Identifying psychological antecedents and predictors of vaccine hesitancy through machine learning: A cross sectional study among chronic disease patients of deprived urban neighbourhood, India

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Ethics approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study was approved by the All India Institute of Medical Sciences Institutional Ethics Committee in Jodhpur (Certificate reference number: AIIMS/IEC/2020/3251).

Informed consent: Each participant was asked to give their informed consent to affirm their willingness. The respondents were given an honest explanation of the survey's intent, benefits, and an invitation to answer any questions they had, as well as confirmation that they were free to withdraw consent and discontinue participation at any time during the study. Throughout the procedure, the privacy and confidentiality of the information gathered was maintained.

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Abstract

COVID-19 vaccine hesitancy among chronic disease patients can severely impact individual health with the potential to impede mass vaccination essential for containing the pandemic. The present study was done to assess the COVID-19 vaccine antecedents and its predictors among chronic disease patients. This cross-sectional study was conducted among chronic disease patients availing care from a primary health facility in urban Jodhpur, Rajasthan. Factor and reliability analysis was done for the vaccine hesitancy scale to validate the 5 C scale. Predictors assessed for vaccine hesitancy were modelled with help of machine learning (ML). Out of 520 patients, the majority of participants were female (54.81%). Exploratory factor analysis revealed four psychological antecedents' "calculation"; "confidence"; "constraint" and "collective responsibility" determining 72.9% of the cumulative variance of vaccine hesitancy scale. The trained ML algorithm yielded an R^2 of 0.33. Higher scores for COVID-19 health literacy and preventive behaviour, along with family support, monthly income, past COVID-19 screening, adherence to medications and age were associated with lower vaccine hesitancy. Behaviour changes communication strategies targeting COVID-19 health literacy and preventive behaviour especially among population sub-groups with poor family support, low income, higher age groups and low adherence to medicines may prove instrumental in this regard.

Key results

- Vaccine hesitancy among urban poor patients is determined by multiple psychological antecedents.
- Machine learning trained algorithms are useful in identifying predictors of COVID-19 vaccine hesitancy and must be validated in future research.
- COVID-19 health literacy and COVID-19 appropriate behaviour are essential predictors to be targeted through behaviour change communication strategies for lowering vaccine hesitancy among urban poor patients.

Introduction

Globally COVID-19 pandemic has created unresolved challenges and pressing issues. It is the third multi-country outbreak caused by Coronavirus, the previous two being acute respiratory syndromes in 2003 and Middle East respiratory syndrome in 2012 [1,2].

In India, COVID-19 has caused more than 30 million cases, and approximately 0.4 million confirmed deaths [3]. Urban areas especially urban slums are noted for high population density. The risk perceptions towards COVID-19 and vaccine acceptance are reportedly low making them vulnerable [4]. Mass vaccination is recommended to contain COVID-19 with around 60% of the population to be vaccinated or are required to be infected to acquire herd immunity. The recent introduction of several effective vaccinations caused most countries to schedule mass immunization programs in an attempt to acquire herd immunity and contain COVID-19.

The countrywide rolled out vaccination drive since 1st March 2021 prioritized the front-line workers; elderly and patients of chronic diseases above 45 years of age as preferable recipients of the COVID-19 vaccine. This was an essential strategy to contain pandemic as the elderly and people of any age who have serious underlying chronic medical conditions are at higher risk for developing more serious complications from COVID-19 illness [5]. The odds of hospital re-admission increase with age and the presence of chronic health conditions.

COVID-19 infodemic has influenced people perception and trust regarding offered vaccines and incited misinformation and dis-information fuelling concerns about vaccine safety, efficacy and side effects. This was driven by conspiracy theories and a lack of trust in government palpable across India and many other countries. The concerns regarding COVID-19 vaccination is part of a long-standing debate about vaccination dynamics and vaccine hesitancy declared as one of the global challenges by WHO.

Vaccine hesitancy is playing a tremendous detrimental effect in thwarting mass vaccination for COVID-19 worldwide even among high-risk group patients. Guaraldi *et al*. [5] reported a considerable hesitancy (14%) was in a diabetic cohort, with fear of side effects being a major negative predictor.

Betsch *et al.* [6] proposed the 5C scale to evaluate 5 psychological antecedents to vaccination in form of confidence, complacency, constraints, calculation, and collective responsibility sub-scales. These 5 subscales offer insight into human mental representations, attitudes, and behavioural patterns influenced by the respondent's environment and background offering explanations that how an individual thinks and feels about vaccination and being vaccinated. COVID-19 vaccine hesitancy among chronic disease patients is likely to have a severe impact on individual health; community levels of COVID-19 exposure and overall health systems as experienced during the second wave of the pandemic in India leading to an unprecedented number of hospitalisations and deaths due to COVID-19 [7]. Concerns must be assessed to address them, as, with ease of lockdown measures, approaching festival season, India is expected to soon experience the third wave of the pandemic.

This study aimed at assessing the COVID-19 vaccine antecedents and its predictors among chronic disease patients availing care from an urban primary facility in Jodhpur, Rajasthan.

Methods

A cross-sectional study was conducted from February 2021 to April 2021 among chronic disease patients availing care from a primary health facility in urban Jodhpur, Rajasthan. Out of a total population of 36,87,165, about one third (34%) lives in urban areas [8]. All chronic disease patients aged 18 and above seeking treatment at the urban primary health centre were included for the study. As per the National Program for Prevention and Control of Cancers, Diabetes, Cardiovascular diseases and Stroke, the primary health facilities are required to provide diagnostic and treatment services to patients with hypertension and diabetes while referring complicated cases to higher facilities [9]. Thus, patients predominantly suffering from either hypertension or diabetes or both were availing services from the NCD clinic. An interviewer-administered semi-structured questionnaire, pilot tested and validated before initiation of data collection was used. The predictors assessed were modelled with help of machine learning as it assumes no pre-conceived rules about the relationship of different variables and attempts to find the model with the best accuracy [10]. The urgency and extent of vaccination on a global scale have no parallels in recent history, hence, we relied on machine learning to provide insights from the varied human psychological responses to the prospect of getting vaccinated.

Sample size

In a multi-country study, the mean (95% confidence interval) COVID-19 vaccine acceptance for India was observed to be 83.1% (77.6 -88.5) among >55 year age group [11] based on the above proportion and absolute precision of 5%, alpha value of 5% and maximum expected non-response rate of 20% and with a design effect of 2, the sample size, using Epi-info7 software, was calculated to be 432:

$$N = (Z_{1-\alpha/2})^2 * p * (1-P)/d^2$$

where: N=sample size; Z=value of Z statistic at α level of significance; P=prevalence; d= precision of the estimate.

However, in our study, a total of 520 patients were included.

Parameters measured

Socio-demographic details (age, gender, marital status, education status, type of family and family income, enrolment in social security schemes, number of family members) and clinical profile (information about the disease and its duration, comorbidities, medications, family history, dietary history, physical activity) were assessed for the study population. Other essential parameters assessed were:

Health literacy

Health literacy is the ability to access, understand, appraise, and apply health information, making it crucial for navigating Coronavirus and COVID-19 information environments.

HLS-COVID-Q22

In the context of the Coronavirus pandemic, the HLS-COVID-Q22 contains 22 items grouped into four subscales: accessing (six items), understanding (six items), appraising (five items), and applying (five items) health-related details [12]. The HLS-COVID-Q22 mean scores are based on responses ranging from 1 to 4, as indicated by Srensen and colleagues [13,14]. Mean scores can then be easily interpreted depending on the response range. With the assistance of language experts, the tool was translated into the local language and retranslated to English, with inconsistencies resolved via discussion.

COVID-19 preventive behaviour

An interviewer-administered, semi-structured, pre-tested questionnaire was developed to assess COVID-19 personal preventive behaviour using a 9-item tool [15]. In the past seven days, the COVID-19 personal preventive behaviour was evaluated using an instrument that measured the following domains: cough etiquette, use of face masks, and handwashing (either fabric or medical masks), restriction of outdoor movements, practising hand hygiene, and adhering to social distancing. The response was recorded as "sometimes," "seldom," "never" and "often". The responses of "never", "seldom", "sometimes", and "often" were given a score of 0, 1, 2 and 3, respectively.

Vaccine hesitancy

Vaccine hesitancy was assessed with the help of a pre-tested questionnaire which consisted of 11 questions. Perception regarding the safety of vaccines, convenience to receive vaccinations, understanding the topic of vaccination, and concept of herd immunity was assessed. Based on Betsch *et al*.'s recommendations, a 5-point scale was used "Please evaluate how much you disagree or agree with the following statements." (1=strongly disagree, 2=somewhat disagree, 3=neutral (or: neither disagree nor agree), 4=somewhat agree, 5=strongly agree). The minimum score possible was 11 while the maximum score was 55; lower scores exhibited low vaccine hesitancy while higher scores represented high vaccine hesitancy [6].

Statistical analysis

Responses were coded and entered in Microsoft Excel. No items were reverse coded for data analysis. The distribution of the responses was inspected for each item to eliminate items with low discriminative power. These were i) items with 95% or more of the given answers in the same category, and ii) items with a standard deviation lower than 0.75.

Validation of vaccine hesitancy scale

The scale was validated as suggested by Betsch *et al*. [6]. Translation of existing items in Hindi language and back translation was done by two independent investigators. The original items were then compared with back-translated items by both investigators to finalize the items and words in scale to be administered. Thereafter, expert evaluation was done by four public health experts to critically examine whether agreed on translation covers all the required antecedents. Based on the expert's feedback, the items which were not specifically related to COVID-19 vaccination were removed from the scale. These items were "*Vaccination is unnecessary because vaccine-preventable diseases are not common anymore"* and "*For each and every vaccination, I closely consider whether it is useful for me*". Two items "*Everyday stress prevents me from being vaccinated* "and "*When everyone else is vaccinated, I don't have to be vaccinated, too*" was removed as during the time of study nationwide lockdown was in place and based on government guidelines only front-line workers, patients of chronic diseases and elderly were recommended to get vaccinated.

For face validity, the investigator administered the pre-final version of the questionnaire to ten patients of chronic disease as considered adequate for reviewing language and appropriateness of questionnaire [6,16]. These ten adults were cognitively briefed and they were asked to identify words or sentences that they did not understand during the interview. Based on alternate suitable and familiar words suggested by the respondents, necessary language edits were done after discussing with other investigators.

The final version of the questionnaire consisted of 11 items. For subsequent analysis, the print version of the questionnaire was administered in form of a face-to-face interview with respondents at the time of visit to the health facility for their routine care.

The collected data was entered into Epi-data version 4.4.1 and exported to SPSS software version 23.0 for analysis. Data were summarized using frequency, proportions, mean, median, standard deviation, and inter-quartile range. Exploratory factor analysis (EFA) and reliability analysis was done for the vaccine hesitancy scale. Sensitivity analysis was conducted by using the 'if item deleted' procedure for each antecedent and a Cronbach's alpha coefficient >0.70 and <0.90 was considered an indicator of reliable scale.

EFA was done to assess construct validity. Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of sphericity were done for the aptness of data. EFA was performed using principal axis factoring with oblique rotation (Promax). Factor retention was based on the Eigen-value of more than one, and the point of inflexion on the Scree plot. Variables with factor coefficients of 0.40 or more were retained.

Machine learning

The dataset was separated into a training set and validation set in 80:20 ratios. Random Forest algorithm was trained over the training set and regressed against final vaccine hesitancy score [17]. The trained algorithm was applied prospectively over the validation set and its accuracy was assessed using R^2. Quantitative effects of each of the variables were obtained using the weights obtained from the trained model. The directional impact of the variables was assessed using the SHAP values [18].

Results

A total of 520 patients with chronic diseases availing care from the urban primary health facility of Jodhpur, Rajasthan were assessed for vaccine hesitancy and possible predictors (Table 1). The study participants comprised mainly female [285 (54.81%)] patients; more than 45 years of age [438 (84.23%)]; with minimal or no formal education [334 (64.23%)]; not gainfully employed [386 (74.23%)] and predominantly of lower or lower-middle socio-economic status [329 (63.27%)]. The mean (SD) age of participants was 57.1 (11.4) years.

Nearly, one-third of participants [164 (31.54%)] were diagnosed with both hypertension and diabetes; reported poor adherence to medications [159 (30.58%)] in past one month; had a duration of disease of fewer than 3 years [174 (33.46%)] and were enrolled in social security schemes [168 (32.31%)]. Nearly one-fourth [144 (27.70%)] reportedly were doing physical activity either often or always and nearly half of participants [245 (47.12%)] had got themselves or one or more family members ever tested for COVID-19.

Health literacy assessed as per HLS-COVID-Q22 scale revealed insufficient health literacy (mean score of <=2.5) for the majority of items except for the affirmative role of authorities; health care providers 'and family members in ensuring understanding regarding protective measures against coronavirus infection (Supplementary Table 1). Regarding COVID-19 preventive behaviour, higher scores were observed for washing hands and wearing fabric masks while going out as compared to other behaviours (Supplementary Table 2).

Table 1. Participants' characteristics and association with COVID-19 vaccination.

Characteristics	Categories	Frequency n (%)	COVID-19 vaccination hesitancy - mean (SD)	F/t value#	p-value
Age group (years)	<30	2 (0.40)	31.0 (2.83)	0.29	0.829
	30-44	80 (15.38)	31.43 (2.45)		
	45-59	186 (35.76)	31.31 (2.82)		
	≥60	252 (48.46)	31.15 (2.53)		
Gender	Male	235 (45.19)	31.08 (2.59)	0.21	0.177
	Female	285 (54.81)	31.39 (2.65)		
Marital status	Married	490 (94.23)	31.23 (2.64)	0.11	0.499
	Separated/divorced/widow	30 (5.77)	31.57 (2.34)		
Year of education	No formal education	256 (49.23)	31.52 (2.47)	9.10	<0.001*
	1-5	78 (15)	31.50 (2.12)		
	6-10	103 (19.81)	31.48 (2.65)		
	>10	83 (15.96)	29.90 (3.07)		
Occupation	Employed	134 (25.77)	31.07 (2.28)	3.05	0.028*
	Unemployed	69 (13.27)	30.94 (2.65)		
	Retired from job	79 (15.19)	32.10 (2.80)		
	Homemaker	238 (45.77)	31.21 (2.71)		
Monthly income quartiles (in Indian rupees)	1000-4999	127 (24.42)	32.06 (2.88)	8.39	<0.001*
	5000-8999	118 (22.69)	31.42 (2.16)		
	9000-14999	111 (21.35)	31.16 (2.51)		
	15000-90000	164 (31.54)	30.56 (2.62)		
Tobacco consumption	Present	99 (19.04)	31.48 (2.47)	1.88	0.327
	Absent	421 (80.96)	31.19 (2.66)		
Alcohol consumption	Present	22 (4.23)	31.59 (3.14)	0.55	0.536
	Absent	498 (95.77)	31.24 (2.60)		
Physical activity	Always	75 (14.42)	28.95 (3.25)	33.15	<0.001*
	Often	69 (13.27)	30.58 (2.79)		
	Sometimes	243 (46.73)	32.00 (1.86		
	Rarely/never	133 (25.58)	31.53 (2.53)		
Medical diagnosis	DM	126 (24.23)	31.43 (2.41)	3.62	0.027*
	HTN	230 (44.23)	31.48 (2.61)		
	DM+HTN	164 (31.54)	30.79 (2.75)		
Duration of disease (years)	<3	174 (33.46)	31.21 (2.55)	27.39	0.007*
	3-5	200 (38.46)	31.65 (2.48)		
	5-10	90 (17.31)	31.03 (2.61)		
	>10	56 (10.77)	30.34 (3.14)		
Number of medications	1	102 (19.62)	32.07 (1.92)	17.43	<0.001*
	2-3	291 (55.96)	31.44 (2.59)		
	≥4	127 (24.42)	30.17 (2.84)		
Frequency of medications	Once daily	184 (35.38)	31.78 (2.37)	2.49	0.001*
	Twice a day/more	336 (64.62)	30.96 (2.71)		
How frequently your family members support you in intake of medications	Always	149 (28.65)	29.85 (3.10)	45.02	<0.001*
	Often	204 (39.23)	31.31 (2.18)		
	Sometimes/rarely/never	167 (32.12)	32.44 (1.98)		
Adherence to medications in past one month*	Forgets medications usually/sometimes	159 (30.58)	15.23 (3.84)	12.44	<0.001*
	Forgets medications never/rarely	361 (69.42)	17.13 (4.47)		
COVID test undergone by family members	Yes	245 (47.12)	30.39 (2.77)	14.03	<0.001
	No	275 (52.88)	32.02 (2.23)		
Enrolment in social security schemes	Yes	168 (32.31)	30.95 (2.84)	7.42	0.08
	No	352 (67.69)	31.34 (2.50)		
COVID health literacy score (quartiles)	20-43	92 (17.69)	31.88 (1.97)	14.75	<0.001*
	44-50	167 (32.12)	32.04 (2.02)		
	51-58	126 (24.23)	30.94 (3.06)		
	59-83	135 (25.96)	30.14 (2.81)		
COVID preventive behaviour score (quartiles)	20-43	92 (17.69)	31.88 (1.97)	16.78	<0.001*
	44-50	167 (32.12)	32.04 (2.02)		
	51-58	126 (24.23)	30.94 (3.06)		
	59-83	135 (25.96)	30.14 (2.81)		

#ANOVA test/Independent sample *t*-test; *Self-perceived adherence to medications in past one month; Good adherence: Never or once in a while, forgets to take medications in past one month; Poor adherence: All the time, usually or sometimes forgets to take medications in past one month. Interim considerations: Preparing for the potential management of anaphylaxis at COVID-19 vaccine sites.

Significant bivariate association of vaccine hesitancy was observed with years of education (p<0.001), occupational status (p=0.028), monthly income (p<0.001), physical activity (p<0.001), duration of disease (p=0.007), diagnosed conditions (p=0.027), family support ensuring intake of medicine s(p<0.001). number of medicines (p<0.001), frequency of medicines (p=0.001), adherence to medicines in the past one month (p<0.001) and past COVID-19 test by patient or family members (p=<0.001).

Nearly majority of participants (ranging from 44% to 67%) reported neutral perception towards one or more items of vaccine hesitancy scale (Table 2).

Exploratory factor analysis

The Kaiser-Meyer-Olkin (KMO) test value was 0.648 for 9 items and was considered acceptable.[19] KMO values for individual items were well above the acceptable limit of 0.5 [19]; Bartlett test of sphericity was significant (p<0.001). Therefore, the data was suitable for identifying factors using exploratory factor analysis. Based on the Scree plot and Kaiser criterion with an eigenvalue of more than 1, factor extraction showed that the instrument contained four factors which represented 72.9% cumulative variance. The item designation criterion (factor loading of more than 0.4, and cross-loading of less than 0.35) was used for the reduction of the instrument to a simple factor structure. Table 3 shows the pattern matrix of factor loading of each item with a factor loading of more than 0.4. The first and third factors included three items each while the second factor included two items and the fourth factor only had one item. Based on Betsch *et al.*'s recommendation [6], the second factor was labelled as "confidence"; the third factor as collective responsibility" and the fourth factor as "constraint". The first factor was labelled as "calculation" as discussed by Betsch *et al.* as it highlights the individual level considerations while reaching an informed decision.

Reliability analysis

Cronbach's alpha was 0.72 for 9 item scale.

Machine learning

The dataset of 503 responses (after dropping of rows with one or more missing values, n=17) was separated into training and validation sets comprising 80% (n=418) and 20% (n=105) of the responses respectively. The trained ML algorithm applied over the test set yielded an R^2 of 0.33. Based on the feature weights of our model, the variables that contributed to 80% of the model explanation are shown in Table 4. Higher values of family support, health literacy, COVID-19 behavioural score, monthly income, history COVID-19 test, adherence to medications and age, were all associated with lower vaccine hesitancy and *vice-versa* (Figure 1).

Sub-component analysis of the vaccine hesitancy score was done using linear regression which yielded an R^2 of 0.96 over the test set. The coefficients of each of the factors varied from 0.92 to 1.10. All factors contributed substantially to the final score with 'Constraint' (1.10), 'Confidence' (0.99), 'Calculation' (0.93) and 'Collective responsibility' (0.92) contributing in descending order.

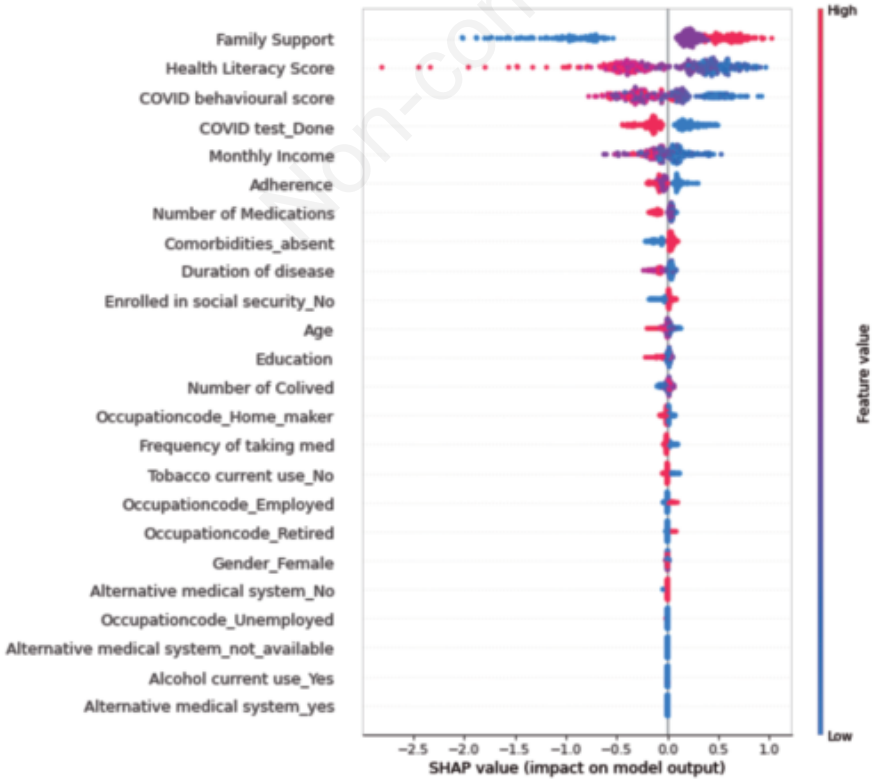

Figure 1. Directional view of the impact of variables on COVID-19 vaccination hesitancy score as per their SHAP values. *Low score for family support represents higher support on the Likert scale, hence red (less family support) depicts higher vaccine hesitancy. For the rest of the variables higher scores represent higher values on the Likert scale.

Discussion

While many studies are published estimating the prevalence of vaccine hesitancy for COVID-19 in India, only a few discuss its determinants among chronic disease patients. The current study is one of the first attempts from India to use a valid and reliable measure to understand the psychological antecedents determining COVID-19 vaccination hesitancy among chronic disease patients, residing in a deprived urban neighbourhood with low education and low socioeconomic status. During the study period, the Government of India prioritized 20 chronic diseases for COVID-19 vaccination [20]. Lower vaccine hesitancy among patients with chronic diseases as observed in our study is previously reported [21]. COVID-19 vaccine hesitancy scale among our population sub-group was validated as per the recommendations by Betsch *et al*. [6]. Reliability and exploratory factor analysis revealed four factors with 9 items in contrast to the original scale comprising of five factors. Based on ML algorithms, it was apparent from the largely similar coefficients for each of the factors that all of these were important determinants of final vaccine hesitancy. Our study highlights that any interventions towards addressing vaccine uptake must investigate antecedents namely 'Confidence', 'Calculation', 'Constraints' and "Collective responsibility" among chronic disease patients.

Table 2. COVID-19 vaccination hesitancy among study participants (n=520).

S. No.	Statement	Responses					Vaccine hesitancy score - mean (SD)
		Strongly disagree n (%)	Disagreen (%)	Neutral n (%)	Agree n (%)	Strongly agree n (%)	
1	I am completely confident that vaccines are safe	0	23 (4.4)	273 (52.5)	205 (39.4)	19 (3.7)	2.97 (0.44)
2	Vaccines are effective	2 (0.4)	19 (3.7)	230 (44.2)	254 (48.8)	15 (2.9)	2.99 (0.41)
3	Regarding vaccines, I am confident that public authorities decide in the best interest of community	1 (0.2)	19 (3.7)	229 (44)	227 (43.7)	44 (8.5)	2.87 (0.61)
4	My immune system is so strong, it also protects me against diseases	15 (2.9)	96 (18.5)	319 (61.3)	85 (16.3)	5 (1)	2.78 (0.54)
5	COVID disease is not so severe that I should get vaccinated	23 (4.4)	149 (28.7)	305 (58.7)	39 (7.5)	4 (0.8)	2.64 (0.60)
6	For me, it is inconvenient to receive vaccinations	8 (1.5)	181 (34.8)	264 (50.8)	62 (11.9)	5 (1)	2.64 (0.56)
7	Visiting the doctors makes me feel uncomfortable; this keeps me from getting vaccinated	29 (5.6)	210 (40.4)	248 (47.7)	33 (6.3)	0	2.48 (0.60)
8	It is important for me to fully understand the topic of vaccination, before I get vaccinated	3 (0.6)	70 (13.5)	331 (63.7)	103 (19.8)	13 (2.5)	2.90 (0.50)
9	Vaccination is a collective action to prevent the spread of diseases	0	14 (2.7)	247 (47.5)	252 (48.5)	7 (1.3)	3.0 (0.28)
10	I get vaccinated because I can also protect people with a weaker immune system	1 (0.2)	14 (2.7)	350 (67.3)	137 (26.3)	18 (3.5)	2.96 (0.41)
11	When I think about getting vaccinated, I weigh benefits and risks to make the best decision possible	3 (0.6)	32 (6.2)	353 (67.9)	117 (22.5)	15 (2.9)	3.02 (0.45)

Table 3. Results from factor analysis of COVID-19 vaccination hesitancy scale.

S. No.	Statements	Factor loading			
		1	2	3	4
7	Visiting the doctor's makes me feel uncomfortable; this keeps me from getting vaccinated	0.723			
5	COVID-19 disease is not so severe that I should get vaccinated	0.677			
3	Regarding vaccines, I am confident that public authorities decide in the best interest of the community	0.618			
2	Vaccine is effective		0.896		
1	I am completely confident that vaccines are safe		0.667		
9	Vaccination is a collective action to prevent the spread of diseases			0.863	
11	When I think about getting vaccinated, I weigh benefits and risks to make the best decision possible			0.461	
10	I get vaccinated because I can also protect people with a weaker immune system			0.429	
6	For me, it is inconvenient to receive vaccinations				0.859

The extraction method was principal axis factoring with an oblique (Promax with Kaiser normalization) rotation; Factor loadings above 0.40 are mentioned; n=520.

The trained ML algorithms modelled COVID-19 health literacy, COVID-19 preventive behaviour, family support, monthly income, history of COVID-19 test, adherence to medications and age as significant predictors of vaccine hesitancy.

The health promotion glossary by the WHO defines health literacy as "*The cognitive and social skills which determine the motivation and ability of individuals to gain access to, understand and use information in ways which promote and maintain good health*" [22]. Thus, health literacy enables an individual to make rational decisions about his health-related matters resulting in better health outcomes [23]. Similar to published studies relating to influenza and COVID-19 vaccination, our study observed that health literacy is associated with low vaccine hesitancy [24,25]. Thus, improving acceptance and uptake of the COVID-19 vaccine requires focus on improving health literacy and disseminating information *via* multiple channels to improve general awareness and foster trust. COVID-19 vaccine communication strategy by the Indian health ministry is a notable step in this regard [26]. An actionable toolkit has been released by the ministry to increase the level of awareness about COVID appropriate behaviour and vaccination among youngsters and is widely disseminated through posters, social media handles, healthcare workers and organizing virtual live sessions [27].

A report by the Centre for Disease Control (CDC) in 2021 revealed poor COVID-19 vaccination coverage among people of low socioeconomic status [28]. Low monthly income leading to high vaccine hesitancy as seen in our study is also previously reported [4,29]. Incentivizing vaccination, ensuring free vaccine availability and easy accessibility to reduce travel costs is likely to increase vaccine uptake.

Family support was associated with low vaccine hesitancy in our study. A meta-analysis of 122 studies found that adherence to medications was better among patients with family support [30]. Role modelling, assurance of guaranteed support in the presence of adverse events if any, shared decision making, motivation, and emotional support from family members may probably play an influential role in enhancing vaccine uptake in the same manner in which they improve medication adherence [31]. A study from Japan showed that the recommendation by a patient's family member and the presence of vaccinated family members influenced his decision to take influenza vaccination [32]. Both Japan and India have a "collectivistic" family system where families are a source of physical, emotional and financial support, security and growth [33]. As family centred decision making is prevalent, family support and influence play an important role in COVID-19 vaccine uptake in India.

Vaccine hesitancy was low among individuals with high COVID-19 preventive behavioural scores, who had earlier undergone testing for COVID-19 and those who were adherent to their medications. This reflects better general awareness and hence health literacy among these individuals.

Increasing age was associated with low vaccine hesitancy in our study. A study from the US and Saudi Arabia also showed low vaccine hesitancy among the elderly population [34,35]. Practical issues such as vaccine availability, logistic or financial inconvenience in accessing vaccines, service quality and satisfaction are likely to delay vaccination or lead to its complete refusal [36]. In this regard, near to home COVID-19 vaccination centres (NHCVC) and mobile COVID-19 vaccination units are initiated in India and other countries [37-39]. Strategies such as arranging transport facilities and making vaccination centres disabled friendly will also prove helpful. However, ensuring optimal vaccine storage temperatures during transport and the ability to manage adverse events at community centres or homes is a challenge. The Centres for disease control and prevention (CDC) guidelines would help to overcome these challenges [40]. History of previous vaccinations particularly influenza vaccination has been reported to improve vaccine acceptance [38]. The emphasis on adult immunization is poor in low- and middle-income countries including India and thus it is likely that majority of our participants might have not received any vaccination for the past many years [39,40]. Government emphasis on adult vaccination and availability of appropriate delivery channels may influence vaccine hesitancy and is an essential area of future research.

The current study reveals that chronic disease patients availing care from primary health facilities during the COVID-19 pandemic were predominantly suffering from diabetes and hypertension. Disruption in treatment and routine check-ups among chronic disease patients was observed during COVID-19 pandemic [41]. Vaccine hesitancy among other sub-groups of patients especially those suffering from cancers, chronic respiratory diseases and chronic kidney diseases is an essential area to investigate and future studies must consider including these patients.

This study is one of the first attempts to adapt and validate 5 C scale in developing economies especially in population sub-group with low education and low socioeconomic status in contrast to WEIRD (Western, Educated, Industrialized, Rich, Democratic) societies where it was developed and administered as online survey [40].

One of the major weaknesses of this study is the unavailability of data on vaccine uptake among participants, thus limiting the predictive validity of the scale. Role of characteristics such as ethnic background and religion were also not explored about vaccine hesitancy. Further, this study was conducted among urban patients availing care from a single primary health facility and thus influences the generalizability of results. However, personal interviews and no remuneration benefits to participants addresses the potential non-response bias and establish the validity of these results among chronic disease patient population subgroup from deprived neighbourhoods of urban India and future studies in other low and middle economies are warranted to substantiate our findings. Past COVID-19 infections and severe consequences if any, the result of the COVID-19 test of family members, and history of past vaccinations were not studied in the current study. These factors may influence COVID-19 vaccine hesitancy and must be investigated in future research.

Table 4. Feature weights of the variables in the model in descending order of their importance and their effect on COVID-19 vaccination hesitancy.

Feature	Variable	Effect
Family support	High	Low hesitancy
Health literacy score	High	Low hesitancy
COVID-19 behaviour score	High	Low hesitancy
Monthly income	High	Low hesitancy
COVID-19 test	Done	Low hesitancy
Adherence	High	Low hesitancy
Age in years	High	Low hesitancy

Conclusions

Vaccination is one of the most effective tools to fight the COVID-19 pandemic. Targeted interventions towards vaccine

adoption need to address multiple antecedents influencing vaccine hesitancy. Behaviour change communication strategies currently are essentially contributing towards COVID-19 health literacy with an emphasis on COVID-19 preventive behaviour and the need for tests among the general population. Focussing on population sub-groups with poor family support, low income, higher age groups and low adherence to chronic disease medicines could prove instrumental in reducing vaccine hesitancy among chronic disease patients, one of the most vulnerable populations during the COVID-19 pandemic.

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