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ORIGINAL RESEARCH

Prevalence of Metabolic Dysfunction-Associated Steatotic Liver Disease: Mapping Across Different Indian Populations (MAP Study)

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ABSTRACT

Introduction: Metabolic dysfunction-associated steatotic liver disease (MASLD) is a growing global health concern. MASLD is strongly linked to obesity, sedentary lifestyles, and metabolic syndrome. In India, the prevalence of MASLD exhibits regional variations because of genetic, dietary, and socioeconomic factors. Liver stiffness measurement (LSM) and controlled attenuation parameter (CAP) are standardized non-invasive tools for assessing fibrosis and steatosis in MASLD. This study aimed to determine the prevalence and severity of MASLD across different Indian regions and examine regional disparities in MASLD burden.

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Methods: This retrospective, multicenter, cross-sectional study analyzed the data of 13,750 adults from 105 diabetes and endocrine clinics across six geographic zones in India between May 2023 and February 2024. Participants underwent LSM and CAP assessment using FibroScan™. Based on LSM, liver fibrosis was categorized as F0-F1 (2–7 kPa), F2 (7–10 kPa), F3 (10–14 kPa), and F4 (≥ 14 kPa). Based on CAP, MASLD was classified as mild (238–260 dB/m), moderate (261–292 dB/m), and severe (≥ 293 dB/m).

Results: The prevalence of MASLD was 68.2% (CAP ≥ 238 dB/m), and the prevalence of fibrosis was 33.7% (LSM ≥ 7 kPa). The highest MASLD burden was observed in North India (73.3%), particularly in Uttarakhand (80.0%). Severe fibrosis (F4) was highly prevalent in Kerala (20.0%), whereas severe steatosis (S3) was highly prevalent in Jammu and Kashmir (50.3%). The prevalence of MASLD was significantly associated with regional variations ($P < 0.001$) but not with age.

Conclusion: This study highlights significant regional disparities in MASLD burden. The high burden in North India calls for region-specific public health interventions, standardized screening, and preventive strategies.

Keywords: Metabolic dysfunction-associated steatotic liver disease; Liver stiffness measurement; Controlled attenuation parameter; Non-invasive liver diagnostics; MASLD in India

Key Summary Points
Why carry out this study?
Metabolic dysfunction-associated steatotic liver disease (MASLD) is a growing health concern in India, with regional variations influenced by genetic, dietary, and socioeconomic factors
Large-scale, multicenter data on MASLD prevalence and severity using standardized diagnostic tools are limited
The study aimed to assess MASLD prevalence and severity across Indian regions using FibroScan™
What was learned from the study?
MASLD prevalence was 68.2%, with the highest burden in North India (73.3%) and severe fibrosis most common in Kerala (20.0%)
Significant regional disparities highlight the need for targeted screening and prevention strategies to address MASLD in India

INTRODUCTION

Metabolic dysfunction-associated steatotic liver disease (MASLD) includes a spectrum of liver disorders characterized by excessive fat accumulation in the liver, independent of excessive alcohol consumption. MASLD can progress from simple steatosis (fatty liver) to fibrosis and cirrhosis, posing a significant global health burden [1]. With the increasing incidence of metabolic syndrome including obesity and sedentary lifestyles, MASLD has become a leading cause of chronic liver disease worldwide. Previous studies have shown that up to 65.33% of individuals with type 2 diabetes mellitus have MASLD [2]. Furthermore, the Global Burden of Disease Study 2019 reported

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0.17 million MASLD-related deaths, indicating an 80.2% increase since 1990 [3].

Urbanization and lifestyle changes associated with economic development have significantly contributed to the increasing prevalence of MASLD, particularly in metropolitan areas where obesity, insulin resistance, and metabolic syndrome are common. Understanding the regional prevalence of MASLD is essential for public health planning and resource allocation. In India, the prevalence of MASLD varies widely, ranging from 9 to 53%, and is influenced by genetic, dietary, and socioeconomic factors [4, 5]. A higher prevalence has been reported in the northern region due to dietary habits and metabolic risk factors, whereas the high prevalence in the southern region is shaped by genetic predispositions and lifestyle differences. Conversely, a relatively lower prevalence has been reported in the eastern region [6]. However, most studies in India were single-center studies with varying diagnostic methods, limiting direct comparisons [4].

Liver stiffness measurement (LSM) and the controlled attenuation parameter (CAP) are non-invasive tools for assessing liver fibrosis and steatosis in MASLD. LSM quantifies liver stiffness using transient elastography, aiding in fibrosis staging, whereas CAP estimates liver fat content through ultrasound-based technology, facilitating disease monitoring [7, 8]. Given their reliability in diagnosing and tracking MASLD progression, LSM and CAP provide a standardized approach for large-scale epidemiological assessments. This study aimed to analyze regional disparities in the prevalence and severity of MASLD across India using these standardized non-invasive techniques. The findings of this study can help highlight variations in disease burden and the effectiveness of LSM and CAP in assessing the severity and progression of MASLD among different demographic groups.

METHODS

Study Design

This retrospective, observational, multicenter, cross-sectional study included adults of both sexes aged 18–88 years and was conducted at diabetes and endocrine clinics across multiple regions and states in India between May 2023 and February 2024. Data were obtained from the FibroScan™ vault, which is used for liver health screening, at 105 diabetes and endocrine clinics distributed across six zones, central, east, north, south, west, and northeast, covering 23 states and union territories.

Ethical Approval

This study was approved by the Drug Controller General of India approved ethics committee (Royal Pune Independent Ethics Committee) and conducted in accordance with the principles of the Helsinki Declaration. Informed consent was obtained as part of routine clinical practice to ensure compliance with ethical standards and data privacy regulations, allowing the use of anonymized data for research purposes. This study was registered in the ISRCTN registry (ISRCTN18116615).

Sampling Strategy

A sample size of 13,750 participants was calculated using Open Epi 3.01 based on an expected MASLD prevalence of 38.6%, a 95% confidence interval (CI), an absolute error of 1%, and a non-response rate of 30%.

Study Participants

All individuals aged ≥ 18 years who were visiting the endocrine clinics for metabolic dysfunction and tested for liver health using FibroScan™ 502 Touch (ECHOSENS, Paris, France) were enrolled in this study. Men and women consuming > 30 and 20 g of alcohol per day, respectively; individuals with chronic liver disorders, continuous corticosteroid use,

or positive hepatitis B/C antigens; pregnant or breastfeeding women; and individuals who did not consent to data inclusion were excluded from the study.

Clinical Assessment and Data Collection

Demographic data were collected, and all individuals visiting the study site for health checkups underwent vibration-controlled transient elastography (VCTE) with FibroScan™ 502 Touch by a trained technician using either M or XL probes to measure the CAP and LSM. The distance between the skin and liver capsule, known as the probe-to-liver capsule distance, was determined to establish the ideal probe size. The M probe was employed if it was < 25 mm, whereas the XL probe was used if it was > 25 mm.

Based on LSM, liver fibrosis was graded as normal (F0–F1: 2–7 kPa), moderate scarring (F2: 7–10 kPa), severe scarring (F3: 10–14 kPa), and cirrhosis (F4: ≥ 14 kPa). The CAP values obtained from the device were used when the VCTE examination was valid for that signal and expressed in decibels per meter (dB/m). The CAP value of ≥ 238 dB/m indicated hepatic steatosis or MASLD. Based on CAP, hepatic steatosis or MASLD was graded as mild (S1: 238–260 dB/m), moderate (S2: 261–292 dB/m), and severe (S3: ≥ 293 dB/m). These values were provided by the FibroScan™ manufacturer.

Statistical Analysis

Data analysis was performed using MedCalc and Epi Info 7. Qualitative variables were presented as proportions and percentages. Quantitative data variables were first assessed for normality using histograms and the D'Agostino-Pearson test. Parametric quantitative variables were presented as mean and standard deviation (SD), whereas non-parametric quantitative variables were presented as median and interquartile range (IQR). Comparisons were performed using a *t*-test and ANOVA for parametric quantitative variables, the Kruskal-Wallis test for non-parametric quantitative variables, and the chi-square test for qualitative variables. A P value < 0.05 was considered statistically significant at a 95% CI.

RESULTS

Participants' Characteristics

The data of 13,750 individuals were analyzed (Fig. 1). Table 1 shows the demographic and sample size distributions of the participants from different zones. Additionally, Table 1 shows the state-wise sample size distribution. The median age of the participants was 44 years. LSM (r = 0.128, 95% CI = 0.112–0.145) and CAP (r = 0.137, 95% CI = 0.120–0.153) were not correlated with age.

Prevalence of Fibrosis and Steatosis Based on LSM and CAP Values Across the Country

The prevalence of fibrosis and steatosis was estimated using the LSM and CAP values, respectively, in different country zones. Based on LSM values, the prevalence of fibrosis was 33.7% (4641/13750) in the overall country and 34.2% (1103/3220), 29.9% (541/1804), 38.1% (2042/5366), 30.2% (430/1422), 27.1% (443/1629), and 27.1% (84/309) in the central, west, north, south, east, and northeast zones, respectively. Conversely, the absence of hepatic steatosis or metabolic dysfunction-associated steatohepatitis based on CAP values was detected in 4365 (31.8%) participants. Based on CAP values, the prevalence of MASLD (CAP ≥ 238 dB/m) was 68.2% (9383/13750) in the overall country and 69.4% (2235/3220), 60.9% (1099/1804), 73.2% (3931/5366), 67.3% (957/1422), 60.2% (982/1629), and 58.6% (181/309) in the central, west, north, south, east, and northeast zones, respectively. The degree of fibrosis was graded based on the LSM values from F0 to F4, whereas the degree of steatosis was graded based on the CAP values from S0 to S3. Figure 2A, B shows the zone-wise prevalence of different degrees of fibrosis and steatosis across the country.

Zones were defined as the collection of data from different states. Therefore, the state-wise

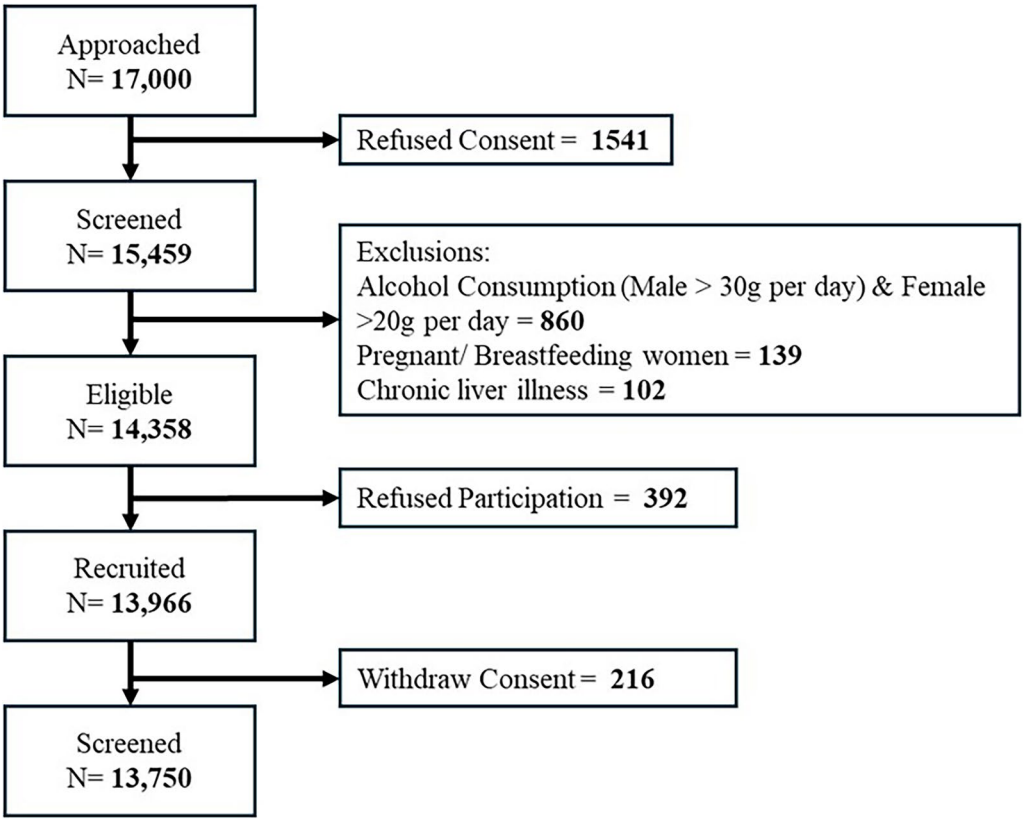

Fig. 1 Flowchart of participant enrollment

prevalence of different grades of fibrosis and steatosis based on the LSM and CAP categories, respectively, was recorded. The highest prevalence of LSM grade F4 (likely cirrhosis) was observed in Kerala (20.0%). Additionally, the highest zonal prevalence was observed in the central (Uttar Pradesh; 15.4%), west (Maharashtra; 9.7%), north (Punjab; 19.4%), south (Kerala; 20.0%), east (Odisha; 16.7%), and northeast (Assam; 13.6%) zones (Fig. 3). The highest prevalence of severe steatosis (CAP category S3) was observed in Jammu and Kashmir (50.3%). Additionally, the highest zonal prevalence of severe steatosis (S3) was observed in the central (Uttarakhand; 40.0%), west (Gujarat; 25.0%), north (Jammu and Kashmir; 50.3%), south (Karnataka; 36.1%), east (Odisha; 28.7%), and northeast (Assam; 25.9%) zones (Fig. 4).

Regional Disparity in the Degree of Fibrosis Based on LSM and CAP Values Across the Country

Considering the prevalence of cirrhosis (F4), the mean (SD) LSM values were 8.49 (9.46), 7.7 (8.54), 8.28 (8.88), 6.98 (5.53), 7.23 (7.98), and 7.64 (7.55) in the central, west, north, south, east, and northeast zones, respectively, with statistically significantly higher values in the central and north zones ($P < 0.001$). Figure 5 shows the map of the mean LSM values across various states categorized into F1-F4, indicating the prevalence of MASLD (Fig. 5A–D). The central and northeastern zones demonstrated the highest median (IQR) scores (Table 2). Considering the prevalence of steatosis (S3), the mean (SD) CAP values were 262.2 (53.32), 253.58 (52.41), 267.68 (50.62), 261.44 (49.88), 252.93 (53.17), and 250.78 (55.23) in the central, west,

Table 1 Demographic and sample size distributions of the study participants across different zones in India

	No. of participants ($n = 13,750$)	Frequency (%)
Demographics		
Age (mean, SD) (years)	45.22 ± 13.91	
Gender		
Male	9613	69.9
Female	4137	30.1
Sample size distribution		
Central zone	3220	23.4
Chhattisgarh	30 (0.9%)	0.9
Madhya Pradesh	250 (7.8%)	7.8
Uttar Pradesh	2880 (89.4%)	89.4
Uttarakhand	60 (1.9%)	1.9
West zone	1804	13.1
Gujarat	192 (10.6%)	10.6
Maharashtra	1612 (89.4%)	89.4
North zone	5366	39.0
Chandigarh	144 (2.7%)	2.7
Delhi	2263 (42.2%)	42.2
Haryana	100 (1.9%)	1.9
Jammu and Kashmir	748 (13.9%)	13.9
Punjab	997 (18.6%)	18.6
Rajasthan	1114 (20.8%)	20.8
South zone	1422	10.3
Andhra Pradesh	314 (22.1%)	22.1
Karnataka	255 (17.9%)	17.9
Kerala	50 (3.5%)	3.5
Tamil Nadu	803 (56.4%)	56.4
East zone	1629	11.8
Bihar	540 (33.1%)	33.1
Jharkhand	102 (6.3%)	6.3
Orissa	114 (6.9%)	6.6
West Bengal	873 (53.7%)	53.6
Northeast zone	309	2.2
Assam	309 (100.0%)	100

north, south, east, and northeast zones, respectively, with statistically significantly higher values in the central and north zones ($P < 0.001$) (Fig. 6A–C). The north and central zones demonstrated the highest median (IQR) scores (Table 2).

DISCUSSION

The results of this study underscore the significant regional disparities in the prevalence and severity of MASLD across various states and zones in India. Such disparities highlight the complex interplay of genetic, cultural, dietary, and socioeconomic factors in influencing the prevalence of MASLD and fibrosis.

Regional Prevalence and Contributing Factors

This study revealed that the prevalence of MASLD varies significantly across regions in India. Previous studies have shown that the prevalence rates of MASLD and fibrosis in India are 55%–75% and 25%–38%, respectively [9]. Consistent with the existing literature, our study showed that the prevalence rates of MASLD, fibrosis, and cirrhosis in India were 68.2%, 33.7%, and 12.2%, respectively.

The north zone demonstrated the highest prevalence of MASLD (73.3%), and Uttarakhand demonstrated the highest prevalence among all states (80.0%). Similarly, the north zone demonstrated the highest prevalence of severe fibrosis (38.1%), and Punjab (47.6%) demonstrated the highest prevalence among all states. Conversely, the east and northeast zones demonstrated the

Fig. 2 Zone-wise distribution of the participants. **A** Fibrosis based on liver stiffness measurement (LSM) categories. **B** Steatosis based on controlled attenuation parameter (CAP) categories

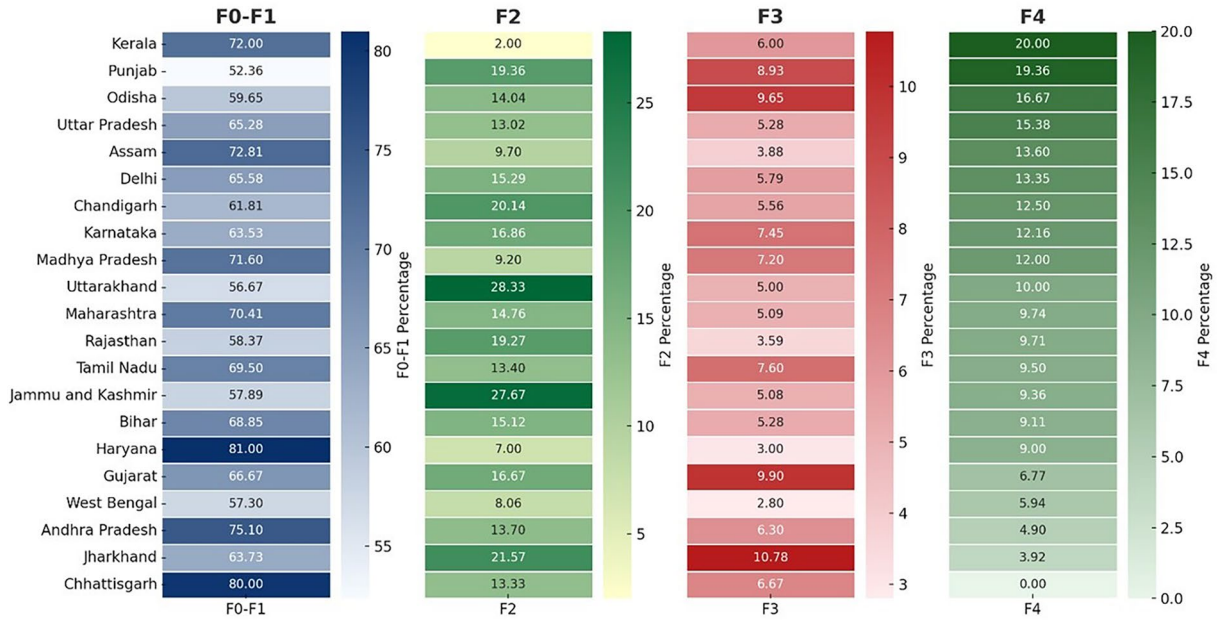

Fig. 3 State-wise distribution of the participants based on liver stiffness measurement (LSM) categories of fibrosis

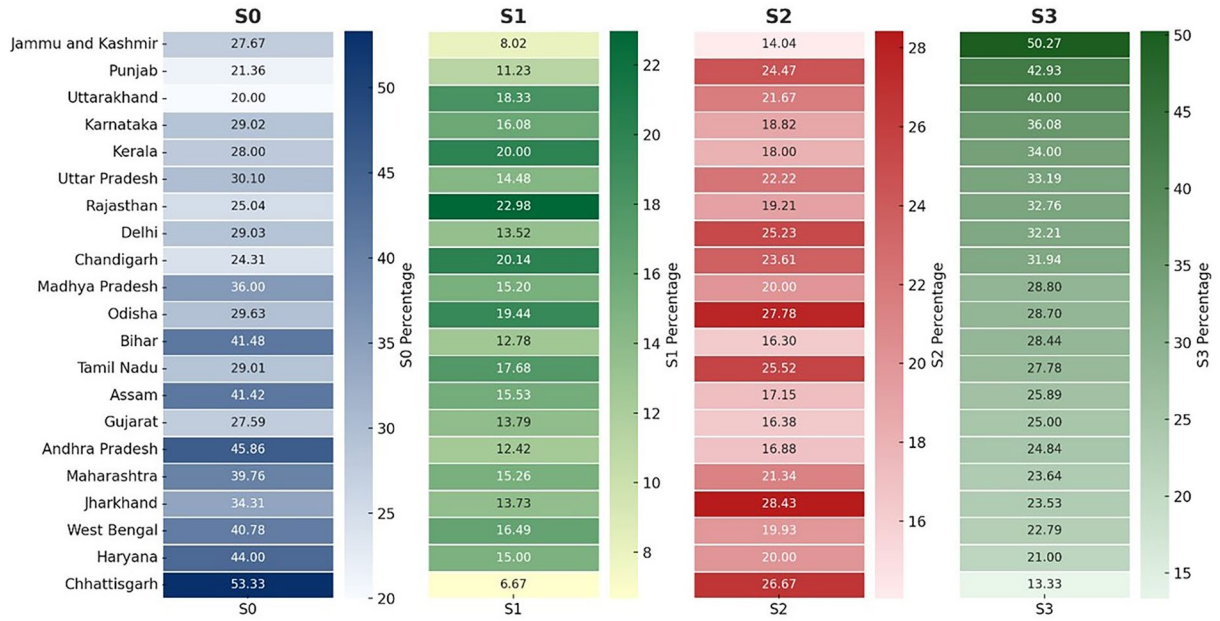

Fig. 4 State-wise distribution of the participants based on controlled attenuation parameter (CAP) categories of steatosis

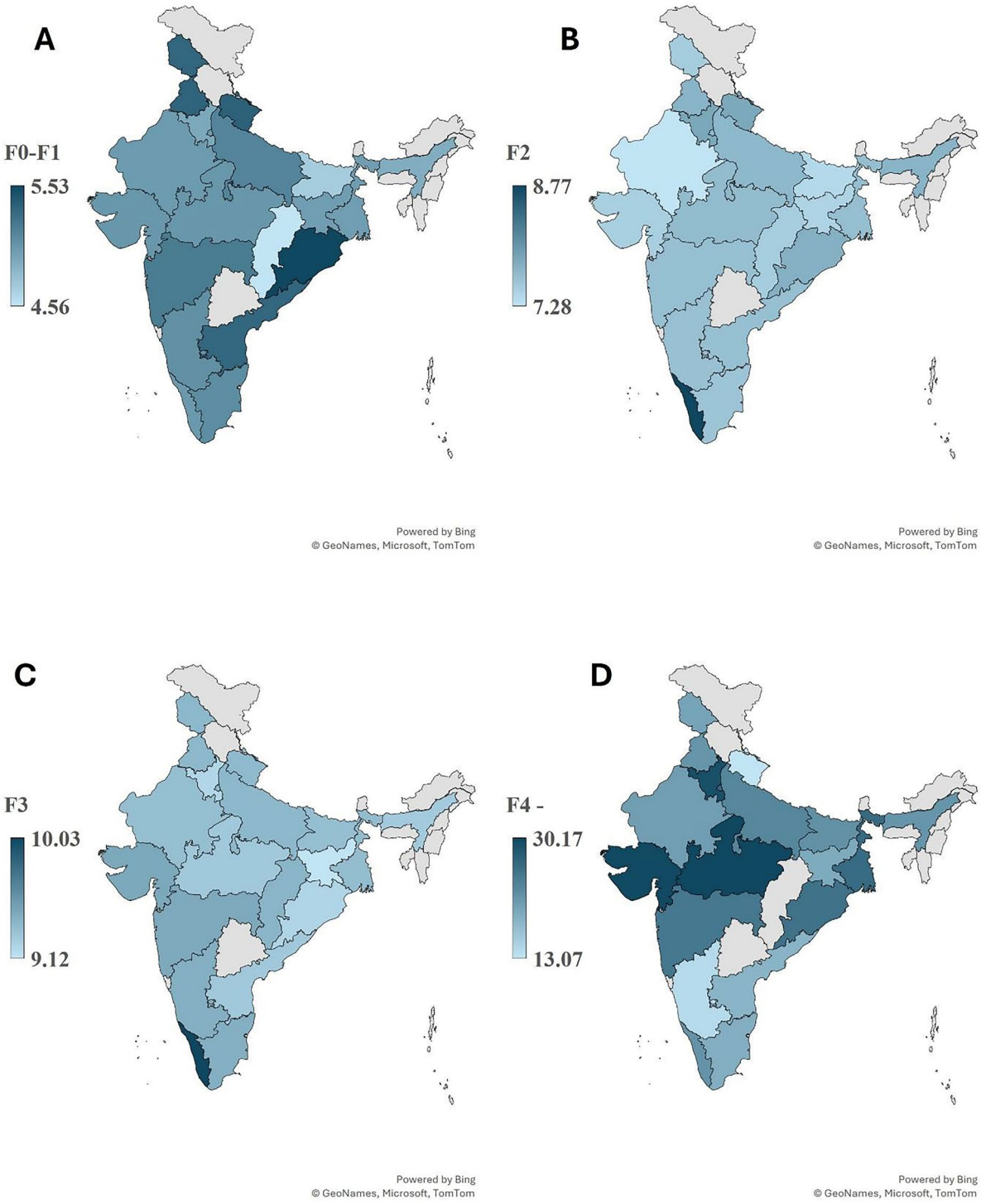

Fig. 5 State-wise distribution of mean liver stiffness measurement (LSM) values indicating the degree of fibrosis across the country. **A** Distribution of mean LSM values indicating the prevalence of F1 fibrosis across the country. **B** Distribution of mean LSM values indicating the prevalence of F2 fibrosis across the country. **C** Distribution of mean LSM values indicating the prevalence of F3 fibrosis across the country. **D** Distribution of mean LSM values indicating the prevalence of F4 fibrosis across the country

Table 2 Regional disparity in the median LSM and CAP scores across the country

Zone and state	Total no. of participants (*n* = 13,750)	Prevalence of fibrosis (F2-F4), *n* (%)	LSM (median (IQR))	Post hoc analysis for LSM	Prevalence of MASLD (S1–S3), *n* (%)	CAP (median (IQR))	Post hoc analysis for CAP
Overall	13,750	4643 (33.8)	9.8 (8.2–14)		9385 (68.2)	286 (262–313)	
Central (C)	3220	1103 (34.3)	10.2 (8.5–15.7)	E, NE, S, and W	2235 (69.4)	287 (263–314)	E, NE, N, and W
West (W)	1804	541 (29.9)	9.8 (8.3–13.35)	C, E, S, and W	1099 (60.9)	279 (259–311)	C, N, and S
North (N)	5366	2042 (38.0)	9.7 (8.1–14.2)	C, N, S, and W	3931 (73.3)	289 (261–314)	C, NE, E, S, and W
South (S)	1422	430 (30.2)	9.5 (8.3–11.4)	C, NE, E, and N	957 (67.3)	283 (260–313)	NE, E, S, and W
East (E)	1629	443 (27.2)	9.5 (8–13)	C, N, S, and W	982 (60.3)	282 (259–312.7)	C, N, and S
Northeast (NE)	309	84 (27.2)	11.8 (8.6–17.5)	C, N, S, and W	181 (58.6)	282 (259–311.5)	C, N, and S
***P* value**			$P < 0.0001$	$P < 0.05$		$P < 0.0001$	$P < 0.05$
Central							
Chhattisgarh (CH)	30	6 (20.0)	7.9 (7.3–9.03)	MP, UP, and UT	14 (46.7)	274 (271–286.3)	UP and UT
Madhya Pradesh (MP)	250	71 (28.4)	9.6 (8.25–17.35)	CH, UP, and UT	160 (64.0)	285 (261–309)	UT
Uttar Pradesh (UP)	2880	1000 (34.7)	9.65(7.9–14.43)	CH and MP	2013 (69.9)	287 (263–314)	CH
Uttarakhand (UT)	60	26 (43.3)	8.35 (7.63–9.78)	CH and MP	48 (80.0)	291 (261.8–316.8)	CH and MP
***P* value**			$P < 0.0005$	$P < 0.05$		$P = 0.0044$	$P < 0.05$
East							
Bihar (BH)	540	162 (30.0)	8 (7–11.75)	JH and OD	316 (58.5)	290 (262.8–320)	JH, OD
Jharkhand (JH)	102	37 (36.3)	8 (7–9)	BH and OD	67 (65.7)	280 (266–305)	BH and OD

Table 2 continued

Zone and state	Total no. of participants ($n = 13,750$)	Prevalence of fibrosis (F2-F4), *n* (%)	LSM (median (IQR))	Post hoc analysis for LSM	Prevalence of MASLD (S1–S3), *n* (%)	CAP (median (IQR))	Post hoc analysis for CAP
Odisha (OD)	114	46 (40.3)	9.3 (8.13–12.43)	BH, JH, and WB	82 (75.9)	282 (259.3–309.5)	BH, JH, and WB
West Bengal (WB)	873	198 (22.7)	8.7 (7.63–12.4)	OD	517 (59.2)		OD
P value			$P < 0.0001$	$P < 0.05$		$P = 0.06$	$P < 0.05$
Northeast							
Assam	309	84 (27.2)	10.25 (8–16.73)	–	181 (58.6)	282 (258.8–311.3)	–
North							
Chandigarh (CG)	144	55 (38.2)	8.6 (7.75–11.3)	DL, HR, PB, and RA	109 (75.7)	278 (259–313)	HR and PB
Delhi (DL)	2263	779 (34.4)	9.1 (7.7–14.15)	CG, HR, PB, and JK	1606 (70.9)	286 (264–313)	HR, PB, and JK
Haryana (HR)	100	19 (19.0)	9.8 (8.35–23.1)	CG, DL, PB, JK, and RA	56 (56.0)	277 (256–306.3)	CH, DL, PB, JK, and RA
Jammu and Kashmir (JK)	748	315 (42.1)	7.7 (7.25–9.8)	DL, HR, PB, and RA	541 (72.3)	296(283–307)	DL, HR, and PB
Punjab (PB)	997	475 (47.6)	9.3 (7.9–13)	CG, DL, HR, JK, and RA	784 (78.6)	293 (271–317.3)	CH, DL, HR, JK, and RA
Rajasthan (RA)	1114	399 (35.8)	8 (7–11.05)	CG, HR, PB, and JK	835 (74.9)	281 (254–330)	HR and PB
P value			$P < 0.0001$	$P < 0.05$		$P < 0.0001$	$P < 0.05$
South							
Andhra Pradesh (AP)	314	78 (25.9)	8.45 (7.5–9.6)	–	170 (54.1)	283 (260–311.5)	KN, KL, and TN
Karnataka (KN)	255	93 (36.5)	9 (7.7–10.9)	–	181 (70.9)	290 (265–324)	AP
Kerala (KL)	50	14 (28.0)	13 (10.28–19)	–	36 (72.0)	288 (258.3–323)	AP

Table 2 continued

Zone and state	Total no. of participants ($n = 13,750$)	Prevalence of fibrosis (F2-F4), *n* (%)	LSM (median (IQR))	Post hoc analysis for LSM	Prevalence of MASLD (S1–S3), *n* (%)	CAP (median (IQR))	Post hoc analysis for CAP
Tamil Nadu (TN)	803	245 (30.3)	9 (7.7–11)	–	570 (70.9)	282 (257–314)	AP
P value			$P < 0.014$			$P < 0.0001$	$P < 0.05$
West							
Gujarat	192	64 (33.3)	8.65 (7.38–9.83)	–	128 (66.7)	285 (260.5–320)	–
Maharashtra	1612	477 (29.6)	8.7 (7.5–12)	–	971 (60.2)	278 (259–309.5)	–
P value			$P = 0.6695$			$P = 0.02$	

CAP controlled attenuation parameter, *LSM* liver stiffness measurement, *MASLD* metabolic dysfunction-associated steatotic liver disease

lowest prevalence of MASLD and fibrosis, and Chhattisgarh (46.7%) demonstrated the lowest prevalence of MASLD among all the states studied. These findings are consistent with those of previous studies, which showed a high prevalence of MASLD and fibrosis in the northern states and a low prevalence in the eastern zone [10–12]. The prevalence of MASLD is strongly associated with metabolic syndrome [13, 14]. The high prevalence in the northern states may be due to dietary habits rich in saturated fats and a higher incidence of metabolic syndrome. These findings are consistent with those of previous studies, which showed that urbanization and lifestyle changes, such as increased consumption of high-calorie diets and reduced physical activity, are associated with MASLD [15, 16]. Despite showing a high prevalence of MASLD, the southern states such as Karnataka (MASLD, 70.9% and fibrosis, 36.5%) and Tamil Nadu (MASLD, 70.9% and fibrosis, 30.3%) demonstrate distinct regional patterns. Our results are consistent with those of previous studies, which showed a high prevalence of MASLD in Chennai (61.5%) [17], Kerala (49.8%), and Tamil Nadu (29.7%). In these regions, dietary practices characterized by higher consumption of rice and coconut oil and genetic predispositions may play a role in these patterns [4, 18–20]. Eastern and northeastern states, such as Bihar (MASLD, 58.5% and fibrosis, 30%), West Bengal (MASLD, 59.2% and fibrosis, 22.6%), and Assam (MASLD, 58.6% and fibrosis, 27.2%), demonstrated a lower prevalence than other regions. This discrepancy may be due to differences in dietary habits and lower urbanization rates [4, 21]. Consistent with our study results, a recent study showed that the prevalence is approximately 57% [9].

The western and central parts of India demonstrated a high prevalence of MASLD and severe liver fibrosis. Additionally, the prevalence of MASLD was 80.0%, 69.9%, 66.7%, and 60.2% in Uttarakhand, Uttar Pradesh, Gujarat, and Maharashtra, respectively. Very few studies have been conducted in this part of India. A previous study reported a prevalence of 43.6% in Bhopal [22], whereas another reported a prevalence of 16% in Mumbai. However, this study was conducted a decade ago [23]. A recent study conducted in Mumbai showed that the prevalence rates of steatosis and fibrosis in patients with diabetes were 75.1% and 28.0%, respectively. In our study, the prevalence rate was higher than that reported in these studies. Notably, this study reported data from certain states, such as Uttarakhand, Chhattisgarh, Jammu and Kashmir, Bihar, and

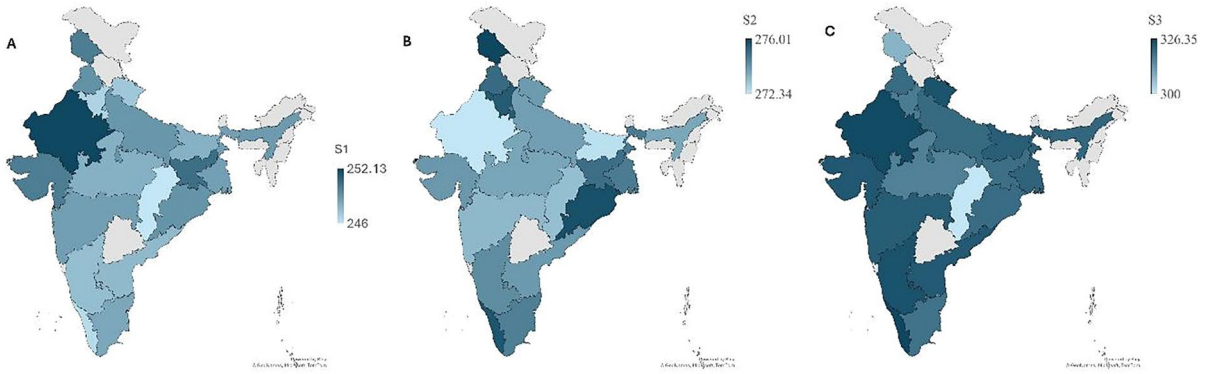

Fig. 6 State-wise distribution of mean controlled attenuation parameter (CAP) values indicating the degree of steatosis across the country. **A** Distribution of mean CAP values indicating the prevalence of S1 steatosis across the country. **B** Distribution of mean CAP values indicating the prevalence of S2 steatosis across the country. **C** Distribution of mean CAP values indicating the prevalence of S3 steatosis across the country

Jharkhand, for which no studies have been conducted.

Most studies on the prevalence of MASLD in India are limited by their single-center, region-specific nature and the use of varying diagnostic methodologies, which hinder direct comparisons across studies [4–6, 10, 17, 24]. Multicentric studies that provide comprehensive nationwide data, particularly involving tertiary care centers, are needed. To the best of our knowledge, this is the first cross-sectional study to encompass the maximum number of states across all zones in India and use a standardized diagnostic technique to assess the prevalence of MASLD.

Community-based screening for liver disorders was not feasible earlier because liver biopsy was the gold standard for diagnosing MASLD. Ultrasound was widely used but could not differentiate among steatosis, fibrosis, and inflammation. MRI-based techniques have also been explored. However, liver biopsy is invasive and primarily used for research, whereas ultrasound and MRI have limitations in routine screening due to cost, accessibility, and feasibility for large-scale studies. VCTE is the globally used and validated elastography technique. Tissue elasticity can be measured using VCTE and is directly correlated with liver stiffness (LSM), which is correlated with the extent of fibrosis. In addition to measuring LSM, VCTE yields CAP, which measures liver fat and indicates the degree of MASLD [25]. The use of LSM and CAP in this study provided a more consistent, reliable, and thus comparable assessment of liver fibrosis and steatosis across regions.

The findings indicate that a significant proportion of the population exhibits varying degrees of fibrosis and steatosis, with notable regional differences. For example, the highest prevalence of cirrhosis (F4) was observed in states such as Uttar Pradesh (15.4%), Odisha (16.7%), Assam (13.6%), Punjab (19.4%), Kerala (20.0%), and Maharashtra (9.7%) in different zones of the country. Similarly, the highest prevalence of severe steatosis (S3) was observed in states such as Uttarakhand (40.0%), Bihar (29.4%), Assam (25.9%), Jammu and Kashmir (50.3%), Karnataka (36.1), and Gujarat (30.2%) in different zones of the country. These findings emphasize the need for standardized diagnostic criteria and methods for epidemiological studies on MASLD and liver fibrosis. The variability in diagnostic methods has been a major limitation in understanding the actual burden of MASLD and liver fibrosis in India and globally.

This study highlights the significant impact of socioeconomic factors and awareness on the prevalence of MASLD. A higher prevalence was observed in regions with higher socioeconomic status and better healthcare infrastructure, such as Uttar Pradesh, Gujarat, Maharashtra, Chandigarh, Delhi, Karnataka, and Tamil Nadu. This could be due to better diagnostic facilities and greater health awareness, leading to more

frequent and accurate diagnoses. Increased health awareness may lead individuals to visit health camps organized in nearby regions with better infrastructure. Conversely, lower prevalence in less developed regions, such as Northeast India, Bihar, Jharkhand, and Chhattisgarh, may reflect underdiagnosis due to limited access to healthcare and lack of awareness of MASLD. Additionally, the lack of regular health checkups and screening programs in many parts of India contributes to the underestimation of the prevalence of MASLD. Public health initiatives aimed at increasing awareness and promoting regular screening, especially in rural and less developed areas, are crucial for the early detection and treatment of MASLD.

This study has some limitations. The selection of participants across various sites might have introduced bias and influenced the results, potentially affecting the generalizability of the results. However, the study covered most states to understand the nationwide distribution of the disease via a standardized approach. Furthermore, the cross-sectional study design offered only a snapshot of the prevalence of MASLD without assessing causality or temporal changes. Our study has used LSM and CAP obtained using FibroScan to assess the prevalence of MASLD. However, this approach is reported to be less accurate for patients with BMI > 30 kg/m^2, especially while using M probe. We tried to overcome this limitation of the technique by using the XL probe to improve the reliability of the results [26]. Therefore, future studies with broader geographic coverage and detailed comorbidity data are needed to more comprehensively understand the prevalence of MASLD in India.

CONCLUSION

This study provides cross-sectional pan-India data, including regional disparities in the prevalence and severity of MASLD and fibrosis. The findings highlight the need for region-specific public health interventions and tailored strategies to reduce the growing burden of metabolic liver diseases, such as MASLD, which can result in fibrosis, cirrhosis, and even hepatocellular carcinoma. Standardizing diagnostic methods, especially for screening, and increasing awareness of MASLD is a crucial step toward effective treatment and prevention of this condition. Further studies are needed to investigate the underlying cultural and socioeconomic factors associated with these regional differences and to develop targeted strategies for combating MASLD in India.

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Data Availability. The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of Interest. Viswanathan Mohan, Shashank Joshi, Saket Kant, Altamash Shaikh, L Sreenivasa Murthy, Banshi Saboo, Parminder Singh, Aravind R. Sosale, Debmalya Sanyal, G Shanmugasundar, Santosh Kumar Singh, A K Pancholia, Sunetra Mondal, Rishi George, Ashok Jaiswal, Kunal Jhaveri declare no competing interests.

Ethical Approval. This study was approved by the Drug Controller General of India approved ethics committee (Royal Pune Independent Ethics Committee) and conducted in accordance with the principles of the Helsinki Declaration. Written informed consent was obtained from all participants before participation. This study was registered in the ISRCTN registry (ISRCTN18116615).

REFERENCES

1. Teng ML, Ng CH, Huang DQ, et al. Global incidence and prevalence of nonalcoholic fatty liver disease. Clin Mol Hepatol. 2023;29(Suppl):S32–42.
2. Younossi ZM, Golabi P, Paik JM, et al. The global epidemiology of nonalcoholic fatty liver disease (NAFLD) and nonalcoholic steatohepatitis (NASH): a systematic review. Hepatology. 2023;77(4):1335–47.
3. Jiang W, Mao X, Liu Z, et al. Global burden of nonalcoholic fatty liver disease, 1990 to 2019: findings from the global burden of disease study 2019. J Clin Gastroenterol. 2023;57(6):631–9.
4. De A, Duseja A. Nonalcoholic fatty liver disease: Indian perspective. Clin Liver Dis (Hoboken). 2021;18(3):158–63.
5. Duseja A, Najmy S, Sachdev S, et al. High prevalence of non-alcoholic fatty liver disease among healthy male blood donors of urban India. JGH Open. 2019;3(2):133–9.
6. Das K, Das K, Mukherjee PS, et al. Nonobese population in a developing country has a high prevalence of nonalcoholic fatty liver and significant liver disease. Hepatology. 2010;51(5):1593–602.
7. Cao Y, Xiang L, Qi F, et al. Accuracy of controlled attenuation parameter (CAP) and liver stiffness measurement (LSM) for assessing steatosis and fibrosis in non-alcoholic fatty liver disease: a systematic review and meta-analysis. Clin Med. 2022;51: 101547.
8. Eddowes PJ, Sasso M, Allison M, et al. Accuracy of FibroScan controlled attenuation parameter and liver stiffness measurement in assessing steatosis and fibrosis in patients with nonalcoholic fatty liver disease. Gastroenterology. 2019;156(6):1717–30.
9. Sinha A, Bankura B. Prevalence of nonalcoholic fatty liver disease in type 2 diabetes mellitus patients from the Eastern region of India. Diabet Epidemiol Manag. 2023;12: 100161.
10. Asadullah M, Shivashankar R, Shalimar, et al. Rural-Urban differentials in prevalence, spectrum and determinants of non-alcoholic fatty liver disease in North Indian population. PLoS One. 2022;17(2):e026.
11. Duseja A, Singh SP, Saraswat VA, et al. Non-alcoholic fatty liver disease and metabolic syndrome-position paper of the Indian national association for the study of the liver, endocrine society of India, Indian college of cardiology and Indian society of gastroenterology. J Clin Exp Hepatol. 2015;5(1):51–68.
12. Nagappa B, Ramalingam A, Rastogi A, et al. Number needed to screen to prevent progression of liver fibrosis to cirrhosis at primary health centers:

an experience from Delhi. J Family Med Prim Care. 2021;10(3):1412–8.

13. Duseja A, Singh SP, Mehta M, et al. Clinicopathological profile and outcome of a large cohort of patients with nonalcoholic fatty liver disease from south Asia: interim results of the indian consortium on nonalcoholic fatty liver disease. Metab Syndr Relat Disord. 2022;20(3):166–73.

14. Radu F, Potcovaru C-G, Salmen T, et al. The link between NAFLD and metabolic syndrome. Diagnostics (Basel). 2023;13(4):614.

15. Krishnamoorthy Y, Rajaa S, Murali S, et al. Prevalence of metabolic syndrome among adult population in India: a systematic review and meta-analysis. PLoS ONE. 2020;15(10): e0240971.

16. Singh PN, Arthur KN, Orlich MJ, et al. Global epidemiology of obesity, vegetarian dietary patterns, and noncommunicable disease in Asian Indians. Am J Clin Nutr. 2014;100(1):359–64.

17. (PDF) Prevalence of Non-Alcoholic Fatty Liver Disease in Urban Adult Population in a Tertiary Care Center, Chennai. ResearchGate [Internet]. 2024 [cited 2025 Mar 12]; https://doi.org/10.4103/ijcm.ijcm_437_22.

18. Bale G, Steffie AU, Ravi Kanth VV, et al. Regional differences in genetic susceptibility to non-alcoholic liver disease in two distinct Indian ethnicities. World J Hepatol. 2017;9(26):1101–7.

19. Banerjee P, Reddy GB, Panda H, et al. Diets, lifestyles and metabolic risk factors among corporate information technology (IT) employees in South India. Nutrients. 2023;15(15):3404.

20. Venkatesan P, Prakash SS, Ramasamy J. Association of dietary patterns and health outcomes by spatial regression analysis of nationally representative survey data from India. Indian J Public Health. 2023;67(3):399–407.

21. Mandal DRK, Alam DMA, Kundra DRS. Urbanization trend in North East India: an empirical study. J Positive School Psychol. 2022;6(9):4641–53.

22. Singhai A, Yadav V, Joshi R, et al. Prevalence, metabolic profile, and associated risk factors of non-alcoholic fatty liver disease in an adult population of India. Cureus. 2023;15(1): e33977.

23. Amarapurkar D, Kamani P, Patel N, et al. Prevalence of non-alcoholic fatty liver disease: population based study. Ann Hepatol. 2007;6(3):161–3.

24. Shalimar A, Elhence A, Bansal B, et al. Prevalence of non-alcoholic fatty liver disease in India: a systematic review and meta-analysis. J Clin Exp Hepatol. 2022;12(3):818–29.

25. Zhang S, Mak L-Y, Yuen M-F, et al. Screening strategy for non-alcoholic fatty liver disease. Clin Mol Hepatol. 2023;29(Suppl):S103–22.

26. Accuracy of non-invasive liver stiffness measurement and steatosis quantification in patients with severe and morbid obesity - Eilenberg - Hepatobiliary Surgery and Nutrition [Internet]. [cited 2025 Apr 17]. Available from: https://hbsn.amegroups.org/article/view/64389/html.