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RESEARCH PAPER

Developing and validating a Chinese multimorbidity-weighted index for middle-aged and older community-dwelling individuals

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Abstract

Objective: To develop and validate an index to quantify the multimorbidity burden in Chinese middle-aged and older community-dwelling individuals.
Methods: We included 20,035 individuals aged 45 and older from the China Health and Retirement Longitudinal Study (CHARLS) and 19,297 individuals aged 65 and older from the Chinese Longitudinal Healthy Longevity Survey (CLHLS). Health outcomes of physical functioning (PF), basic and instrumental activities of daily living (ADL and IADL) and mortality were obtained. Based on self-reported disease status, we calculated five commonly used western multimorbidity indexes for CHARLS baseline participants. The one that predicted the health outcomes the best was selected and then modified through a linear mixed model using the repeated individual data in CHARLS. The performance of the modified index was internally and externally evaluated with CHARLS and CLHLS data.
Results: The multimorbidity-weighted index (MWI) performed the best among the five indexes. In the modified Chinese multimorbidity-weighted index (CMWI), the weights of the diseases varied greatly (range 0.2–5.1). The top three diseases with the highest impact were stroke, memory-related diseases and cancer, corresponding to weights of 5.1, 4.3 and 3.4, respectively. Compared with the MWI, the CMWI showed better model fits for PF and IADL with larger R^2 and smaller Akaike information criterion, and comparable prediction performances for ADL, IADL and mortality (e.g. the same predictive accuracy of 0.80 for ADL disability).
Conclusion: The CMWI is an adequate index to quantify the multimorbidity burden for Chinese middle-aged and older community-dwelling individuals. It can be directly computed via disease status examined in regular community health check-ups to facilitate health management.

Keywords: multimorbidity-weighted index, linear mixed model, disease burden, older people

Key Points

- The multimorbidity-weighted index (MWI) performed the best in measuring multimorbidity burden for Chinese among five commonly used western multimorbidity indexes.
- The Chinese multimorbidity-weighted index (CMWI) was modified from the MWI with the weights of chronic disease tailored to Chinese middle-aged and older community-dwelling individuals.
- The CMWI performed better than or comparably with the MWI when quantifying the multimorbidity burden for middle-aged and older Chinese.

Introduction

Alongside rapid population ageing, multimorbidity, i.e. multiple, concurrent morbid conditions, is becoming a major public health concern. It has been considered as a norm but not an exception in most high-income countries [1], and also is becoming increasingly prevalent in low- and middle-income countries [2]. Therapeutic advances in chronic disease treatment further promote the increases in prevalence of multimorbidity, especially among older adults [3]. Research on multimorbidity has received extensive attention internationally. There is considerable evidence that multimorbidity affects functional status or health-related quality of life (HRQL) [4, 5], activities of daily living (ADL) and instrumental activities of daily living (IADL) [6], health resource utilization [7], mortality [8], and so on. Hence, multimorbidity not only affects quality of life, but can also bring with it a heavy social and economic burden for individuals, families and society as a whole.

Accumulating methodological research on multimorbidity measures reveals five indexes most used to quantify the burden of multimorbidity [9, 10]. A simple disease count (Count) counts all chronic diseases or conditions an individual may have without weighting [11]. The Charlson comorbidity index (CCI) includes 19 chronic conditions weighted 1, 2, 4 or 6 based on their associations with 1 year mortality, developed in 559 hospitalized patients [12]. It was widely used to predict mortality mainly in hospital settings. The Elixhauser comorbidity index (ECI) includes 30 conditions associated with inpatient mortality, cost and length of stay based on a sample size of >1 million hospitalized patients [13]. The health-related quality of life comorbidity index (HRQL-CI) weights 20 medical conditions based on their association with the short form-12 (SF-12) physical component summary, and it has been proved to outperform the CCI in explaining physical functioning (PF), but has not been widely used [14]. Moreover, the SF-12 cannot provide as much information as the SF-36 [15]. A multimorbidity-weighted index (MWI) was then developed from three population-based prospective cohorts by summing the weightings of 98 chronic diseases on SF-36 PF scores [16]. It has been applied to predict physical or mental health and mortality of communities [17], with good model performances in comparison with the previously mentioned indexes [18].

Having originated from western populations, few studies have applied these multimorbidity indexes to the Chinese population. A handful of studies only applied the CCI [19, 20] or ECI [21, 22] to small hospitalized samples and most were based on retrospective cohorts. There is as yet no study on the latest developed indexes, such as the HRQL-CI or MWI, in the Chinese population. Moreover, previous studies directly applied these western population-based indexes to the Chinese population without disease weight modification, and the validity of these indexes is unknown. For example, conflicting findings have been reported in studies when comparing the validity of the CCI and ECI to predict in-hospital mortality in Chinese patients [21, 23]. Given the multimorbidity prevalence of 51.6% and 81.3% in the middle-aged and in the older groups, respectively [24], and an upward trend over time in China [25], it is imperative to identify or develop a multimorbidity index that best quantifies the multimorbidity burden tailored for the Chinese population.

Our study aimed to develop and validate a multimorbidity index for Chinese middle-aged and older community-dwelling individuals. By comparing the model performance of the five commonly used multimorbidity indexes in ageing cohorts representative of the Chinese population against several health outcomes (PF, ADL, IADL and mortality), the index with the best model fit would be selected and modified to measure the multimorbidity burden of the Chinese middle-aged and older population.

Methods

Study sample

The study population were obtained from two nationwide prospective cohort studies, i.e. the China health and retirement longitudinal study (CHARLS) [26] and the Chinese longitudinal healthy longevity survey (CLHLS) [27], where the former focuses on middle-aged and older people (i.e. aged ≥45) while the latter includes people aged ≥65. Both studies applied a household survey to collect the high-quality micro-data representing the Chinese community-dwelling individuals, covering a wide range of information on demographic characteristics, socioeconomic status, chronic disease, physical function, healthcare, insurance, etc. In terms of sampling method, CHARLS adopts a multi-stage and random probability sample with probability proportional to size [28], while CLHLS adopts a multi-stage disproportionate target random sampling method [29], and both sampling methods show good representativeness. The baseline surveys were conducted in 2011 for CHARLS and in 1998 for CLHLS, and they were followed up every 2–3 years. Considering that information on several diseases (e.g. rheumatism) has only been collected since 2011 in CLHLS, we used the CHARLS data of all waves (i.e. 2011, 2013, 2015 and 2018) as well as the CLHLS data of the 2011, 2014 and 2018 waves for analysis. We included participants who both reported the status (presence or absence) of physician-diagnosed chronic diseases and answered the items responding to PF, ADL and IADL in the same year.

Chronic disease assessment

Physician-diagnosed diseases were assessed during each wave of both studies. Participants were asked questions such as 'Have you been diagnosed with ... by a doctor?' We considered the 16 most common or important chronic diseases, investigated in the CHARLS questionnaire with a binary response of presence or absence, as targeted diseases for calculation of multimorbidity indexes [30]. These are hypertension, dyslipidaemia (e.g. elevation of total cholesterol), diabetes or high blood sugar, cancer or malignant

tumour (excluding mild skin cancers), chronic lung diseases (e.g. chronic bronchitis, emphysema, excluding tumours or cancer), liver disease (except fatty liver, tumours and cancer), heart disease (e.g. coronary heart disease, angina or congestive heart failure), stroke, kidney disease (excluding tumours or cancer), stomach or other digestive diseases (except for tumour or cancer), emotional, nervous or psychiatric problems, memory-related diseases (defined as diseases related to memory in this study, e.g. dementia, brain atrophy and Parkinson's disease), arthritis or rheumatism, asthma, prostate diseases and glaucoma. Diseases with a positive association with PF were excluded in the development of the final modified index.

Outcome variables

We considered four health-related outcome variables, namely PF, ADL, IADL and mortality, to measure the multimorbidity burden. PF, a particularly effective indicator evaluating the functional status of physical activities, was assessed by seven items resembling the PF scale of SF-36 [31]. As CLHLS did not provide enough items for PF, this outcome was only considered for CHARLS data. The ADL [32] and IADL [33], evaluating the status of basic and instrumental activities of daily living, respectively, were assessed as binary indicators. If there were any difficulties in one or more activities, the participant was defined as having ADL or IADL disability [34]. Mortality, the most severe health outcome for an individual, was collected in both cohorts. We calculated survival time for baseline participants. As the exact time of death was not reported in CHARLS, the survival time for participants who died during follow-up was measured as the difference between the baseline year and the median year of the last two waves. Details for the treatment of missing data in the status of chronic diseases and outcome variables are given in Supplementary Text I available at *Age and Ageing* online.

Statistical methodology

First, we calculated the five multimorbidity indexes (i.e. MWI, CCI, ECI, HRQL-CI and Count) for each eligible baseline participant in the 2011 wave who were followed up to the 2018 wave in CHARLS, based on the reporting of disease status and the corresponding weights given by the indexes. We compared the distributions of the five indexes in CHARLS baseline participants and measured the Pearson correlation coefficient between each pair of indexes (Supplementary Table 1 available at *Age and Ageing* online). Each of the indexes was further used as the predictor to estimate the four health outcomes (i.e. PF, ADL, IADL and mortality) in the 2018 wave of CHARLS. Linear models were used for PF, and the model performance was assessed by the Akaike information criterion (AIC) and R^2; binary outcomes of ADL and IADL were fit by logistic models, with the AIC and accuracy to evaluate the model fitting [35]; and Cox proportional hazard models were adopted for mortality, with the AIC and C-statistics to assess the performance [17]. The index with the best model fit for Chinese middle-aged and older adults was selected for the subsequent modification.

As results from the above analysis showed that the MWI had the best model fit, we developed a Chinese-MWI (CMWI) with the outcome variable PF and the 16 candidate chronic diseases considered as predictors. For the development of the CMWI with CHARLS data, we adopted a linear mixed model with all study waves of data, including the repeated measures of PF and the disease status of each participant in each wave, in order to better estimate the weights of each disease in the multimorbidity burden [36]. After adjusting for age, sex and other chronic diseases, we quantified the impact of each chronic disease on PF with the corresponding regression coefficient, the absolute value of which was denoted as the weight of the disease. Subsequently, the CMWI was constructed by summing up the weights of the diseases, which were reported as presence per individual (Supplementary Text II available at *Age and Ageing* online). In addition, as studies found that chronic disease may affect patients differently with age [37], we also developed a linear mixed model by adding the age–disease interaction term as a covariate. The corresponding index was denoted as the interaction-CMWI.

Furthermore, the predictive performance of the CMWI and interaction-CMWI were validated, and compared with that of the MWI, using CHARLS as internal and CLHLS as external data, for the four health outcomes. In comparison of the performances of the multimorbidity indexes, we used only the disease status on baseline as the predictor, to assess the prediction ability of the indexes on the four health outcomes (i.e. PF, ADL, IADL and mortality) in the 2018 wave. All statistical analyses were conducted using R, version 4.0.5.

Results

Participant characteristics

A total of 89,733 observations from 39,332 participants who met the inclusion criteria were included in the study, comprising 62,750 observations from 20,035 participants in four waves of CHARLS and 26,983 observations from 19,297 participants in three waves of CLHLS. Fourteen diseases were included in the final analysis and they varied widely in prevalence (range 1.7–38.2%). The top three prevalent diseases were arthritis (38.2%), hypertension (32.2%) and digestive disease (27.3%), while the disease with the lowest prevalence was cancer (1.7%). Participants in the baseline survey of CHARLS had an average age of 59.6 (standard deviation, 9.8) years, and 51.1% were female, while those in CLHLS were on average 26 years older, with an average age of 85.6 (standard deviation, 11.1), and 54.4% were female. Description of the four health outcomes and characteristics of baseline participants and those who were followed up to the 2018 wave are shown in Table 1.

Comparison of the five commonly used indexes

For the health outcome prediction, the MWI had the best model fit, with the highest R^2 (=0.25) for PF and the smallest AIC for ADL (=12,073) and IADL (=14,594). However,

Table 1. Characteristics of baseline participants in CHARLS and CLHLS, China, 2011 and 2018

Characteristics	CHARLS				CLHLS			
	2011 ($n = 16,569$)		2018 ($n = 12,798$)		2011 ($n = 8,310$)		2018 ($n = 2,286$)	
	No.	%	No.	%	No.	%	No.	%
Age, years[b]	59.6 (9.8)		65.4 (8.9)		85.6 (11.1)		84.7 (9.1)	
Sex, female	8,458	51.1	6,703	52.4	4,521	54.4	1,167	51.1
PF score[b]	48.64 (9.9)		46.00 (11.3)		N/A[a]		N/A[a]	
ADL disability	2,765	16.7	2,862	22.4	2,081	25.0	473	20.7
IADL disability	3,556	21.5	4,517	35.3	4,553	54.8	1,166	51.0
Death[c]	N/A[a]		1,690		N/A[a]		2,153	

Abbreviations: ADL, activities of daily living; CHARLS, the China Health And Retirement Longitudinal Study; CLHLS, the Chinese Longitudinal Healthy Longevity Survey; IADL, instrumental activities of daily living; N/A, not applicable or not available; PF, physical functioning. [a]Information about PF in CLHLS participants and death in all baseline participants was not available. PF was not considered in CLHLS because only four of 10 items about PF were asked. There were no deaths in the baseline survey. [b]Values for age and PF score are expressed as mean (standard deviation). [c]Number of baseline participants who died during the wave from 2011 to 2018.

Table 2. Performance of five commonly used multimorbidity indexes in CHARLS, China, 2011–2018

Multimorbidity index	PF		ADL disability		IADL disability		Mortality	
	AIC	R^2	AIC	Accuracy	AIC	Accuracy	AIC	*C*-statistic
MWI	94,566	0.25	12,073	0.78	14,594	0.71	28,052	0.78
CCI	95,066	0.22	12,352	0.78	14,771	0.70	28,024	0.78
HRQL-CI	94,652	0.25	12,077	0.78	14,642	0.70	28,081	0.78
ECI	95,022	0.23	12,336	0.78	14,752	0.70	28,046	0.78
Count	95,066	0.22	12,077	0.78	14,687	0.70	28,068	0.78

Abbreviations: ADL, activities of daily living; AIC, Akaike information criterion; CCI, Charlson comorbidity index; Count, simple disease count; *C*-statistic, the concordance statistic; ECI, Elixhauser comorbidity index; HRQL-CI, health-related quality of life comorbidity index; IADL, instrumental activities of daily living; MWI, multimorbidity-weighted index; PF, physical functioning; R^2, the adjusted coefficient of determination.

for mortality, the CCI and ECI showed a slightly better fit than the MWI, with a lower AIC (Table 2). In addition, indicators for predictive performance were similar among the five indexes: the identical predictive accuracy (=0.78) for ADL disability, comparative predictive accuracy (0.71 for MWI and 0.70 for others) for IADL disability and the identical C-statistic (=0.78) for mortality. According to the distributions of the five indexes in CHARLS baseline participants (Figure 1), the MWI showed the widest range (0–27) and a two-peak distribution (one lying in the zero and the other in four), capturing both the high and low extremes of multimorbidity and better differentiating the multimorbidity burden. The five multimorbidity indexes correlated significantly with each other, with the Pearson correlation coefficients ranging from 0.73 to 0.94 (Supplementary Table 1 available at *Age and Ageing* online). Accordingly, the MWI showed the best performance to assess the multimorbidity burden, and thus was selected for the subsequent modification for the Chinese data.

Development of CMWI

Among the 16 types of chronic diseases investigated in CHARLS, glaucoma and prostate disease were excluded in development of the final index because of their positive association with PF. The 14 chronic diseases included were associated with reduction on PF score. However, different diseases showed various impacts on PF, with regression coefficients ranged from −5.1 to −0.2 (Table 3). The top three diseases with the greatest adverse impact on PF were stroke (= − 5.1), memory-related diseases (= − 4.3) and cancer (= − 3.4). However, these three diseases had different orders regarding their impact on PF in the MWI, with stroke having a lower impact than memory-related diseases. The distribution of the CMWI was similar as that of the MWI in CHARLS baseline participants, ranging from 0 to 20.5, with one peak lying in the zero score and the other in two (Figure 1).

Validation of CMWI

Generally, the MWI, CMWI and interaction-CMWI showed similar performance for prediction of multimorbidity-related health outcomes, as the accuracies of model prediction of the three indexes on ADL and IADL, as well as the *C*-statistics on mortality were the same in both internal (with CHARLS data) and external (with CLHLS data) validation (Table 4). The identical predictive accuracy for ADL and IADL, and the *C*-statistic for mortality were 0.78, 0.71 and 0.78, respectively, for internal validation; while these numbers were 0.80, 0.73 and 0.77, respectively, for external validation. Furthermore, except for the model fitting

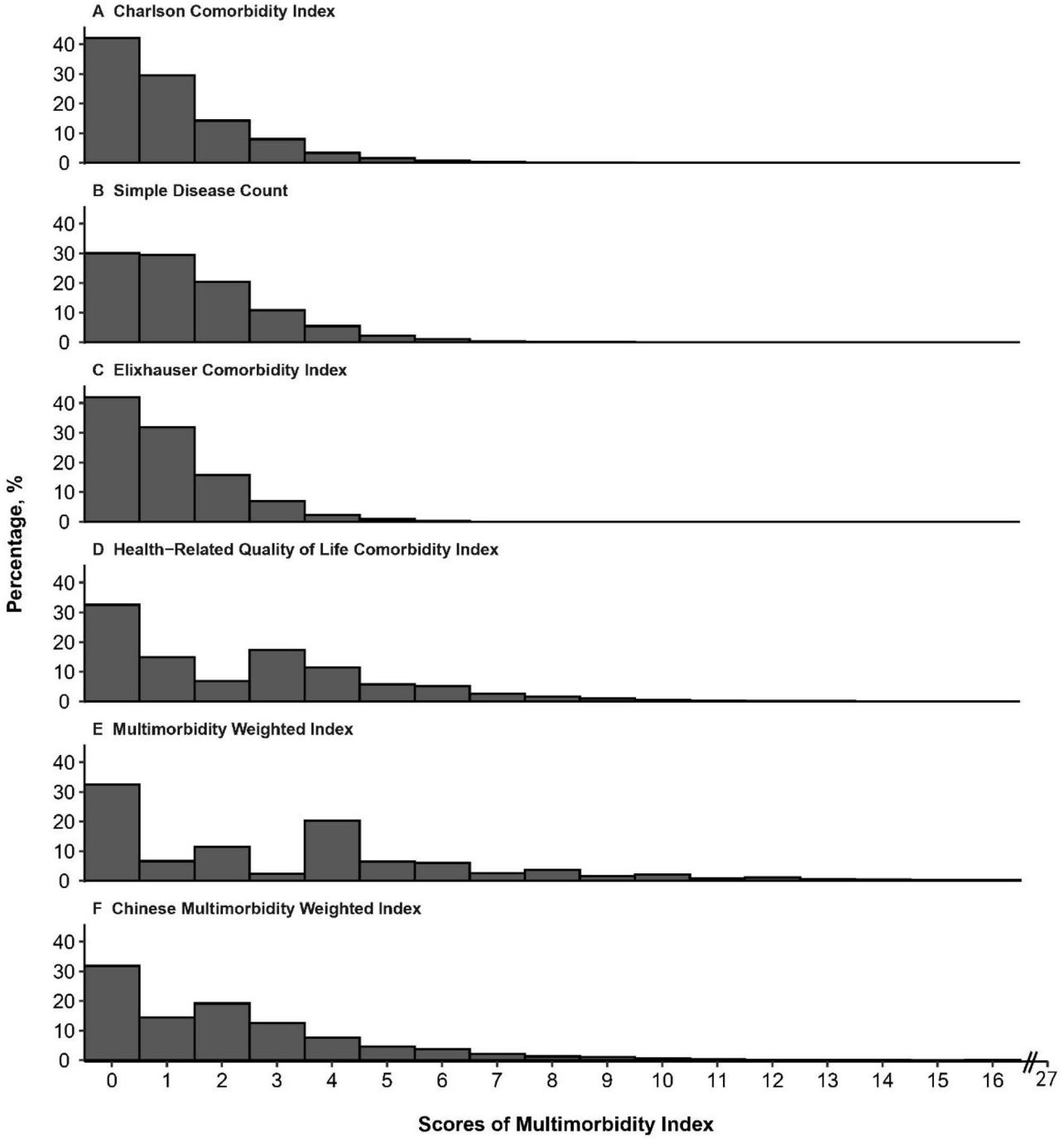

Figure 1. Distribution of the five commonly used multimorbidity indexes and the developed Chinese multimorbidity-weighted index for baseline participants from the CHARLS (2011, $n = 16{,}569$)

on mortality in CLHLS data and that on ADL in CHARLS data, the CMWI had the smallest AIC of all other model fits, suggesting a better performance of CMWI compared with the bMWI and interaction-CMWI.

Discussion

Our study found that the MWI performed the best in quantifying the multimorbidity burden of Chinese patients among the five commonly used indexes. Based on the MWI, the modified CMWI with the disease weights tailored to Chinese middle-aged and older community-dwelling individuals showed a better or comparable model performance in predicting several health outcomes.

We found that the MWI had the widest distribution and was the best measure of multimorbidity burden for Chinese community-dwelling individuals among the five commonly used indexes. It is consistent with the results

Table 3. The development of the CWMI using 14 chronic diseases with SF-36 PF as outcome in CHARLSa, China, 2011–2018

Chronic disease	No.	Percentage (%)[b]	Coefficient[c]	SE	*P* value[d]
Stroke	2,975	4.5	-5.1	0.170	<0.001
Memory-related disease (e.g. dementia, brain atrophy, Parkinson's disease)	1,936	2.9	-4.3	0.210	<0.001
Cancer or malignant tumour (excluding minor skin cancers)	1,118	1.7	-3.4	0.270	<0.001
Asthma	3,620	5.5	-2.4	0.190	<0.001
Arthritis or rheumatism	25,255	38.2	-2.2	0.090	<0.001
Emotional, nervous, or psychiatric problems	1,315	2.0	-2.1	0.260	<0.001
Heart disease (e.g. coronary heart disease, angina, congestive heart failure)	10,965	16.6	-1.7	0.110	<0.001
Chronic lung diseases (e.g. chronic bronchitis, emphysema, excluding tumours or cancer)	8,614	13.0	-1.6	0.120	<0.001
Hypertension	21,291	32.2	-1.3	0.090	<0.001
Kidney disease (except for tumour or cancer)	5,608	8.5	-1.1	0.140	<0.001
Diabetes or high blood sugar	6,295	9.5	-1.0	0.130	<0.001
Stomach or other digestive disease (except for tumour or cancer)	18,053	27.3	-0.7	0.090	<0.001
Dyslipidaemia (e.g. elevation of total cholesterol)	10,912	16.5	-0.2	0.100	0.020
Liver disease (except fatty liver, tumours, and cancer)	3,742	5.7	-0.2	0.160	0.200

Abbreviations: CHARLS, the China Health and Retirement Longitudinal Study; SF-36 PF, the physical functioning scale in the 36-item short form survey; SE, standard error. [a]These analyses were based on a total of 62,750 observations gathered in CHARLS from waves 2011 to 2018. [b]Percentage of the disease was calculated by the number of observations presenting the disease divided by the number of all observations. [c]Regression coefficients of PF scores were adjusted for age, sex and all other chronic diseases. [d]The significance level was set at a *P*-value <0.05.

Table 4. Comparisons of the MWI, CMWI and interaction-CMWI on model fits in CHARLS and CLHLS, China, 2011–2018

Multimorbidity index	PF		ADL disability		IADL disability		Mortality	
	AIC	R^2	AIC	Accuracy	AIC	Accuracy	AIC	*C*-statistic
CHARLS								
MWI	94,566	0.25	12,073	0.78	14,594	0.71	28,052	0.78
CMWI	94,510	0.26	12,161	0.78	14,565	0.71	28,038	0.78
interaction-CMWI	94,517	0.26	12,089	0.78	14,586	0.71	28,047	0.78
CLHLS								
MWI	N/A[a]		2,030	0.80	2,524	0.73	58,433	0.77
CMWI	N/A[a]		2,029	0.80	2,524	0.73	58,434	0.77
interaction-CMWI	N/A[a]		2,029	0.80	2,525	0.73	53,976	0.77

Abbreviations: ADL, activities of daily living; AIC, Akaike information criterion; CHARLS, the China Health And Retirement Longitudinal Study; CLHLS, the Chinese Longitudinal Healthy Longevity Survey; CMWI, Chinese multimorbidity-weighted index; *C*-statistic, the concordance statistic; IADL, instrumental activities of daily living; interaction-CMWI, Chinese multimorbidity-weighted index calculated with age–disease interaction considered; MWI, multimorbidity-weighted index; N/A, not applicable or not available.; PF, physical functioning; R^2, the adjusted coefficient of determination. [a]PF was not considered in CLHLS as it did not provide enough items for PF assessment.

of Wei *et al.* [18], who also found that the ICD-coded MWI performed best in predicting PF and mortality. In addition, our study extended their finding by including two extra physical function measures (i.e. ADL and IADL). For health outcomes associated with physical functions (i.e. PF, ADL and IADL), it was noted that the MWI demonstrated the best model fit, followed by the HRQL-CI. This may be because the MWI and HRQL-CI assigned weights to each disease by impact on SF-36 PF and SF-12 physical component summary, respectively. Both PF and physical component summary are about physical functions, but the former contains more information. In contrast, the CCI and ECI assigned weights to each disease by impact on mortality, which is a more serious outcome than physical function [12, 13]. For mortality, the MWI had the same C-statistic as the others, despite the fact that it was not developed by measuring mortality risk. Wei et al. [18] found a slightly different result in that the *C*-statistics were similar but not the same in five indexes. Moreover, prior studies that compared the ability of the CCI and ECI to predict mortality in Chinese subjects also resulted in a disagreement. For example, Yang *et al*. [23] concluded that the CCI was better than the ECI, while others [21, 38] found the opposite result. However, the numerical difference in *C*-statistics was <0.1 despite the ranking difference of the two indexes.

The newly developed CMWI had a better than or comparable performance with the MWI, and it quantified the multimorbidity burden on PF tailored to Chinese middle-aged and older adults. For specific diseases, both indexes indicated the strong impact of memory-related diseases on

PF, highlighting the great effect of both dementia and Parkinson diseases on middle-aged and older adults across high- and middle-income countries [39]. As regards stroke, it was weighted and ranked a little differently in the two indexes. The weight of stroke was 4.3 in the CMWI which ranked the first among the 14 diseases, while it was 3.8 in the MWI, ranked 11th out of 98 diseases. Previous studies have shown that in China, adherence to evidence-based recommendations and clinical practice for stroke, the quality of stroke care and the rehabilitation after stroke were worse than in the USA [40, 41]. This may be the reason why stroke had a greater impact on PF in Chinese than in Americans. Due to these modifications, the CMWI developed by this study turned out to perform better than the original MWI when using PF and IADL as outcomes, showing a smaller AIC and higher R^2. The interaction-CWMI showed comparable performance with the CMWI so for simplicity we recommended the CMWI to measure the multimorbidity burden. Also, approximately 66% of the sample was composed of middle-aged adults, which may result in insufficient power to test the age–disease interaction.

Our study contributes to the literature by providing the first estimation of the weights of 14 chronic diseases on the multimorbidity burden for Chinese. By and large, previous research on multimorbidity in China mainly addressed its prevalence and risk factors [34, 42, 43], patterns of multimorbidity [44, 45] and the impact of multimorbidity on health-related outcomes and healthcare utilization [46, 47]. We found that multimorbidity was prevalent among Chinese middle-aged and older adults, and was associated with lower PF, higher ADL/IADL disability and higher mortality risk, which is in line with prior studies [34, 42–44]. However, in most of these studies, multimorbidity was qualitatively defined as the simultaneous presence of two or more chronic diseases [48], different from the quantitative measure used in this study. By developing and validating the CMWI, our study improved on prior studies by directly estimating the quantitative impact of multimorbidity on several health outcomes [31, 44]. In addition, prior studies had proved that the prevalence and patterns of multimorbidity varied in different regions [49], which suggested that there may also be regional difference in the degree of the impact of disease on health, thus raising the question about the applicability of western-based indexes to the Chinese population. This study answered this question, with CMWI having a slightly better performance than western indexes when used for Chinese subjects.

Several limitations of our study should be noted. First, only 14 chronic diseases were included in the CMWI, much lower than the 98 in the MWI, which may lead to underestimation of multimorbidity burden. Nevertheless, our index already covered the key chronic diseases with high prevalence in high- and low-income countries that significantly affect the health of older adults [49]. Second, both CHARLS and CLHLS collected self-reported doctor-diagnosed diseases. As well as potential reporting bias, the classification of diseases is imprecise, with several similar diseases lumped together. The lack of specific disease information prevented us from exploring the synergistic effect of multimorbidity, but we assuming an additive effect as in most prior studies [12–14]. Third, the CMWI was quantified as the disease burden on physical function without consideration of mental function, due to limited mental health measures of SF-36 available in both cohorts. Last, our study validated the performance of the CMWI using health-related outcomes only, while the extent to which the CMWI would contribute to other health economic indicators should be further verified [45, 46].

Conclusion

In this study, we found that the CMWI was an adequate index to quantify the multimorbidity burden for Chinese middle-aged and older community-dwelling individuals. It can be directly computed via disease status routinely examined during annual health checkups at community healthcare centres, which will facilitate its application to health management and patient communication.

Supplementary Data: Supplementary Data mentioned in the text are available to subscribers in *Age and Ageing* online.

Declaration of Conflicts of Interest: None.

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References

1. Multimorbidity: A Priority for Global Health Research. 2018; https://acmedsci.ac.uk/file-download/82222577 (2 May 2021, date last accessed).
2. Arokiasamy P, Uttamacharya U, Jain K *et al.* The impact of multimorbidity on adult physical and mental health in low- and middle-income countries: what does the study on global ageing and adult health (SAGE) reveal? BMC Med 2015; 13: 178–94.
3. Ryan BL, Bray Jenkyn K, Shariff SZ *et al.* Beyond the grey tsunami: a cross-sectional population-based study of multimorbidity in Ontario. Can J Public Health-Rev Can Sante Publ 2018; 109: 845–54.
4. Gu J, Chao J, Chen W *et al.* Multimorbidity and health-related quality of life among the community-dwelling elderly: a longitudinal study. Arch Gerontol Geriatr 2018; 74: 133–40.
5. Pati S, Swain S, Knottnerus JA, Metsemakers JFM, van den Akker M. Health related quality of life in multimorbidity: a

primary-care based study from Odisha. India Health Qual Life Outcomes 2019; 17: E116.
6. Li H, Wang A, Gao Q *et al.* Prevalence of somatic-mental multimorbidity and its prospective association with disability among older adults in China. Aging-US 2020; 12: 7218–31.
7. Aubert CE, Fankhauser N, Marques-Vidal P *et al.* Multimorbidity and healthcare resource utilization in Switzerland: a multicentre cohort study. BMC Health Serv Res 2019; 19: E708.
8. Rizzuto D, Melis RJF, Angleman S, Qiu C, Marengoni A. Effect of chronic diseases and multimorbidity on survival and functioning in elderly adults. J Am Geriatr Soc 2017; 65: 1056–60.
9. Griffith LE, Gruneir A, Fisher KA *et al.* Key factors to consider when measuring multimorbidity: results from an expert panel and online survey. J Comorb 2018; 8: 1–9.
10. Nicholson K, Almirall J, Fortin M *et al.* The measurement of multimorbidity. Health Psychol Rev 2019; 38: 783–90.
11. Ferraro KF, Wilmoth JM. Measuring morbidity: disease counts, binary variables, and statistical power. J Gerontol Ser B-Psychol Sci Soc Sci 2000; 55: S173–89.
12. Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J Chronic Dis 1987; 40: 373–83.
13. Elixhauser A, Steiner C, Harris DR, Coffey RM. Comorbidity measures for use with administrative data. Med Care Res Rev 1998; 36: 8–27.
14. Mukherjee B, Ou H-T, Wang F, Erickson SR. A new comorbidity index: the health-related quality of life comorbidity index. J Clin Epidemiol 2011; 64: 309–19.
15. Schofield MJ, Mishra G. Validity of the SF-12 compared with the SF-36 health survey in pilot studies of the Australian longitudinal study on women's health. J Health Psychol 1998; 3: 259–71.
16. Wei MY, Kawachi I, Okereke OI, Mukamal KJ. Diverse cumulative impact of chronic diseases on physical health related quality of life: implications for a measure of multimorbidity. Am J Epidemiol 2016; 184: 357–65.
17. Wei MY, Mukamal KJ. Multimorbidity, mortality, and long-term physical functioning in 3 prospective cohorts of community-dwelling adults. Am J Epidemiol 2018; 187: 103–12.
18. Wei MY, Ratz D, Mukamal KJ. Multimorbidity in medicare beneficiaries: performance of an ICD-coded multimorbidity-weighted index. J Am Geriatr Soc 2020; 68: 999–1006.
19. Chan T-C, Luk JK-H, Chu L-W, Chan FH-W. Validation study of Charlson comorbidity index in predicting mortality in Chinese older adults. Geriatr Gerontol Int 2014; 14: 452–7.
20. Liu H, Wu X, Cao J *et al.* Effect of comorbidity assessed by the Charlson comorbidity index on the length of stay and mortality among immobile hemorrhagic stroke patients younger than 50 years. Front Neurol 2020; 11: Article 487.
21. Stephan BCM, Pakpahan E, Siervo M *et al.* Comparing the performance of Charlson and Elixhauser comorbidity indices to predict in-hospital mortality among a Chinese population. Clin Epidemiol 2020; 12: 307–16.
22. Liu C, Luo L, Duan L *et al.* Factors affecting in-hospital cost and mortality of patients with stroke: evidence from a case study in a tertiary hospital in China. Int J Health Plann Manage 2021; 36: 399–422.
23. Yang C-C, Fong Y, Lin L-C *et al.* The age-adjusted Charlson comorbidity index is a better predictor of survival in operated lung cancer patients than the Charlson and Elixhauser comorbidity indices. Eur J Cardiothorac Surg 2018; 53: 235–40.
24. Wang X, Yao S, Wang M *et al.* Multimorbidity among two million adults in China. Int J Environ Res Public Health 2020; 17: E3395.
25. Zhang L, Sun F, Li Y *et al.* Multimorbidity in community-dwelling older adults in Beijing: prevalence and trends, 2004-2017. J Nutr Health Aging 2021; 25: 116–9.
26. Zhao Y, Hu Y, Smith JP *et al.* Cohort profile: the China health and retirement longitudinal study (CHARLS). Int J Epidemiol 2014; 43: 61–8.
27. Gu D, Feng Q, Chen H, Zeng Y. Chinese longitudinal healthy longevity survey (CLHLS). In: Gu D, Dupre ME, eds. Encyclopedia of gerontology and population aging. Cham: Springer International Publishing, 2020; 1–14.
28. Chen X, Smith J, Strauss J, Wang Y, Zhao Y. China health and retirement longitudinal study (CHARLS). In: Pachana NA, ed. Encyclopedia of Geropsychology. Singapore: Springer Singapore, 2015; 1–8.
29. Zheng Z. Twenty years' follow-up on elder people's health and quality of life. China Popul Dev Stud 2020; 3: 297–309.
30. Wu F, Guo Y, Kowal P *et al.* Prevalence of major chronic conditions among older Chinese adults: the study on global AGEing and adult health (SAGE) wave 1. PLoS One 2013; 8: e74176.
31. Ware J, Kosinski M, Keller S. SF-36 Physical and Mental Health Summary Scales: A User's Manual. Boston, MA: Health Assessment Lab, 1994.
32. Katz S, Ford AB, Heiple KG, Newill VA. Studies of illness in the aged. The index of ADL: a standardized measure of biological and psychosocial function. JAMA 1963; 185: 914–9.
33. Lawton MP, Brody EM. Assessment of older people: self-maintaining and instrumental activities of daily living. Gerontologist 1969; 9: 179–86.
34. Zhang Y, Zhou L, Liu S *et al.* Prevalence, correlates and outcomes of multimorbidity among the middle-aged and elderly: findings from the China health and retirement longitudinal study. Arch Gerontol Geriatr 2020; 90: 104135.
35. Ritt M, Ritt JI, Sieber CC, Gassmann KG. Comparing the predictive accuracy of frailty, comorbidity, and disability for mortality: a 1-year follow-up in patients hospitalized in geriatric wards. Clin Interv Aging 2017; 12: 293–304.
36. Fitzmaurice GM, Laird NM, Ware JH. Applied Longitudinal Analysis. Boston, MA: John Wiley & Sons, Inc, 2011.
37. Piazza JR, Charles ST, Almeida DM. Living with chronic health conditions: age differences in affective well-being. J Gerontol B Psychol Sci Soc Sci 2007; 62: P313–21.
38. Xu Y, Li N, Lu M *et al.* Comparison of risk adjustment methods in patients with liver disease using electronic medical record data. BMC Gastroenterol 2017; 17: 5.
39. Alzheimer's Association. 2021 Alzheimer's disease facts and figures. Alzheimers Dement 2021; 2021: 327–406.
40. Li Z, Wang C, Zhao X *et al.* Substantial progress yet significant opportunity for improvement in stroke care in China. Stroke 2016; 47: 2843–9.
41. Asakawa T, Zong L, Wang L, Xia Y, Namba H. Unmet challenges for rehabilitation after stroke in China. Lancet 2017; 390: 121–2.

42. Zhang L, Ma L, Sun F, Tang Z, Chan P. A multicenter study of multimorbidity in older adult inpatients in China. J Nutr Health Aging 2020; 24: 269–76.
43. Yi JY, Kim H, Chi I. Urban-rural differences in multimorbidity and associated factors in China and Korea: a population-based survey study. Geriatr Gerontol Int 2019; 19: 1157–64.
44. Yao SS, Cao GY, Han L *et al.* Prevalence and patterns of multimorbidity in a nationally representative sample of older Chinese: results from the China health and retirement longitudinal study. J Gerontol A Biol Sci Med Sci 2020; 75: 1974–80.
45. Yu J, Song F, Li Y *et al.* Multimorbidity analysis of 13 systemic diseases in northeast China. Int J Environ Res Public Health 2020; 17: E1817.
46. Zhao Y, Zhang P, Oldenburg B *et al.* The impact of mental and physical multimorbidity on healthcare utilization and health spending in China: a nationwide longitudinal population-based study. Int J Geriatr Psychiatry 2021; 36: 500–10.
47. Chen H, Cheng M, Zhuang Y, Broad JB. Multimorbidity among middle-aged and older persons in urban China: prevalence, characteristics and health service utilization. Geriatr Gerontol Int 2018; 18: 1447–52.
48. Storeng SH, Vinjerui KH, Sund ER, Krokstad S. Associations between complex multimorbidity, activities of daily living and mortality among older Norwegians. A prospective cohort study: the HUNT Study, Norway. BMC Geriatr 2020; 20.
49. Garin N, Koyanagi A, Chatterji S *et al.* Global multimorbidity patterns: a cross-sectional, population-based, multi-country study. J Gerontol A Biol Sci Med Sci 2016; 71: 205–14.

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