RESEARCH ARTICLE

Association between relative handgrip strength and hypertension in Chinese adults: An analysis of four successive national surveys with 712,442 individuals (2000-2014)

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Abstract

Objectives

This study aimed to identify the 15-year trends of handgrip strength-to-weight (relative HS) and assess the association between relative HS and hypertension among Chinese adults aged 20–69.

Methods

Using a complex, stratified, multistage probability cluster sampling, we analyzed data collected from 712,442 adults aged 20–69 years in four successive national surveys (2000–2014). We used a handheld dynamometer to measure strength and divided by body weight to calculate the relative HS. Blood pressure was recorded with a sphygmomanometer and hypertension was defined as resting systolic blood pressure at least 140 mmHg or diastolic at least 90 mmHg. The Mann-Kendall trend test examined trends in relative HS over time. We also computed odd ratios (OR) and 95% confidence intervals (95% CI) by tertile of relative HS and examined the association between relative HS and hypertension.

Results

The relative HS level decreased with the increase of age in both male and females (p trend <0.001). In each of four surveys, one interquartile decrease in relative HS was associated with an increased risk of hypertension by 44% (OR = 1.44, 95%CI: 1.40–1.47), 58% (OR = 1.58, 95%CI: 1.54–1.62), 48% (OR = 1.48, 95%CI: 1.45–1.52), 43% (OR = 1.43, 95%CI: 1.40–1.47), respectively.
Conclusion
In the Chinese adult population, the relative HS level decreased from 2000 to 2014 across all ages in both males and females. A lower relative HS was associated with a higher risk of hypertension. The findings provided evidence for the association between muscle strength and hypertension in large-scaled population.

Introduction
Hypertension is a common health problem worldwide [1]. The China Patient-Centered Evaluative Assessment of Cardiac Events (PEACE) study indicated that nearly half of Chinese adults aged 35–75 years old had hypertension, and fewer than one in twelve were in control of their blood pressure [2]. The poor blood pressure control warrants greater efforts on primary prevention in China [2, 3].

Regular exercise is an essential component of a lifestyle intervention for the primary prevention of hypertension [4]. Absolute handgrip strength (HS) is commonly used as a surrogate measurement of overall muscle strength, which can be developed by regular exercise [5, 6]. There is global variation in absolute HS across different countries and regions, with the HS level being higher in Western countries than in Asian countries [7]. In a previous study, we have observed a decreasing absolute HS with rising age in both sexes among the Chinese population during the past 15 years [8].

The evidence regarding the association between absolute HS and hypertension is inconclusive. A meta-analysis summarized that an increase of absolute HS exercise was associated with a lower risk of hypertension in adults, but these findings had limitations given the small number of low-quality randomized controlled trials [9]. Two cross-sectional studies conducted in Western countries (the Netherlands and the USA) indicated that increased absolute HS was associated with higher blood pressure in the general population [10, 11]. We found only one relevant study conducted in rural areas in China, reporting that increased absolute HS was associated with a higher risk of hypertension in women [12].

The above studies had one common feature: they used absolute HS, rather than relative HS (handgrip strength to body weight or BMI ratio), which might be more comparable among people with different body mass [13, 14]. When using the relative HS, three studies conducted in Asian countries (Korea and China) indicated that a higher relative HS was associated with a lower blood pressure, especially in the adult men [13–15]. However, the sample sizes were limited in the previous studies with the numbers of participants ranging from 927 to 5,014.

In the present study, we analyzed the Chinese National Survey on Adults’ Fitness in 2000, 2005, 2010, and 2014. The study aimed to identify the 15-year trends of relative HS in different age and sex groups from 2000 to 2014 and assess the association between relative HS and hypertension among Chinese adults aged 20–69.

Methods
Study design and participants
We used the data from 2000, 2005, 2010, and 2014 Chinese National Survey on Adults’ Fitness, the largest nationally representative survey of civilians in China, using a complex, stratified, multistage probability cluster sampling design. The detail of the recruitment has been described elsewhere [8].
In brief, the 31 provinces, autonomous regions, and municipalities in mainland China were covered in the first stage. At the second stage, subject to their economic positions weighted by GDP assessment, three sub-provincial or prefectural-level cities (i.e., a division ranked between province and county in China’s administrative structure) were randomly selected from each province. At the third stage, three urban districts (or three rural counties) of each city were picked out. At the fourth stage, three city streets (or rural towns) were chosen. At the fifth stage, two street community societies (or villages) were selected. At the final stage, at each street community society (or village), eligible participants living there for more than three years were selected by systematic sampling method.

The study protocol had approval from the ethical review committee of the China Institute of Sport Science. Each enrolled participant signed an informed consent form.

**Procedures**

Through the questionnaire survey and standard physical and physiological measurement, the trained investigators collected the data. We investigated career, education, urban and rural place, nationality (Han or minority) with the questionnaire. For exercise time, the participants were asked to recall the number of days and the exercise duration in the usual past week during the last year. The questionnaire was validated among Chinese adults (n = 2014, aged 20–75 years) [8].

Participants’ weight and height were measured using a calibrated digital scale, stadiometer (Jianmin II, China). Before the measurement, participants with lightweight clothes took off their shoes. The measured weight was rounded up to 0.1kg and height was rounded up to 0.1cm, respectively. The blood pressure measurement was conducted by the auscultatory method by qualified medical staff. The Riva-Rocci sphygmomanometer, and a medical stethoscope (Yuwell, China) were used for the measurement. The systolic pressure was defined as the first sound heard after releasing the occluded artery. The diastolic pressure corresponded to the final sound heard [16]. Systolic and diastolic blood pressures were recorded in mmHg.

The following measures were taken before and during the data collection:

1. The subjects were asked not to engage in vigorous physical activity within 1–2 hours before the test.
2. The subjects were asked to sit on the chair in silence for 10–15 minutes before the test, and relax.
3. The mercury column of the sphygmomanometer was checked before measurement. If the column was not at the “0” position, the position was corrected. Furthermore, the mercury column was inspected for the presence of bubbles, and if there were bubbles, it was not used.
4. When measuring blood pressure, it was ensured that the upper arm was not pressed tightly by the sleeve of the jacket. It was ensured that the lower edge of the cuff was located at least 2.5 cm above the cubital fossa.
5. When re-testing was needed (the first test was failed by some reasons), it was ensured that the mercury column of the sphygmomanometer dropped to zero before re-testing. Blood pressure re-testing was carried out 10–15 minutes rest on chair after the initial test. Hypertension was defined as resting systolic blood pressure at least 140 mmHg or diastolic at least 90 mmHg according to the common standard [17].
Handgrip measurement
We used the handgrip meter (Jianmin II, China) to measure the dominant hand handgrip strength. Before the measurement, the subjects held the grip handles with dominant hand and adjusted the grip width to the appropriate force grip. During the measurement, the participants' body was upright, feet were naturally separated at shoulder width, while arms were inclined and drooping. After three consecutive tests, with adequate rest interval in between, we recorded each participant’s best score as the final result. The grip strength test value is in kg, rounded up to 0.1kg.

Body fat measurement
We used the Skinfold Thickness Meter (Jianmin II, China) to measure the skinfold thickness from three different body sites (triceps, subscapular, and abdomen). We measured three times for each body position and took the median value or two of the same value as the final result. We added three different skinfold thickness measurements to reflect the body fat (skinfold thickness).

Statistical analyses
We described the median (interquartile, IQR) of relative HS (HS to body weight ratio) in different survey years since relative HS was not normally distributed. In the study, the bootstrap percentile method (the number of bootstrap replicates is 500 times) was used to calculate confidence intervals for medians [18, 19]. We used the Mann–Whitney U test or Kruskal–Wallis test to detect the difference in relative HS between sex, urban-rural, nationality, inner-province socio-economic status, education levels, career, nutritional status in the same survey year. We performed the Mann-Kendall trend test to examine the relative HS trend and survey years or increase age groups [20].

To explore the relationship between relative HS and hypertension, we used the tertiles to separate the subjects into three groups (low relative HS, middle relative HS, and high relative HS) according to the different sex, survey year, and age group, then calculated the prevalences of hypertension in different relative HS groups. The Mann-Kendall trend test was used to examine the trend of hypertension prevalences in different years among different tertiles of relative HS.

We used the general linear mixed model to estimate the effect value and odd ratios. Relative HS was analyzed both as a continuous variable and a categorical variable (tertiles, with the highest group as the reference group). We presented the results of two statistical models, in which the province of each participant was used as the random effect. We only put exposure and outcome variables in the crude model. In model 1, we adjusted with age and sex as covariates; In model 2, we further adjusted for the region (rural or urban), the inner-province socio-economic status (low, middle, high), the nationality (Han or minority, data available in three surveys in 2005, 2010 and 2014), the education level (data available in three surveys in 2005, 2010 and 2014), career (government official, technical staff, office staff, commercial and service, agriculture, forestry, animal husbandry and fishery, production, and transportation, soldier, other), and exercise level (whether taking exercise for at least 60 minutes in the usual past week) as covariates.

In the sensitivity analyses [21, 22], we additionally adjusted for the sum of skinfold thickness based on the adjusted model 2. Besides, we calculated another index (HS to BMI ratio) to reflect relative HS and used the same models to analyze its association with hypertension. We did the stratified analysis among underweight, normal, overweight and obesity groups using the body mass index for the category (below 18.5 kg/m² for underweight group, between 18.5
kg/m$^2$ and 23.9 kg/m$^2$ for normal group, above 24.0 kg/m$^2$ for overweight and obesity group) [23].

All the statistical analyses were performed with R software, version 3.6.1. A two-sided $p$-value $<0.05$ was considered as statistical significance.

Results

We included 712,442 participants (177,517 in 2000; 188,521 in 2005; 179,870 in 2010; 166,534 in 2014), while 8,838 participants were excluded for missing main outcome and exposures. The general characteristics and HS levels of the study population in each of the four national surveys were shown in Table 1. Both absolute HS and relative HS had a decreasing trend across the different survey years.

The median of relative HS decreased across all age groups in both men and women from 2000 to 2014 (all $p$ trend $<0.001$, Fig 1, S1 Table). The relative HS median was higher in men than in women across different survey years (all $p < 0.001$). It also decreased in urban and rural areas from 2000 to 2014 (all $p$ trend $<0.001$, Fig 2). The median of relative HS in women was higher in urban areas than those in rural areas across different survey years except for the year 2000 ($p<0.001$ for 2005, 2010, and 2014; $p = 0.828$ for the year 2000, S2 Table). Men who lived in urban areas had a lower median of relative HS than those who lived in rural areas in the year 2000 and 2005 ($p<0.001$, S2 Table), while the median of the male relative HS was higher in urban areas than those in rural areas in the year of 2010 ($p < 0.001$, S2 Table), and there was no difference in the year of 2014 ($p = 0.079$, S2 Table).

As shown in Fig 3 (details in S3 Table), the high relative HS groups had the lowest prevalence of hypertension in both sexes across different survey years ($p<0.001$). In addition, the prevalence of hypertension increased with increasing age groups ($p$ trend $<0.001$) and was higher in men than in women in different survey years (all $p < 0.05$, details in S4 Table).

As shown in Table 2, the higher relative HS was consistently associated with a lower risk of hypertension in different survey years in the adjusted models. Compared with the high relative HS group, the middle and low relative HS groups had a higher risk of hypertension in different survey years ranging from 1.26 to 1.31 and from 1.58 to 1.72, respectively. Using the continuous variable of relative HS, we also found an association between relative HS and the risk of hypertension in different survey years (Table 3). One interquartile range (IQR) deviation decrease in relative HS was associated with higher risk of hypertension in different survey years (OR = 1.44, 95%CI:1.40–1.47 for 2000; OR = 1.58, 95%CI:1.54–1.62 for 2005; OR = 1.48, 95%CI:1.45–1.52 for 2010; OR = 1.43, 95%CI:1.40–1.47 for 2014).

All the sensitivity analyses showed results similar to our main results. We further adjusted the skinfold thickness based on Model 2. The odd ratios of middle and low tertiles for hypertension were 1.10–1.16 and 1.26–1.34, respectively (all $p<0.0001$, S5 Table). Furthermore, another sensitive analysis showed that HS to BMI ratio was also associated with hypertension, which was directionally consistent with the main results (S6 and S7 Tables). In the stratified analysis, the odd ratios of middle and low tertiles for hypertension in model 2 were 1.04–1.07 and 1.04–1.12 in normal weight group, respectively. And the odd ratios of middle and low tertiles for hypertension in model 2 were 1.02–1.08 and 1.18–1.24 in overweight and obesity group (S8 Table). We also separate different sex (S9 and S10 Tables) and age groups (S11 Table) to do the subgroup analysis. The result is correspondence with the main result.

Discussion

This study found that the relative HS was negatively associated with hypertension in national surveys data for Chinese adult population. One interquartile decrease in relative HS was
### Table 1. The general characteristic and handgrip strength levels of the study population in each of the four national surveys from 2000 to 2014.

|                        | 2000     | 2005     | 2010     | 2014     |
|------------------------|----------|----------|----------|----------|
| Sample Size            | 177,517  | 188,521  | 179,870  | 166,534  |
| **sex**                |          |          |          |          |
| male                   | 89,340   | 94,002   | 90,350   | 83,184   |
| female                 | 88,177   | 94,519   | 89,520   | 83,350   |
| **Regions**            |          |          |          |          |
| Rural                  | 61,977   | 67,185   | 63,739   | 58,130   |
| Urban                  | 115,540  | 121,336  | 116,131  | 108,404  |
| **Age group**          |          |          |          |          |
| 20–24                  | 19,330   | 20,306   | 19,407   | 18,726   |
| 25–29                  | 19,262   | 20,292   | 19,210   | 18,768   |
| 30–34                  | 19,191   | 20,582   | 19,362   | 18,697   |
| 35–39                  | 19,126   | 20,214   | 19,265   | 18,419   |
| 40–44                  | 19,209   | 20,696   | 19,358   | 17,486   |
| 45–49                  | 18,927   | 20,038   | 19,297   | 17,217   |
| 50–54                  | 18,701   | 20,022   | 19,328   | 16,988   |
| 55–59                  | 17,910   | 19,460   | 19,156   | 16,380   |
| 60–64                  | 13,129   | 13,740   | 12,813   | 12,279   |
| 65–69                  | 12,732   | 13,171   | 12,673   | 11,574   |
| **Inner-province socio-economic status** |          |          |          |          |
| capital city           | 63,121   | 64,819   | 58,972   | 55,584   |
| fair economy           | 54,084   | 63,087   | 63,053   | 55,671   |
| low economy            | 51,810   | 60,615   | 57,845   | 55,279   |
| **Education**          |          |          |          |          |
| no formal education    | NA       | 14,363   | 10,368   | 7,558    |
| primary school         | 25,258   | 21,499   | 17,694   |          |
| junior high            | 48,865   | 47,319   | 40,849   |          |
| senior high            | 49,426   | 47,156   | 41,414   |          |
| University or above    | 50,596   | 53,521   | 58,859   |          |
| **Career**             |          |          |          |          |
| government official    | 13,218   | 15,385   | 18,011   | 9,365    |
| technical staff        | 25,294   | 28,766   | 27,144   | 25,269   |
| officer staff          | 23,233   | 20,771   | 22,409   | 25,647   |
| Commercial and service | 11,235   | 12,315   | 14,890   | 17,005   |
| Agriculture, forestry, animal husbandry and fishery | 55,576 | 53,137 | 39,204 | 31,143 |
| Production and transport | 38,739 | 32,945 | 28,440 | 26,284 |
| soldier                | NA       | 357      | 669      | 272      |
| other(including no occupation) | 9,885 | 24,824 | 29,083 | 28,794 |
| **Nation**             |          |          |          |          |
| Han                    | NA       | 167,193  | 157,437  | 145,031  |
| Minority               | 21,328   | 22,433   | 21,484   |          |
| **Nutritional status** |          |          |          |          |
| height                 | 162.4    | 162.5    | 162.8    | 163.5    |
| weight                 | 61.4     | 61.7     | 63.0     | 63.8     |
| BMI(kg/m2)             | 23.2     | 23.3     | 23.7     | 23.8     |
| skinfold thickness     | 57.2     | 58.1     | 56.2     | 59.8     |
| Thinness               | 9,085    | 9,847    | 7,593    | 6,530    |
| Normal weight          | 101,487  | 105,765  | 93,973   | 85,717   |

(Continued)
Table 1. (Continued)

|            | 2000        | 2005        | 2010        | 2014        |
|------------|-------------|-------------|-------------|-------------|
| overweight | 53,111(29.9%) | 56,864(30.2%) | 59,666(33.2%) | 55,889(33.6%) |
| obese      | 13,834(7.8%) | 15,969(8.5%) | 18,508(10.3%) | 18,007(10.2%) |
| Absolute HS$\uparrow$ | 34.3(18.1) | 33.5(18.2) | 33.0(18.2) | 32.3(17.8) |
| Relative HS$\uparrow$ | 0.577(0.223) | 0.563(0.219) | 0.543(0.211) | 0.526(0.205) |

* In year 2000, 8502(4.79%) participants are missing Inner-province socio-economic status data.

$\uparrow$ In year 2000, no investigation on Education, Nation and soldier career.

$\uparrow$ Present the median (interquartile, IQR), since variables are not normally distributed.

$\uparrow$ Add triceps, subscapular, and abdomen skinfold thickness together.

Fig 1. The medians with 95% confidence intervals of relative handgrip strength among different age groups in four survey years (error bars represent 95% confidence intervals for medians).

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associated with an increased risk of hypertension in the range of 43% to 58%. This finding was based on a big number of individuals (712,442 adults) and this is a strength of our study. Finally, relative HS significantly decreased during the past 15 years in both men and women in China. A similar trend was seen in different age groups, in both urban and rural areas.
Fig 3. The prevalence of hypertension among three tertile groups of handgrip strength across different age groups in four survey years (error bars represent 95% confidence intervals for medians, "*" represent $p<0.001$).

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The finding of a 43–58% reduction of risk in hypertension with one interquartile decrease in relative HS is of public health significance. High blood pressure is the leading modifiable risk factor for cardiovascular disease and premature death worldwide [24]. In our data, one interquartile change of HS is translated to 0.15 to 0.17 for males and 0.12 to 0.14 for females among different age groups. In the 60–69 age group of the year 2014, if a man with 60kg body-weight could improve his absolute handgrip strength by 5.02kg or a woman with 50kg body-weight could improve his absolute handgrip strength 2.20kg, their reduction of risk in hypertension would decrease 43%. This improvement of muscle strength can be achievable for a person by doing exercise [25, 26].

The decline of HS, which may reflect the change in whole body strength [6], has been found to have detrimental effects on health, including sarcopenia in the elderly [27], chronic non-communicable diseases [28], and have a higher risk of all-cause mortality [29]. The increased risk of hypertension in the adult population with lower relative HS found in our study is consistent with the results from the Korean Longitudinal Study on Health and Aging, in which relative HS was inversely associated with risk of hypertension in adults [15, 30]. However, several studies that used absolute HS had found different results. Taekema et al [10] measured blood pressure and handgrip strength in 670 middle-aged adults and 550 older people. They found that a high blood pressure was associated with higher HS among the elderly. Samely, in children and adolescents, the absolute HS is also found to be positive with blood pressure among participants [31, 32]. The conflicting results may be due to the difference between absolute and relative HS. It was found that body height and weight were independently associated with HS [33]. Some studies reported that the relative value of HS had an advantage for comparing

| Year | Crude | Model 1 | Model 2 |
|------|-------|---------|---------|
| 2000 | Crude | REF     | 1.26(1.22–1.30) | 1.53(1.48–1.57) |
|      | Model 1 | REF     | 1.28 (1.24–1.32) | 1.58 (1.54–1.63) |
|      | Model 2 | REF     | 1.31 (1.26–1.35) | 1.61 (1.56–1.66) |
| 2005 | Crude | REF     | 1.23(1.20–1.27) | 1.64 (1.59–1.69) |
|      | Model 1 | REF     | 1.26 (1.22–1.30) | 1.71 (1.66–1.77) |
|      | Model 2 | REF     | 1.27 (1.23–1.31) | 1.72 (1.67–1.77) |
| 2010 | Crude | REF     | 1.25(1.22–1.29) | 1.59(1.55–1.64) |
|      | Model 1 | REF     | 1.27 (1.24–1.31) | 1.65 (1.61–1.71) |
|      | Model 2 | REF     | 1.28 (1.24–1.32) | 1.65 (1.60–1.70) |
| 2014 | Crude | REF     | 1.23(1.19–1.27) | 1.53(1.48–1.58) |
|      | Model 1 | REF     | 1.24 (1.20–1.28) | 1.58 (1.53–1.63) |
|      | Model 2 | REF     | 1.26 (1.22–1.30) | 1.58 (1.53–1.64) |
different weight groups [14, 34, 35]. Chatterjee et al [36] found that HS was positively correlated with body weight (r = 0.86 to 0.87, both hands, aged from 7–73 years). So, we make reasonable inferences that the relative HS would be more comparable at the population level.

Our findings suggested that relative HS is inversely associated with the risk of hypertension. Furthermore, in the sensitive analysis, stratified BMI groups’ analysis showed that the body mass index did not affect the negative association between relative HS and hypertension, which was in agreement with a recent study [37]. One possible explanation of strength level associated with hypertension is that people who participate in physical activities more frequently have higher relative HS. The strength-related activities could cause shear stress on vessels in the whole body, which might raise the level of nitric oxide synthase and endothelium-derived nitric oxide [38–40].

We found that relative HS has been decreasing among Chinese male and female adults in both urban and rural areas since 2000. The results extended findings from the previous study, which reported the decreasing trend in absolute HS in these successive national surveys [8]. In recent years, there has been a decreasing trend in occupational, physical activity, domestic physical activity, and leisure time activity in China [8, 41], which was probably associated with the decrease of relative HS [42, 43]. To our knowledge, this is the first study which provides HS reference values for Asian population based on a very big representative sample. Accordingly this data could be used as reference values, for future comparisons [44].

This is the first national study to display the difference of relative HS between male and female in China, and its result, higher relative HS in male adult was consistent with the studies of relative HS in other populations [45, 46]. Moreover, the urban-rural disparity should be paid attention to. Men and women living in the rural area seemed to have lower relative HS

| Year | OR (95%CI) | p |
|------|------------|---|
| 2000 | Crude 1.45(1.42–1.47) | <0.001 |
|      | Model 1 1.43 (1.39–1.46) | <0.001 |
|      | Model 2 1.44(1.40–1.47) | <0.001 |
| 2005 | Crude 1.38 (1.35–1.40) | |
|      | Model 1 1.58 (1.54–1.62) | <0.001 |
|      | Model 2 1.58(1.54–1.62) | <0.001 |
| 2010 | Crude 1.26(1.24–1.28) | <0.001 |
|      | Model 1 1.49 (1.46–1.53) | <0.001 |
|      | Model 2 1.48 (1.45–1.52) | <0.001 |
| 2014 | Crude 1.15(1.13–1.17) | <0.001 |
|      | Model 1 1.43 (1.40–1.47) | <0.001 |
|      | Model 2 1.43 (1.40–1.47) | <0.001 |

Notes: HS = handgrip strength; IQR = interquartile; OR = odds ratio; CI = confidence interval.
Crude Model: with the province of each participant was used as the random effect.
Model 1: adjusted for age and sex.
Model 2: adjusted for age, sex, region (urban or rural), inner-province economic status (low, middle, high), nationality, education level, career, exercise (at least 60 mins/week or not).

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than those in urban areas. The possible explanation could be that there was less manual work with progressive years than before in the rural area, especially with regards to the female population. In contrast, the fast changing environment reinforcing physical activity and training in urban cities, like the building of exercise facilities, may explain the higher strength level reported for the urban population in our study [47, 48].

This study had notable strengths, identifying epidemiological characteristics of relative HS with a sizeable nationally-representative sample size in China and repeated measures during the past 15 years. However, the study had several limitations that should be noted. First, the cross-sectional nature of the national representative data precluded causal inference. Longitudinal studies should be conducted to demonstrate the relationship between relative HS and hypertension using a stronger experimental design. Second, we did not collect hypertension-related risk factors such as energy intake, sodium and potassium intake. It was infeasible to collect comprehensive diet information in large-scale national surveys. However, the consistent association results was found in different survey years and stratified analyses by gender, urban / rural, normal-weight /overweight or obese, indicating the potential bias due to unadjusted factors might be minor. Third, we used body weight and BMI to calculate relative HS and hence we were unable to distinguish between lean and fat mass. Although the sensitive analysis with adjusting for skinfold thickness has confirmed the main results, future studies should include precise measurements such as dual-energy X-ray absorptiometry to study the association between relative HS (calculated by fat mass) and hypertension.

Conclusion
The relative HS level decreased during the last 15 years in urban and rural areas across different sex- and age-groups of the Chinese adult population. Lower relative HS was associated with a higher risk of hypertension. Considering the relative strength reflected the overall strength level, the findings provided evidence for the association between muscle strength and hypertension in large-scaled population.

Supporting information
S1 Table. The medians and interquartile of relative HS (HS to weight ratio) in four survey years.
(DOCX)

S2 Table. The medians and interquartile of relative HS (HS to weight ratio) in rural or urban areas in four survey years.
(DOCX)

S3 Table. The prevalence of hypertension in different tertile groups of relative HS(HS to weight ratio) in four survey years.
(DOCX)

S4 Table. The prevalence of hypertension in different tertile groups of relative HS (HS to weight ratio) across different age groups in 2014.
(DOCX)

S5 Table. Sensitivity analysis of relative HS (HS to weight ratio, category variable) in participants in the model adjusted for the skinfold thickness.
(DOCX)
S6 Table. Sensitive analysis of the association between another relative HS index (HS to BMI ratio, continuous variable) and hypertension (per IQR decrease).

S7 Table. Sensitive analysis of the association between another relative HS index (handgrip strength to BMI ratio, category variable) and hypertension.

S8 Table. Sensitive analysis of the associations between relative HS (category variable) and hypertension among different BMI groups from year 2005 to year 2014.

S9 Table. Sensitive analysis of the associations between relative HS (category variable) and hypertension in male.

S10 Table. Sensitive analysis of the associations between relative HS (category variable) and hypertension in female.

S11 Table. Sensitive analysis of the associations between relative HS (category variable) and hypertension among different age groups.

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References
1. Mills KT, Bundy JD, Kelly TN, Reed JE, Kearney PM, Reynolds K, et al. Global Disparities of Hypertension Prevalence and Control: A Systematic Analysis of Population-Based Studies From 90 Countries. Circulation. 2016; 134(6):441–50. Epub 2016/08/10. https://doi.org/10.1161/CIRCULATIONAHA.115.018912 PMID: 27502908.

2. Lu J, Lu Y, Wang X, Li X, Linderman GC, Wu C, et al. Prevalence, awareness, treatment, and control of hypertension in China: data from 1.7 million adults in a population-based screening study (China
3. Gu D, Reynolds K, Wu X, Chen J, Duan X, Muntner P, et al. Prevalence, Awareness, Treatment, and Control of Hypertension in China. Hypertension. 2002; 40(6):920–7. https://doi.org/10.1161/01.hyp.0000042639.46119.d5 PMID: 12468580

4. Hegde SM, Solomon SD. Influence of Physical Activity on Hypertension and Cardiac Structure and Function. Curr Hypertens Rep. 2015; 17(10):77. Epub 2015/08/19. https://doi.org/10.1007/s11906-015-0588-3 PMID: 26277725.

5. Labott BK, Bucht H, Morat M, Morat T, Donath L. Effects of Exercise Training on Handgrip Strength in Older Adults: A Meta-Analytical Review. Gerontology. 2019; 65(6):686–98. Epub 2019/09/10. https://doi.org/10.1159/000501203 PMID: 31499496.

6. Bohannon RW. Muscle strength: clinical and prognostic value of hand-grip dynamometry. Curr Opin Clin Nutr Metab Care. 2015; 18(5):465–70. Epub 2015/07/07. https://doi.org/10.1097/MCO.0000000000000202 PMID: 26174527.

7. Leong DP, Teo KK, Rangarajan S, Kutty VR, Lanas F, Hui C, et al. Reference ranges of handgrip strength from 125,462 healthy adults in 21 countries: a prospective urban rural epidemiologic (PURE) study. J Cachexia Sarcopenia Muscle. 2016; 7(5):535–46. Epub 2016/04/23. https://doi.org/10.1002/jcsm.12112 PMID: 27104109.

8. Tian Y, Jiang C, Wang M, Cai R, Zhang Y, He Z, et al. BMI, leisure-time physical activity, and physical fitness in adults in China: results from a series of national surveys, 2000–14. Lancet Diabetes Endocrinol. 2016; 4(6):487–97. Epub 2016/05/03. https://doi.org/10.1016/S2213-8587(16)00081-4 PMID: 27133172.

9. Kelley GA, Kelley KS. Isometric handgrip exercise and resting blood pressure: a meta-analysis of randomized controlled trials. Journal of Hypertension. 2010; 28(3):411–8. https://doi.org/10.1097/HJH.0b013e328357d16 PMID: 20009767

10. Taekema DG, Maier AB, Westendorp RGJ, Craen AJMd. Higher Blood Pressure Is Associated With Higher Handgrip Strength in the Oldest Old. American Journal of Hypertension. 2011; 24(1):83–9. https://doi.org/10.1038/ajh.2010.185 PMID: 20814409.

11. Ji C, Zheng L, Zhang R, Wu Q, Zhao Y. Handgrip strength is positively related to blood pressure and hypertension risk: results from the National Health and nutrition examination survey. Lipids in health and disease. 2018; 17(1):86-. https://doi.org/10.1186/s12944-018-0734-4 PMID: 29665844.

12. Mallia MA, Liu M, Liu Y, Xu H-F, Wu X-J, Chen X-T, et al. Association of handgrip strength with the prevalence of hypertension in a Chinese Han population. Chronic Dis Transl Med. 2019; 5(2):113–21. https://doi.org/10.1016/j.cdtm.2019.05.004 PMID: 31367700.

13. Byeon JY, Lee MK, Yu M-S, Kang MJ, Lee DH, Kim KC, et al. Lower Relative Handgrip Strength is Significantly Associated with a Higher Prevalence of the Metabolic Syndrome in Adults. Metabolic Syndrome and Related Disorders. 2019; 17(5):280–8. https://doi.org/10.1089/met.2018.0111 PMID: 30945974

14. Lee WJ, Peng LN, Chiou ST, Chen LK. Relative Handgrip Strength Is a Simple Indicator of Cardiometabolic Risk among Middle-Aged and Older People: A Nationwide Population-Based Study in Taiwan. PLoS One. 2016; 11(8):e0160876. Epub 2016/08/26. https://doi.org/10.1371/journal.pone.0160876 PMID: 27559733.

15. Yi DW, Khang AR, Lee HW, Son SM, Kang YH. Relative handgrip strength as a marker of metabolic syndrome: the Korea National Health and Nutrition Examination Survey (KNHANES) VI (2014–2015). Diabetes Metab Syndr Obes. 2018; 11:227–40. Epub 2018/06/07. https://doi.org/10.2147/dmsoc.16875 PMID: 29872330.

16. James GD, Gerber LM. Measuring arterial blood pressure in humans: Auscultatory and automatic measurement techniques for human biological field studies. Am J Hum Biol. 2018; 30(1). Epub 2017/09/25. https://doi.org/10.1002/ajhb.23063 PMID: 28940503.

17. Poulter NR, Prabhakaran D, Caulfield M. Hypertension. Lancet. 2015; 386(9995):801–12. Epub 2015/04/03. https://doi.org/10.1016/S0140-6736(14)61468-9 PMID: 25832858.

18. Carpenter J, Bithell J. Bootstrap confidence intervals: when, which, what? A practical guide for medical statisticians. Statistics in Medicine. 2000; 19(8):1141–64. PMID: 10797513

19. Pattengale Nicholas D. A M, Bininda-Emonds Olaf R.P., Moret Bernard M.E., and Stamatakis Alexandros. How Many Bootstrap Replicates Are Necessary? Journal of Computational Biology. 2010; 17(3):337–54. https://doi.org/10.1089/cmb.2009.0175 PMID: 20377449.

20. Libiseller C, Grimvall A. Performance of partial Mann–Kendall tests for trend detection in the presence of covariates. Environmetrics. 2002; 13(1):71–84. https://doi.org/10.1002/env.507
Association between relative handgrip strength and hypertension

21. Groenwold RH, Sterne JA, Lawlor DA, Moons KG, Hoes AW, Tilling K. Sensitivity analysis for the effects of multiple unmeasured confounders. Ann Epidemiol. 2016; 26(9):605–11. Epub 2016/09/01. https://doi.org/10.1016/j.annepidem.2016.07.009 PMID: 27576907.

22. VanderWeele TJ, Ding P. Sensitivity Analysis in Observational Research: Introducing the E-Value. Ann Intern Med. 2017; 167(4):268–74. Epub 2017/07/12. https://doi.org/10.7326/M16-2607 PMID: 28693043.

23. Wildman RP, Gu D, Reynolds K, Duan X, He J. Appropriate body mass index and waist circumference cutoffs for categorization of overweight and central adiposity among Chinese adults. J Am Clin Nutr. 2004; 80(5):1129–36. Epub 2004/11/09. https://doi.org/10.1093/jamc/80.5.1129 PMID: 15531658.

24. Mills KT, Stefanescu A, He J. The global epidemiology of hypertension. Nat Rev Nephrol. 2020; 16(4):223–37. Epub 2020/02/07. https://doi.org/10.1038/s41588-019-0244-2 PMID: 32024986.

25. Karatrantou K, Gerodimos V, Manouras N, Vasilopoulou T, Melissopoulou A, Mesiarakis AF, et al. Health-Promoting Effects of a Concurrent Workplace Training Program in Inactive Office Workers (HealPWokers): A Randomized Controlled Study. Am J Health Promot. 2020; 34(4):376–86. Epub 2020/01/18. https://doi.org/10.1177/0890117119899781 PMID: 31950855.

26. Gerodimos V, Karatrantou K, Kakardaki K, Iaokimidis P. Can maximal handgrip strength and endurance be improved by an 8-week specialized strength training program in older women? A randomized controlled study. Hand Surg Rehabil. 2020. Epub 2020/12/20. https://doi.org/10.1016/j.hansur.2020.11.007 PMID: 33340721.

27. Larsson L, Degens H, Li M, Salviati L, Lee Yi, Thompson W, et al. Sarcopenia: Aging-Related Loss of Muscle Mass and Function. Physiological Reviews. 2019; 99(1):427–511. https://doi.org/10.1152/physrev.00061.2017 PMID: 30427277.

28. Ko K-J, Kang S-J, Lee K-S. Association between cardiorespiratory, muscular fitness and metabolic syndrome in Korean men. Diabetes & Metabolic Syndrome: Clinical Research & Reviews. 2019; 13(1):536–41. https://doi.org/10.1016/j.dsx.2018.11.025 PMID: 30641761.

29. Garcia-Hermoso A, Cavero-Redondo I, Ramirez-Vélez R, Ruiz JR, Ortega FB, Lee DC, et al. Muscle Strength as a Predictor of All-Cause Mortality in an Apparently Healthy Population: A Systematic Review and Meta-Analysis of Data From Approximately 2 Million Men and Women. Arch Phys Med Rehabil. 2016; 99(10):2100–13.e5. Epub 2018/02/10. https://doi.org/10.1016/j.apmr.2018.01.008 PMID: 29425700.

30. Kim BM, Yi YH, Kim YJ, Lee SY, Lee JG, Cho YH, et al. Association between Relative Handgrip Strength and Dyslipidemia in Korean Adults: Findings of the 2014–2015 Korea National Health and Nutrition Examination Survey. Korean J Fam Med. 2020. Epub 2020/02/13. PMID: 32045964.

31. Dong B, Wang Z, Arnold L, Song Y, Wang HJ, Ma J. The association between blood pressure and grip strength in adolescents: does body mass index matter? Hypertens Res. 2016; 39(12):919–25. Epub 2016/07/08. https://doi.org/10.1038/hr.2016.84 PMID: 27383511.

32. Díez-Fernández A, Sánchez-López M, Guías-González R, Notario-Pacheco B, Cañete García-Prieto J, Arias-Palencia N, et al. BMI as a mediator of the relationship between muscular fitness and cardiometabolic risk in children: a mediation analysis. PLoS One. 2015; 10(1):e0116506. Epub 2015/01/16. PMID: 25590619 (www.icmje.org/coi_disclosure.pdf) and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous years; no other relationships or activities that could appear to have influenced the submitted work.

33. Chandrasekarann B, Ghosh A, Prasad C, Krishnan K, Chandrasharma B. Age and Anthropometric Traits Predict Handgrip Strength in Healthy Normals. Journal of Hand and Microsurgery. 2010; 2(2):58–61. https://doi.org/10.1007/s12593-010-0015-6 PMID: 22282669.

34. Lawman HG, Troiano RP, Perna FM, Wang CY, Fryar CD, Ogden CLJAJoPM. Associations of Relative Handgrip Strength and Cardiovascular Disease Biomarkers in U.S. Adults, 2011–2012. 2016; 50(6): 2004; 80(5):1129–36. Epub 2004/11/09. https://doi.org/10.1093/jamc/80.5.1129 PMID: 15531658.

35. Ahn KH, Lee Y, Sohn TY, Kim DY, Ryu M, Gym H, et al. Association between Relative Handgrip Strength and Osteoporosis in Older Women: The Korea National Health and Nutrition Examination Survey 2014–2018. Ann Geriatr Med Res. 2020; 24(4):243–51. Epub 2021/01/05.

36. Chatterjee S, Chowdhuri BJ. Comparison of grip strength and isometric endurance between the right and left hands of men and their relationship with age and other physical parameters. J Hum Ergol (Tokyo). 1999; 20(1):41–50. Epub 1991/06/01. PMID: 1820379.

37. Chon D, Shin J, Kim JH. Consideration of body mass index (BMI) in the association between hand grip strength and hypertension: Korean Longitudinal Study of Ageing (KLoSA). PLoS One. 2020; 15(10): e0241360. Epub 2020/10/30. https://doi.org/10.1371/journal.pone.0241360 PMID: 33119673.
38. Delp MD, Laughlin MH. Time course of enhanced endothelium-mediated dilation in aorta of trained rats. Medicine and science in sports and exercise. 1997; 29(11):145–61. https://doi.org/10.1097/00005768-199711000-00011 PMID: 9372482.

39. Koller A, Huang A, Sun D, Kaley G. Exercise training augments flow-dependent dilation in rat skeletal muscle arterioles. Role of endothelial nitric oxide and prostaglandins. Circ Res. 1995; 76(4):544–50. Epub 1995/04/01. https://doi.org/10.1161/01.res.76.4.544 PMID: 7534658.

40. Sun D, Huang A, Koller A, Kaley G. Adaptation of flow-induced dilation of arterioles to daily exercise. Microvasc Res. 1998; 56(1):54–61. Epub 1998/07/31. https://doi.org/10.1006/mvre.1998.2083 PMID: 9683563.

41. Ng SW, Howard AG, Wang HJ, Su C, Zhang B. The physical activity transition among adults in China: 1991–2011. Obes Rev. 2014; 15 Suppl 1(0 1):27–36. Epub 2013/12/18. https://doi.org/10.1111/obr.12127 PMID: 24341756.

42. Genin PM, Desseenne P, Finaud J, Pereira B, Thivel D, Duclos M. Health and Fitness Benefits But Low Adherence Rate: Effect of a 10-Month Onsite Physical Activity Program Among Tertiary Employees. J Occup Environ Med. 2018; 76(9):e455–e62. Epub 2018/07/19. https://doi.org/10.1097/JOM.0000000000002114 PMID: 30020214.

43. Dodds R, Kuh D, Aihie Sayer A, Cooper R. Physical activity levels across adult life and grip strength in early old age: updating findings from a British birth cohort. Age Ageing. 2013; 42(6):794–8. Epub 2013/08/29. https://doi.org/10.1093/ageing/aft124 PMID: 23981980.

44. WHO Child Growth Standards based on length/height, weight and age. Acta Paediatr Suppl. 2006; 450:76–85. Epub 2006/07/05. https://doi.org/10.1111/j.1651-2227.2006.tb02378.x PMID: 16817681.

45. Byeon Ji Yong L MK, Yu Mi-Seong, Kang Min Jae, Lee Dong Hoon, Kim Kyong Chol, Im Jee Aee, et al. Lower Relative Handgrip Strength is Significantly Associated with a Higher Prevalence of the Metabolic Syndrome in Adults. Metabolic Syndrome and Related Disorders. 2019; 17(5):280–8. https://doi.org/10.1089/met.2018.0111 PMID: 30945974.

46. Ji C, Xia Y, Tong S, Wu Q, Zhao Y. Association of handgrip strength with the prevalence of metabolic syndrome in US adults: the national health and nutrition examination survey. Aging (Albany NY). 2020; 12(9):7818–29. Epub 2020/05/05. PMID: 32365052.

47. McCormack GR, Frehlich L, Blackstaffe A, Turin TC, Doyle-Baker PK. Active and Fit Communities. Associations between Neighborhood Walkability and Health-Related Fitness in Adults. Int J Environ Res Public Health. 2020; 17(4). Epub 2020/02/15. https://doi.org/10.3390/ijerph17041131 PMID: 32053915.

48. Shaffer K, Bopp M, Papalia Z, Sims D, Bopp CM. The Relationship of Living Environment with Behavioral and Fitness Outcomes by Sex: an Exploratory Study in College-aged Students. Int J Exerc Sci. 2017; 10(3):330–9. Epub 2017/05/19. PMID: 28515831.