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Unique attributes of obesity in India: A narrative review

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Abstract

Obesity has become a burgeoning epidemic in India, even though the country is still dealing with undernutrition. As a significant determinant of the Metabolic Syndrome (MetS) and non-communicable diseases (NCDs) such as type 2 diabetes mellitus (T2DM) and cardiovascular disease (CVD), understanding the Indian context of the problem and learning how to deal with the obesity epidemic in this country has gained paramount importance.

This narrative review points to the unique features of the obesity epidemic in India and its associated contributing factors, including the evolving nature of the Indian diet, the peculiarity of the increased adiposity at lower BMIs, unique obesity-associated genetic variants in Indians, the contribution of the gut microbiome, the impact of chronic inflammation and the role of ambient air pollution, and the contribution of decreased physical activity levels concerning the rapid urbanisation and the built environment. We believe that disseminating our insights into these unique features influencing the development of obesity in India will help increase global awareness and pave the way for better control and management of this obesity epidemic.

Keywords

obesity; India; epidemic; body mass index

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The authors' contributions to the manuscript are as follows – AM and AV-P: conceptualised the idea for this review; NN, SA and PCN: wrote the manuscript; NN and SA: analysed data and prepared the tables and figures. All authors critically reviewed the manuscript, and read and approved the final version.

1 Introduction

Obesity is defined as excessive fat accumulation leading to impairment in the health of an individual(1). The threat of obesity comes from the severity of its associated risk of noncommunicable diseases such as type 2 diabetes mellitus (T2DM), cardiovascular disease (CVD), stroke, musculoskeletal disorder, fatty liver disease and cancer, thereby contributing to disability for life, decrease in life expectancy (2) and economic disruption.

The imbalance between calories consumed and expended is the primary determinant of positive energy balance leading to obesity. Factors such as increased sedentary lifestyle, decreased physical activity, and increased intake of high-calorie food rich in fat and sugars contribute to its increasing prevalence. As India is the second-most populous country in the world and going through a rapid economic transition, it is easy to understand the magnitude of the health burden risk posed by the increasing prevalence of obesity. A few recent reviews on obesity in India have focused on the prevalence of obesity in India, forecasting prevalence in the near future, with specific emphasis on socioeconomic factors and the epidemiology of childhood obesity(3–7). However, to develop a comprehensive strategy with a chance to control/mitigate the epidemic of obesity in India, it is essential to understand the contribution of and connection between diverse factors, such as the population, geographical condition, lifestyle, socioeconomic state (SES), dietary patterns and biology of obesity.

2 Trends in the prevalence of obesity in India

The Indian National Family Health Surveys (NFHS)(8–11) provide combined prevalence data for overweight and obesity (BMI ≥ 25 kg/m^2). Time/trends of overweight and obesity (BMI ≥ 25 kg/m^2) prevalence in Indian adults from the NFHS surveys(8–11) indicate a countrywide increase over time. On the whole, the prevalence of overweight and obesity (BMI ≥ 25 kg/m^2) in India has increased from 12% to 23% in men; and from 15% to 24% in women in the same period (2005-2019)(8–10). Of relevance, these changes in prevalence are not homogeneous in the whole territory, exhibiting major variability ranges amongst the Indian states. States like Jammu & Kashmir and Manipur have witnessed skyrocketing increases in prevalence among men and women, respectively, between 2005-2006 (NFHS 3) and 2019-2021 (NFHS 5) (Figure 1, Table 1). In contrast, states like Punjab and Gujarat have witnessed minimal change, but at higher and lower prevalence levels, respectively, likely due to ethnic differences.

These findings, heterogeneity and cultural influence, are in line with those by the NCD Risk Factor Collaboration, where 2416 population-based studies were pooled to track worldwide time trends in the prevalence of overweight (BMI 25–30 kg/m^2) and obesity (BMI >30 kg/m^2) between 1975 to 2016(12). Their findings showed that obesity in India has ballooned up much faster than in the rest of the world. Among men, the prevalence of overweight and obesity has increased by about four-fold (from 4.45% to 15.66%) and sixteen fold (from 0.17% to 2.87%) respectively in India compared to two fold (from 17.75% to 28.37%) a four-fold (from 3.05% to 11.55%) worldwide. Among women who were overweight and obese, these increases were three fold (from 6.03% to 17.10%) and nine fold (from 0.56% to

5.31%) respectively, higher in India compared to 1.5 fold (from 17.06% to 24.77%) and 2.4 fold (from 6.56% to 15.70%) worldwide(12).

The complexity of tackling the problem of overweight and obesity in India is exacerbated because its prevalence varies between states, rural and urban populations, men and women, geographical conditions, lifestyle, SES and dietary patterns(13). Moreover, although obesity is lower in rural populations, the upward trend is clear, and ~20% of rural Indian adults have been predicted to become overweight or obese by 2030(14). In contrast with other nations, the National Family Health Survey (NFHS) survey conducted in 2015-16 reported a higher incidence of obesity in those with higher socioeconomic status, linked to their sedentary lifestyle and high-calorie intake(9).

In terms of regional variations, Mohan *et al.* in 2008 reported clear regional differences in the prevalence of both obesity and abdominal obesity (prevalence high to low: South India > North India > East India > West India)(15). This regional disparity continues more than a decade later, as evident from NFHS-5 data released in 2019-21(10, 11), and is likely linked to regional disparities in prevailing economic conditions. The Southern states have consistently fared better in terms of both Gross State Domestic Product (Constant prices) as well as Per Capita Net State Domestic Product (Constant prices) compared to the Northern or Eastern states(16, 17). However, the Western states stand as an anomaly, usually faring the highest in terms of both Gross State Domestic Product (Constant prices) as well as Per Capita Net State Domestic Product (Constant prices)(16, 17) but the lowest in obesity prevalence(10, 11). Historically, these states were the major conduit for all the major invasions into the country; therefore, the likely mixing of local with non-local gene pools could be a reason for this observed disparity(18).

3 Relevance of understanding obesity in a traditionally undernourished country

India is in a transitional state of nutrition, facing a dual paradoxical burden where undernutrition and obesity coexist(19). The prevalence of undernutrition is consistently decreasing in parallel with an increase in obesity. Based on India's National Family Health Surveys (NFHS) data collected in 1998-1999, 2005-2006, 2015-2016 and 2019-2021, the prevalence of underweight has consistently reduced from 36% (in 1998-1999) to 19% (in 2019-2021) of Indian women (age 15-49 years) and from 28% (in 2005-2006) to 16% (in 2019-2021) of Indian men (age 15-49 years)(8–11). Conversely, the prevalence of overweight and obesity (BMI ≥ 25 kg/m^2) in the same age group (age 15-49 years) has steadily gone up from 11% (in 1998-1999) to 24% (in 2019-2021) amongst Indian women and from 12% (in 2005-2006) to 23% (in 2019-2021) amongst Indian men(8–10, 20). Young *et al.* attribute the reduction in the prevalence of underweight (from 33% to 19%) and simultaneous increase in the prevalence of overweight and obesity (BMI ≥ 25 kg/m^2) (from 15% to 24%) in Indian women (age 20-49 years) to improved SES, progressive urbanisation, improved diet diversity, latrine use, and higher education levels and decision-making and ownership of money(21).

Obesity is a significant risk factor for noncommunicable diseases (NCDs) such as CVD, T2DM, and hypertension. These comorbidities increase the burden of death and disability in India(22). According to the World Health Organization's (WHO) NCD progress monitor of 2015, it estimated that 61% of the total deaths in India were attributed to NCDs, and about 23% of the total population was at risk of premature death from NCDs(23). The shift in principal causes of premature mortality and morbidity from communicable, maternal, and neonatal conditions to NCDs has been observed rapidly in India since the 1990s(24). In India, ischemic heart disease - the most common form of cardiovascular disease – was ranked sixth in 1990 as the leading cause of disability-adjusted life-years (DALYs), and has been ranked second in 2019(24). T2DM was the ninth leading cause of DALYs in 2019(24). Non-alcoholic fatty liver disease (NAFLD) is another NCD associated with obesity, gaining prominence fast. NAFLD, a medical condition in which excess fat deposits in the liver, is a leading cause of chronic liver diseases globally. NAFLD affects about 25% of the global adult population ranging from 13.5% in Africa to 31.8% in the Middle East(25). In India, a recent systematic review reported an estimated pooled prevalence of 38.6% among adults and 35.4% among children(26). Moreover, major risk factors for NCDs, including high systolic blood pressure, high fasting plasma glucose, high total cholesterol, and high body-mass index, have consistently worsened in India between 1990 to 2016(27).

In terms of the economic impact of obesity and its associated complications, Okunogbe *et al.* recently utilised a cost-of-illness approach to calculate and compare the cost of obesity per capita in 2019 in eight countries representing diverse economic and geographical contexts(28). Their model included direct and indirect costs but could not include a few indirect cost components such as early retirement costs or long-term disability costs due to the feasibility of data availability across the eight countries. Though the cost of obesity per capita was lowest in India (United State Dollars (USD) 17), compared to USD 940 in Australia (highest) in 2019, the authors of the study projected a 17 times increase in these costs (USD 290) for India versus a three-fold increase (USD 2956) for Australia in 2060. In a 2015 study with data from 325 (15-49-year-old) women, the authors noted a significant increase in the individual average health expenditure per month amongst women, and this increase was correlated to the BMI. Mean expenditure increased steadily, from normal weight (BMI 18.5 – 24.9 kg/m^2) – Indian Rupees (INR) 68 (±133.4 SD), overweight (BMI 25-30 kg/m^2) – INR 132.7 (±234.4 SD), obese (BMI >30 kg/m^2) – INR 143.7 (±204.9 SD), to morbidly obese (BMI >35 kg/m^2) – INR 224.8 (±370.9 SD)(29). In their analysis of the economic burden of overweight and obesity on the public health system in the South Indian state of Andhra Pradesh conducted in 2017, Panda *et al.* concluded that the estimated total cost in one year due to all diseases related to overweight and obesity was USD 55 million, of which the lion’s share (~18%) was due to cardiovascular disease(30).

4 Causes and possible mechanisms contributing to obesity and comorbidities in India

4.1 The Evolving Indian Diet

To revise the Recommended Daily Allowance (RDA) values of nutrients for Indians, the Indian Council of Medical Research (ICMR)–National Institute of Nutrition (NIN) Expert

Committee on RDA (2020) has defined the normal BMI reference for Indian adult man and woman of 19-39 years as weighing 65 and 55 kg respectively in contrasts with the 60 and 50 kg, respectively, considered by the earlier committees of 1989 and 2010(31). This change in the Indian reference was based on the evolving anthropometry and, therefore, the dietary needs of Indians. Further, as a nod toward the recognition of obesity as an increasingly significant problem for India, the ICMR-NIN Expert Committee on RDA (2020) reduced the Estimated Average Requirement (EAR) for energy for a sedentary Indian man by 9.1% [2320 kcal/day to 2110 kcal/day] and by 12.6% [1900 kcal/day to 1660 kcal/day] for a sedentary Indian non-pregnant, non-lactating woman, compared to the recommendations provided in 2010(32).

A study using data obtained from the Consumption Expenditure Survey (CES) compared the average daily calorie consumption in India with the EAT-Lancet recommendations and found that the calories gained are predominantly through the consumption of cereals than through the consumption of proteins, fruits, vegetables and legumes, pointing to the nutritional reasons for deficiency of protein and micronutrients(33). Similarly, another cross-sectional study on Asian Indian adolescents and youth reported a disproportionate consumption of micro and macronutrients(34). The consumption of fruits, vegetables, tubers, roots, milk products, sweets and oils was more than 9.0% (210 kcal/day) of the recommended daily allowance, and the daily energy percentage obtained from protein consumption was markedly less compared to the energy obtained from carbohydrates and fat. Also, fat consumption was way higher than the daily recommended allowance(34).

To identify components of the Indian diet likely contributing to the increasing prevalence of obesity, we utilised the TATA-NIN dashboard(35), a centralised data repository with harmonised datasets about crop production, nutrient intake and health outcomes. Using this dashboard, we analysed correlations between state-level intakes of foods and the prevalence of overweight and obesity (BMI ≥ 25 kg/m^2) for all food types for which both intake and high BMI prevalence data were available for >10 states (Table 2).

As expected, intake of 'all oils' (includes data on mustard oil, groundnut/peanut oil, refined oil – sunflower, soybean, safflower, hydrogenated fats, and all other edible oils) was positively associated with the prevalence of high BMI in both men and women (Figure 2A). Intake of 'cereals' (includes all rice/rice products, wheat/wheat products, millets, and all other cereals and bread) was negatively associated with high BMI in both men and women (Figure 2B). There can be at least two reasons for this observation. One, *'cereals'* primarily reflect whole grain cereals, not refined grains, as intake of refined grains has been documented under 'packaged foods'. Whole grain cereals benefit body weight regulation by providing more dietary fibre, vitamins, and minerals than refined versions(36, 37). Two, expenditure on non-cereal foods has consistently increased in rural and urban India, at the expense of expenditure on cereal-based foods, primarily due to an increase in income levels across the board(38, 39). As such, levels of cereal intake could act as a proxy for the SES of the population, with higher SES having a higher prevalence of high BMI. The positive association between intake of *'spices'* and the prevalence of high BMI (Figure 2C) can similarly be explained by the intake of spices acting as a proxy for the purchasing power and, therefore, SES of the population(40).

For both intakes of *'all meat and egg'* (includes eggs, fish/prawns and meats: chicken, beef, pork and all other kinds of meat consumed) (Figure 2D) and '*pulses*' (includes all pulses/ legumes and legume products consumed) (Figure 2E), we observed positive association of intakes with the prevalence of high BMI. This was expected as protein foods (meats and eggs represent non-vegetarian sources and legumes represent vegetarian sources) account for the largest share of the food budget(41, 42), and higher intake levels are likely due to higher SES.

Our analysis also unexpectedly identified a female-specific positive association between intake of *'sugar'* (includes sugar distributed through the public distribution system, honey, candy, jaggery and rock sugar) with the prevalence of high BMI (Figure 2F). Of note, this was seen despite a similar mean monthly sugar intake for men (range of mean monthly intake: 591-2262 g) and women (range of mean monthly intake: 483-1874 g). This could be based on findings of Chukijrungroat *et al.*(43) in rats due to a higher likelihood of women being prone to hepatic steatosis via a higher capacity for *de novo* lipogenesis from sugar (sucrose, broken down into glucose and fructose in our body). Female rats exhibited significantly higher levels of hepatic steatosis but less hepatic inflammation than male rats after consuming a high-fat, high-fructose diet for 12 weeks(43). Despite the strong evidence of whole-body metabolism being sexually dimorphic, studies on human metabolism are usually done on subjects from only one sex, primarily males(44, 45). Therefore, further in-depth exploration of these findings, using study designs that compare the metabolic effects of various foods on body weight regulation between men and women, will be needed for understanding the underlying causes and appropriate remedial measures.

Beyond the kind of foods consumed, the level of processing of foods plays a significant role in overall caloric intake and health outcomes. In mice, body mass increased on the consumption of cooked meat compared to uncooked meat, and this increase was not attributable to differences in activity or intake levels(46). Similarly, in an inpatient, randomised controlled trial on 20 weight stable adults, Hall *et al.* reported exposure to an ultra-processed diet for 14 days resulted in increased *ad libitum* energy intake and weight gain when compared to exposure to an unprocessed diet for an equal period, even after matching the two diets in calories, fat, sugar, fibre sodium and macronutrients(46). A recent systematic review and meta-analysis concluded that consumption of ultra-processed foods and health status were associated with a worse cardiometabolic profile (including significantly increased risk of obesity) and a higher risk of CVD and all-cause mortality(47). Pandav *et al.* have recently highlighted the accelerating growth of the market for packaged junk foods and soft drinks in India; the retail value of these products went up by 42 times between 2006 and 2019(48). Singh *et al.* reported in 2021 that amongst 13,274 Indian children aged 9-14 years, 53% consumed packed foods or packaged sweetened beverages at least once a day(49).

4.2 Adiposity

Beyond body weight, BMI is a robust and easy measure of adiposity(50, 51). However, adiposity measured as BMI is susceptible to misinterpretations in individuals with high physical activity levels or when generalised between ethnic groups(52, 53). Regional fat content and distribution influence metabolic health more significantly (54). Central adiposity or centralised fat distribution, as measured by waist circumference, waist-to-hip ratio or waist-to-height ratio, are better predictors of CVD risk than BMI in populations as diverse as original from Europe, the USA, Thailand and Peru(55–59).

The latest NFHS survey (NFHS – 5, 2019-2021) reported the prevalence of adults with a high-risk waist-to-hip ratio (women ≥0.85 and men ≥0.90) for the first time(11). More than half the women (56.7%) and nearly half of the men (47.7%) surveyed had a high-risk waist-to-hip ratio.

These numbers emphasise the potential contribution and need for a better understanding of the role of central obesity in metabolic health amongst Indians.

Indians have lower muscle mass and higher body fat content than other ethnicities(60). This results in BMI being a relatively insensitive cardiometabolic risk predictor of overweight in Indians. Two decades back, Dudeja *et al.* (61) reported 15% of males and 27% of females as overweight and obese when using BMI ≥25kg/m^2 as a cut-off, which leapt up to 35% of males (2.3 times) and 89% of females (3.3 times) as overweight when they used percentage body fat as cut-off (25% for males and 30% for females)(62, 63). Based on these observations, recommendations were made to change the BMI cut-offs for Indians to BMI ≥23 kg/m^2 for overweight and >30 kg/m^2 for obese, respectively(64). However, these modified BMI cut-offs for Indians are yet to be widely adopted, likely either due to a lack of awareness or to maintain uniformity when collecting data, to be able to compare anthropometric and clinical characteristics of Indians with those of other ethnicities.

Though in absolute terms, Indian neonates with birth weights appropriate for gestational age (AGA) do not have a higher fat mass than those from other populations, both AGA neonates and those with birth weights small for gestational age (SGA) are much better at preserving fat mass, but not fat-free mass(65, 66). In Indian children, the progressive increase in adiposity was related to the nutritional status of the mothers during pregnancy, parental health and genetics(67, 68).

Comorbidities of obesities, such as insulin resistance(69, 70) and CVD risk(71, 72), appear at lower BMI in Indians than in other ethnic groups. Migration to developed countries with a western obesogenic environment further exacerbates these problems(73), with multiple existing reports of higher levels of obesity and associated coronary risk factors in Indians living in those countries, compared to those in India(74, 75). Lifestyle factors leaning toward positive energy balance, either through the reduction in physical activity levels or an increase in calorie consumption in Indians, therefore, can easily tip the balance towards increased risk of metabolic syndrome and associated NCDs.

4.3 Genetics

The genetic component of obesity, as measured by heritability estimates (proportion of phenotypic variation attributed to genetic variation), is substantial. It ranges from 40 to 70%, with the highest estimates from monozygotic twin studies(76). The genetic basis of monogenic forms of obesity, both syndromic and non-syndromic, has been successfully identified(77). However, the ever-increasing number of obesity-susceptibility loci [~1000 Single nucleotide polymorphisms (SNPs)] can still explain only ~10% of the heritability of obesity, underlying the need for further technological advances and larger sample sizes to identify the large remaining heritability of obesity(60).

Heritability estimates of obesity have shown minimal ethnicity-based differences(76). Reports from large-scale genome-wide association studies (GWAS) in Indians are only now becoming available, which could shed light on any India-specific loci contributing to obesity. Though genetic loci reported being associated with obesity specifically in the Indian population are not widespread, a few novel ones have recently been reported: rs1526538, an intronic SNP of *THSD7A*(78), rs6913677 in *BAI3,* rs2078267 *SLC22A11* and rs8100011 in *ZNF45*(79).

Compounded with obesity, obesity-associated complications and comorbidities are also heritable and have ethnicity-specific components. Indian- or South Asian-specific novel genetic loci associated with multiple comorbidities of obesity, such as T2DM (five intronic SNPs: rs9552911 in *SGCG*(80), rs998451 in *TMEM163*(81), rs16861329 in *ST6GAL1,* rs7178572 in *HMG20A* and rs4812829 in *HNF4A*(82); rs3923113 located near *GRB14* and rs1802295 located in the exonic region of *VPS26A*(82)), glycaemic control (a missense variant in *G6PD* and a non-coding variant near *PIEZ01* associated with HbA1c levels(83)) and heart failure (a deletion of 25 bp in *MYBPC3*(84)) have been reported. Whole-exome sequencing in individuals with low BMI but NAFLD and controls revealed variants in Phosphatidylethanolamine N-methyltransferase (*PEMT*) and Oxysterol-binding protein-related protein 10 (*OSBPL10*), which have a role in dietary choline and cholesterol homeostasis, respectively. They could potentially be used to identify the exacerbated risk of NAFLD(85). Few obesity traits were mapped to the intronic region of Alpha-Ketoglutarate Dependent Dioxygenase (*FTO*) (rs9939609) and Melanocortin 4 receptor (*MC4R*) (rs17782313) by Vasan *et al.*(86). Also, among the 32 susceptible genetic variants to predict T2DM and related comorbidities, Janipalli *et al.* found that *MC4R* showed the most association with BMI(87). Genetic variants in intronic regions of the genes Rhomboid domain containing 1 (*RHBDD1*) (rs2177596), Mitogen-activated protein kinase 1 (*MAPK1*) (rs17759796), *FTO* (rs1121980) and *MC4R* (rs6567160) were associated with BMI and Alzheimer's disease(88). These trends might indicate that whereas the Indian population might not be more genetically susceptible to obesity than other populations, they might have genetic trains that might make them more susceptible to cardiometabolic complications. Future large-scale GWAS studies incorporating in-depth phenotyping of the subjects will shed further light on India-specific obesity-susceptible loci and their role in the aetiology of obesity and its complications in Indians.

4.4 The gut microbiome

Animal model studies have shown that the obesity-associated gut microbiome has a higher capacity for energy harvest from food and that the colonisation of germ-free mice can transmit this trait with 'obese microbiota'(89). An obese-type gut microbial profile associated with altered bacterial genes and metabolic pathways and reduced bacterial diversity has also been reported for humans (89). However, considering the large inter-individual variability of human gut microbial profiles and multiple confounding factors, such as diet, antibiotic intake, stool consistency, and many others, consistency has been lacking amongst reports of a human *'obese-type'* gut microbial profile(90).

The Indian gut microbiome has its peculiarities, being characterised by a community rich in genera *Prevotella, Bacteroides, Roseburia* and *Megasphaera*(90–93). This flora reflects the predominantly plant-based, whole-grain carbohydrate and fibre-rich habitual diets of Indians(94). As far as gut microbial profiles of obesity amongst Indians is concerned, very few studies have been reported. Patil *et al.* reported prominence of genus *Bacteroides* and high archaeal density with elevated faecal short-chain fatty acids (SCFA) levels among individuals with obesity(95).

Levels of faecal *Faecalibacterium prausnitzii* were higher in 11-14-year-old Indian children with obesity than in the non-obese children(96).

Harnessing the power of gut microbiome modulation for managing and controlling obesity is still in its infancy and will need many future studies focusing on identifying and controlling the confounders of obesity-gut microbiome associations(94). Stool consistency and stool transit time explain the lion's share of interindividual(94) and temporal intraindividual variation in human gut microbial profiles(94). These factors are heavily influenced by dietary composition, especially the soluble and insoluble fibre content of food(97), which varies considerably in different parts of India(92). In-depth studies linking geographically regular diets, associated gut microbial profiles and the prevalence of obesity in other parts of India are needed to understand the link between diet, the gut microbiome and obesity in Indians.

4.5 Chronic systemic inflammation: Role of pollution

Obesity and its associated metabolic disorders, T2D and CVD, are now well known to be associated with chronic systemic inflammation (CSI)(97, 98). Multiple studies have reported the existence of CSI in overweight Indians, with or without T2DM(99–102). Though pro-inflammatory cytokines are known to increase energy expenditure, evident in exercise-induced inflammation or cancer-associated inflammation leading to cachexia, obesity is considered a state of ‘inflammation resistance’ whereby the increased energy expenditure response to pro-inflammatory cytokines is blunted(103). As such, CSI might be linked to body composition, preferential expansion of intraabdominal adipose tissue depots, harmful effects of ectopic lipotoxicity, or severe pro-inflammatory responses induced by nutritional overload.

Another factor of great relevance to India is ambient air pollution. The localised inflammatory response in the lungs driven by exposure to fine particulate matter ($PM_{2.5}$) causes adipose tissue dysfunction in animal models (loss of brown adipose tissue and their transition toward a white adipose phenotype; increased inflammation, insulin resistance and lipolysis in white adipose tissue), thereby leading to vascular inflammation and endothelial cell insulin resistance(104). A few studies have reported associations between either gases or particulate matter and markers of CSI in Indians(105, 106), underlining the role of air quality on CSI and, in turn, on cardiometabolic health. Pollution is a matter of grave concern as Indian cities, such as New Delhi, are routinely featured among the most polluted cities in the world(107). Factors apart from air pollutants contributing to CSI in Indians need to be systematically delineated to add to the arsenal of preventing measures in the fight against obesity and related disorders.

4.6 The built environment and physical activity

Among South Asian countries, India had the highest (34%) prevalence of insufficient physical activity in 2016(108). The ICMR-INDIAB study conducted in 2014 reported that more than half of Indians are inactive, and inactivity is more prevalent in urban areas and among females(109). Against this backdrop, it is a matter of grave concern that the rapid economic transition in India has brought about unprecedented levels of rural to urban migration(110, 111).

The Indian cities have seen rapid expansions in the last couple of decades due to the migration of people into cities searching for better opportunities(112, 113). According to the World Urbanization Prospects 2018 published by the United Nations, >50% of the Indian population will live in urban areas by 2046(114). The infrastructure of these cities was not built to accommodate and withstand such a rapid onslaught(113). This is leading to the accelerated shrinking of urban green spaces, including public parks, walkable roads, and sidewalks(115, 116). Access to urban green spaces is a well-appreciated factor in increasing physical activity levels, reducing the risk of obesity and CVD, and improving the overall health of the residents(117–119).

Such rapid expansions have also contributed to longer commute times, further eating into the availability of time to increase physical activity levels(120). Additionally, a mismatch between rapid urbanisation and a slower pace of development of public transport systems is leading to increasing use of personal doorstep transport options(121), and increased usage of public transport has been reported to be associated with a decrease in the prevalence of obesity(122). A combination of these factors is likely to have an ever-worsening effect on the metabolic health of Indians unless remedial measures are sought, planned, and implemented at least at the same rate at which urbanisation is happening in this country.

5 Conclusion

The second-most populous country in the world is becoming fat, and fast. This review has delineated this country's unique facets of obesity (Figure 3). India and many other developing countries are witnessing rapid economic and associated nutrition and health transition(123). Jaacks *et al.* have proposed a four-stage model of obesity, and India is in stage 1 of that model. India’s obesity is characterised by a higher prevalence of obesity in women than men, in those with higher SES than in lower SES, and in adults compared to children(124). Therefore, the worst seems yet to be as far as the epidemic of obesity in India is concerned. Progress to a high prevalence of obesity and other NCDs as part of economic progress is not predetermined(125). As outlined for CVDs, one of the NCDs associated with obesity, a comprehensive public health approach can stem this progress(126).

The next obvious question is what needs to be done to contain the escalating obesity epidemic in India. At a micro level, large-scale funding needs to be made available for in-depth research into the molecular characterisation of the peculiarities of obesity, adiposity and increased susceptibility to comorbidities in Indians and its correlation with human whole-body physiology and epidemiological studies. Support systems, including improved public transport and infrastructure and urban green spaces, must be available at a macro-social level. Awareness programs must be planned and conducted in schools, workplaces, and communities. Further, insights into the effectiveness of these programs through implementation research also need to be encouraged. Only such a multi-pronged approach can succeed in stemming this tide of the rapid increase in obesity amongst Indians.

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Abbreviations

T2DM	Type 2 Diabetes Mellitus
CVD	Cardiovascular Disease
SES	Socio-Economic Status
BMI	Body Mass Index
NCD	Non-Communicable Disease
WHO	World Health Organization
DALY	Disability-Adjusted Life - Year
NAFLD	Non-Alcoholic Fatty Liver Disease
GDP	Gross Domestic Product
NFHS	National Family Health Survey
RDA	Recommended Daily Allowance
ICMR	Indian Council of Medical Research
NIN	National Institute of Nutrition
EAR	Estimated Average Requirement
CES	Consumption Expenditure Survey
AGA	Appropriate for Gestational Age
SGA	Small for Gestational Age
SNP	Single Nucleotide Polymorphism

GWAS	Genome-Wide Association Study
SCFA	Short-Chain Fatty Acid
CSI	Chronic Systemic Inflammation

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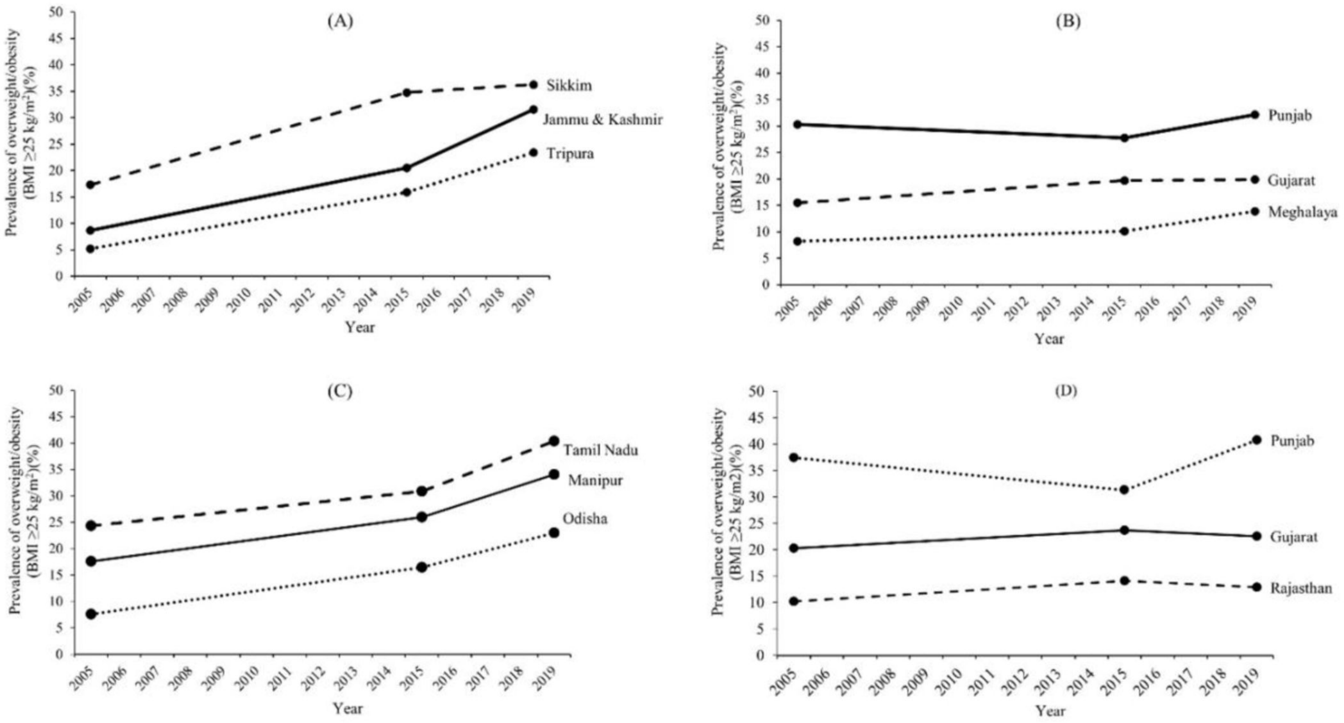

Figure 1. Prevalence of overweight and obesity (BMI ≥25 kg/m^2) in select Indian states.

Prevalence of overweight and obesity (BMI ≥25 kg/m^2) in select Indian states with high or low change in prevalence (% per year) between 2005 and 2019 (National Family Health Survey NFHS 3 – 5)(8–11). Jammu & Kashmir, Sikkim and Tripura had the highest (**A**) and Punjab, Gujarat and Meghalaya had the lowest change in the rate of prevalence (**B**) amongst men. Manipur, Tamil Nadu and Odisha had the highest (**C**) and Gujarat, Rajasthan and Punjab had the lowest change in the rate of prevalence (**D**) amongst women.

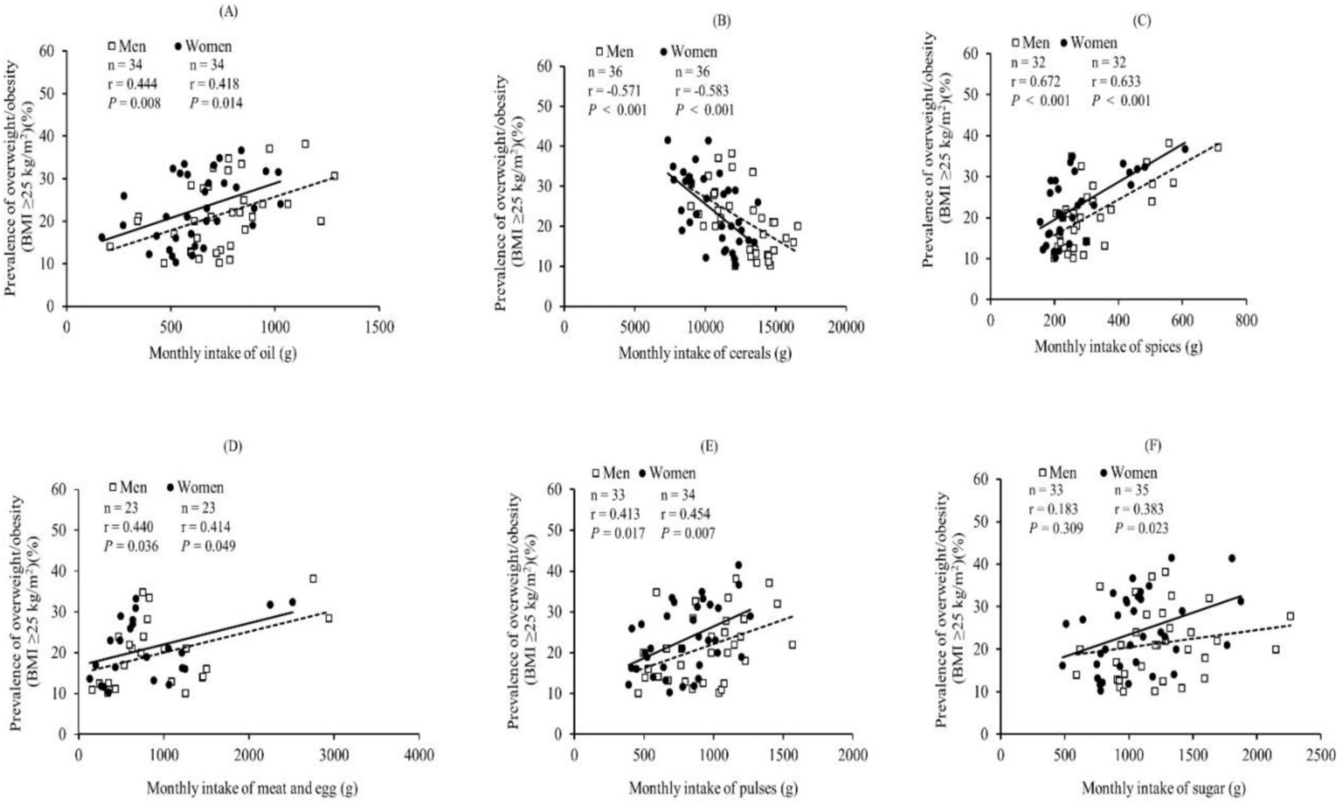

Figure 2. Scatter plots of correlations between state-wise mean monthly intakes and prevalence of overweight and obesity (BMI ≥25 kg/m^2).

Scatter plots of correlations between state-wise mean monthly intakes of (**A**) oil, (**B**) cereals, (**C**) spices, (**D**) meat and egg, (**E**) pulses and (**F**) sugar and prevalence of overweight and obesity (BMI ≥25 kg/m^2) in men (open squares) and women (filled circles)(35). Monthly intake values labelled as imprecise in the TATA-NIN dashboard(35) were removed from this analysis.

Figure 3. Framework of obesity in India.

Overall framework of obesity in India and its risk factors.

Table 1

Rate of change (% change per year) of prevalence of overweight and obesity (BMI ≥25 kg/m^2) between [National Family Health Survey (NFHS) 3 (2005-2006)](8) and NFHS 5 (2019-2021)(10, 11). The prevalence for states/union territories that were not included in either of the data sets are represented as '-’ and have been excluded in the analysis. *Data from Dadra and Nagar Haveli and Daman and Diu was merged during the NFHS 5 survey, and the cumulative data is represented here.

State/Union Territory	Men			Women		
	NFHS 3 (2005-2006)	NFHS 5 (2019-2021)		NFHS 3 (2005-2006)	NFHS 5 (2019-2021)	
	Prevalence of overweight and obesity (BMI ≥25 kg/m^2)	Prevalence of overweight and obesity (BMI ≥25 kg/m^2)	Rate of change of prevalence (% change per year)	Prevalence of overweight and obesity (BMI ≥25 kg/m^2)	Prevalence of overweight and obesity (BMI ≥25 kg/m^2)	Rate of change of prevalence (% change per year)
Andaman & Nicobar Islands	-	45.3	-	-	31.8	-
Andhra Pradesh	17.6	31.1	0.96	17.7	36.3	1.33
Arunachal Pradesh	10.6	27.6	1.21	10.5	23.9	0.96
Assam	6.7	16.2	0.68	9.0	15.2	0.44
Bihar	8.5	14.7	0.44	5.3	15.9	0.76
Chandigarh	-	34.4	-	-	44.0	-
Chhattisgarh	6.5	14.9	0.60	6.7	14.1	0.53
Dadra & Nagar Havelli	-	21.4	-	-	26.8	-
Daman & Diu	-		-	-		-
Goa	20.8	32.6	0.84	27.0	36.1	0.65
Gujarat	15.5	19.9	0.31	20.3	22.6	0.16
Haryana	14.4	28.3	0.99	21.0	33.1	0.86
Himachal Pradesh	16.0	30.6	1.04	17.3	30.4	0.94
Jammu & Kashmir	8.7	31.6	1.64	22.7	29.3	0.47
Jharkhand	5.3	15.1	0.70	5.9	11.9	0.43
Karnataka	14.0	30.9	1.21	18.1	30.1	0.86
Kerala	24.3	36.4	0.86	34.0	38.1	0.29
Lakshadweep	-	41.3	-	-	33.5	-
Madhya Pradesh	5.4	15.6	0.73	8.6	16.6	0.57
Maharashtra	15.9	24.7	0.63	17.1	23.4	0.45
Manipur	13.4	30.3	1.21	17.6	34.1	1.18
Meghalaya	8.2	13.9	0.41	7.1	11.5	0.31

State/Union Territory	Men			Women		
	NFHS 3 (2005-2006)	NFHS 5 (2019-2021)		NFHS 3 (2005-2006)	NFHS 5 (2019-2021)	
	Prevalence of overweight and obesity (BMI ≥25 kg/m^2)	**Prevalence of overweight and obesity (BMI ≥25 kg/m^2)**	**Rate of change of prevalence (% change per year)**	**Prevalence of overweight and obesity (BMI ≥25 kg/m^2)**	**Prevalence of overweight and obesity (BMI ≥25 kg/m^2)**	**Rate of change of prevalence (% change per year)**
Mizoram	16.9	31.9	1.07	12.0	24.2	0.87
Nagaland	8.4	23.9	1.11	8.9	14.4	0.39
NCT of Delhi	24.0	38.0	1.00	32.9	41.3	0.60
Puducherry	-	43.3	-	-	46.2	-
Punjab	30.3	32.2	0.14	37.5	40.8	0.24
Rajasthan	8.4	15.0	0.47	10.2	12.9	0.19
Sikkim	17.3	36.3	1.36	19.5	34.7	1.09
Tamil Nadu	19.8	37.0	1.23	24.4	40.4	1.14
Telangana	-	32.3	-	-	30.1	-
Tripura	5.2	23.4	1.30	7.8	21.5	0.98
Uttar Pradesh	9.9	18.5	0.61	11.1	21.3	0.73
Uttarakhand	11.4	27.1	1.12	16.0	29.7	0.98
West Bengal	6.1	16.2	0.72	12.5	22.7	0.73
Odisha	6.9	22.2	1.09	7.6	23.0	1.10

Table 2

Pearson's correlation (r) between state-wise mean monthly intake of foods and prevalence of overweight and obesity (BMI ≥25 kg/m^2) in men and women(35).

Food type	**Men**			**Women**		
	n	**r**	***P***	**n**	**r**	***P***
Oil (g)	34	**0.444**	**0.008**	34	**0.418**	**0.014**
Cereals (g)	36	**-0.571**	**<0.001**	36	**-0.583**	**<0.001**
Spices (g)	32	**0.672**	**<0.001**	32	**0.633**	**<0.001**
Meat and egg (g)	23	**0.440**	**0.036**	23	**0.414**	**0.049**
Pulses (g)	33	**0.413**	**0.017**	34	**0.454**	**0.007**
Sugar (g)	33	0.183	0.309	35	**0.383**	**0.023**
Milk (g)	23	0.176	0.421	23	0.300	0.164
Vegetable (g)	32	-0.131	0.473	33	-0.230	0.199
Fruits (g)	32	0.083	0.652	33	0.004	0.982
Tobacco and ganja (g)	10	0.007	0.985	12	0.068	0.834
Packaged processed food (g)	22	0.348	0.112	22	0.409	0.059
Salt (g)	33	-0.027	0.880	33	-0.100	0.578

n = number of states for which monthly intake data is available.

$P < 0.05$ are shown in bold