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Original Article

Risk-stratified lifetime risk and incidence of hip fracture and falls in middle-aged and elderly Chinese population: The China health and retirement longitudinal study

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ABSTRACT

Background: Hip fracture (HF) is one of the most prevalent orthopedic conditions among the elderly, with falls being the primary risk factor for HF. With the surge of aged population, China is facing great challenges from HF and falls. However, a comprehensive long-term observation of risk factors affecting HF and falls and their association are little reported at a national level.
Methods: The longitudinal cohort was established using the China Health and Retirement Longitudinal Study (CHARLS) data from 2011 to 2018. The incidence density and multi-risk-stratified lifetime risk (up to 90 years of age) of falls and HF were studied at index ages of 50, 60, and 70, as well as the lifetime risk stratified by six regions in China, based on the modified Kaplan–Meier method with Statistical Analysis System (SAS).
Results: This study identified 17 705 subjects aged 50–89. The incidence density of falls was 65.07 and 47.53 per 1000 person-years in women and men, respectively. The incidence density of HF was also higher in women at 5.58 per 1000 person-years than in men at 4.88. By age 50, the lifetime risk of experiencing a HF was 18.58 % for women and 13.72 % for men. Vision and hearing abilities were significantly related to the lifetime risk of both falls and HF. Obesity-related factors presented age-relevant relationships with lifelong risks. Lack of naps, poor lower limb strength, and physical capabilities were indicative of HF risk. The north-western region of China had the lowest lifetime risk of falls but highest risk of HF, while other regions showed a consistent trend between falls and HF.
Conclusion: The aging population worldwide faces a considerable risk of falls and HF. Several risk factors were identified in this study using a Chinese population, relating to disease history, lifestyle habits, health status and physical function, and the risks differed among six regions in China. Future precautionary management programs, as well as patient self-awareness are necessary for improving the prevention of falls and HF to reduce their incidence in the aging population.
The translational potential of this article: With the greatest aged population worldwide, China faces the unparalleled challenge on public health. The study poses the lifetime risk of hip fracture and falls stratified by multiple

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risk factors in people from 45 to 90 in a national scale, which would shed a light on the early and continuous prevention of such injury.

1. Introduction

Hip fracture (HF) is one of the most prevalent orthopedic conditions among the elderly, affecting 190 women and 166 men per 100 000 in their lifetime at an average age of 80 years or above [1]. Patients who have experienced HF are often severely affected by pain and immobility, which may lead to long-term and irreversible impairment in health status and health-related quality of life [2,3]. Moreover, chronic mobility impairment may render HF patients at higher risk of suffering from co-morbidities such as cardiovascular disease [4]. Due to the higher prevalence of HF in the elderly, many patients are not suitable candidates for surgery, while up to one-third of those who do receive timely surgery endure various surgical and non-surgical complications due to the complexity of the operation and the declining health status of elderly patients [5,6]. For these reasons, HF is known as the "last bone fracture of life", where 12–17 % of patients who have sustained HF would die within the first year due to complications and co-morbidities, and survivors are subjected to a doubled long-term risk of death [7,8]. The globally aging population contributes to a continuously staggering growth in the incidence of HF, where the number of affected individuals is projected to reach 4.5 million by 2050 [9]. The estimated treatment cost for HF has already reached 17 billion dollars in the US, compounded by the additional expense for rehabilitation ranging from $19,000 to $66,000 per capita [9]. The social and economic consequences of HF place a huge burden on families and communities globally. China, with the world's second highest population, is grappling with the challenge of having a rapidly growing percentage of individuals aged 65 and above, which has already reached approximately 14 % of the total population [10,11]. This demographic shift exposes a substantial portion of the population to the risk of HF, projecting an estimated 1.3 million HF in those aged over 65 by 2050 [12]. Such a rapidly growing pool of elderly HF patients will inevitably place great demand on an already stretched medical system to provide chronic care and management [13]. Early prediction and prevention of HF in individuals at higher risk is therefore essential to minimize the impact of these long-term socioeconomic consequences.

Falls, being the primary risk factor for HF, are the leading cause of injury in individuals aged 65 and above [8]. Screening the population with high incidence density of falls and comparing the long-term risk factors of falls with those of HF across different age groups would contribute to the development of an effective prevention strategy. This could aid the design and implementation early intervention measures for both falls and HF, and effectively alleviate the healthcare burden associated with the elderly population in China and worldwide.

Although the epidemiological characteristics of HF and falls have been separately explored in other populations, China still lacks detailed national investigation on age-specific incidence density of HF and falls especially for those aged over 50 [14–16]. The risk factors of either HF or falls have been discussed in recent studies [17,18]. However, most studies were based on a short-term observation and focused on the elderly population aged over 60, overlooking the potential risk factors affecting the middle-aged population [19,20]. In this space, a recent study based on the China Health and Retirement Longitudinal Study (CHARLS) investigated the long-term risk factors of HF in the Chinese population, and another study assessed lifetime risk of HF stratified by age and gender in an Australian population [21,22]. However, there is limited evidence on the association between falls and HF in a middle-aged population, as well as whether any commonly identified risk factors play a role in lifetime risk of HF and falls. In particular, this evidence is missing in the Chinese population.

Both incidence density and lifetime risk play a vital role in the epidemiological estimation of disease occurrence and risk within a population. Incidence density evaluates the frequency of a certain disease during a given time period, which is useful for identifying high risk populations [18]. Lifetime risk estimates the residual lifetime risk of disease from an age when the risk of disease becomes of concern to a person [23]. With an added scale of time or age, lifetime risk offers a more comprehensive view of the relationship between risk factors and disease in the long term compared to using incidence density alone. Accordingly, an up-to-date comprehension of both the incidence density and lifetime risk of HF and falls will improve the design and implementation of precautionary management programs, as well as better meet the healthcare demands of patient populations [24].

In this study, we utilized the CHARLS database to investigate for the first time the incidence density and long-term preventable risk factors of HF and falls in the middle-aged and elderly population, capturing data from Chinese individuals aged 50 and above. We used a modified Kaplan–Meier method that considered competing risks in relation to mortality. We also examined differences in lifetime risk of HF and falls among six geographical regions of China. This study gave a comprehensive insight into multi-dimensional risk factors associated with HF and falls, including disease history, lifestyle habits, health status and physical function, and geographical region.

2. Materials and methods

2.1. Study population

The data for this study were derived from CHARLS surveys conducted in 2011, 2013, 2015, and 2018 [25]. CHARLS is a longitudinal survey representative of the Chinese population aged 45 and above. Its primary objective is to construct a high-quality public database encompassing multi-dimensional population information such as socioeconomic and health status, to meet the needs of gerontological scientific research.

To employ the best data collection methods and ensure the international comparability of results, CHARLS designed its survey methods by referring to a series of international aging studies, including the Health and Retirement Study in the United States. CHARLS adopted the probability-proportional-to-size sampling approach, aiming for unbiased and representative samples. In the first stage, excluding Tibet, all counties across China were categorized into eight major regions based on their urban-rural classification and per capita GDP. Subsequently, 150 counties or districts were randomly selected in proportion to their population size. In the second stage, within each selected county-level unit, three secondary sampling units (village committees or neighborhood committees) were randomly selected with a probability proportional to their population size. Considering the challenges of updating household lists at the village/neighborhood level due to population mobility, CHARLS developed mapping/listing software. This software utilized Google Earth map imagery to list all residential units in residential buildings, creating a sampling frame. In each selected household, enumerators used a brief screening form to determine if there were eligible members based on age criteria. If there were individuals aged 45 and above who met the residency criteria, one person was randomly selected for sampling. The selected individual over 45 years would become the main respondent, and their spouse would also be interviewed. Therefore, the baseline survey of CHARLS targeted one middle-aged to elderly person aged 45 or above and their spouse in each household. Moreover, to maintain representativeness of the population aged 45 and above, CHARLS reserved individuals aged 40–44 as backup samples during the baseline survey for future use. That is, if a household randomly selected during the baseline survey included individuals aged 40 and above, one person would be randomly selected. When this individual turned 45 in subsequent follow-up surveys, he/she became the main respondent, and their spouse would also be interviewed. Ultimately, the baseline survey covered 150 national/regional units, and 450 villages/city communities, involving 17 708 individuals from 10 257 households. The response rate for the baseline survey was 80.5 %, with rates of 94 % in rural areas and 69 % in urban areas, which constituted a representative sample of the middle-aged and elderly population in China.

To avoid the influence of small sample size beyond the margin of the investigated age groups in the CHARLS cohort, only those aged 45 years or older were included in this study. Participants were excluded if [1] the age information was unknown [2]; vital status information was unclear; or [3] the information on falls or HF was not recorded. Each round of the CHARLS survey received approval from the Biomedical Ethics Committee of Peking University. The fieldwork plan for this round of household questionnaire surveys has also been approved, with approval number IRB00001052-11015.

2.2. Measurement of risk factors

Factors relevant to lifetime risk of falls and HF were informed by previous studies and a WHO report, including bone mineral density (BMD), skeletal geometry and genetic influences, falls, physical capability, and body status [20,26,27]. Accordingly, we selected risk factors investigated in CHARLS aligning with the aforementioned factors, including chronic diseases that might affect BMD, body indexes and physical function affecting vulnerability to HF and falls, and daily habits that might impact susceptibility to injuries. The research validity of the factors was listed in supplemental file 1.

The exposure status of individuals to relevant risk factors was obtained through both questionnaire assessments and physical examination, which were conducted at the individual's home by data collectors.

2.2.1. Questionnaire

2.2.1.1. Chronic disease history. Interviewees were presented with cards listing common chronic diseases including hypertension; dyslipidemia; diabetes or hyperglycemia; cancer or malignant tumor; chronic lung disease such as chronic bronchitis or emphysema; liver disease; heart disease such as heart attack, coronary heart disease, angina, congestive heart failure or other heart problems; stroke; kidney disease; gastric or other digestive diseases; emotional, nervous, or psychiatric problems; memory-related diseases; arthritis or rheumatic diseases; and asthma. Participants indicated their chronic disease history by answering "yes" or "no" to each condition listed.

2.2.1.2. Smoking and alcohol consumption. Participants who had cumulatively smoked over 100 cigarettes were counted as “past smoking”. Participants who had regular alcohol consumption in the past 1 year were counted as “past drinking”.

2.2.1.3. Nap habits. The general duration of a nap after lunch in the past month was documented, otherwise counted as 0.

2.2.1.4. Sensory abilities (vision and hearing). Participants were asked about their ability to recognize distant objects after wearing glasses (if needed), such as whether they were capable of identifying friends across the street, with responses recorded as "good", "fair", or "poor" for far vision ability. Near vision ability was assessed by asking participants about their ability to see close objects after wearing glasses (if needed), such as reading text on a newspaper, with responses recorded as "good", "fair", or "poor". Daily hearing ability (corrected by hearing aid if routinely used) was self-evaluated as “good”, “fair” or “poor”.

2.2.1.5. Physical capability. Physical capability levels were categorized as "good", "fair", or "poor" based on whether individuals could complete a 1 km run or 1 km walk.

2.2.1.6. Activities of daily living. Ability to carry out activities of daily living was assessed based on the level of difficulty experienced in getting dressed, bathing, eating, getting in and out of bed, using the toilet, and bowel movements. Participants with difficulties in any of these activities (excluding those expected to be resolved within three months) were recorded as having poor daily living abilities; otherwise, abilities were deemed good.

2.2.1.7. Self-rated health status. Participants were asked to report self-rated health status as “excellent”, “very good”, “good”, “fair”, “poor”. The first three options were integrated as “good” in the reported data.

2.2.2. Physical examination

2.2.2.1. Height and weight. Body mass index (BMI) was calculated as an individual's weight divided by the square of their height (kg/m^2), which was categorized as underweight (BMI $<$18.5), normal (BMI $=$ 18.5–23.9), and overweight or obese (BMI $>$23.9).

2.2.2.2. Waist circumference. Waist circumference was taken by positioning the measuring tape horizontally around the participant's waist at the level of the navel during normal breathing and breath-holding at the end of exhalation. A measurement greater than or equal to 90 cm for males and greater than or equal to 85 cm for females indicated central obesity.

2.2.2.3. Balance. Balance capabilities were determined by the participant's ability to stand with the big toe of either foot next to the flank of the heel on the other foot, and by standing with the feet in a straight line.

2.2.2.4. Lower limb strength. Lower limb strength was assessed based on the participant's ability to perform five sit-to-stand movements from a chair within 12 s; failure to do so was categorized as poor lower limb strength.

2.3. Definitions of hip fracture and falls

The history of HF and falls was primarily collected through face-to-face questionnaires encompassing sequential questions, such as: "Have you experienced a fall in the past two years?" and "Have you experienced a hip bone fracture?", and the responses were categorized as “yes” or “no”. A participant was defined as having a history of either HF or falls depending on their positive responses to the questions.

2.4. Statistical analysis

The age at which individuals entered the CHARLS cohort in the initial survey year 2011 was considered the entry age, while the date of occurrence for the event of interest, death, or termination of follow-up was considered the endpoint to calculate the survival age.

To calculate the lifetime risk of falls and HF, an adapted Kaplan–Meier method was employed. Compared to multi-decrement life-table and traditional Kaplan–Meier methods for calculating lifetime risk, the modified Kaplan–Meier approach not only allows for a better understanding of factors affecting disease occurrence, but also incorporates consideration of competing risks (usually death), resulting in more realistic outcomes [28]. The modified Kaplan–Meier method conducted the analysis on the scale of age rather than survival time, and considered all causes of death as a competing risk to falls or HF [28]. In our study, a lifetime risk and incidence density analysis was conducted by grouping individuals aged 50 to 89 by every five years of age, and the calculation method is listed in Supplemental file 2.

This study also estimated the lifelong risk of falls and HF from age 50, 60, and 70 to 89, respectively, with 95 % confidence intervals, and calculated the lifetime risk grouped by multiple influencing factors. The lifetime risk stratified by six regions in China was obtained using the same method. All computations were performed using SAS 9.4. All reported p-values were calculated through two-sided z-test, with $p < 0.05$ considered statistically significant, and the significance level α was set at 0.05. We also explored some conditions when the p-value was over 0.05 but below 0.1, for which we suspected a possible correlation warranting more specific clinical studies.

3. Results

A total of 17 705 individuals were identified for possible inclusion in this study. Among these, 493 were excluded as they were below 45 years of age, along with 8 who had unknown age information, and 1223 who had unknown vital status information. The remaining 15 981 individuals were retained for analysis. For the investigation of falls, samples for 5486 individuals were excluded due to the absence of falls information in subsequent follow-up surveys, while another 227 samples were excluded lacking information of falls beyond age 50, leaving 10268 cases for analysis. For the investigation of HF, samples for 3913 individuals were excluded as they lacked information on HF in subsequent follow-up surveys, while another 136 samples were excluded with no information of hip fracture beyond 50, leaving 11932 cases for analysis. Baseline characteristics are shown in Table 1, and a flow diagram of the selection process is shown in Fig. 1. Some disparity between included and excluded population is shown in Supplemental file 3.

3.1. Incidence density of falls

From 2011 to 2018, a total of 10 268 participants (5028 males and 5240 females) aged 50–89 years contributed at least one year of follow-up time for falls, amounting to 61 553 person-years. During this period, there were 3464 participants who experienced a fall, 866 who died without experiencing a fall and were withdrawn from the study, and 5938 who neither experienced a fall nor died at the end of the study. Fig. 2A illustrates the incidence density of falls in different age groups of participants, showing an increasing trend with advancing age until 84 years. Overall, the incidence density of falls for females aged 50–89 years was 65.07 per 1000 person-years, significantly higher than that for males at 47.53 per 1000 person-years.

3.2. Incidence density of HF

During 2011–2018, there were 11 932 participants (5705 males and 6227 females) aged 50–89 years who contributed at least one year of follow-up time for HF, giving a total of 80 299.5 person-years. During this period, 421 participants experienced HF, while 1260 died without experiencing HF and were withdrawn from the study, and 10 251 neither experienced HF nor died by the end of the study. As shown in Fig. 2B, the increasing trend of HF with older age is concomitant with that observed for falls, where HF incidence density peaked at ages 80–84. Like with falls, the incidence density of HF was higher in females at 5.58 per 1000 person-years compared to males at 4.88 per 1000 person-years, although the difference was not statistically significant ($p = 0.168$).

3.3. Lifetime risk of falls

At age 50, the estimated lifetime risk of falls was 72.81 % (70.46–75.17) for males and 86.61 % (84.43–88.78) for females, as shown in Fig. 3A. The lifetime risk of falls in women was significantly higher than in men across all age groups (Table 2).

Fig. 4 shows the statistically significant ($p < 0.05$) factors affecting

Table 1
Baseline characteristics of participants in falls and hip fractures.

	Fall		Hip fracture	
	No	Yes	No	Yes
Gender				
Male	3561(70.8 %)	1467(29.2 %)	5517(96.7 %)	188(3.3 %)
Female	3243(61.9 %)	1997(38.1 %)	5994(96.3 %)	233(3.7 %)
BMI				
Low	3010(65.8 %)	1566(34.2 %)	5156(96.3 %)	196(3.7 %)
Normal	394(64.2 %)	220(35.8 %)	696(95.2 %)	35(4.8 %)
High	2450(67.8 %)	1161(32.2 %)	4102(96.9 %)	130(3.1 %)
Waist				
Central obesity	3543(67.1 %)	1739(32.9 %)	5927(96.5 %)	213(3.5 %)
Normal	2267(65.7 %)	1183(34.3 %)	3947(96.5 %)	145(3.5 %)
Balance				
Good	4522(68.5 %)	2084(31.5 %)	7368(96.7 %)	248(3.3 %)
Fair	1165(61.3 %)	736(38.7 %)	2234(96.3 %)	87(3.7 %)
Poor	109(62.3 %)	66(37.7 %)	220(95.2 %)	11(4.8 %)
Lower limb strength				
Fair	4128(68.5 %)	1894(31.5 %)	6754(97.3 %)	184(2.7 %)
Poor	1560(62.7 %)	927(37.3 %)	2881(95 %)	151(5 %)
Hypertension				
Yes	1595(64.8 %)	866(35.2 %)	2813(96.1 %)	113(3.9 %)
No	5179(66.8 %)	2578(33.2 %)	8638(96.6 %)	305(3.4 %)
Dyslipidemia				
Yes	587(65.7 %)	306(34.3 %)	1031(96.7 %)	35(3.3 %)
No	6086(66.3 %)	3095(33.7 %)	10248(96.4 %)	383(3.6 %)
Diabetes or hyperglycemia				
Yes	346(62.5 %)	208(37.5 %)	658(95.4 %)	32(4.6 %)
No	6400(66.5 %)	3221(33.5 %)	10746(96.5 %)	387(3.5 %)
Cancer and other malignancies[a]				
Yes	73(75.3 %)	24(24.7 %)	118(97.5 %)	3(2.5 %)
No	6701(66.2 %)	3425(33.8 %)	11338(96.5 %)	417(3.5 %)
Chronic lung disease				
Yes	636(62.0 %)	390(38.0 %)	1218(96.1 %)	50(3.9 %)
No	6146(66.8 %)	3057(33.2 %)	10254(96.5 %)	367(3.5 %)
Liver disease				
Yes	229(59.0 %)	159(41.0 %)	454(95 %)	24(5 %)
No	6532(66.6 %)	3277(33.4 %)	10970(96.5 %)	395(3.5 %)
Heart disease				
Yes	734(61.5 %)	459(38.5 %)	1377(95.4 %)	67(4.6 %)
No	6037(66.9 %)	2984(33.1 %)	10070(96.6 %)	350(3.4 %)
Stroke				
Yes	101(52.3 %)	92(44.7 %)	240(95.2 %)	12(4.8 %)
No	6687(66.6 %)	3359(33.4 %)	11240(96.5 %)	407(3.5 %)
Kidney disease				
Yes	368(58.7 %)	259(41.3 %)	731(94.7 %)	41(5.3 %)
No	6390(66.8 %)	3178(33.2 %)	10698(96.6 %)	378(3.4 %)
Gastric or digestive system disease				
Yes	1409(63.0 %)	829(37.0 %)	2653(96 %)	111(4 %)
No	5375(67.2 %)	2625(32.8 %)	8826(96.6 %)	308(3.4 %)
Emotional and mental problems[a]				
Yes	68(64.2 %)	38(35.8 %)	137(96.5 %)	5(3.5 %)
No	6703(66.3 %)	3414(33.7 %)	11319(96.5 %)	415(3.5 %)
Memory disease				
Yes	67(58.3 %)	48(41.7 %)	140(94.6 %)	8(5.4 %)
No	6713(66.3 %)	3405(33.7 %)	11331(96.5 %)	411(3.5 %)
Arthritis and rheumatic diseases				
Yes	2009(59.2 %)	1384(40.8 %)	3959(95.3 %)	194(4.7 %)
No	4782(69.8 %)	2073(30.2 %)	7528(97.1 %)	227(2.9 %)
Asthma				
Yes	231(65.6 %)	121(34.4 %)	425(95.1 %)	22(4.9 %)
No	6549(66.3 %)	3330(33.7 %)	11043(96.5 %)	396(3.5 %)
Past smoking				
Yes	2889(70.0 %)	1237(30.0 %)	4602(96.6 %)	160(3.4 %)
No	3911(63.7 %)	2227(36.3 %)	6905(96.4 %)	261(3.6 %)
Past drinking				
Yes	956(66.0 %)	493(34.0 %)	1644(96.2 %)	65(3.8 %)
No	4091(65.0 %)	2206(35.0 %)	7003(96.5 %)	251(3.5 %)
Habit of napping				
Yes	3661(67.5 %)	1763(32.5 %)	6023(96.5 %)	218(3.5 %)
No	3143(64.9 %)	1701(35.1 %)	5488(96.4 %)	203(3.6 %)
Self-rated health				
Good	1786(71.8 %)	702(28.2 %)	2659(97.6 %)	66(2.4 %)
Fair	3263(67.5 %)	1572(32.5 %)	5358(96.6 %)	187(3.4 %)
Poor	1753(59.6 %)	1189(40.4 %)	3491(95.4 %)	168(4.6 %)
Visual acuity (far vision)				

(continued on next page)

Table 1 (*continued*)

	Fall		Hip fracture	
	No	Yes	No	Yes
Good	2835(70.7 %)	1176(29.3 %)	4314(97.1 %)	131(2.9 %)
Fair	2617(65.4 %)	1387(34.6 %)	4489(96.6 %)	160(3.4 %)
Poor	1296(59.6 %)	878(40.4 %)	2621(95.3 %)	128(4.7 %)
Visual acuity (near vision)				
Good	2386(69.5 %)	1045(30.5 %)	3740(97 %)	115(3 %)
Fair	2895(66.2 %)	1475(33.8 %)	4921(96.4 %)	186(3.6 %)
Poor	1468(61.5 %)	919(38.5 %)	2758(95.9 %)	118(4.1 %)
Hearing ability				
Good	3308(70 %)	1418(30 %)	5102(97 %)	157(3 %)
Fair	2647(64 %)	1491(36 %)	4769(96.4 %)	180(3.6 %)
Poor	846(60.6 %)	551(39.4 %)	1632(95.1 %)	84(4.9 %)
Motor skills				
Good	3521(71.3 %)	1418(28.7 %)	5366(97.5 %)	138(2.5 %)
Fair	2328(62.5 %)	1396(37.5 %)	4252(96.4 %)	161(3.6 %)
Poor	838(58.3 %)	600(41.7 %)	1702(93.9 %)	111(6.1 %)
Activities of daily living				
Normal	2775(65.1 %)	1488(34.9 %)	4744(96.4 %)	177(3.6 %)
Disability	4026(67.1 %)	1976(32.9 %)	6763(96.5 %)	244(3.5 %)

[a] The maximum age of the group was 84 to avoid extremity value owing to the small amount of sample at the margin.

the lifetime risk of falls in specified age groups. Each age group had a different combination of factors influencing the lifetime risk of falls.

For individuals at age 50, conditions associated with a higher lifetime risk of falls included gastric or digestive system diseases, as well as arthritis and rheumatic diseases. Other individuals with increased lifetime risk were those without a habit of napping or had poor auditory and visual abilities. On the other hand, individuals with cancer and other malignancies had a lower lifetime risk of falls, as well as those who had a history of smoking or alcohol consumption.

Individuals at age 60 no longer showed gastric diseases or alcohol consumption as statistically significant factors for increased lifetime risk of falls compared to those at age 50. In addition to arthritis and rheumatic diseases, cancer and other malignancies, smoking history, napping, and visual and auditory abilities, central obesity became a new factor that significantly increased the lifetime risk of falls.

For individuals at age 70, the effects of napping and hearing ability on the lifetime risk of falls were no longer statistically significant in comparison to those at age 60. Vision had an effect on the lifetime risk of falls at the $p = 0.1$ rather than $p = 0.05$ level (Supplemental file 4). Factors relating to body composition, abnormal blood lipids, and physical capability became significant in influencing the lifetime risk of falls. Individuals with high BMI, central obesity, and dyslipidemia were estimated to have a higher lifetime risk of falls. Meanwhile, compared to individuals with good motor skills, those with poor motor skills had a lower lifetime risk of falls. Among all aforementioned factors, only arthritis and rheumatic diseases, cancer and malignancies, and smoking history consistently influenced the lifetime risk of falls in the 50s, 60s, and 70s age groups at the $p = 0.05$ level.

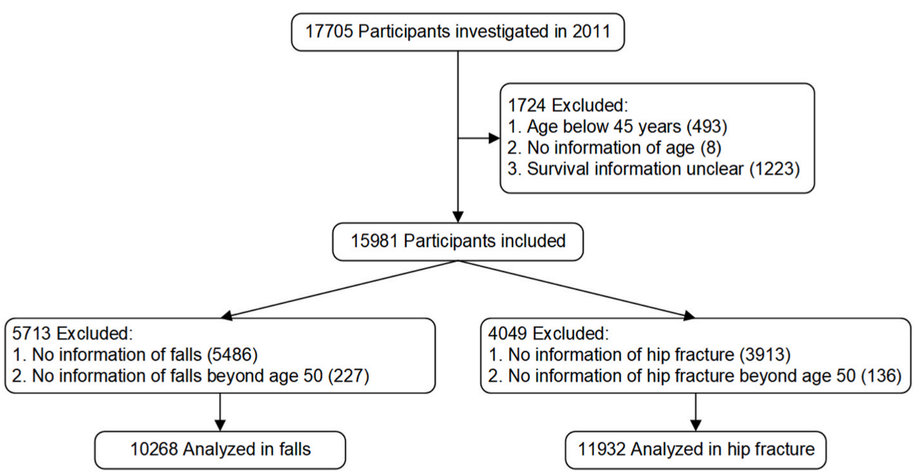

Fig. 1. Flow diagram of the selection process.

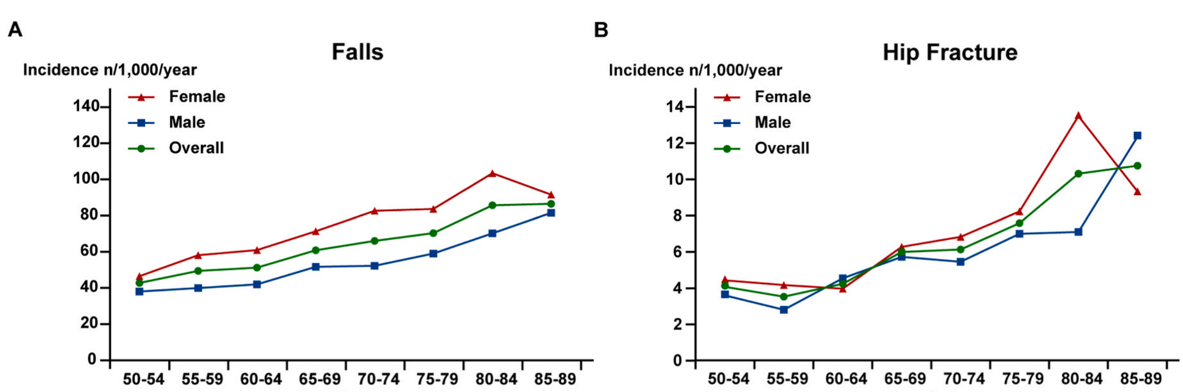

Fig. 2. Incidence of falls and HF with increasing age.
The incidence rate of falls (A) and hip fracture (B) divided by every 5 years of age is shown. The rate for females, males and the overall population is separately analyzed.

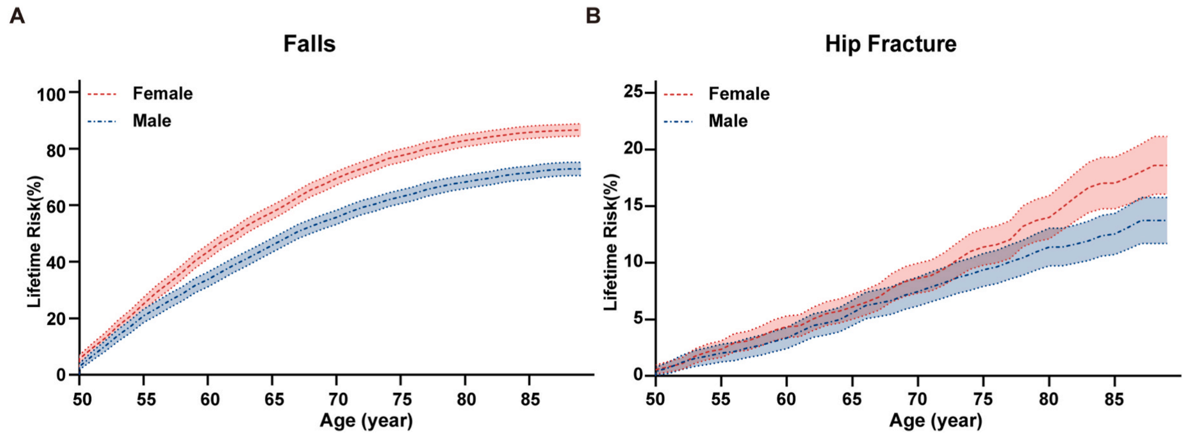

Fig. 3. Lifetime risk of falls and HF in males and females from 50 years of age.
The lifetime risk of falls (A) and hip fracture (B) from 50 to 89 years of age is shown. The rate for females and males is separately analyzed.

Table 2
Age-specific and sex-specific mortality-adjusted 10-year, 20-year, 30-year and lifetime risk of falls.

	Fall			
	Short-term and intermediate-term risks			Lifetime risk
	10 year	20 year	30 year	
Female				
50	40.28 (37.72–42.83)	67.32 (64.89–69.75)	82.00 (79.74–84.25)	86.61 (84.43–88.78)
60	47.06 (44.37–49.74)	72.60 (70.01–75.19)	··	80.62 (78.20–83.05)
70	52.66 (48.71–56.60)	··	··	69.19 (65.32–73.05)
Male				
50	31.59 (29.01–34.17)	54.23 (51.72–56.74)	67.44 (65.04–69.84)	72.81 (70.46–75.17)
60	35.28 (32.85–37.70)	55.87 (53.26–58.48)	··	64.24 (61.63–66.85)
70	37.16 (33.79–40.54)	··	··	52.27 (48.62–55.93)

Risks shown as percentages (95 % CI). Comparison of HF or falls risk in corresponding age and sex categories with z-test. $p < 0.05$.

3.4. Lifetime risk of HF

The lifetime risk of HF was significantly higher in females than in males at all age groups (Table 3), which was in alignment with the trend observed for falls. At age 50, the lifetime risk of HF was 13.72 % (11.70–15.75) for males and 18.58 % (16.04–21.12) for females, as shown in Fig. 3B. The lifetime risk of HF for males aged 60 was 11.65 % (9.64–13.66) and for females was 15.67 % (13.08–18.26). Those aged 70 showed HF lifetime risk as 8.58 % (6.44–10.73) for males and 12.35 % (9.63–15.06) for females. The statistically significant ($p < 0.05$) factors influencing the lifetime risk of HF differed among age groups and were also different compared to those observed for falls, as shown in Fig. 4.

For individuals at age 50, those with weaker lower limb strength had a higher lifetime risk of HF compared to healthy individuals, as well as those with arthritis or rheumatic diseases, those who self-rated their health as poor, and those with poor motor skills. Interestingly, individuals with a history of smoking had a lower lifetime risk of HF. Based on a significance level of $p = 0.1$, individuals with poor distant vision or poor hearing ability had a higher lifetime risk of HF compared to those with good abilities. Those with fair near vision also had higher risk than those with good vision. To our surprise, BMI was not a factor affecting the risk of HF in any of the age groups (Supplemental file 4).

For individuals at age 60, compared to those at age 50, their near vision and hearing ability became significant factors influencing the lifetime risk of HF at the $p = 0.05$ level, while far vision was no longer a significant factor at the $p < 0.1$ level. Individuals with fair near vision, rather than poor near vision, had a higher lifetime risk of HF compared to those with good vision, while those with poor hearing had higher risk than people with good hearing. Individuals with poor motor skills had a higher risk of HF compared to those with good motor skills. Although not statistically significant, a higher waist circumference showed correlation with lifetime risk of HF in individuals aged 60 and above (Supplemental file 4).

For individuals at age 70, compared to those at age 60, most factors no longer had statistical significance in influencing the lifetime risk of HF at the $p = 0.05$ level, including lower limb strength, arthritis or rheumatic diseases, self-rated health status, hearing ability, and motor skills. The exceptions were smoking history and near vision, which continued to have a significant effect on increasing lifetime risk of HF. At the $p = 0.1$ level, individuals with poorer lower limb strength, arthritis or rheumatic diseases, and poorer self-rated health were estimated to have a higher lifetime risk of HF. Surprisingly, among all investigated factors, only smoking history was a common factor influencing the lifetime risk of both falls and HF in the 50s, 60s, and 70s age groups at the $p = 0.05$ level. Additionally, arthritis and rheumatic diseases influenced the lifetime risk of both falls and HF in all age groups at the $p = 0.1$ level.

3.5. Region-stratified lifetime risk of falls and HF

The lifetime risk of falls (Fig. 5) and HF (Fig. 6) was additionally analyzed by geographical region, by dividing the sampled population into six regions of China including north-east, north, north-west, east, central-south, and south-west. The north-west region accounted for the highest lifetime risk of HF, yet the lowest risk of falls. The south-west and central-south regions reached the highest risk of falls and moderate risk of HF. The north, east, and north-east regions generally showed lower risk of both HF and falls than other regions.

4. Discussion

This was the first study to have examined a large sample size of middle-aged and elderly Chinese individuals for their lifetime risk of falls and HF. Multi-dimensional influencing factors were identified, such as disease history, obesity-related factors, hearing abilities, physical indexes including lower limb strength and motor skills, and several daily habits. Uniquely, this study also identified the pattern of vision affecting on HF, and included stratification of lifetime risk among six regions in China. The findings of this study give novel insight into the contributions

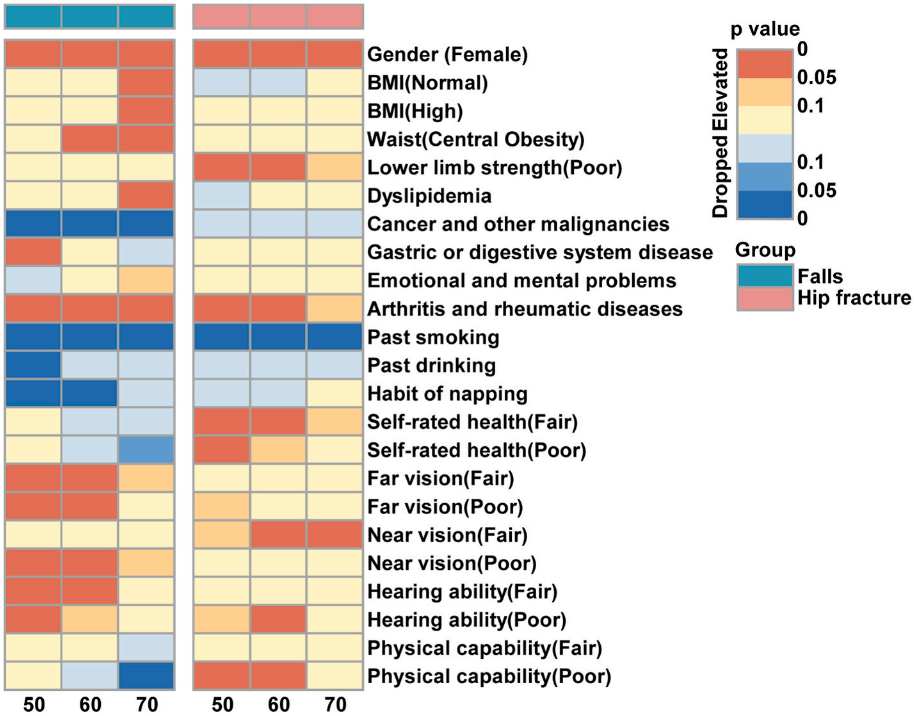

Fig. 4. Risk-stratified lifetime risk of falls and HF from 50, 60, and 70 years of age. All patients (those with the listed factors) were compared with healthy individuals (those without the factors; or male when referring female; or those with low level when referring BMI; or those with good level when referring self-rated health, far vision, near vision, hearing ability or motor skills).

Table 3
Age-specific and sex-specific mortality-adjusted 10-year, 20-year, 30-year and lifetime risk of HF.

	Hip fracture			
	Short-term and intermediate-term risks			Lifetime risk
	10 year	20 year	30 year	
Female				
50	4.01 (3.09–4.94)	8.34 (7.05–9.63)	13.73 (11.86–15.59)	18.58 (16.04–21.12)
60	4.65 (3.64–5.67)	10.45 (8.67–12.24)	..	15.67 (13.08–18.26)
70	6.50 (4.80–8.19)	..	..	12.35 (9.63–15.06)
Male				
50	3.03 (2.12–3.95)	7.15 (5.89–8.40)	10.95 (9.34–12.56)	13.72 (11.70–15.75)
60	4.48 (3.51–5.45)	8.63 (7.14–10.12)	..	11.65 (9.64–13.66)
70	4.96 (3.57–6.35)	..	..	8.58 (6.44–10.73)

Risks shown as percentages (95 % CI). Comparison of HF or falls risk in corresponding age and sex categories with z-test. $p < 0.05$.

of diverse risk factors to the long-term risk of falls and HF, as well as how these risk factors may change in different age groups.

In this study, the lifetime risk of HF in women was found to be higher than men across all age groups, which also escalated with age. Overall, we found 18–20 % lifetime risk of HF in females, similar to that seen in other populations such as Japan and USA [29,30]. The significantly higher risk of HF in women, particularly with advancing age could be explained by drastic hormonal changes after menopause, which is intimately associated with bone and muscle health. The post-menopausal drop in estrogen levels leads to subsequent bone loss and hence a higher risk of HF, compared to males in the same age group who continue to be protected by testosterone in bone growth and maintenance [31]. In addition, reduced estrogen induces muscle loss [32–34], where the decline in muscle mass particularly in the lower limbs contributes to a higher risk of both falls and HF in the elderly. This is in line with the pattern observed in our study on the lifetime risk of falls, which increased to a greater extent in females compared to males with advancing age.

Interestingly, our study found that overall lifetime risk of HF at age of 50 in Chinese males was significantly higher than other populations such as Japan, USA, Sweden, and Botswana by approximately 3%–10 % [29,30,35]. The risk of falls in our survey of the Chinese males was also higher than in Japan and the USA [36,37]. A possible reason is the high incidence density of accidental fractures in China. As a developing country with high overall population and high population density in many regions, a majority of middle-aged and elderly individuals in China predominantly rely on physical modes of transportation such as cycling. The susceptibility to falls due to loss of balance and external collisions makes cycling the leading contributor to accidental HF in China, accounting for half of the total incidences of HF in males compared to only 30 % in females [38]. China is also confronted with significant imbalance between a rapidly growing aged population and an unmet need in programs on falls and HF prevention, both through official intervention and self-awareness [39]. Although guidelines have recently emerged regarding osteoporotic HF in the Chinese population, few official documents were implemented to advocate a comprehensive HF prevention strategy [40]. Our findings highlight the importance of considering the gender-specific long-term risk of HF in the male Chinese population, which might have been previously overlooked.

Interestingly, we also found that the incidence of both falls and HF in females had a peak at age 80–84 followed by subsequent decline at ages over 85. As shown in supplemental file 4, in the calculation of incidence density, each death contributes half of the person's time at risk, weighted according to their age at death. Excess mortality, as a competing risk, could "substitute" the increase in risk of observed events, potentially resulting in a lower incidence. Compared to Chinese women in the 80–84 age group, those aged over 85 show a surge in mortality by approximately 70 %, while the increase in mortality is

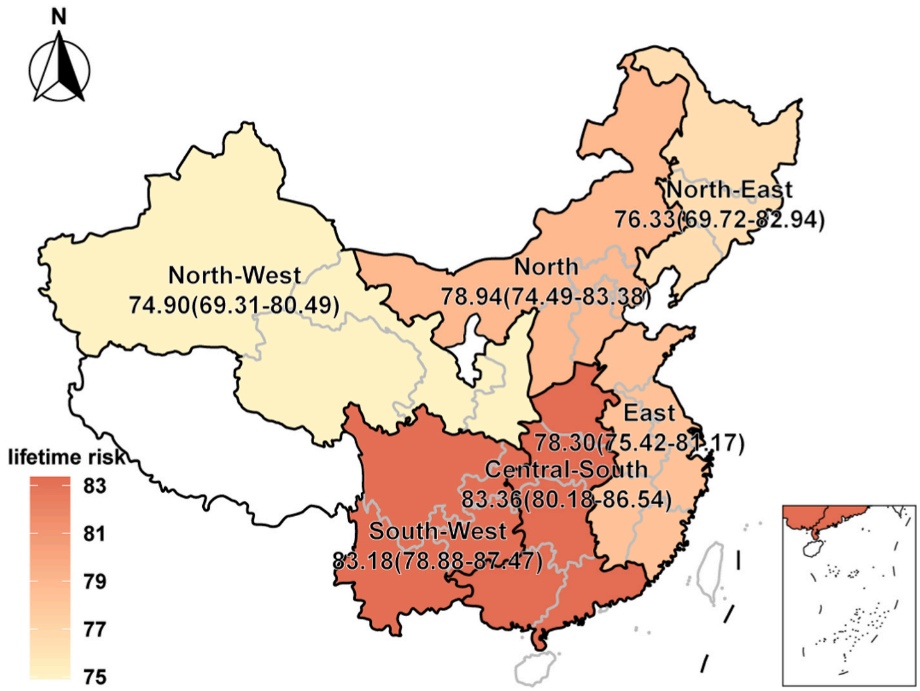

Fig. 5. Region-stratified lifetime risk of falls.

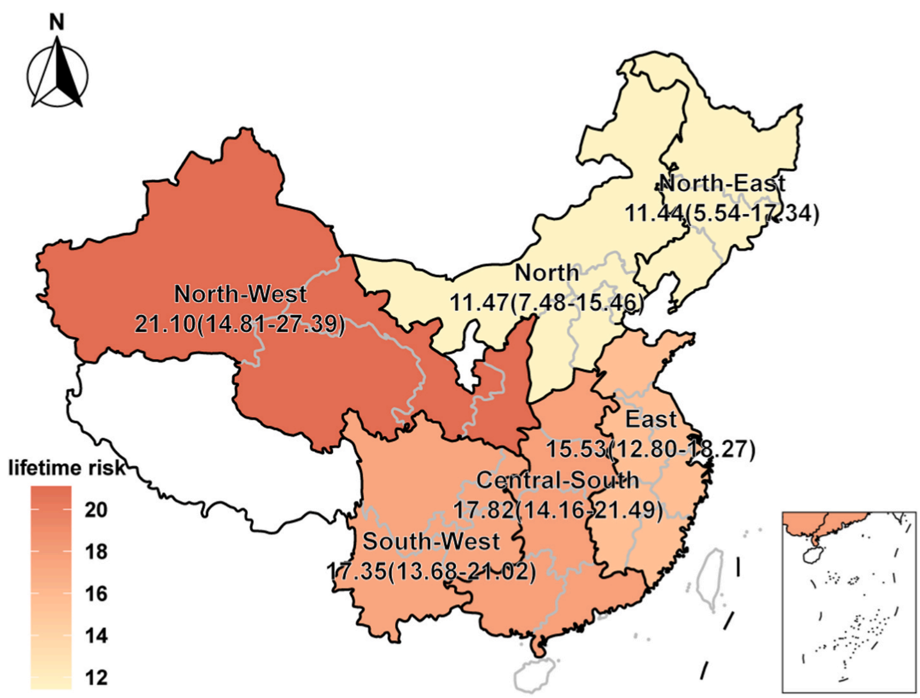

Fig. 6. Region-stratified lifetime risk of HF.

lower for men from the 80–84 age group to the >85 age group, by about 56 % [41]. Furthermore, the reduced incidence of falls and HF with age in women could be related to reduced mobility caused by other diseases. For instance, the incidence of malignancies peaks at age 80–84 in women, while mortality peaks beyond age 85, which may imply that a notable portion of female patients over 85 suffer from terminal stages of cancer or consuming conditions before death, constraining them to indoor activities or the bed and hence reducing the chance of falls or HF [42,43]. Likewise, the prevalence of cardiovascular diseases leading to activity intolerance is higher in women over 85 than in men [44], which could result in reduced physical activity in aged women and contribute to lessening the occurrence of falls or HF. However, our observations require validation with recent data from different populations, as the same pattern of reduced incidence of falls and HF in older women was not found in other research studies on the Chinese population [45,46].

Factors relating to body indexes indicated that weight gain and obesity were correlated with higher lifetime risks of both HF and falls, with greater influences on the latter. People over 60 with higher waist circumference (as a measure of central obesity) faced higher risk of HF, an observation that was in alignment with a meta-analysis reporting positive correlation between abdominal obesity and HF [47]. Furthermore, we found that the risk of falls was more significantly influenced by obesity-related factors as individuals aged. At 60 years of age, central obesity increased the lifetime risk of falls, while at 70 years many more obesity-related factors including BMI, central obesity, and dyslipidemia all became significantly associated with falls risk. This pattern might be explained by alterations in body composition during aging, whereby adipose tissue is redistributed to have lower subcutaneous fat accompanied by increased visceral fat as well as intramuscular and bone marrow deposits [48], rendering individuals more susceptible to musculoskeletal problems such as sarcopenia. Moreover, a study reported that only 13.8 % of the intermediate effect of BMI on fractures was attributable to falls, which might explain our findings where individuals with higher BMI were more prone to falls but did not necessarily have a heightened risk of HF [49]. Although falls are not necessarily correlated with a higher risk of HF, prevention is essential in elderly people due to the greater likelihood of morbidity and mortality, particularly for those with high BMI and central obesity, and simultaneous weight loss programs might be helpful.

Our study found some interesting patterns on factors relating to body functions. One of the findings was that far vision only impacted the susceptibility to falls and not HF, while only fair near vision significantly increased the risk of HF rather than other kinds of incompetent vision. A few explanations might be offered. For instance, people with incompetent far vision might only be able to focus on their close surroundings without overall awareness of the environment, which makes them more susceptible to accidents and collisions involving other pedestrians or objects, hence leading to more frequent falls. Meanwhile, poor near vision such as due to presbyopia or severe myopia would dramatically increase the risk of tripping over and falling compared to fair near vision [50]. Nevertheless, these types of falls are more likely to result in the person stumbling and hitting the floor with their knees, rather than a lateral force to the hip or thigh that might directly lead to HF [51]. Moreover, those with poor eyesight, either poor far vision or near vision, are more likely to reduce their outdoor activity [52], while compared to the fair far vision, fair near vision leads to a much dumber reaction to the environment, rendering an increased risk of severe accidents and HF, possibly explaining why only people with fair near vision have higher risk of HF due to the increased chance of outdoor collisions. Increasing accessibility of aging individuals to sensory aids such as prescription glasses might help contribute to falls and HF prevention.

Another finding was that individuals with weaker lower limb strength or poorer motor skills had significantly higher lifetime risk of HF compared to those with normal physical abilities. Lower limb muscles are essential for balance control, making individuals with weaker muscles more likely to experience loss of balance and hence fractures during physical activity such as walking or running [53]. Moreover, loss of lower extremity muscle mass is frequently accompanied by reduced BMD, constituting another factor that increases fracture risk [54]. Regular ambulatory activity is therefore recommended to reduce the risk of falls and HF, which might help with improving motor skills, building up lower limb muscle strength, and reducing bone loss [55,56]. Aerobic exercise could also delay or prevent the development of osteoarthritis, which is a vital factor influencing the lifetime risk of both falls and HF [57]. Therefore, regular and sustained lower limb exercises might be recommended to enhance physical capabilities and provide long-term protective effects against falls and HF for the 50s–70s age groups.

Surprisingly, individuals with a history of alcohol consumption were found to have lower lifetimes risks of falls and HF. A potential explanation was that people with light alcohol consumption were included as having drinking history along with heavy drinkers. Although heavy alcohol consumption (>50 g/day) is toxic to bones, light alcohol consumption (0–12.5 g/day) might actually help increase BMD in the hip and other weight-bearing locations, promote calcitonin release, and decrease bone resorption [58–60]. These effects are beneficial for maintaining physical skills and activities, and hence might result in a lower risk of falls and HF. Furthermore, we found that individuals aged 50–60 who habitually took naps had lower lifetime risk of falls, while the effect of napping was no longer significant in the 70s age group. We speculated that napping might supplement insufficient sleeping time at night and improve focus, particularly for middle-aged individuals in the 50–60 age group who were not yet retired, and hence were more likely to be affected by nighttime sleeping problems due to stress. This proposition aligned with a recent finding that short night sleep duration accompanied with napping could be effective in preventing falls [61]. Napping after lunch or during the day may be more of a cultural habit particularly in China, but might be worth considering as part of a falls prevention strategy in other global regions.

Following from the above discussion, two well-supported approaches for lowering the risk of falls and HF are recommended for the middle-aged population. The first recommendation is to build up physical strength, especially lower limb strength and physical capability, for which a mixture of aerobic and anaerobic exercise is strongly advised. Secondly, a timely and suitable aid for any vision or hearing impairment is needed, as mediocre effectiveness may even increase the risk of injury. Furthermore, chronic diseases such as digestive system disorders may affect the risk of falls and HF. Studies have shown that people with cirrhosis are prone to falls injury, followed by a doubling in mortality rate. Frailty in cirrhosis patients may be associated with damaged protein metabolism for maintaining lower limb strength, imbalanced serum sodium level for maintaining neurotransmission and cognitive function, as well as poor quality of life [62,63]. Gastropathy patients taking proton pump inhibitor are also more likely to develop HF, although the mechanism remains unclear [64]. Altogether, a good physical form, optimal sensory aids, and health status may help to reduce the long-term risk of falls and HF in the middle-aged population.

The observed regional variations in falls and HF risk could be explained by geographical and socioeconomic factors. The north-west region of China is at a higher altitude with minimal precipitation compared to other regions. It is possible that long-term hypoxia due to high altitude might contribute to a lower BMD and greater likelihood of trabecular bone deterioration [65,66]. Resulting bone fragility might partly explain the highest risk of HF in this region despite a minimal risk of falls. Low precipitation levels might also encourage more outdoor physical activities that increase the risk of accidental fracture. In other regions, the trend of HF risk generally matched that of falls risk. The south-west and central-south regions have rugged and mountainous terrains, which might make residents more susceptible to falls and subsequent HF, while the other regions are relatively flat and show reduced risks of both falls and HF. Among the regions with flatter terrain, east China shows a relatively higher risk of HF. This might be associated with the more developed economic status and urbanization seen in this region compared to the rest of China. As residents have easier access to public facilities and have greater need for recreation and other activities, they become more susceptible to accidental injuries. This is in alignment with the reported higher incidence of HF in developed countries, although the risk of HF in more developed areas of China might also drop in the future according to the patterns experienced by developed countries [46,67].

Research on lifetime risk of health-related conditions or events, especially in the field of orthopedics, is currently lacking in China. A major advantage of this study is the systematic exploration of age-specific incidence density and lifetime risks of falls and HF with a much broader scope compared to the limited available evidence (including physiological indicators, lifestyle habits, and chronic diseases), and among a more extensive population (representing the entire country, rather than a specific region). The increased precision and knowledge gain offered by this study is credited to the utilization of a nationally representative longitudinal survey for the Chinese middle-aged to elderly population, enabling accurate extrapolation of results.

Some study limitations need to be acknowledged. Firstly, unclear death records in the CHARLS database might lead to underestimating the competing risk of mortality when predicting lifetime risk, where the next survey date was taken as the date of death for individuals who have passed away between surveys. Secondly, we did not conduct a multivariate analysis on the included risk factors, thus neglecting the interaction effects between factors and the influence of confounding factors. Thirdly, the data collectors could not reach Ningxia, Xizang, Hainan and Taiwan to enable data collection from these provinces. The data and outcomes presented in this study should therefore be interpreted with the notion that they may not be fully representative of the whole population of China. Moreover, there was disparity in baseline characteristics between the included and excluded population. The difference may affect the validity of the analysis, and further study is needed for the robustness of the outcome. It should be noted that many of the factors may have causal effects on each other, such as between obesity-related factors and arthritic conditions, which warrant more extensive characterization in future studies to increase the accuracy of findings on their contribution to risk of falls and HF.

5. Conclusion

The lifetime risks of falls and HF are significant in the Chinese middle-aged to elderly population. Various factors relating to body composition, physical function, daily habits, and chronic diseases affect the lifetime risk of falls and HF, and the level of risk differed among six regions in China. These findings are important for directing future programs aimed at prevention and self-awareness of falls and HF in China, and may offer effective comparison for studies on other global populations.

Data availability statement

All the data generated or analyzed during this study are included in this published article and its supplementary files. Individual's reports are available and can be retrieved from the China Health and Retirement Longitudinal Study (http://charls.ccer.edu.cn/charls/).

Author contribution

Guangyuan Du, Zijuan Fan, Kenan Fan conceptualized the article theme, searched and critically reviewed the relevant literature, wrote the article and approved its final version. Haifeng Liu, Jing Zhang, Dijun Li, Lei Yan, Jingwei Jiu, Ruoqi Li, Xiaoke Li, Songyan Li, Yiqi Yang, Ligan Jia, Xuanbo Liu, Yijia Ren, and Huachen Liu visualized and validated the data. Bin Wang and Jiao Jiao Li Funding acquisition, reviewed the writing, administrated and supervised the project.

The use of AI and AI-assisted technologies in scientific writing

We declare no AI or AI-assisted technology was used.

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Declarations of competing interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jot.2024.10.013.

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