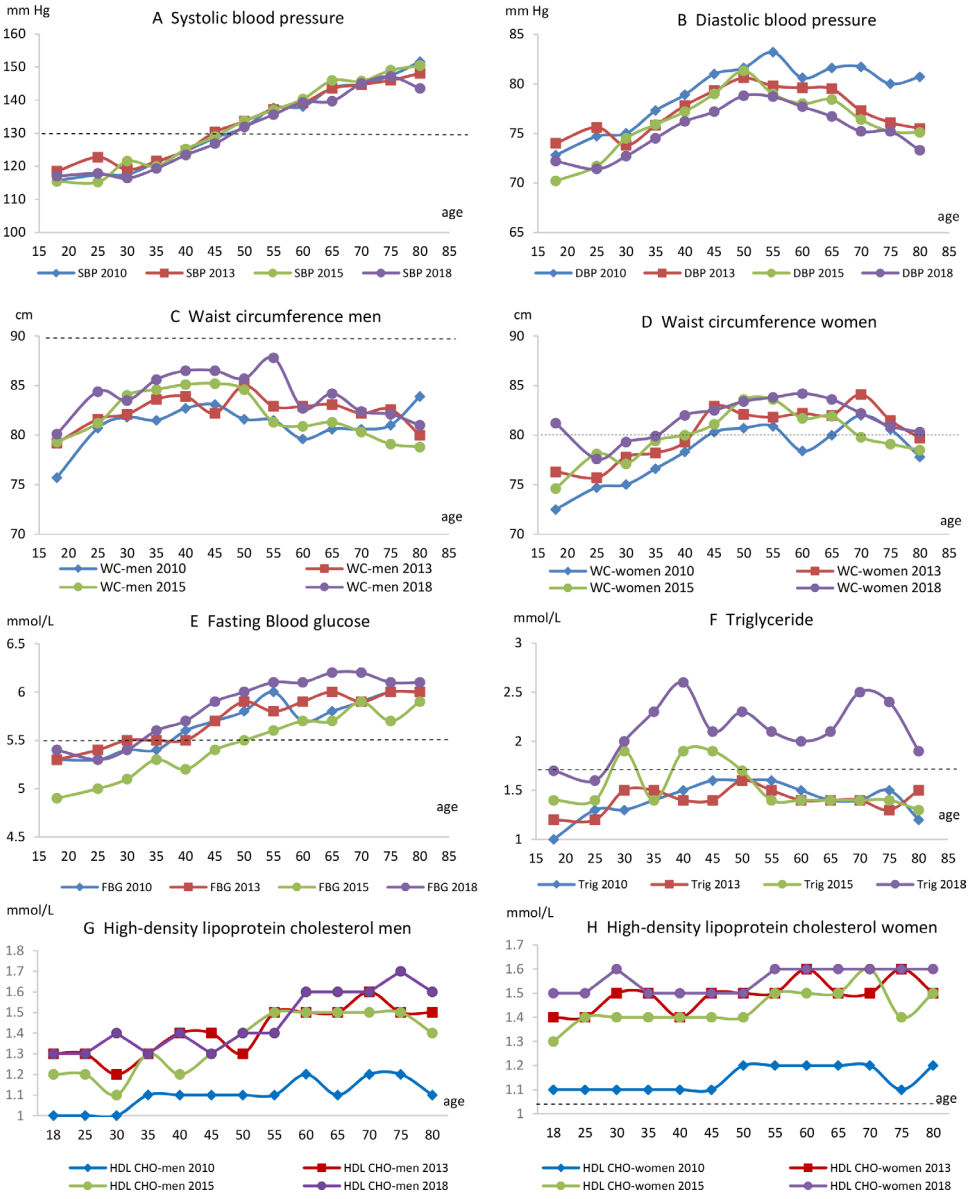

Figure 2 The distribution of basic values of metabolic syndrome components in different age groups in 2010, 2013, 2015 and 2018. The prevalence of metabolic syndrome was related to the values of blood pressure, fasting blood glucose, waist circumference, triglycerides and high-density lipoprotein cholesterol. In general, the diastolic blood pressure increased and then decreased with increasing age. Systolic blood pressure and fasting blood glucose increased with increasing age, and males experienced a rapid rise in waist circumference earlier than females. Triglycerides and high-density lipoprotein cholesterol values fluctuated with age.

prevalence ranged from 21.4% to 27.8% and remained basically stable within the 95% CI.

The distribution of the five MS components is shown by a Venn diagram (online supplemental figure 3). As related components of MS, BP, FBG, WC, TRIG and HDL-CHO were compared in groups stratified by age or survey year (figure 2). In general, the diastolic blood pressure increased and then decreased with increasing age. Systolic blood pressure and FBG increased with increasing age, and males experienced a rapid rise in WC earlier than females. TRIG and HDL-CHO values fluctuated with age. The fluctuation across survey years was the smallest in systolic blood pressure. The diastolic pressure was lower in 2018 (except in the 18–24and 80 age groups). The FBG values were higher in 2018 (except in the 25–34age group). The HDL-CHO levels in 2010 for both males and females were the lowest. In different years, the systolic blood pressure in all age groups over 50 years was higher than the criterion for MS. The FBG values in 2010, 2013 and 2018 in different age groups over age 45 years were higher than the cut-off value, and were higher in the age group over 55 years for 2015.

Main risk analysis (diet and other factors)

According to the average daily intake of fresh vegetables, fruits and red meat recommended by the WHO and the World Cancer Fund, the proportion of the population with an insufficient intake of vegetables and fruits (<400 g/day) was 43.76% in 2018. The proportion of the population

Table 1 The prevalence of the main risk factors for metabolic syndrome (diet and behaviour) from 2010 to 2018 (%)

Proportion of the population	2010	2013	2015	2018
Insufficient intake of vegetables and fruits (<400 g/day)-total	50.94 (35.72–66.17)	42.94 (33.6–52.28)	50.58 (40.08–61.09)	43.76 (35.68–51.84)
Male	52.61 (37.47–67.74)	44.54 (35.03–54.05)	51.84 (39.35–64.32)	43.25 (35.82–50.68)
Female	49.27 (33.85–64.7)	41.33 (30.92–51.75)	49.32 (40.45–58.18)	44.27 (34.67–53.87)
Excessive consumption of red meat (>100 g/day)-total	56.45 (38.23–74.66)	52.49 (43.38–61.6)	31.61 (21.35–41.87)	36.92 (30.33–43.51)
Male	61.94 (44.16–79.72)	61.05 (50.86–71.24)	40.72 (28.45–52.98)	48.95 (39.02–58.87)
Female	50.71 (31.71–69.71)	43.91 (36.24–51.58)	22.43 (13.71–31.15)	24.81 (19.25–30.38)
Smoking more than 20 cigarettes per day-total	44.7 (41.52–47.88)	45.2 (38.41–51.98)	46.11 (40.9–51.32)	38.59 (31.62–45.55)
Male	46.84 (43.88–49.81)	46.95 (40.41–53.49)	46.8 (41.78–51.81)	39.38 (32.19–46.57)
Female	8.09 (2.87–13.3)	16.05 (6.34–25.76)	27.07 (-1.06–55.2)	16.82 (11.44–22.19)
Insufficiently active (CATEGORY 1)-total	19.33 (9.09–29.57)	18.36 (14.57–22.15)	22.28 (18.47–26.09)	21.6 (15.05–28.15)
Male	20.68 (8.81–32.55)	20.29 (16.46–24.12)	27.72 (24.28–31.16)	26.08 (18.5–33.67)
Female	17.97 (8.91–27.03)	16.42 (11.97–20.86)	16.83 (12.06–21.59)	17.1 (9.97–24.23)
Minimally active (CATEGORY 2)-total	29.33 (20.36–38.31)	26.11 (20.6–31.63)	25.94 (20.14–31.74)	27.8 (18.92–36.69)
Male	28.18 (20.53–35.83)	24.39 (17.1–31.68)	22.63 (17.25–28.01)	24.95 (13.95–35.95)
Female	30.49 (20.09–40.88)	27.84 (21.26–34.43)	29.26 (22.69–35.84)	30.67 (23.77–37.56)
HEPA active (CATEGORY 3)-total	51.34 (33.73–68.95)	55.53 (48.56–62.5)	51.78 (43.25–60.31)	50.6 (38.74–62.45)
Male	51.14 (33.24–69.03)	55.32 (47.64–63)	49.65 (41.49–57.81)	48.97 (35.46–62.48)
Female	51.54 (33.44–69.64)	55.74 (46.68–64.79)	53.91 (44.39–63.44)	52.23 (41.25–63.21)

Insufficient intake of vegetables and fruits meant intake less than 400 g per day, and excessive consumption of red meat meant intake greater than 100 g per day, according to the WHO and the World Cancer Fund. More than 20 cigarettes was set as the cut-off point for smoking because one packet usually contains 20 cigarettes. According to the definition of the IPAQ analysis guide, HEPA activity meant (a) vigorous-intensity activity on at least 3 days achieving a minimum of at least 1500 MET-min/week OR (b) seven or more days of any combination of walking, moderate-intensity or vigorous intensity activities achieving a minimum of at least 3000 MET-min/week; minimally active meant (a) three or more days of vigorous activity of at least 20 min per day OR (b) five or more days of moderate-intensity activity or walking of at least 30 min per day OR (c) five or more days of any combination of walking, moderate-intensity or vigorous intensity activities achieving a minimum of at least 600 MET-min/week; insufficiently active meant individuals who did not meet the criteria for minimally active or HEPA.
HEPA, health enhancing physical activity; IPAQ, International Physical Activity Questionnaire; MET, metabolic equivalent task.

with excessive consumption of red meat (>100 g/day) was 36.92%. The proportion of smokers consuming over 20 cigarettes per day was 38.59%. According to the guidelines for data processing and analysis of the International Physical Activity Questionnaire (IPAQ),[35 36] the ratios of three categories of physical activity (insufficiently active, minimally active, health enhancing physical activity (HEPA active))[35] were 21.60%, 27.80% and 50.6% in 2018 (table 1). The values from 2010 to 2018 for the main diet and behaviour factors fluctuated to a certain extent, although no significant difference was found when evaluating the trend.

Risk assessment regarding nutrient intake

Meal review surveys were completed by 3293 adults who were investigated in 2015. Fifty-one adults with abnormal energy intake (<500 or >8000 kcal) were excluded, and approximately 1109 adults without chronic disease were assessed (table 2). The percentage of the total energy intake from carbohydrates was in line with the AMDR in 28.28% (males 22.79%, females 33.43%) of adults without chronic disease. The adults whose energy contribution from fats met the AMDR accounted for only 9.25% (males 7.94%, females 10.47%). For the daily intake value of vitamin C, potassium and sodium, 2.64% (males 3.67%, females 1.68%), 1.11% (males 0.91%, females 1.29%) and 11.48% (males 9.81%, females 13.05%) conformed to the PI-NCD, respectively. For dietary fibre, approximately 2.14% (males 2.21%, females 2.07%) conformed to the SPL. In the group aged 60 and above, the assessment results for carbohydrates and fat were highest (34.2% and

Table 2 The risk associated with nutrient intake in 2015 by AMDR, PI and SPL (%)

		Total	18–44	45–59	60 and above	Male	Female
CHO	Lower	66.29	66.52	68.7	59.08	71.43	61.47
	Conform	28.28	27.79	27.1	34.2	22.79	33.43
	Higher	5.43	5.69	4.2	6.72	5.78	5.11
Fat	Lower	2.78	2.89	2.5	2.75	3.43	2.17
	Conform	9.25	9.68	7.14	11.42	7.94	10.47
	Higher	87.97	87.43	90.36	85.83	88.63	87.36
Vit_C	Lower	97.36	96.71	98.89	97.9	96.33	98.32
	Conform	2.64	3.29	1.11	2.1	3.67	1.68
K	Lower	98.89	98.67	99.25	99.47	99.09	98.71
	Conform	1.11	1.33	0.75	0.53	0.91	1.29
NA	Conform	11.48	11.94	11.09	9.47	9.81	13.05
	Higher	88.52	88.06	88.91	90.53	90.19	86.95
DF	Conform	2.14	2.22	2.23	1.4	2.21	2.07
	Lower	97.86	97.78	97.77	98.6	97.79	97.93

The daily intake of carbohydrates, fat, vitamin C, potassium, sodium and dietary fibre was assessed by three new indicators (AMDR, PI and SPL) related to chronic diseases in the China Dietary Reference Intake (DRI, 2013 edition) guidelines. A total of 1109 adults without chronic disease (hypertension, dyslipidaemia and self-reported diabetes, cancer, asthma, chronic obstructive pulmonary disease, myocardial infarction or stroke) were assessed. AMDR reflected whether the percentage of energy from macronutrients of the total food energy intake met the recommended value. PI-NCD and SPL reflected whether the daily intake value of a particular nutrient met the recommended value.
AMDR, acceptable macronutrient distribution range; CHO, cholesterol; PI-NCD, proposed intakes for preventing non-communicable chronic disease; SPL, specific proposed level.

11.42%, respectively). In contrast, the conformed proportions of K, NA and DF intake from food were lowest in this group.

Exploration of related factors

In total, 23 708 samples (from individuals≥18 years old) from the four cross-sectional surveys were used to explore factors related to MS. The random effect of the null model at level 2 was statistically significant ($p<0.05$), which suggested that the prevalence of MS may vary among counties/districts and that the individual data presented aggregation at level 2.

The final model (table 3) contained variables from the two levels with a random effect at level 2 and fixed effects at both levels, which were statistically significant ($p<0.05$). First, the study showed that the fixed effects of urbanisation rate and number of beds in medical institutions per 1000 population were both positive. Moreover, the fixed effect of the number of doctors in healthcare institutions per 1000 people was negative and protective. The fixed effects of survey year were all negative compared with 2010.

Second, the results showed that the risk of MS increased with age group. The risk in the 45–59-year-old group was 1.99 times that in the reference group under 45 years of age (OR=1.99, 95% CI=1.82 to 2.18) and was 1.98 times that in the 60 years of age and older group (OR=1.98, 95% CI=1.8 to 2.19). Females were 1.49 times more likely to have MS than males. The group with a college education or above had a 33% lower risk of MS than the group with a primary education or less. In addition, the risk of MS was 49% lower in the unmarried or single group than in the divorced, widowed or separated group. Compared with individuals of Han ethnicity, individuals of ethnic minorities had a relatively lower risk of MS.

Meanwhile, the study showed that the ORs of MS in people smoking at least 20 cigarettes/day and eating excessive amounts of red meat were 1.10 (95% CI 0.98 to 1.22) and 1.16 (95% CI 1.09 to 1.25), respectively. Taking the group consuming fruit or vegetable juice weekly as a reference, the group with a lower frequency of intake had a 19% increased risk of MS (OR 1.19, 95% CI 1.01 to 1.40), and the group that did not consume fruit or vegetable juice at all had a 27% increased risk (OR 1.27, 95% CI 1.09 to 1.48). Monthly consumption of carbonated soft drinks was associated with a 19% lower risk of MS than weekly consumption of such beverages (OR 0.81, 95% CI 0.68 to 0.97). The groups with sedentary time outside of work of 1.2–2.0 hours, 2.0–3.1 hours and more than 3.1 hours had a greater risk of MS than the group with less than 1.2 hours. In particular, the risk in the upper quartile group was 1.19 (95% CI 1.08 to 1.31) times that in the lower quartile group. The MS risk of groups with medium and low levels of physical activity was 1.24 (95% CI 1.15 to 1.34) and 1.35 (95% CI 1.24 to 1.46) times that of the group with a high level of physical activity. In the early stage of building the model, the interactive effects of relevant indicators were also explored, such as sedentary time and physical activity

Table 3 The two-level final model for metabolic syndrome with the multilevel analysis method

Parameter	β	Std	χ^2	P value	OR	95% CI	Parameter	β	Std	χ^2	P value	OR	95% CI
Fixed effect													
Intercept	−1.98	0.14	200.83	0.00									
Level 2 variable													
Urbanisation rate	0.01	0.00	5.44	0.02	1.01	1 to 1.01							
Number of doctors in healthcare institutions per 1000 population	−0.22	0.06	12.19	0.00	0.80	0.71 to 0.91							
Number of beds in medical institutions per 1000 population	0.09	0.02	13.14	0.00	1.09	1.04 to 1.14							
Level 1 variable (the reference groups are in parentheses)							Level 1 variable (the reference groups are in parentheses)						
Year (2010)							Smoking of cigarettes (<20/day)						
2013	−0.04	0.06	0.40	0.52	0.97	0.87 to 1.08	≥20/day	0.09	0.06	2.80	0.09	1.10	0.98 to 1.22
2015	−0.39	0.08	22.83	0.00	0.68	0.58 to 0.80	Red meat intake (≤100 g/day)						
2018	−0.30	0.10	9.57	0.00	0.74	0.62 to 0.90	>100 g/day	0.15	0.04	18.86	0.00	1.16	1.09 to 1.25
Age, years (18–44)							Fruit or vegetable juice intake (every week)						
45–59	0.69	0.05	223.70	0.00	1.99	1.82 to 2.18	Intake but not every week	0.17	0.08	4.45	0.03	1.19	1.01 to 1.40
60 and above	0.69	0.05	180.40	0.00	1.98	1.80 to 2.19	Never	0.24	0.08	9.80	0.00	1.27	1.09 to 1.48
Sex (males)							Consumption of carbonated soft drinks (every week)						
Females	0.40	0.04	116.87	0.00	1.49	1.39 to 1.60	Every month	−0.21	0.09	5.24	0.02	0.81	0.68 to 0.97
Education (primary and lower)							Every year	−0.19	0.09	4.13	0.04	0.83	0.69 to 0.99
Junior middle school	−0.03	0.04	0.60	0.44	0.97	0.90 to 1.05	Never	−0.17	0.08	4.75	0.03	0.84	0.72 to 0.98
Senior high school or technical (specialised) secondary school	−0.04	0.07	0.36	0.55	0.96	0.84 to 1.10	Sedentary time outside of work (<1.2 hours)						
College or above	−0.40	0.11	12.66	0.00	0.67	0.54 to 0.84	1st quartile–median, 1.2–2	0.01	0.07	0.01	0.92	1.01	0.88 to 1.15
Marriage (divorced, widowed or separated)							Median–third quartile, 2–3.1	0.10	0.04	6.00	0.01	1.10	1.02 to 1.19
Married or cohabiting	0.00	0.06	0.00	0.96	1.00	0.90 to 1.11	>3rd quartile, ≥3.1	0.17	0.05	12.32	0.00	1.19	1.08 to 1.31
Unmarried or single group	−0.67	0.12	32.86	0.00	0.51	0.41 to 0.65	Physical activity (HEPA active)						
Ethnicity (Han)							Minimally active	0.21	0.04	29.83	0.00	1.24	1.15 to 1.34
Yi	−0.06	0.10	0.34	0.56	0.94	0.77 to 1.15	Insufficiently active	0.30	0.04	50.68	0.00	1.35	1.24 to 1.46
Other ethnic minorities	−0.32	0.12	6.58	0.01	0.73	0.57 to 0.93							
Random effect	**β**	**Std**	**χ^2**	**P value**									

Continued

Table 3 Continued

Parameter	β	Std	χ^2	P value	OR	95% CI	Parameter	β	Std	χ^2	P value	OR	95% CI
Level 2 variance	0.06	0.02	6.48	0.01									
Level 1 scale parameter	1.00	0.00											

The random effect at level 2 and fixed effects at both levels were statistically significant. The results of the variables in level 2 suggested that people living in a place with relatively abundant prehospital and outpatient medical service resources, rather than places with more beds, had a relatively lower risk of metabolic syndrome (MS). The results at level 1 showed that a higher education level was an individual protective factor under the same external environmental situation. Age, female sex, excessive red meat intake, a higher frequency of carbonated soft drink consumption and longer time spent sedentarily elevated the risk of MS. Improving the human resources component of medical services, such as the number of doctors, increasing the availability of public sports facilities and E-health tools and improving individual dietary quality and education level might help prevent MS.
HEPA, health enhancing physical activity.

level, but none were statistically significant. Additional results are presented in table 3.

DISCUSSION

Although this study showed that the prevalence of MS in Sichuan Province (27.8% in 2010, 27.4% in 2018, age≥18 years) was lower than previous reports in China (33.9% in 2010, probably overestimated by using 80 cm as the WC cut-off value for females age≥18 years),[37] the USA (34.7% in 2011–2012, age≥20 years),[38] the Portugal (36.5% from 2007 to 2009, aged≥18 years),[39] it was close to the study results of Asian countries Korea (31.3% in 2007, aged≥20 years)[37] and India (30% from 2004 to 2019, aged≥18 years).[40] Three other studies have also showed the prevalence of MS fluctuated by country, definition and time of study (20%–37% in Bangladesh, 31%–54% in Mexico, about 24.3% in Europe).[41–43] Furthermore, the population with metabolic syndrome in Sichuan is approximately 18.24 million according to the prevalence estimates in this study, which suggests that the burden of disease caused by metabolic disorders should not be ignored. To explore risk factors in this study, a multilevel logistic regression model was used to further clarify the aggregation effect at the county/district level, instead of the complicated single-level sampling logistic regression model used previously.[32] This kind of aggregation has been reported to be associated with development inequalities between regions.[44–47] Inequalities at the regional level have been reported in terms of income, socioeconomic status, educational status and the availability and affordability of medicine, health services and sports facilities.[45 47–50] Whether high socioeconomic stress and social anxiety increase the risk of chronic disease (obesity, diabetes and so on) was discussed, and the physiological mechanisms were considered to be related to an increase in cortisol secretion, leading to accelerated lipolysis, truncal obesity and insulin resistance.[51 52]

In our study, the number of beds in medical institutions per 1000 people was the index of a city's infrastructure and was considered reflective of socioeconomic stress at the county/district level, similar to the urbanization rate. Both indices were found to have positive effects in the final model. In contrast, the number of doctors in healthcare institutions per 1000 people was an index of a city's human resources, indirectly reflecting the quality of health education, diagnosis and treatment services from outpatient services and out-of-hospital clinics. In areas with relatively abundant prehospital and outpatient doctor-medical resources, the risk of disease was relatively low. This result was consistent with the view that improving medical and health services (such as making preventative medicines more available and affordable) was crucial to prevent NCD.[48 49] The positive effect (number of beds) and negative effect (number of doctors) also suggested that human resources aspect of medical services should receive more attention while infrastructure is improved.

Compared with previous research results based on complex sampling logistic regression models,[32] the findings of the present analysis stratified by ethnicity were different. After separating the random effect of county/district in this multilevel logistic regression, there was no significant difference between the Yi ethnicity and Han ethnicity with regard to the risk of MS, while the individuals of other ethnic minorities had lower levels of risk than those of Han ethnicity.

After adjusting for the external socioeconomic environment, this study suggested that the higher the level of individual education is, the lower the OR of MS, which could be explained by higher personal health literacy. The study also suggested that because of a more stable lifestyle, single individuals in the same age group had a lower risk of MS than those who had adverse changes in partnership.

Moreover, the effect directions of dietary and behavioural variables included in the final model were almost unchanged compared with those observed in the single-level analysis.[32] Age, female sex, excessive red meat intake, higher frequency of consumption of carbonated soft drinks and more sedentary time outside of work elevated the risk of MS. In contrast, increasing fruit and vegetable juice consumption and increasing the amount of time or intensity of physical activity per week were beneficial to reducing the risk of MS. These results were in agreement with published views that the relationship between sedentary behaviour and MS was independent of physical activity, which might be explained by the significant reductions in muscle lipoprotein lipase activity occurring during sedentary activity.[53]

The assessment of nutrient intake in 2015 also indicated that most people urgently need to adjust the proportions of their food energy sources, especially males and young people, to maintain their energy balance, increasing their intake of carbohydrates and reducing their intake of fat. Combined with previous studies on the effects of nutrients on chronic diseases, such as cardiovascular disease and colorectal cancer, the current microelement intake situation of Sichuan residents is in urgent need of improvement. It is necessary to strengthen the propaganda and interventions promoting diets rich in fibre and potassium and low in sodium for elderly individuals. Middle-aged people and women should be encouraged to eat more fruits and vegetables.

The limitation of this study was that the results of the study reflect the association between disease and influencing factors but not necessarily causality, as the study is based on cross-sectional surveys. Therefore, subjects who pursued behavioural changes after being diagnosed with chronic disease were not included in the model to reduce confounding. However, we did find that there were differences in the proportion of individuals with insufficient intake of vegetables and fruits, excessive consumption of red meat, a habit of smoking more than 20 cigarettes per day and different activity levels between the groups of subjects included in the model and the subjects excluded from the model ($p<0.05$). In 2020, we began following up with these subjects, which will support higher levels of evidence in future studies.

Overall, the study suggested that in modern society, with its fast pace and increasing pressures, unreasonable proportions of energy contribution and micronutrient intake values and a low percentage of individuals with high levels of physical activity are the major challenges to public health in western China. Furthermore, while exploring the individual factors that cause MS, the influence of environmental factors, especially socioeconomic stress, should not be ignored. People living in a place with relatively abundant prehospital and outpatient medical service resources, rather than a place with more beds, had a relatively lower risk of MS, which means that human resources component of medical services should receive great attention. A higher education level was an individual protective factor under the same external environmental situation. To prevent the MS and its components, we also suggest building healthy cities by increasing the availability of public sports facilities, offering more E-health tools, reducing the prices of facilities and improving safety levels, which might modestly reduce absolute area inequalities, especially in communities with high population density.[50 54]

Author affiliations
[1]Department of Chronic and Non-communicable Disease Control and Prevention, Sichuan Center for Disease Control and Prevention, Chengdu, Sichuan, China
[2]Department of Global Health & Social Medicine, King's College London, London, UK
[3]School of Biomedical Informatics, The University of Texas Health Science Center at Houston, Houston, Texas, USA
[4]National Center for Chronic and Non-communicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention, Beijing, China
[5]West China School of Nursing, Department of Anesthesia and Operation Center, West China Hospital,Sichuan University, Chengdu, Sichuan, China
[6]Department of Nutrition and Food Safety, Sichuan University, Chengdu, Sichuan, China
[7]Sichuan Center for Disease Control and Prevention, Chengdu, Sichuan, China

Contributors XX, XW and YD conceived and designed the research; XX, YD, JZ, TD, XZha, SC, GY and YL performed the surveys and data extraction; XX analysed the data, drew the figures and was a major contributor in writing the manuscript; XX and LN finished the Supplementary Appendix; WY, XZho, MZ and LZ provided substantive suggestions for revision. All authors read and approved the final manuscript. The authors thank the staff of the local Center for Disease Control and Prevention for collecting data and all the respondents for their participation and contribution. XW is responsible for the overall content as guarantor.

Funding This study was supported by the 'Tianfu Famous Doctor Fund' and funds from the 'National Key R&D Program of China' (grant number 2018YFC1311401).

Competing interests None declared.

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

Patient consent for publication Not required.

Ethics approval This study involves human participants and was approved by The Medical Ethics Committee of the Chinese National Center for Chronic

and Non-communicable Disease Control and Prevention (NCNCD) approved the four investigations (No. 201010, 201307, 201519-A, 201819). Written informed consent was obtained from the participants. Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request. The data are currently not publicly available due to legal restrictions of the data and the rules of the project but are available part from the corresponding author upon reasonable request after application to and approval from the Sichuan Center for Disease Control and Prevention.

ORCID iD

Xinyin Xu http://orcid.org/0000-0001-5474-3174

REFERENCES

1 Organization WH. *Global status report on noncommunicable diseases 2014*. Geneva: World Health Organization, 2014.
2 Liu S, Li Y, Zeng X, *et al*. Burden of cardiovascular diseases in China, 1990-2016: findings from the 2016 global burden of disease study. *JAMA Cardiol* 2019;4:342–52.
3 Bundy JD, He J. Hypertension and related cardiovascular disease burden in China. *Ann Glob Health* 2016;82:227–33.
4 Zhou M, Wang H, Zhu J, *et al*. Cause-specific mortality for 240 causes in China during 1990-2013: a systematic subnational analysis for the global burden of disease study 2013. *Lancet* 2016;387:251–72.
5 Galassi A, Reynolds K, He J. Metabolic syndrome and risk of cardiovascular disease: a meta-analysis. *Am J Med* 2006;119:812–9.
6 Said S, Mukherjee D, Whayne TF. Interrelationships with metabolic syndrome, obesity and cardiovascular risk. *Curr Vasc Pharmacol* 2016;14:415–25.
7 Mottillo S, Filion KB, Genest J, *et al*. The metabolic syndrome and cardiovascular risk a systematic review and meta-analysis. *J Am Coll Cardiol* 2010;56:1113–32.
8 The China National Health and Family Planning Commission. *Report on Chinese residents' chronic disease and nutrition*. 1st ed. Beijing, China: People's Medical Publishing House, 2016.
9 Sichuan Provincial Health and Family Planning Commission. *2015 Report on the health and important diseases status of Sichuan Province*. 1st ed. Chengdu, China: Sichuan Science and Technology Press, 2016.
10 Yang X, Zhai F. *2002 Research of Chinese nutrition and health condition-Part III-the physique and nutrition status*. 1st ed. Beijing, China: People's Medical Publishing House, 2006.
11 Chenc. *1990-2000 Ten-year follow-up of nutritional status in China*. 1st ed. Beijing, China: People's Medical Publishing House, 2004.
12 Kang J, Wu X. *2002 Report on the nutrition and health status of Sichuan Province*. 1st ed. Chengdu, China: Sichuan University Publishing House, 2006.
13 Chang J, Wang Y. *Report on the monitoring of nutrition and health status of Chinese residents in 2010-2013*. 1st ed. Beijing, China: Peking University Medical Press, 2016.
14 China Center for Disease Control and Prevention. *Report on chronic disease risk factor surveillance in China 2004*. 1st ed. Beijing, China: Peking Union Medical College Press, 2009.
15 China Center for Disease Control and Prevention. *Report on chronic disease risk factor surveillance in China 2007*. 1st ed. Beijing, China: People's Medical Publishing House, 2010.
16 China Center for Disease Control and Prevention. *Report on chronic disease risk factor surveillance in China 2010*. 1st ed. Beijing, China: Military Medical Science Press, 2012.
17 China Center for Disease Control and Prevention. *Report on chronic disease risk factor surveillance in China 2013*. 1st ed. Beijing, China: Military Medical Science Press, 2016.
18 Xu P, Liu A, Li F, *et al*. Associations between metabolic syndrome and four heavy metals: a systematic review and meta-analysis. *Environ Pollut* 2021;273:116480.
19 Hassannejad R, Kazemi I, Sadeghi M, *et al*. Longitudinal association of metabolic syndrome and dietary patterns: a 13-year prospective population-based cohort study. *Nutr Metab Cardiovasc Dis* 2018;28:352–60.
20 Forouhi NG, Krauss RM, Taubes G, *et al*. Dietary fat and cardiometabolic health: evidence, controversies, and consensus for guidance. *BMJ* 2018;361:k2139.
21 Shridhar K, Satija A, Dhillon PK, *et al*. Association between empirically derived dietary patterns with blood lipids, fasting blood glucose and blood pressure in adults - the India migration study. *Nutr J* 2018;17:15.
22 Tong TYN, Wareham NJ, Khaw K-T, *et al*. Prospective association of the Mediterranean diet with cardiovascular disease incidence and mortality and its population impact in a non-Mediterranean population: the EPIC-Norfolk study. *BMC Med* 2016;14:135.
23 Lee KW, Shin D. A healthy beverage consumption pattern is inversely associated with the risk of obesity and metabolic abnormalities in Korean adults. *J Med Food* 2018;21:935–45.
24 Perng W, Fernandez C, Peterson KE, *et al*. Dietary patterns exhibit sex-specific associations with adiposity and metabolic risk in a cross-sectional study in urban Mexican adolescents. *J Nutr* 2017;147:1977–85.
25 Li M, Shi Z. Dietary pattern during 1991-2011 and its association with cardio metabolic risks in Chinese adults: the China health and nutrition survey. *Nutrients* 2017;9:E1218.
26 Hajiluian G, Abbasalizad Farhangi M, Jahangiry L. Mediterranean dietary pattern and VEGF +405 G/C gene polymorphisms in patients with metabolic syndrome: an aspect of gene-nutrient interaction. *PLoS One* 2017;12:e0171637.
27 Du H, Li L, Bennett D, *et al*. Fresh fruit consumption in relation to incident diabetes and diabetic vascular complications: a 7-y prospective study of 0.5 million Chinese adults. *PLoS Med* 2017;14:e1002279.
28 Wang S-H, Hsiao P-C, Hsiao CK, *et al*. Multilevel analysis of habitual physical activity and metabolic syndrome in Northern Taiwan. *Prev Med* 2011;53:34–8.
29 Yang G, Hu J, Rao KQ, *et al*. Mortality registration and surveillance in China: history, current situation and challenges. *Popul Health Metr* 2005;3:3–11.
30 Xu Y, Wang L, He J. China noncommunicable disease surveillance Group. prevalence and control of diabetes in Chinese adults. *JAMA* 20102013;310:948–59.
31 Hou X, Lu J, Weng J, *et al*. Impact of waist circumference and body mass index on risk of cardiometabolic disorder and cardiovascular disease in Chinese adults: a national diabetes and metabolic disorders survey. *PLoS One* 2013;8:e57319.
32 Xu X, Wu X, Deng Y, *et al*. The influence of diet and behaviour on metabolic syndrome and the prevalence of metabolic syndrome according to different definitions in West China. *Asia Pac J Clin Nutr* 2018;27:1040–7.
33 Alberti KGMM, Zimmet P, Shaw J. Metabolic syndrome--a new world-wide definition. A Consensus Statement from the International Diabetes Federation. *Diabet Med* 2006;23:469–80.
34 The China National Health and Family Planning Commission. *Criteria of Weight for Adults*. 1st ed. Beijing, China: Standards Press of China, 2013.
35 Prince SA, Kristjansson EA, Russell K, *et al*. A multilevel analysis of neighbourhood built and social environments and adult self-reported physical activity and body mass index in Ottawa, Canada. *Int J Environ Res Public Health* 2011;8:3953–78.
36 Committee IR. "Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire (IPAQ)—Short and Long Forms", 2005. Available: http://www.ipaq.ki.se/scoring.pdf
37 Lu J, Wang L, Li M, *et al*. Metabolic syndrome among adults in China: the 2010 China noncommunicable disease surveillance. *J Clin Endocrinol Metab* 2017;102:507–15.
38 Aguilar M, Bhuket T, Torres S, *et al*. Prevalence of the metabolic syndrome in the United States, 2003-2012. *JAMA* 2015;313:1973–4 http://dx.doi.org/
39 Raposo L, Severo M, Barros H, *et al*. The prevalence of the metabolic syndrome in Portugal: the PORMETS study. *BMC Public Health* 2017;17:555.

40 Krishnamoorthy Y, Rajaa S, Murali S, *et al*. Prevalence of metabolic syndrome among adult population in India: a systematic review and meta-analysis. *PLoS One* 2020;15:e0240971.
41 Chowdhury MZI, Anik AM, Farhana Z, *et al*. Prevalence of metabolic syndrome in Bangladesh: a systematic review and meta-analysis of the studies. *BMC Public Health* 2018;18:308.
42 Chowdhury MZI, Anik AM, Farhana Z, *et al*. Prevalence of metabolic syndrome in Bangladesh: a systematic review and meta-analysis of the studies. *BMC Public Health* 2018;18:308.
43 Scuteri A, Laurent S, Cucca F, *et al*. Metabolic syndrome across Europe: different clusters of risk factors. *Eur J Prev Cardiol* 2015;22:486–91.
44 Leischik R, Dworrak B, Strauss M. Plasticity of health. *German J Med* 2016;1:1–17.
45 Niessen LW, Mohan D, Akuoku JK, *et al*. Tackling socioeconomic inequalities and non-communicable diseases in low-income and middle-income countries under the sustainable development agenda. *Lancet* 2018;391:2036–46.
46 von dem Knesebeck O, Vonneilich N, Lüdecke D. Income and functional limitations among the aged in Europe: a trend analysis in 16 countries. *J Epidemiol Community Health* 2017;71:584–91 http://jech.bmj.com/content/early/2017/01/06/jech-2016-208369.abstract
47 US Burden of Disease Collaborators, Mokdad AH, Ballestros K, *et al*. The state of US health, 1990-2016: burden of diseases, injuries, and risk factors among US states. *JAMA* 2018;319:1444–72 http://dx.doi.org/
48 Khatib R, McKee M, Shannon H, *et al*. Availability and affordability of cardiovascular disease medicines and their effect on use in high-income, middle-income, and low-income countries: an analysis of the pure study data. *Lancet* 2016;387:61–9 https://doi.org/
49 Niessen LW, Khan JAM. Universal access to medicines. *Lancet* 2016;387:9–11 https://doi.org/
50 Blok DJ, van Lenthe FJ, de Vlas SJ. The impact of individual and environmental interventions on income inequalities in sports participation: explorations with an agent-based model. *Int J Behav Nutr Phys Act* 2018;15:107 https://www.ncbi.nlm.nih.gov/pubmed/30382862
51 Healy AM, Schwartz FL. The role of socioeconomic stress in the risk for obesity and diabetes: potential new targets of treatment. *Osteopathic Family Physician* 2010;2:180–6.
52 Jaremka LM, Pacanowski CR. Social anxiety symptoms moderate the link between obesity and metabolic function. *Psychoneuroendocrinology* 2019;110:104425.
53 Edwardson CL, Gorely T, Davies MJ, *et al*. Association of sedentary behaviour with metabolic syndrome: a meta-analysis. *PLoS One* 2012;7:e34916.
54 Leischik R, Schwarz K, Bank P, *et al*. Exercise improves cognitive Function-A randomized trial on the effects of physical activity on cognition in type 2 diabetes patients. *J Pers Med* 2021;11:530 https://www.mdpi.com/2075-4426/11/6/530