Iran J Public Health, Vol. 55, No.1, Jan 2026, pp.133-142

Original Article

Trends and Distributional Characteristics of Forced Vital Capacity and Forced Vital Capacity Adjusted for Weight among Chinese Children and Adolescents Over the Three Decades

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(Received 09 Jul 2025; accepted 16 Oct 2025)

Abstract

Background: To assess trends and distributional characteristics of forced vital capacity (FVC) and vital capacity index (VCI) (a measure of FVC adjusted for weight) among Chinese children and adolescents aged 7-18 years from 1985 to 2019.

Methods: FVC and VCI data for Chinese children and adolescents were obtained from the Chinese National Surveillance on Students' Constitution and Health surveys in 1985, 1995, 2000, 2005, 2010, 2014 and 2019. VCI (ml/kg) = FVC (ml)/weight (kg). Trends were estimated by sample-weighted regressions with post-stratification population-weighted procedures. The trends in the distributional characteristics were visually described.

Results: For the total population, FVC improved by 78.7 ml (95% confidence interval: -203.3 to 360.7 ml) or 0.12 effect size (ES) (-0.42 to 0.66 ES), which was a negligible improvement. VCI decreased by 11.5 ml/kg (4.8 to 18.3 ml/kg) or 0.84 ES (0.34 to 1.34 ES), which was a large decrease from 1985 to 2019. The sex, residence, and age-stratified VCI both experienced significant moderate to large decreases. Stratified by period, the FVC and VCI decreased dramatically until the 21st century, and the decrease stabilized from 2000 to 2010 and thereafter improved. FVC decreased in the lower percentile and increased in the higher percentile. For the VCI, the larger the percentile was, the smaller the decrease was.

Conclusion: Absolute levels of lung function among Chinese children and adolescents have stabilized over the past three decades, but relative levels of lung function have declined significantly. The government should implement health promotion programs to improve respiratory health.

Keywords: Forced vital capacity; Vital capacity index; Child; Distribution; Public health

Introduction

Forced vital capacity (FVC), which represents the total expiratory volume after maximal inspiration, is commonly used as a valid indicator to assess lung health and respiratory function in children and adolescents (1-2). In children and adolescents, there are negative associations between

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DOI: https://doi.org/10.18502/ijph.v55i1.20979

FVC and respiratory and cardiometabolic diseases, adiposity, physical activity (PA), and cognitive performance (1,3-5). In addition, adverse exposures in early childhood can have lifelong effects on respiratory health and are also associated with early all-cause morbidity and mortality (6). Therefore, it is necessary to analyze the changes in FVC and to make timely interventions to improve the respiratory health of children and adolescents.

FVC among children and adolescents aged 7-18 years in China decreased from 1985 to 2014, with a negative trend from 1985 to 2005 and a positive trend from 2005 to 2014 (7). Gan et al. (8) reported the same trends among children and adolescents aged 7-22 years during the same period by sex and residence. Subnational trends in FVC or FVC Z-scores were reported in Xinjiang, China, from 1985 to 2014; FVC decreased generally but had a positive trend until the 21st century (1,9). Recently, Zhang et al. (10) reported that there were sex, age, residence, and subnational differences in these trends. In summary, the current study has several limitations. First, in children and adolescents, FVC is associated not only with demographic characteristics but also with body size, such as height and weight (5,9). Therefore, to reflect the actual level of lung function, the vital capacity index (VCI) is commonly used (11). The VCI is the FVC adjusted for weight. VCI was calculated as FVC in milliliter (ml) divided by weight in kilograms (kg). No studies have used the VCI to estimate trends in lung function. The use of body size-adjusted indicators for estimation is essential because positive trends in body size have been observed in Chinese children and adolescents over the past decades (9,12), and changes in FVC do not represent changes in the actual level of lung function. Second, information on the distributional characteristics of lung function among national children and adolescents has not been reported. These insights are useful for developing targeted strategies for groups at different levels, promoting health equity and improving the health of the general population.

Therefore, by the Chinese National Surveillance on Students' Constitution and Health (CNSSCH) from 1985 to 2019, we aimed to examine the direction, pace, demographic and distributional characteristics of trends in forced vital capacity and vital capacity index among Chinese children and adolescents aged 7-18 years.

Methods

Study design and subjects

FVC and VCI among Han Chinese children and adolescents aged 7-18 years were obtained from published summary statistics by the CNSSCHs in 1985, 1995, 2000, 2005, 2010, 2014 and 2019 (13). The CNSSCH used a multistage stratified cluster sampling design, and the sampling procedure was performed as previously described in detail (7,10,13). The study included only Han Chinese students, who made up 91% of the total Chinese Han population, and 30 provincial regions, except for Tibet, Hong Kong, Macau and Taiwan. Since 1985, sampling has yielded equal numbers at three socioeconomic status groups (prefecture-level cities) within each province. Then, the participants were stratified by urban or rural area according to their place of residence, with at least 50 Han Chinese students in each age group included in the survey. The 1991 CNSSCH only sampled the capital city of each province, and the data were not nationally representative, so they were excluded. In addition, there are only FVC data and no VCI data for 1995. From 1985 to 2019, 1,711,586 and 1,502,150 children and adolescents were tested for FVC and VCI respectively. The sex-, region- and age-specific sample sizes, means and standard deviations (SDs) in each survey year are shown in Supplementary Tables 1-4 (Not published).

The study was performed in accordance with the ethical standards of the Declaration of Helsinki. The participants provided their written informed consent to participate. The data analyzed during this study from CNSSCHs have been published openly and are freely available in publicly available books (13).

Measurements

The test time ranged from March to June in 1985, and the test time ranged from September to November of 1995 to 2019. All participants were given complete tests at all survey sites following the same protocol. The staff at all survey sites received rigorous training. Measures included:

1) Weight: Weight was measured to the nearest 0.1 kg by an electronic scale, with all participants wearing underwear and barefoot.

2) FVC: An rotary spirometer in 1985, an electronic spirometer/needle spirometer/rotary spirometer in 1995, an electronic spirometer/rotary spirometer in 2000 and an electronic spirometer from 2005 to 2019 were used to measure FVC to the nearest 1 ml.

Rotary spirometer: The participants stand and do one or two chest expansion movements or deep breathing before measurement. Then try to inhale deeply and exhale deeply into the mouth of the spirometer until they can no longer exhale. After the rotary cylinder stops, read the value on the position of the vernier indicator. Measure three times per person and finally select the maximum value to record.

Needle spirometer: Check whether there is any air leakage between the metal hose and the air inlet of the instrument, and then adjust the knob to return the pointer to zero. The participants inhale deeply and exhale into the air inlet until they cannot exhale. The value shown on the scale of the instrument is the FVC value of the participant.

Electronic spirometer: The participant takes a standing position and can do 1~2 deep breaths, holding the handle of the venturi. They try to inhale deeply and then slowly exhale to the mouthpiece until they cannot exhale. At this point, the value shown on the display is the FVC value. The test was performed twice and the staff recorded the maximum value.

3) VCI: VCI was calculated as FVC in ml divided by weight in kg.

Statistical analysis

Using the published summary statistics, FVC and VCI results are expressed as the means and SDs. Data were classified by test, sex, residence and age, and best-fitting sample-weighted regressions (linear or quadratic or cubic regressions) were performed. The change was expressed as absolute change (i.e., the slope B of the regression), percentage change (% per year, i.e., the slope of the regression as a percentage of the sample-weighted mean of all means in the regression), and standardized (Cohen's) effect size (ES) (i.e., the slope of the regression divided by the combined SD of all SDs in the regression). Note that a series of slopes on the polynomial curve were calculated by differentiating for each test year. Following the procedure described by Liu et al. (14), population-weighted average changes and 95% confidence intervals (CIs) were calculated by combining sex-residence-age-specific changes using stratified population weighting. The 95% CIs for the average changes were obtained as average change ± 1.96 standard errors (SEs). SEs were calculated as the SD of the annual changes entering into the calculation in a period, divided by the square root of the number of data points (14). The population weighting was derived from the population data from the 2020 Population Census in China (15). The changes per decade from 1985 to 2000, 2000 to 2010 and 2010 to 2019 also were calculated. To account for the magnitude of changes in the mean, ESs of 0.2, 0.5, and 0.8 were used as thresholds for small, medium, and large, respectively, with ESs of <0.2 considered negligible changes (16).

To investigate distributional characteristics, trends were estimated for each percentile value using the method described above. The sex-residence-age-specific 3rd (worst level), 5th, 10th, 25th, 30th, 50th, 70th, 75th, 90th, 95th, and 97th (best level) percentile values were extracted. Restricted triple spline curves were used to plot changes per decade for a series of percentiles. All the statistical analyses were performed by Stata 17.0.

Results

Trends in FVC and VCI

The means, SDs, and sample sizes for FVC and VCI among Chinese children and adolescents are shown in Fig. 1 and Supplementary Tables 1-4. For the total population, there was a negligible improvement in FVC from 1985 to 2019, increasing by an average of 78.7 ml or 3.0% or 0.12 ES. Trends by residence (urban and rural) and age (children and adolescents) were consistent with those of the total population. In terms of the VCI, for the total population, there was a large decrease from 1985 to 2019, decreasing by an average of 11.5 ml/kg or 21.5% or 0.84 ES. There were significant decreases for each subgroup, but adolescents experienced a moderate decrease (-0.75 ES) (Table 1).

Table 1: Changes in means forced vital capacity and vital capacity index among Chinese children and adolescents from 1985 to 2019

Tests	Categories	N	M±SD	Change in means (95% CI)		
				Absolute	Percent (%)	Standardized ES
Forced vital capacity (ml)	Total	1711586	2239.0±955.1	78.7 (-203.3, 360.7)	3.0 (-10.2, 16.1)	0.12 (-0.42, 0.66)
	Boys	856981	2504.1±1090.3	144.7 (-128.9, 418.4)	5.3 (-6.1, 16.8)	0.22 (-0.26, 0.70)
	Girls	854605	1973.2±702.7	3.0 (-288.6, 294.6)	0.3 (-14.8, 15.3)	0.01 (-0.61, 0.62)
	Urban	857965	2305.1±968.9	75.2 (-203.7, 354.0)	2.5 (-9.8, 14.8)	0.11 (-0.41, 0.62)
	Rural	853621	2172.6±936.3	84.3 (-202.9, 371.6)	3.7 (-10.8, 18.1)	0.14 (-10.8, 18.1)
	Children	857494	1605.3±544.1	66.4 (-160.8, 293.6)	3.0 (-11.0, 16.9)	0.12 (-0.42, 0.65)
	Adolescents	854092	2875.3±850.1	92.3 (-251.5, 436.1)	3.0 (-9.3, 15.3)	0.12 (-0.43, 0.67)
Vital capacity index (ml/kg)	Total	1502150	53.8±14.3	-11.5 (-18.3, -4.8)	-21.5 (-34.2, -8.7)	-0.84 (-1.34, -0.34)
	Boys	752163	57.6±14.5	-12.2 (-18.6, -5.8)	-21.6 (-32.9, -10.2)	-0.87 (-1.32, -0.41)
	Girls	749987	50.0±13.0	-10.7 (-17.9, -3.5)	-21.3 (-35.7, -7.0)	-0.82 (-1.37, -0.26)
	Urban	752518	53.9±14.4	-11.1 (-17.8, -4.3)	-20.6 (-33.2, -7.9)	-0.81 (-1.31, -0.31)
	Rural	749632	53.7±14.2	-12.2 (-19.0, -5.4)	-22.9 (-35.8, -10.0)	-0.90 (-1.40, -0.39)
	Children	752481	52.2±14.8	-13.5 (-21.2, -5.9)	-25.8 (-40.4, -11.2)	-0.93 (-1.45, -0.40)
	Adolescents	749669	55.4±13.6	-9.3 (-15.1, -3.5)	-16.7 (-27.3, -6.0)	-0.75 (-1.22, -0.28)

Note: Standardized effect sizes (ESs) in means of 0.2, 0.5, and 0.8 are used as thresholds for small, moderate, and large, respectively, with an ES of < 0.2 considered to be negligible. The regression of forced vital capacity uses data points from 1985, 1995, 2000, 2005, 2010, 2014, and 2019. The regression of vital capacity index uses data points from 1985, 2000, 2005, 2010, 2014, and 2019. N is the sample size, M is the mean, SD is the standard deviation, CI is the confidence interval and ES is the effect size. Bold represents significant changes

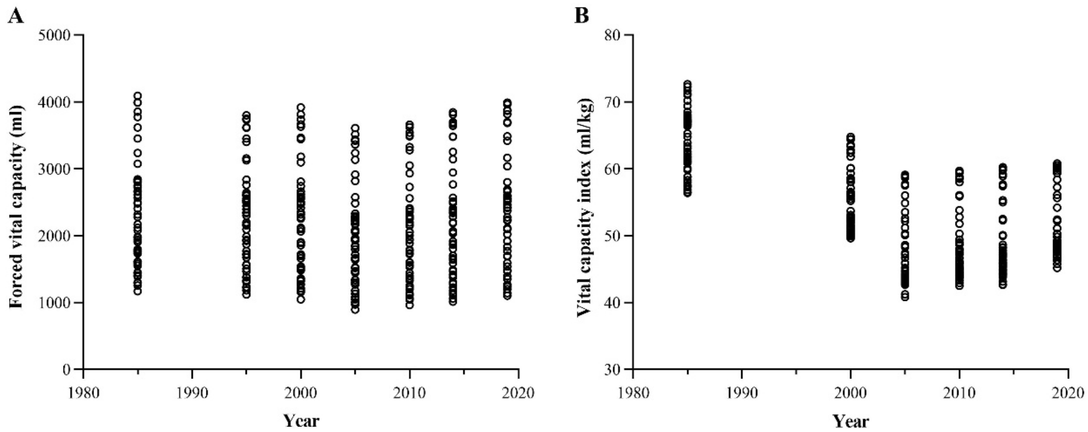

Fig. 1: Means of forced vital capacity (A) and vital capacity index (B) among Chinese children and adolescents from 1985 to 2019. The dots represent sex-residence-age-percentile-specific means. The vital capacity index data for 1995 was not reported

Trends in FVC and VCI by period

For the total population, there was a small decrease per decade in FVC from 1985 to 2000, a negligible decrease per decade from 2000 to 2010, and a moderate improvement per decade from 2010 to 2019 (0.71 ES, 0.48 to 0.94 ES). There a negligible decrease per decade among boys from 1985 to 2000 (-0.18 ES) and a small decrease per decade among girls from 2000 to 2010 (-0.22 ES). In terms of VCI, for the total population, there was a moderate decrease per decade from 1985 to 2000 (-0.51 ES, -0.59 to -0.43 ES), a small decrease per decade from 2000 to 2010 (-0.42 ES, -0.52 to -0.32 ES), and a small improvement per decade from 2010 to 2019 (0.38 ES, 0.17 to 0.59 ES). Adolescents experienced a small decrease per decade from 1985 to 2000 (-0.48 ES) (Fig. 2 and Supplementary Table 5).

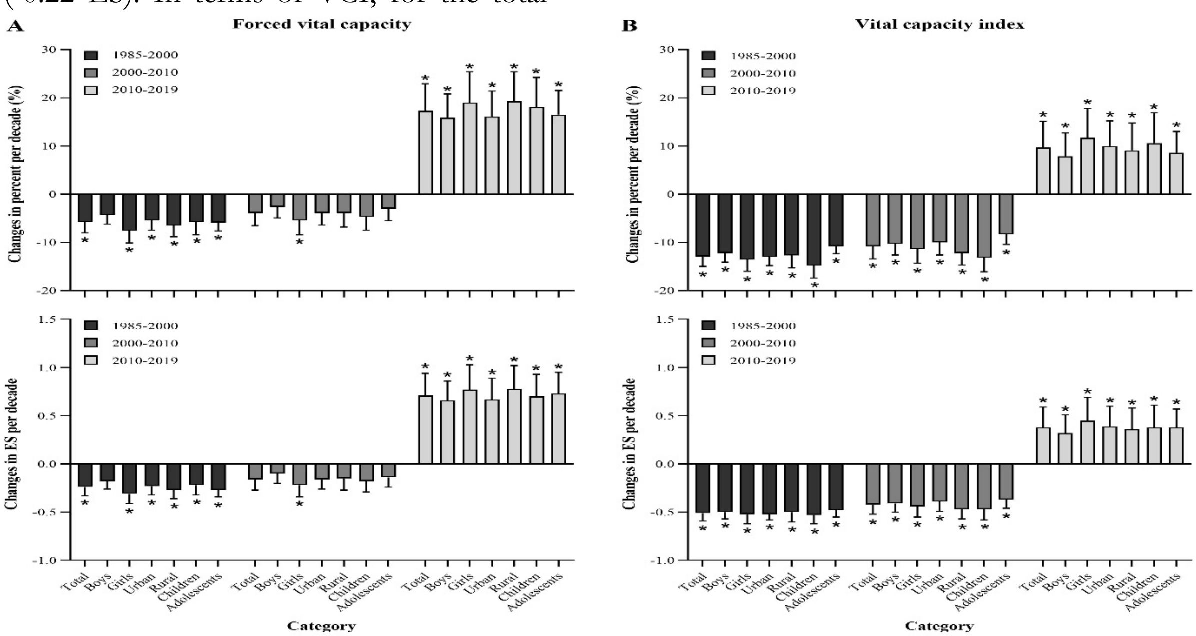

Fig. 2: Changes per decade in means forced vital capacity (A) and vital capacity index (B) among Chinese children and adolescent from 1985 to 2019 across periods. The regression of forced vital capacity uses data points from 1985, 1995, 2000, 2005, 2010, 2014, and 2019. The regression of vital capacity index uses data points from 1985, 2000, 2005, 2010, 2014, and 2019. N is the sample size, M is the mean, SD is the standard deviation, CI is the confidence interval and ES is the effect size * represented significant changes (ES ≥ 0.20)

Distributional characteristics of changes in FVC and VCI

ES increased with increasing percentile in all subgroups. For the total population, there was a small decrease at the 3rd percentile (-0.44 ES) and a large improvement at the 97th percentile in FVC (0.84 ES). The distributional characteristics of each subgroup were consistent with those of the total population. For the VCI, the larger the percentile was, the smaller the decrease was. This means that VCI at higher levels decreases less than VCI at lower levels (Fig. 3).

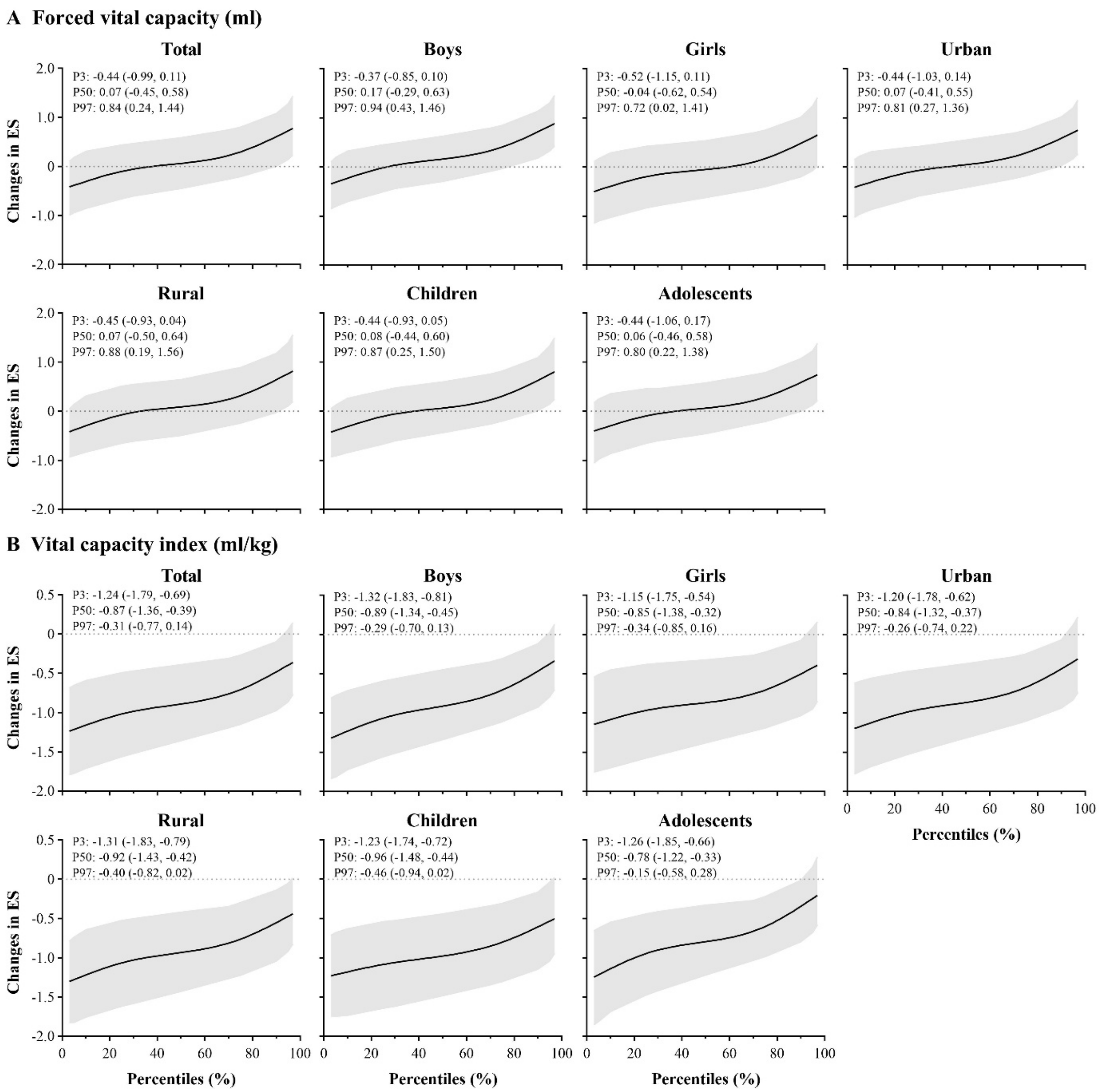

Fig. 3: Changes per decade in means forced vital capacity (A) and vital capacity index (B) among Chinese children and adolescents from 1985 to 2019 across percentiles. The solid lines represent the restricted cubic spline curve and the gray areas represent the 95% confidence intervals

Discussion

This paper estimated population-based trends in FVC and VCI among Chinese children and adolescents from 1985 to 2019. The main findings were that (a) there was a negligible improvement in FVC from 1985 to 2019, increasing by 3.0% or 0.12 ES, but there was a large decrease in VCI from 1985 to 2019, decreasing by 21.5% or 0.84 ES; (b) FVC and VCI continued to decrease from 1985 to 2010 but improved from 2010 to 2019; (c) the distributions of trends in FVC and VCI were uneven, with trends in higher levels of FVC and VCI being relatively positive compared with those in lower levels.

This paper revealed that FVC decreased and then improved from 1985 to 2019, which was consistent with the results of previous studies (8-9,11). However, there was no significant change in FVC over the entire 34 years, which differed from previous studies that reported a decrease (7-10). Differences in estimation methods may be one of the important reasons. This paper used ES as an indicator of estimated change rather than a single observed mean. A decrease of 78.7 ml was also observed in this paper, but this decrease was not statistically significant. The present study revealed a significant decrease in VCI, which suggests a decrease in the relative level of lung function. The difference in trends between VCI and FVC is not surprising. There is a strong relationship between FCV and body size in children and adolescents. Height and weight have increased significantly among Chinese children and adolescents in recent decades (7,12), which is generally accompanied by increases in chest circumference, lung size, and capacity, resulting in a positive effect on FVC.

Trends in lung function may be associated with several factors. Negative associations between undernutrition (or smaller body mass index (BMI)) and overnutrition (or larger BMI) and lung function have been proposed (1,4,7). The CNSSCH reported that the prevalence of overweight and obesity among children and adolescents aged 7-18 years in China increased from 0.7% in 1985 to 20.5% in 2019 (17). However, several surveys and review suggested that the prevalence of overnutrition has stabilized or even declined recently (17-19). Students with stunting had the lowest FVC than students with other nutritional statuses did, and stunting and thinness were strongly associated with FVC (7). The prevalence of stunting among Chinese students decreased from 16.4% to 2.3% from 1985 to 2014 (20). These trends may partially explain the changes in lung function. Unfortunately, few studies have estimated trends in the combination of stunting or undernutrition and overnutrition. These estimates may provide additional insights into the interpretation of trends in lung function.

Changes in lung function can also be explained by PA. A study reported that in children and adolescents, regular PA was associated with greater FVC, and this association was not influenced by weight status or BMI (5). China has experienced rapid economic development over the past few decades, and lifestyle changes have been accompanied by decreasing levels of PA and increasing sedentary time (21-22). However, recent studies have reported positive trends in PA behavior. The total sedentary time decreased from 2011 to 2015 (22). Guo et al. (23) reported no significant change in the percentage of Chinese girls with PA questionnaire for older children scores greater than 2.87 (equivalent to daily moderate-to-vigorous physical activity greater than one hour) from 2017 to 2019. These trends may also explain the observed changes in lung function. Improvements in lung function among Chinese children and adolescents may be linked to recent national policies. Since 2007, when promoting student health was first identified as a national strategy (9), China has implemented measures like guaranteeing school PA time. This commitment was reinforced in 2013, elevating school sports to a national level (24), and further solidified by the 2016 Healthy China 2030 goal for students to engage in moderate to vigorous PA at least three times weekly (25).

Trends in FVC and VCI had demographic differences. Although there was little difference in the change in FVC between children and adolescents, there was a difference in the change in VCI. Children experienced a large decrease in VCI and adolescents experienced a moderate decrease. Changes in actual levels of lung function may be related to the biological maturation process. Earlier puberty in boys and girls is positively associated with height-adjusted FVC at puberty; this may be explained by the development of trunk and thoracic muscles and earlier exposure to sex hormones (26). CHSSCH reported that the median age at menarche progressively decreased from 13.4 to 12.0 years among girls from 1985 to 2019 (27) and that the median age at spermarche among boys decreased from 14.6 years in 1995 to 13.9 years in 2019 (28). Moreover, academic burdens have increased, the amount of time spent performing physical activity has decreased over time for Chinese students, especially for secondary school students, and the effectiveness of implementing physical fitness interventions has been poor (7,29).

The trends in lung function were not always consistent across the population distribution. Decreases occurred mainly in populations with lower levels of lung function, and improvements occurred mainly in populations with higher levels. One possible explanation is that children and adolescents with lower levels of quality may be less willing to participate in PA than their peers with higher levels of quality (30). They may also have lower self-efficacy and lack motivation to work hard to complete the test in quality tests (31). China launched the "Nutrition Improvement Program for Rural Compulsory Education Students" in 2011 to provide nutritional meal subsidies for rural children in poor areas (32). For those with lower levels, policymakers should consider targeted interventions and efforts to improve the health of the whole population.

This paper provided the first population-based trends in FVC and VCI among Chinese children and adolescents over the past 30 years. Nationally representative physical health surveillance data were used. Estimating the VCI trends can reveal the actual level of lung function and provide references for further interventions by the government and relevant departments. This study has several limitations. First, statistical adjustments for other body size/composition (height or BMI), biological maturity, and PA level data were not possible. Second, given the limitations of the data, the lambda mu-sigma method could not be used to calculate percentile values for the test means, which may introduce some errors by ignoring the skewness and dispersion of the data. However, the sample size of this study was very large, which may minimize these errors. Third, this study was a continuous cross-sectional study rather than a cohort study. The estimated trends may be intergenerational trends influenced by confounding factors.

Conclusion

The absolute lung function (measured as FVC) did not change significantly, but relative lung function (measured as VCI) decreased from 1985 to 2019 among Chinese children and adolescents. The decrease in lung function has been reversed since the 21st century. Changes in lung function have demographic differences. These trends were uneven across the population distribution, with trends at lower levels of lung function being more negative than those at higher levels. The government and relevant departments should focus on low-quality populations to promote health in the whole population.

Journalism Ethics considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

Acknowledgements

Thank for all staff who worked on the Chinese National Survey on Students' Constitution and Health from 1985 to 2019.

Conflict of interest

The authors declare no conflict of interests.

Data availability

All supplementary data not published here will be sent to the respected readers for reasonable application. Please contact the corresponding author.

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