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Identifying non-communicable disease multimorbidity patterns and associated factors: a latent class analysis approach

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ABSTRACT

Objective In the absence of adequate nationally-representative empirical evidence on multimorbidity, the existing healthcare delivery system is not adequately oriented to cater to the growing needs of the older adult population. Therefore, the present study identifies frequently occurring multimorbidity patterns among older adults in India. Further, the study examines the linkages between the identified patterns and socioeconomic, demographic, lifestyle and anthropometric correlates.

Design The present findings rest on a large nationally-representative sample from a cross-sectional study.

Setting and participants The study used data on 58 975 older adults (45 years and older) from the Longitudinal Ageing Study in India, 2017–2018.

Primary and secondary outcome measures The study incorporated a list of 16 non-communicable diseases to identify commonly occurring patterns using latent class analysis. The study employed multinomial logistic regression models to assess the association between identified disease patterns with unit-level socioeconomic, demographic, lifestyle and anthropometric characteristics.

Results The present study demonstrates that older adults in the country can be segmented into six patterns: 'relatively healthy', 'hypertension', 'gastrointestinal disorders–hypertension–musculoskeletal disorders', 'musculoskeletal disorders–hypertension–asthma', 'metabolic disorders' and 'complex cardiometabolic disorders'. Additionally, socioeconomic, demographic, lifestyle and anthropometric factors are significantly associated with one or more identified disease patterns.

Conclusions The identified classes 'hypertension', 'metabolic disorders' and 'complex cardiometabolic disorders' reflect three stages of cardiometabolic morbidity with hypertension as the first and 'complex cardiometabolic disorders' as the last stage of disease progression. This underscores the need for effective prevention strategies for high-risk hypertension group. Also, targeted interventions are essential to reduce the burden on the high-risk population and provide equitable health services at the community level.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ The study provides empirical evidence on non-communicable disease patterns using a large nationally-representative sample of older adults.
⇒ The study explored emerging non-communicable multimorbidity classes using a probability-based classification method.
⇒ Non-communicable diseases included in the study are based on self-reporting, leading to misclassification bias.
⇒ Considering the geographical and contextual variations in disease burden and profiling, these results should be explicitly apprehended for the older adults in India.
⇒ The findings were based on a single round of a longitudinal survey; thus, no causality was tested.

BACKGROUND

Estimates generated by the World Bank suggest that life expectancy at birth has increased by 28 years in the past six decades in India.[1] Despite hypothesising this increased life expectancy as a byproduct of improved living conditions and advancement in the healthcare infrastructure and health delivery services, the past two decades have been fettered by the increasing morbidity burden, with a preponderance of non-communicable diseases (NCD) in the country.[2] Despite the ever-growing healthcare sector, India is still not adequately positioned to deal with the mounting NCD prevalence. The major reason for this shortfall is that NCDs result from shared pathophysiologies and risk factors. Thus, they tend to interact and coexist, commonly referred to as associative morbidities.[3]

The vast majority of the existing morbidity research in India still explores various realms of single chronic conditions,[4–6] with scarce focus on the simultaneous occurrence of multiple morbid conditions, also known as multimorbidity.[2 7–9] Moreover, the studies on multimorbidity in India are based on one-dimensional indices like simple count or score, which suffers from the limitation of ill-defined cut-offs.[8 10] In addition to this ongoing debate, these crude measures specifically focus on quantity rather than

the nature of chronic conditions and how they interact. Consequently, the evidence generated by the method above (multimorbidity score) can estimate the multimorbidity burden but is not adequate to form policies or design interventions, majorly due to its deficiencies in understanding the complexities related to multimorbidity.[2 9 11] In the absence of this, it is challenging for a low resource economy like India to satisfy the multifaceted service requirements of the multimorbid older adults in the country.

Recent studies suggest harnessing the advantages of latent class analysis (LCA) to deal with this.[12–14] These studies propose that chronic NCDs are disproportionately distributed in any community setting. Therefore various subgroups of the population have varied healthcare priorities and needs.[14–16] Thus, the disease patterns identified through LCA can be used to reorient the existing healthcare delivery system from a disease-centred model to a more patient-centred approach.[9] Therefore, the present study aims to bridge this knowledge gap and identify frequently occurring NCD multimorbidity patterns among older adults in India. Further, the study would examine the linkages between socioeconomic, demographic, lifestyle and anthropometric factors and the identified non-communicable disease patterns.

MATERIALS AND METHODS

Data source, ethical consideration and sample size

The present study is based on the Longitudinal Ageing Study in India (LASI), 2017–2018. LASI was conducted under the stewardship of the Ministry of Health and Family Welfare, Government of India.[17] The survey included information on individuals aged 45 years or older and their spouses dwelling in the same household, unrelated to age.[17] LASI implemented a multistage stratified probability cluster sampling design to draw nationally representative data from 35 states/union territories (except Sikkim). A detailed account of the survey design and sample size can be seen elsewhere.[17]

LASI received ethical approval from the Indian Council of Medical Research and Institutional Review Board held at International Institute for Population Sciences (IIPS), India. Additional written informed consent was administered from all the study participants.[17] The data were downloaded from the public repository of LASI held at IIPS, Mumbai. The study used merged data sets (N=65 900) containing information from the individual, biomarker and household data files. The final analysis is based on 58 975 individuals aged 45 years or older obtained from this merged data set.

Patient and public involvement

It was not appropriate or possible to involve patients or the public in our research's design, conduct, reporting or dissemination plans.

Measures

The question commissioned to measure each disease based on self-reported medical diagnoses was, 'Has any health professional ever diagnosed you with the following chronic conditions or diseases?'. The list included information on 16 diseases, namely asthma, cancer, chronic bronchitis, chronic heart disease, chronic renal failure, chronic obstructive pulmonary disease, diabetes, gastrointestinal disorder, high cholesterol, hypertension, musculoskeletal disorder, neurological and psychiatric disorders, skin disease, stroke, thyroid disease and urinary incontinence. The diseases mentioned above were recoded as no (1) or yes (2) in accordance to the statistical package used.

The socioeconomic, demographic, lifestyle and anthropometric variables evaluated based on the existing literature included age (45–49/50–54/55–59/60–64/65–69/70–74/75–79/80 years or older), sex (men/women), residence (urban/rural), religion (Hindu/Muslim/Christian/Others), social group (Scheduled Caste (SC)/Scheduled Tribes (ST)/Other Backward Class (OBC)/Others), level of education (no education/less than 5 years/5–9 years/10 years or more), wealth status (poor/non-poor), current marital status (in union/not in a union), current working status (never worked/worked in the past but not currently working/currently work), tobacco consumption (never used tobacco/quit tobacco/currently consuming), ever consumed alcohol (no/yes), physical activity (physically active/physically inactive), body mass index (BMI) (underweight/normal/overweight/obese) and waist–hip ratio (WHR) (low risk/high risk).

Religion and social group (which comprises four major caste categories) are essential, as they build the social structure in the context of India. They play a decisive role in the social acceptance, cultural and dietary aspects of any individual. Four major social groups included in the study are SC, ST, OBC and Others (this comprises all other caste groups). Based on social stratification, SC, ST and OBC are considered socially disadvantaged, while the 'others' category mostly includes the socially accepted 'upper' castes.[18]

Physical activity was categorised into two categories: physically inactive and active. Physically inactive individuals were those who were not engaged in any moderate or vigorous physical activity throughout the week. On the contrary, physically active individuals satisfied one of the three criteria:

1. Only vigorous activities: Those who perform at least 75 min of vigorous-intensity physical activity throughout the week.
2. Only moderate activities: Those who perform at least 150 min of moderate-intensity physical activity throughout the week.
3. Both vigorous and moderate activities: Those who are engaged in a combination of moderate-intensity and vigorous-intensity activity.

LASI included information on weight, height, waist and hip circumference. We used BMI, calculated as weight (in kgs) divided by the square of height (in m^2) and WHR, calculated as waist circumference (in cm) divided by hip circumference (in cm). BMI was categorised into four, namely underweight (BMI ≤18.4 kg/m^2), normal (18.5 kg/m^2 ≤BMI ≤24.9 kg/m^2), overweight (25.0 kg/m^2 ≤BMI ≤29.9 kg/m^2) and obese (BMI ≥30 kg/m^2). WHR was categorised into high and low risk after stratifying for the sex of the individual. Low risk included WHR <0.90 for men and WHR <0.85 for women, while high risk included WHR ≥0.90 for men and WHR ≥0.85 for women.

Statistical analysis

We calculated descriptive statistics, including unweighted frequency and weighted percentages. In addition to this, disease profile, that is, the prevalence of all NCDs included in the study, was also reported. To identify the recurrent disease combinations, all possible two-way combinations ($^{16}C_2$=120) were explored. Further, these were supplemented with χ^2 p values to identify statistically significant associations or associative morbidities.

LCA was used to identify frequently occurring disease patterns. LCA is a statistical procedure used to identify unobserved homogeneous (latent) subgroups within a population.[19 20] These subgroups are identified based on the categorical responses collected from the study population. An array of latent class models was fitted before selecting the optimal number of latent classes (say, n classes). The existing literature defines no definitive way of the best criteria; therefore, the most widely accepted statistical criteria were used.[21] This included reporting multiple fit statistics, along with parsimony and theoretical interpretability.[12 15 19 20] Thus, the selection criterion was based on multiple model fit indices, Akaike information criterion (AIC), Bayesian information criterion (BIC), adjusted Bayesian information criterion (aBIC), consistent Akaike information criterion (cAIC).[12 13] Parsimony and theoretical interpretability were preferred in identifying the optimum number (n) of disease classes. Furthermore, χ^2 goodness of fit, G2 statistics, entropy and likelihood ratio tests were reported in addition to the smallest class count and their respective percentage were also reported.[19 22]

These 'n' classes were labelled based on the item-response probabilities of the selected chronic morbidities included in the study.[12 13] Existing literature suggests that item-response probabilities are similar to factor loadings.[23] Given this, it is recommended that a standard loading of 0.3 or above should be employed to define a particular factor.[24–26] Thus, a cut-off of 0.3 was chosen to assign labels. A particular item (or disease) with an item-response probability of 0.3 or above depicts a strong association with the identified latent pattern or class. Thus, this item was most informative and was used to assign labels to a specific latent class. Once the optimal number of latent classes was selected, the entire study population was segregated into 'n' classes (identified disease classes).[12 14] Finally, a multivariable multinomial logistic regression (posterior analysis) was performed to identify the factors associated with the multimorbidity patterns identified.

Analysis for this study was done using 'poLCA' package in RStudio V.1.1.463 (R Studio).[21] The study followed the Strengthening the Reporting of Observational Studies in Epidemiology reporting guideline (online supplemental file 1). All the estimates generated in the study were presented after suitable application of sampling weights provided by LASI, 2017–2018.[17]

RESULTS

Sample description and distribution of selected chronic conditions

The present analysis is based on 58 975 individuals in age 45 years and above from LASI, wave-1, 2017–2018. Table 1 describes the study population, which comprised 19% of the individuals in the age group 45–49 years. Around 54% of the individuals were women, and 71% lived in rural areas. Around 82% followed the Hindu faith and 45% belonged to the OBC group. Fifty-one per cent received no education, and 74% were currently married. Around 62% never consumed tobacco, 85% were lifetime alcohol abstainers and 29% led a physically inactive lifestyle. Furthermore, 20% were overweight, 7% were obese and 77% had a high-risk WHR.

Disease profile and association between selected NCDs

Figure 1 illustrates the disease profile, linkages and prevalence of all possible two-way combinations between selected NCDs among older adults in India. The values in the diagonal cells (coloured in light blue) represent the prevalence of all the diseases included in the study. Findings suggest that 14 diseases had a prevalence greater than 1%, whereas 11 had a prevalence of greater than 2%. Hypertension (26.9%), gastrointestinal disorders (18.4%), musculoskeletal disorders (16.2%), diabetes (11.7%) and skin diseases (5.2%) were commonly occurring among older adults in India.

The off-diagonal values represent the prevalence rates (in %) of all-possible two-way combinations. In addition, the colours yellow and green indicate the degree of association between the two diseases in any specific combinations. The study explored 120 diseases combinations ($^{16}C_2$=120), out of which 110 were statistically significant and 20 had a prevalence of more than a per cent. The most prevalent disease combinations identified in the present study were 'diabetes-hypertension' (7.8%), 'musculoskeletal disorders-hypertension' (6.4%), 'gastrointestinal disorders-hypertension' (6.1%), 'gastrointestinal disorders-musculoskeletal disorders' (3.9%), 'musculoskeletal disorders-diabetes' (2.7%) and 'chronic heart disease- hypertension' (2.5%). Hypertension was present in five statistically significant associations (links); similarly, gastrointestinal disorders and diabetes were

Table 1 Socio-demographic, lifestyle and anthropometric characteristic of the study population (45 years or older), Longitudinal Ageing Study in India, wave-1, 2017–2018

Correlates	Categories	Unweighted frequency (N=58 975)	Weighted percentage
Age (in years)	45–49	11 917	18.86
	50–54	9863	15.88
	55–59	9057	15.09
	60–64	9195	15.39
	65–69	7981	14.45
	70–74	5126	9.45
	75–79	2990	5.53
	80+	2846	5.34
Sex	Male	27 374	46.21
	Female	31 601	53.79
Place of residence	Rural	38 715	70.68
	Urban	20 260	29.32
Religion	Hindu	43 238	82.45
	Muslim	6968	11.07
	Christian	5984	2.99
	Others	2785	3.50
Social group	Scheduled Castes	9959	19.64
	Scheduled Tribes	10 348	8.70
	Other Backward Class	22 243	45.27
	Others	16 425	26.40
Level of education	No education	27 766	50.93
	Less than 5 years	10 959	17.79
	5–9 years	9380	13.98
	10 years or more	10 870	17.30
Wealth status	Poor	23 537	42.74
	Non-poor	35 438	57.26
Current marital status	In union	44 427	74.39
	Not in union	14 548	25.61
Current working status	Never worked	16 115	25.74
	Worked in past but not currently working	15 510	27.15
	Currently working	27 350	47.11
Tobacco consumption	Never used tobacco	46 028	61.90
	Quit tobacco	1471	4.92
	Currently consuming	11 476	33.18
Ever consumed alcohol	No	48 354	84.81
	Yes	10 621	15.19
Physical activity	Physically active	41 295	71.27
	Physically inactive	17 680	28.73
Body mass index	Underweight	10 822	21.39
	Normal	30 529	51.31
	Overweight	12 651	19.62
	Obese	4298	6.69
	Do not know/Not measured	675	1.00

Continued

Table 1 Continued

Correlates	Categories	Unweighted frequency (N=58 975)	Weighted percentage
Waist-hip ratio	Low risk	11 763	22.72
	High risk	47 212	77.28

present with four links, making them the most interactive diseases.

Latent classes of multimorbidity

Table 2 illustrates the LCA model fit results. AIC, BIC, cAIC and aBIC decreased up to the six-class model. Class 7, 8 and 9 models were not well identified, that is, they could not attain a maximum likelihood even after 10 000 iterations. A six-class model was selected as optimum based on the lowest BIC value (in addition, all other fit indices were in agreement) along with model's theoretical interpretability. Furthermore, a six-class model reported an acceptable level of entropy (entropy=0.62). The selected model had a minimum class count of 457, covering 0.78% of the study sample.

The results from class proportion and item-response probabilities (ρ) are presented in table 3. These estimated item-response probabilities (ρ≥0.3) were employed to assign labels to the six-class model identified. Class 1 comprised individuals with low probabilities for all 16 NCDs compared with other classes. This group comprised 65% of the study population and was labelled as *relatively healthy*. Multimorbidity prevalence in this group was 3.4%, and the average number of chronic conditions was 0.4.

Class 2 comprised 23.6% of the study population was labelled as *hypertension* and reported high probabilities (0.76) for hypertension. Multimorbidity prevalence in this group was 61.76%, and the average number of chronic conditions was 1.8.

Class 3 comprised 6.6% of the study population was labelled as *gastrointestinal disorders–hypertension–musculoskeletal disorders* and reported high probabilities for gastrointestinal disorders (0.53), hypertension (0.35) and musculoskeletal disorders (0.30). Multimorbidity prevalence in this group was 100.0%, and the average number of chronic conditions was 2.8.

Class 4 comprised 0.8% of the study population and was labelled as *musculoskeletal disorders–hypertension–asthma* and reported high probabilities for musculoskeletal disorders (0.30), hypertension (0.33) and asthma (0.30). Multimorbidity prevalence in this group was 100.0%, and the average number of chronic conditions was 3.0.

Class 5 comprised 2.6% of the study population and was labelled as *metabolic disorders* and reported high probabilities for hypertension (0.75), high cholesterol (0.57) and diabetes (0.48). Multimorbidity prevalence in this group was 100.0%, and the average number of chronic conditions was 3.2.

Class 6 comprised 1.5 % of the study population and was labelled as *complex cardiometabolic disorders* and reported high probabilities for hypertension (0.85), along with

	AS	MKS	CA	CB	CRF	COPD	DM	GD	CHD	HC	HYP	NPD	SD	ST	THY	UI
AS	**4.69**															
MKS	**1.26**	**16.23**														
CA	0.03	0.11	**0.58**													
CB	0.23	0.48	0.58	**1.19**												
CRF	0.05	0.18	0.01	0.02	**0.68**											
COPD	0.30	0.52	0.02	0.31	0.04	**1.34**										
DM	0.70	**2.73**	0.12	0.38	0.14	0.39	**11.74**									
GD	**1.02**	**3.88**	0.15	0.26	0.23	0.27	**2.22**	**18.40**								
CHD	0.32	**1.11**	0.04	0.28	0.06	0.31	**1.24**	0.85	**3.86**							
HC	0.13	0.63	0.04	0.04	0.04	0.05	0.70	0.56	0.40	**2.32**						
HYP	**1.68**	**6.40**	0.26	0.63	0.31	0.69	**7.83**	**6.05**	**2.49**	**1.47**	**26.91**					
NPD	0.21	0.92	0.03	0.06	0.04	0.08	0.37	0.65	0.21	0.18	0.99	**2.35**				
SD	0.36	**1.14**	0.03	0.07	0.06	0.09	0.81	**1.54**	0.18	0.19	**1.72**	0.17	**5.21**			
ST	0.11	0.49	0.03	0.02	0.04	0.04	0.49	0.43	0.24	0.09	**1.18**	0.18	0.13	**1.78**		
THY	0.23	0.79	0.05	0.09	0.07	0.10	0.71	0.73	0.19	0.32	**1.47**	0.21	0.24	0.07	**2.75**	
UI	0.29	0.89	0.04	0.09	0.12	0.12	0.62	**1.19**	0.19	0.14	**1.18**	0.19	0.28	0.16	0.19	**2.96**

p<0.01 p<0.05

Figure 1 Disease profile and association between all possible two-way combinations of selected non-communicable diseases among older adults, Longitudinal Ageing Study in India, wave-1, 2017–2018. AS, asthma; CA, cancer; CB, chronic bronchitis; CHD, chronic heart disease; COPD, chronic obstructive pulmonary disorder; CRF, chronic renal failure; DM, diabetes; GD, gastrointestinal disorders; HC, high cholesterol; HYP, hypertension; MKS, musculoskeletal disorder; NPD, neurological and psychiatric disorders; SD, skin disease; ST, stroke; THY, thyroid disorder; UI, urinary incontinence.

Table 2 Model fit and diagnostic criteria for latent class analyses, Longitudinal Ageing Study in India, wave-1, 2017–2018

Class	df	LL	AIC	BIC	cAIC	aBIC	Smallest class count (n)	Smallest class size (%)	G2	X^2 goodness of fit	Entropy	Likelihood ratio test	
												Likelihood ratio	Critical value
2	58942	−182 959.3	365 984.7	366 281.2	366 314.2	366 176.3	11 895	20.17	6347.2	6 096 559	0.5817	–	–
3	58925	−182 347.1	364 794.1	365 243.4	365 293.4	365 084.5	3774	6.40	5122.6	1 779 553	0.6215	1224.4	27.587
4	58908	−182 074.9	364 283.9	364 885.9	364 952.9	364 672.9	1109	1.88	4578.4	227 023.2	0.5453	544.4	27.587
5	58891	−181 959.9	364 087.7	364 842.4	364 926.4	364 575.5	590	1.00	4348.2	295 466.3	0.5812	230.0	27.587
6	58874	−181 853.5	363 909.0	364 816.5	364 917.5	364 495.5	457	0.78	4135.5	126 168	0.6158	–	–
7	Not well identified												
8	Not well identified												
9	Not well identified												

aBIC, Adjusted Bayesian Information Criteria; AIC, Akaike Information Criteria; BIC, Bayesian Information Criteria; cAIC, Consistent Akaike Information Criteria; df, degree of freedom; LL, log likelihood.

musculoskeletal disorders (0.51), diabetes (0.50), gastrointestinal disorders (0.43), high cholesterol (0.28) and heart disease (0.27). It is worth mentioning that item-response probabilities for hypertension, musculoskeletal disorders, diabetes and gastrointestinal disorders are higher than the prescribed cut-off of 0.3. However, the item-response probabilities for high cholesterol (0.28) and chronic heart disease (0.27) can be considered as 0.3 if rounded off to one decimal. Multimorbidity prevalence in this group was 100.0%, and the average number of chronic conditions was 5.1. A detailed description of the socio-demographic, lifestyle and anthropometric characteristics of six identified latent classes is presented in online supplemental file 2.

Posterior analysis

Table 4 depicts multinomial logistic regression analysis findings considering *relatively healthy* class as the base outcome. The findings suggest that higher age increased the likelihood of belonging to any of the five multimorbidity classes. In particular, being woman increased the likelihood of belonging to *hypertension, gastrointestinal disorders–hypertension–musculoskeletal disorders, metabolic disorders and complex cardiometabolic disorders* class. Residing in the urban areas increased the likelihood of belonging to class: *hypertension, metabolic disorders* and *complex cardiometabolic disorders* compared with class *relatively healthy*. The likelihood of belonging to class: *hypertension, gastrointestinal disorders–hypertension–musculoskeletal disorders, metabolic disorders and complex cardiometabolic disorders* was higher for respondents belonging to the Muslim faith compared with the *relatively healthy* class.

Belonging to the ST decreased the likelihood of belonging to class *gastrointestinal disorders–hypertension–musculoskeletal disorders, musculoskeletal disorders–hypertension–asthma, metabolic disorders and complex cardiometabolic disorders* compared with *relatively healthy* class.

In particular, the educated respondents were associated with a higher likelihood of belonging to class *hypertension, metabolic disorders* and *complex cardiometabolic disorders* than respondents from a *relatively healthy* class. Respondents belonging to the wealthy class were more likely to belong to any of the five multimorbidity class than the *relatively healthy* class.

The findings suggest that currently working was associated with a lower likelihood of belonging to *hypertension, gastrointestinal disorders–hypertension–musculoskeletal disorders, musculoskeletal disorders–hypertension–asthma and metabolic disorders.*

Considering the lifestyle and anthropometric predictors, individuals who have quit smoking were more likely to belong to any of the five multimorbid classes as compared with *relatively healthy*. Consumption of alcohol increased the likelihood of belonging to the class *metabolic disorders*. Overweight increased the likelihood of belonging to class *hypertension, gastrointestinal disorders–hypertension–musculoskeletal disorders, metabolic disorders and complex cardiometabolic disorders* compared with the *relatively*

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Table 3 Class proportions and item-response probabilities from six-latent class model of chronic morbidities, Longitudinal Ageing Study in India, wave-1, 2017–2018

Latent class	1	2	3	4	5	6
Assigned labels	Relatively healthy	Hypertension	Gastrointestinal disorders–hypertension–musculoskeletal disorders	Musculoskeletal disorders–hypertension–asthma	Metabolic disorders	Complex cardiometabolic disorders
Class proportion	65.03	23.59	6.57	0.78	2.58	1.45
Non-communicable diseases						
Asthma	0.02	0.03	0.06	**0.30**	0.03	0.12
Cancer	0.00	0.01	0.01	0.01	0.01	0.03
Chronic bronchitis	0.00	0.00	0.01	0.14	0.01	0.05
Chronic heart disease	0.01	0.06	0.03	0.11	0.18	**0.27**
Chronic renal disease	0.00	0.01	0.02	0.02	0.01	0.06
Chronic obstructive pulmonary disease	0.00	0.01	0.01	0.18	0.01	0.06
Diabetes	0.04	0.28	0.10	0.04	**0.48**	**0.50**
Gastrointestinal disorder	0.12	0.16	**0.53**	0.19	0.19	**0.43**
High cholesterol	0.00	0.00	0.02	0.03	**0.57**	**0.28**
Hypertension	0.04	**0.76**	**0.35**	**0.33**	**0.75**	**0.85**
Musculoskeletal disorders	0.08	0.16	**0.30**	**0.34**	0.19	**0.51**
Neurological and psychiatric disorder	0.01	0.02	0.05	0.08	0.01	0.16
Skin disorder	0.03	0.03	0.16	0.07	0.05	0.13
Stroke	0.00	0.04	0.01	0.01	0.03	0.15
Thyroid disorder	0.01	0.03	0.05	0.03	0.14	0.17
Urinary incontinence	0.01	0.02	0.11	0.06	0.01	0.19
Multimorbidity (in %)	3.44	61.76	100.00	100.00	100.00	100.00
Average number of diseases	0.38	1.82	2.75	3.00	3.20	5.12

The bold values depict the diseases which are used in asssigning labels to the identified latent classes.

healthy class. Obesity increased the likelihood of belonging to class any of the five multimorbid classes compared with the *relatively healthy* class. Furthermore, being physically inactive increased the likelihood of belonging to class *hypertension and complex cardiometabolic disorders*. High-risk WHR increased the likelihood of belonging to class *hypertension, gastrointestinal disorders–hypertension–musculoskeletal disorders, metabolic disorders and complex cardiometabolic disorders* compared with *relatively healthy* class.

DISCUSSION

This study used LCA to investigate the emerging multimorbidity patterns and identify its predictors among older adults in India. Based on a nationally representative sample of 58 975 individuals, the study included information on 16 NCDs.

LCA identified six multimorbidity classes, including a predominant *relatively healthy* (65.0%) class, *hypertension (23.6%)*, *gastrointestinal disorders–hypertension–musculoskeletal disorders (6.6%)*, *musculoskeletal disorders–hypertension–asthma (0.78%)*, *metabolic disorders (2.58%)* and *complex cardiometabolic disorders (1.45%)*. Considering 329 775 000 (approximately 0.33 billion) older adult population as per World Population Prospects (2019),[27] we can infer that approximately 0.12 billion individuals belonged to one of the five multimorbidity classes (35.0%).

These resultant classes hinted towards a quantitative distinction, but three of these patterns were quite similar qualitatively. Considering the quantitative aspect, it is clear that *complex cardiometabolic disorders* followed by *metabolic disorders* were the most complicated disease patterns, with many NCDs coexisting simultaneously. Hypertension emerged as the most prevalent NCD with a high membership probability in five multimorbid classes. In addition, the disease patterns *hypertension*, *metabolic disorders* and *complex cardiometabolic disorders* reflect three stages of

Table 4 Multinomial analysis of multimorbidity classes among older adults, Longitudinal Ageing Study in India, wave-1, 2017–2018

Class	2	3	4	5	6
Assigned labels	**Hypertension***	**Gastrointestinal disorders–hypertension–musculoskeletal disorders***	**Musculoskeletal disorders–hypertension–asthma***	**Metabolic disorders***	**Complex cardiometabolic disorders***
Correlates					
Age (in years)					
45–49 (Ref.)	1.00	1.00	1.00	1.00	1.00
50–54	1.45* (1.34 to 1.56)	1.21* (1.08 to 1.37)	1.28 (0.83 to 1.97)	1.70* (1.41 to 2.06)	1.94* (1.38 to 6.72)
55–59	1.78* (1.34 to 1.55)	1.31* (1.16 to 1.48)	1.78* (1.18 to 2.67)	2.22* (1.83 to 2.69)	3.09* (2.22 to 4.29)
60–64	2.02* (1.65 to 1.91)	1.50* (1.33 to 1.69)	2.02* (1.35 to 3.01)	2.79* (2.31 to 3.38)	3.37* (2.43 to 4.68)
65–69	2.52* (1.87 to 2.17)	1.76* (1.55 to 1.99)	2.53* (1.69 to 3.78)	2.85* (2.32 to 3.51)	4.66* (3.34 to 6.46)
70–74	2.72* (2.33to 2.72)	1.93* (1.67to 2.23)	2.76* (1.78to 4.28)	3.29* (2.60 to 4.18)	6.79* (4.80 to 9.61)
75–79	2.76* (2.49 to 2.98)	2.21*(1.86 to 2.62)	3.24* (2.00 to 5.24)	3.26* (2.43 to 4.34)	7.13* (4.84 to 11.04)
80+	2.75* (2.48 to 3.07)	2.53* (2.11 to 3.01)	4.14* (2.57 to 6.67)	1.82* (1.24 to 2.68)	7.04* (4.67 to 11.06)
Sex					
Male (Ref.)	1.00	1.00	1.00	1.00	1.00
Female	1.29* (1.21 to 1.36)	1.44* (1.30 to 1.59)	0.96 (0.72 to 1.28)	1.32* (1.12 to 1.56)	1.50* (1.19 to 1.89)
Place of residence					
Rural (Ref.)	1.00	1.00	1.00	1.00	1.00
Urban	1.30* (1.24 to 1.37)	0.97 (0.90 to 1.05)	1.16 (0.93 to 1.46)	1.61* (1.12 to 1.56)	1.44* (1.22 to 1.69)
Religion					
Hindu (Ref.)	1.00	1.00	1.00	1.00	1.00
Muslim	1.29* (1.21 to 1.39)	1.35* (1.21 to 1.50)	1.17 (0.85 to 1.58)	2.93* (2.52 to 3.39)	1.91* (1.54 to 2.34)
Christian	1.08* (1.24 to 1.37)	0.90 (0.77 to 1.04)	0.56** (0.33 to 0.93)	1.61* (1.32 to 1.96)	0.98 (0.72 to 1.35)
Others	1.23* (1.21 to 1.38)	1.09 (0.91 to 1.13)	0.56 (0.30 to 1.05)	2.52* (2.07 to 3.04)	1.08 (0.78 to 1.52)
Social group					
Scheduled Castes (Ref.)	1.00	1.00	1.00	1.00	1.00
Scheduled Tribes	0.73 (0.66 to 0.78)	0.53* (0.46 to 0.62)	0.51* (0.33 to 0.78)	0.65* (0.51 to 8.39)	0.41* (0.27 to 5.92)
Other Backward Classes	1.00 (0.94 to 1.06)	0.89* (0.81 to 0.98)	1.08 (0.81 to 1.42)	1.14* (0.93 to 1.38)	0.92* (0.72 to 5.92)
Others	1.05 (0.98 to 1.12)	1.01 (0.91 to 1.13)	0.99 (0.73 to 1.36)	1.27 (1.04 to 1.53)	1.12 (0.87 to 1.43)
Level of education					
No education (Ref.)	1.00	1.00	1.00	1.00	1.00
Less than 5 years	1.23* (1.16 to 1.31)	1.33* (1.21 to 1.45)	1.40* (1.08 to 1.81)	2.61* (2.21 to 3.09)	2.10* (1.69 to 2.59)
5–9 years	1.21* (1.13 to 1.29)	1.17* (1.05 to 1.30)	1.11 (0.81 to 1.81)	2.62* (2.19 to 3.13)	2.16* (1.72 to 2.73)
10 years or more	1.23* (1.15 to 1.32)	0.99 (0.89 to 1.12)	0.72 (0.50 to 1.03)	3.63* (3.06 to 4.31)	1.94* (1.53 to 2.46)

Continued

Table 4 Continued

Class	2	3	4	5	6
Assigned labels	**Hypertension***	**Gastrointestinal disorders–hypertension–musculoskeletal disorders***	**Musculoskeletal disorders–hypertension–asthma***	**Metabolic disorders***	**Complex cardiometabolic disorders***
Wealth status					
Poor (Ref.)	1.00	1.00	1.00	1.00	1.00
Non-Poor	1.30* (1.24 to 1.36)	1.37* (1.27 to 1.47)	1.39* (1.13 to 1.71)	1.69* (1.49 to 1.93)	2.13* (1.78 to 2.56)
Current marital status					
In union (Ref.)	1.00	1.00	1.00	1.00	1.00
Not in union	1.16 (1.10 to 1.23)	0.97 (0.89 to 1.06)	1.06 (0.83 to 1.35)	1.05 (0.91 to 1.21)	0.96 (0.79 to 1.15)
Current working status					
Never worked (Ref.)	1.00	1.00	1.00	1.00	1.00
Worked in past but not currently working	1.13 (1.06 to 1.19)	1.04 (0.94 to 1.15)	1.16 (0.88 to 1.54)	0.98 (0.84 to 1.14)	1.31 (1.07 to 1.60)
Currently working	0.73* (0.69 to 0.78)	0.72* (0.65 to 0.79)	0.59* (0.43 to 0.82)	0.52* (0.43 to 6.10)	0.45 (0.34 to 5.78)
Tobacco consumption					
Never used tobacco (Ref.)	1.00	1.00	1.00	1.00	1.00
Quit tobacco	1.12* (1.02 to 1.23)	1.75* (1.52 to 2.03)	3.01* (2.19 to 4.13)	1.43* (1.15 to 1.78)	3.01*(1.95 to 3.27)
Currently consuming	0.89 (0.84 to 1.93)	1.40 (1.28 to 1.52)	1.17 (0.91 to 1.49)	0.56 (0.46 to 6.56)	1.01 (0.82 to 1.24)
Ever consumed alcohol					
No (Ref.)	1.00	1.00	1.00	1.00	1.00
Yes	1.01 (0.94 to 1.08)	1.03 (0.92 to 1.14)	1.20 (0.91 to 1.58)	1.52* (1.27 to 1.81)	1.01 (0.78 to 1.29)
Physical activity					
Physically active (Ref.)	1.00	1.00	1.00	1.00	1.00
Physically inactive	1.13** (1.08 to 1.18)	0.95 (0.89 to 1.03)	1.17 (0.94 to 1.45)	1.08 (0.95 to 1.21)	1.46* (1.25 to 1.72)
Body mass index					
Underweight (Ref.)	1.00	1.00	1.00	1.00	1.00
Normal	1.64* (1.54 to 1.75)	1.30* (1.17 to 1.43)	0.82* (0.63 to 1.05)	2.59* (1.90 to 3.52)	2.10* (1.53 to 2.90)
Overweight	2.78* (2.53 to 4.28)	1.90* (1.69 to 2.14)	0.96 (0.39 to 3.21)	6.26* (4.58 to 8.56)	5.28* (3.78 to 7.38)
Obese	3.88* (3.53 to 4.28)	2.68* (2.30 to 3.13)	2.11* (1.39 to 3.21)	10.50* (7.57 to 11.45)	9.52* (6.62 to 13.68)
Waist-hip ratio					
Low risk (Ref.)	1.00	1.00	1.00	1.00	1.00
High risk	1.24* (1.17 to 1.31)	1.14** (1.04 to 1.26)	1.02 (0.79 to 1.31)	2.38* (1.87 to 3.03)	1.51* (1.15 to 1.97)

*p<0.001, **p<0.05.
*All estimates are computed considering relatively healthy as the base category.

cardiometabolic morbidity. It can be hypothesised that if individuals are affected with hypertension, they are more likely to accumulate other cardiometabolic morbidities, like diabetes, high cholesterol and heart diseases. From a programmatic standpoint, the study findings underscore an urgent need for effective prevention and management strategies for individuals affected with hypertension.

As the present study is the first attempt to explore prominent disease patterns among older adults in India, comparison with other studies is taxing, primarily due to the ambiguities in the operational definition of multimorbidity, differences in the age groups involved and other methodological differences. However, recent studies proposed cardiovascular and metabolic disorders as frequently occurring diseases in the country.[18 28] It is worth mentioning that the studies above included fewer chronic morbidities. In addition, identified disease clusters are in concordance with the systematic review based on 14 studies set in different geographical settings.[29]

Age originated as one of the primary predictors of all identified multimorbidity patterns among older adults. Ageing is a universal process characterised by unescapable alterations in various biological and neurological processes, resulting in progressive functional decline at cellular levels.[30] These alterations might also reflect an added predisposition towards chronic diseases. However, ageing is not synonymous with ill-health or multimorbidity. Consciously employing healthful dietary patterns, incorporating an active lifestyle including physical activities and managing other behavioural aspects and environmental exposures can alter the situation.[31]

Similarly, belonging to the affluent class was significantly associated with all multimorbidity patterns, whereas being educated increased the likelihood of belonging to *hypertension, metabolic disorders* and *complex cardiometabolic disorders*. At the same time, residing in urban areas increased the likelihood of belonging to *hypertension, metabolic disorders* and *complex cardiometabolic disorders*. This hints toward the preponderance of multimorbidity among individuals with better availability and accessibility to early screening, diagnoses and treatment services.[18 32] Through '*Ayushman Bharat*', the government of India has established health and wellness centres across the country for timely detection, prevention and effective management of diseases.[33] Despite this, there are issues like improper referral networks, inefficient supply chain management and staff.[18] In addition, healthcare providers' poor behaviours and low-personal competence have been highlighted by recent studies.[34] This majorly affects the quality of government-managed public health centres. Thus, the individuals who do not have economic or non-economic resources like lack of transportation facilities, having a disability, living in rural areas and work timings face challenges in accessing affordable quality healthcare. However, this might not thoroughly explain the higher disease burden among affluent, educated and urban residents. Additional reasons could be better access to health information and education in this group, enabling them to identify early symptoms of NCDs and better compliance with treatment regimens.[35]

Women were more prone to being in disease class *hypertension, gastrointestinal disorders–hypertension–musculoskeletal disorders, metabolic disorders and complex cardiometabolic disorders*. Our study findings are in concordance with the existing literature, which suggests that India is experiencing feminisation of multimorbidity,[7 18 36] primarily due to increased life expectation and prolonged exposure to social isolation.[8 18]

Belonging to the ST social group decreased the likelihood of belonging to class *gastrointestinal disorders–hypertension–musculoskeletal disorders, musculoskeletal disorders–hypertension–asthma, metabolic disorders and complex cardiometabolic disorders*. Similar findings have also been highlighted in recent studies.[8 37] In a way, this could indicate better health among the ST population. However, as the data used in the present study is self-reported diagnoses, the estimates generated are primarily based on individual's perception and awareness. They thus could indicate an underdiagnosed NCD burden among this population.[38] Tribal population is considered the most disadvantaged population subgroup in India.[39] They reside in remote locations, have inadequate awareness about health risks and have limited access to good quality healthcare.[40 41] Another issue is the low acceptability of healthcare among this social group which is highlighted as a significant cause of low diagnoses and treatment rates. These findings, therefore, hint toward unequal access to healthcare, which in turn suggests an urgent need for adequate awareness, accessibility, affordability, availability and acceptability of the healthcare services by this population.[39 42 43]

The lifestyle predictor: quitting tobacco increased the likelihood of belonging to the five multimorbid classes. As tobacco cessation is the key to NCD reduction, the medical practitioner recommended that multimorbid individuals quit tobacco.[44] Obesity increased the likelihood of belonging to class any of the five multimorbid classes. Furthermore, being physically inactive increased the likelihood of belonging to class: *hypertension and complex cardiometabolic disorders*, whereas high-risk WHR increased the likelihood of belonging to *hypertension, gastrointestinal disorders–hypertension–musculoskeletal disorders, metabolic disorders and complex cardiometabolic disorders*. These findings indicate the importance of lifestyle and anthropometric dynamics in intensifying exposure to associative chronic morbidities in any community, as already highlighted in existing literature for various subsections of the population.[9 18]

The study's major strength is that it provides empirical evidence on recurrent disease patterns using a large nationally-representative sample of older adults. However, the NCDs included in the study are based on self-reporting, which can lead to misclassification bias. No causality was tested in the study as findings are based on a single round of a longitudinal survey. In addition, the methodological limitations of LCA, a data driven technique cannot

be denied. Class assignment is based on the probability-based classification method, which is a potential source of bias. In addition, as the designated class labels are based on the author's discretion thus, subjectivity and naming fallacy cannot be ruled out. Furthermore, considering the geographical and contextual variations in disease burden and profiling, these results should be explicitly apprehended for the older adults in India.

CONCLUSIONS

These findings can recognise associated diseases among patients affected with one or more morbidities during hospital visits. The classes 'hypertension', 'metabolic disorders' and 'complex cardiometabolic disorders' reflect three stages of cardiometabolic morbidity, with hypertension as the first and 'complex cardiometabolic disorders' as the last stage of disease progression. This underscores the need for an effective prevention strategy. These findings can assist physicians and policymakers in devising practical strategies for control, prevention and management for individuals belonging to a specific disease class not to accumulate additional diseases. Thus, advocating policies to reorganise the existing healthcare services in a way to accommodate the rising requirements of the older adult population (45 years and older), which is estimated to reach 0.66 billion by 2050.[27] Alternatively, targeted interventions in the form of equitable prevention strategies, are essential to reduce the burden on the high-risk hypertensive older adult population in the country.

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Ethics approval The study used de-identified data from a secondary data source, Longitudinal Ageing Study in India, 2017–2018. The survey followed all necessary guidelines and received ethical approval from the Indian Council of Medical Research (ICMR), and Institute Review Board held at the International Institute for Population Sciences, Mumbai, India. Participants gave informed consent to participate in the study before taking part.

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