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CORRELATION OF VISCERAL ADIPOSITY INDICES AND HEPATIC STEATOSIS VIA ULTRASONOGRAPHY WITH METABOLIC SYNDROME RISK: A CROSS-SECTIONAL MULTI-CENTER STUDY IN INDUSTRIAL URBAN POPULATIONS

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Abstract

Background: The rising prevalence of metabolic syndrome (MetS) in industrial urban centers presents a significant public health challenge. While Body Mass Index (BMI) is a common metric, it often fails to distinguish between subcutaneous and visceral fat. This study investigates the correlation between specific Visceral Adiposity Indices (VAI), the presence of Hepatic Steatosis (HS) detected via ultrasonography, and the overall risk of MetS.

Methods: A cross-sectional, multi-center study was conducted across tertiary healthcare centers in Durgapur and Ahmedabad. A total of 450 adult participants were screened. Physiological assessments included blood pressure, lipid profiles, and fasting glucose levels to determine MetS status according to NCEP-ATP III criteria. Anthropometric data were used to calculate VAI. Radio-diagnosis specialists performed transabdominal ultrasonography to grade hepatic steatosis (Non-Alcoholic Fatty Liver Disease).

Results: Preliminary findings indicate a strong positive correlation ($r > 0.65$, $p < 0.001$) between elevated VAI and the severity of hepatic steatosis. Subjects with Grade II and III steatosis exhibited a significantly higher incidence of hypertension and dyslipidemia compared to those with normal liver echoes. Furthermore, VAI demonstrated higher sensitivity in predicting metabolic risk than traditional BMI measurements within this industrial cohort.

Conclusion: Integrating physiological markers with radiological screening provides a more robust framework for early MetS detection. The high prevalence of hepatic steatosis in these regions suggests that ultrasonography should be considered a routine screening tool for at-risk urban populations to mitigate long-term cardiovascular and metabolic complications.

Keywords: Visceral Adiposity Index, Hepatic Steatosis, Ultrasonography, Metabolic Syndrome, Industrial Health.

Introduction

The global transition toward urbanization and industrialization has brought about a profound shift in human lifestyle, dietary habits, and disease patterns. While these advancements have driven economic growth, they have simultaneously catalyzed an epidemic of non-communicable diseases (NCDs), with **Metabolic Syndrome (MetS)** emerging as one of the most significant clinical and public health challenges of the 21st century. Characterized by a cluster of interconnected physiological, biochemical, and metabolic abnormalities—including abdominal obesity, insulin resistance, hypertension, and dyslipidemia—MetS serves as a potent precursor to Type 2 Diabetes Mellitus (T2DM) and Cardiovascular Disease (CVD). In the specific context of industrial urban populations, such as those in **Durgapur and Ahmedabad**, the risk profile is further complicated by sedentary occupational environments, high levels of psychological stress, and exposure to environmental pollutants. This study seeks to explore the intricate relationship between **Visceral Adiposity Indices (VAI)**, the radiological presence of **Hepatic Steatosis** (Non-Alcoholic Fatty Liver Disease), and the overarching risk of Metabolic Syndrome. **The Paradigm Shift: From BMI to Visceral Adiposity:** For decades, Body Mass Index (BMI) has been the gold standard for assessing obesity-related health risks due to its simplicity. However, BMI is a blunt instrument; it calculates total body mass relative to height but fails to differentiate between lean muscle mass and adipose tissue, nor does it account for the distribution of fat. Modern physiological research has established that **visceral adipose tissue (VAT)**—the fat stored within the abdominal cavity around internal organs—is metabolically distinct from subcutaneous fat. Visceral fat acts as an active endocrine organ, secreting pro-inflammatory cytokines such as Tumor Necrosis Factor-alpha (TNF-) and Interleukin-6 (IL-6). These adipokines contribute to a state of chronic low-grade inflammation, which is a primary driver of insulin resistance. The **Visceral Adiposity Index (VAI)** has emerged as a superior mathematical model to quantify this risk. By integrating both anthropometric (Waist Circumference) and metabolic (Triglycerides and HDL Cholesterol) parameters, the VAI provides a gender-specific surrogate marker for visceral fat function and distribution. Unlike BMI, a high VAI is directly linked to cardiometabolic risk, even in "normal-weight" individuals, making it a critical tool for identifying the "metabolically obese, normal-weight" (MONW) phenotype common in South Asian populations. **The Liver as a Metabolic Mirror: Hepatic Steatosis:** The liver plays a central role in lipid and glucose metabolism. When the influx of free fatty acids from the diet or adipose tissue exceeds the liver's capacity for oxidation or export, lipids begin to accumulate within hepatocytes—a condition known as **Hepatic Steatosis** or Non-Alcoholic Fatty Liver Disease (NAFLD). Hepatic steatosis is increasingly recognized as the hepatic manifestation of Metabolic Syndrome. The relationship is bidirectional: insulin resistance promotes the accumulation of fat in the liver, and a "fatty liver" further exacerbates systemic insulin resistance by interfering with glucose signaling pathways. **Radio-diagnosis**, specifically **Transabdominal Ultrasonography**, remains the first-line diagnostic modality for identifying hepatic steatosis. It offers a non-invasive, cost-effective, and highly accessible means of grading the severity of fat infiltration (Grade I to Grade III). In an industrial clinical setting, where rapid screening is essential, ultrasound serves as a vital bridge between physiological markers and definitive clinical diagnosis. Identifying the correlation between ultrasound-proven steatosis and VAI scores could provide clinicians with a powerful predictive matrix for cardiovascular events. **The Industrial Urban Context: Durgapur and Ahmedabad:** The geographical focus of this study—Durgapur in West Bengal and Ahmedabad in Gujarat—is highly significant. Both cities are major industrial hubs characterized by a workforce that often faces unique health stressors:

- **Occupational Sedentary Behavior:** Long shifts in manufacturing or administrative roles often lead to physical inactivity.
- **Dietary Transitions:** Urban industrial workers often transition toward "Westernized" diets high in refined carbohydrates and saturated fats.
- **Environmental Factors:** Particulate matter and industrial pollutants have been linked in recent studies to systemic inflammation and altered lipid metabolism.

The South Asian population, in general, possesses a "thin-fat" phenotype—higher body fat percentages and higher visceral adiposity at lower BMI levels compared to Western cohorts. This genetic and environmental predisposition makes the study of VAI and hepatic steatosis particularly urgent for the Indian medical community. **Rationale for a Multidisciplinary Approach,** This research leverages a unique synergy between **Physiology, Community Medicine, and Radiology**.

- From a **Physiological** perspective, we analyze the systemic imbalances and biochemical markers that define metabolic health.
- Through **Radio-diagnosis**, we visualize the structural changes in the liver that precede overt clinical disease.
- Via **Community Medicine**, we apply these findings to a broader population, aiming to develop screening protocols that are feasible in a public health framework.

Research Objectives

The primary objectives of this study are:

1. To evaluate the **Visceral Adiposity Index (VAI)** in an industrial urban cohort and compare its efficacy against traditional BMI in predicting Metabolic Syndrome.
2. To assess the prevalence and severity of **Hepatic Steatosis** via ultrasonography among patients with varying degrees of metabolic risk.
3. To determine the correlation between VAI scores and the radiological grading of fatty liver.
4. To provide evidence-based recommendations for integrating radiological and physiological screening in routine industrial health check-ups.

Materials and Methods

1. Study Design and Setting

This cross-sectional, multi-center observational study was conducted over a period of twelve months (2024 – 2025). The research was carried out simultaneously across three tertiary healthcare and academic institutions:

- **IQ-City Medical College, Durgapur, West Bengal** (Physiology and Clinical assessment hub).
- **SAL Institute of Medical Sciences, Ahmedabad, Gujarat** (Community Medicine and Epidemiological screening hub).
- **Gouri Devi Institute of Medical Sciences and Hospital, Durgapur, West Bengal** (Radiological imaging center).

2. Study Population and Sampling

The study targeted adult populations residing in the industrial urban corridors of Durgapur and Ahmedabad.

- **Inclusion Criteria:** Subjects aged 18–65 years visiting the outpatient departments (OPD) for routine health check-ups or minor ailments.
- **Exclusion Criteria:** * History of significant alcohol consumption (>20g/day for women; >30g/day for men).
  - Pre-existing chronic liver diseases (Hepatitis B/C, Wilson's disease, autoimmune hepatitis).
  - Use of hepatotoxic drugs or medications known to affect lipid metabolism (e.g., systemic corticosteroids, amiodarone).
  - Pregnancy or lactation.
  - End-stage renal or cardiac failure.

Sample Size: Using a power of 80% and a confidence interval of 95%, a total sample size of **450 participants** (approximately 150 per center) was determined to be statistically significant for correlation analysis.

3. Clinical and Physiological Assessment

A detailed clinical history was recorded using a standardized proforma.

● **Anthropometric Measurements:** Height (cm) and weight (kg) were measured to calculate **Body Mass Index (BMI)**. Waist Circumference (WC) was measured at the midpoint between the lower costal margin and the iliac crest using a non-stretchable tape.

● **Hemodynamic Parameters:** Blood pressure (BP) was recorded in a seated position after 10 minutes of rest using a calibrated digital sphygmomanometer. The average of two readings taken 5 minutes apart was recorded.

4. Biochemical Analysis

Venous blood samples were collected after an overnight fast (10–12 hours). The following parameters were analyzed using automated chemistry analyzers:

1. **Fasting Plasma Glucose (FPG)**
2. **Serum Triglycerides (TG)**
3. **High-Density Lipoprotein Cholesterol (HDL-C)**

Visceral Adiposity Index (VAI) Calculation:

The VAI was calculated using gender-specific mathematical formulas where WC is in cm, BMI is in kg/m^2, TG is in mmol/L, and HDL is in mmol/L:

● **Males:** VAI = left{39.68 + (1.88/times BMI)} \right) \times \left({TG}{1.03} \right) \times \left(\frac{1.31}{HDL} \right)

● **Females:** VAI = \left(\frac{WC}{36.58 + (1.89 \times BMI)} \right) \times \left(\frac{TG}{0.81} \right) \times \left({1.52}{HDL} right)

5. Radiological Evaluation

All participants underwent **Transabdominal Ultrasonography (USG)** of the upper abdomen using high-resolution ultrasound machines (e.g., GE Voluson or Philips Affiniti) with a 3.5–5 MHz curvilinear probe. Scans were performed by experienced radiologists blinded to the subjects' biochemical data.

Hepatic Steatosis (HS) Grading:

HS was categorized into four grades based on liver echogenicity, visualization of the diaphragm, and intrahepatic vessel definition:

● **Grade 0 (Normal):** Normal liver echogenicity.

● **Grade I (Mild):** Slight diffuse increase in fine echoes; diaphragm and vessel borders appear normal.

● **Grade II (Moderate):** Moderate diffuse increase in fine echoes with slightly impaired visualization of the diaphragm and intrahepatic vessels.

● **Grade III (Severe):** Marked increase in echoes; poor or no visualization of the diaphragm, vessels, and posterior portion of the right lobe.

6. Definition of Metabolic Syndrome (MetS)

MetS was diagnosed based on the **NCEP-ATP III criteria**, requiring at least three of the following:

1. **Waist Circumference:** >102 cm (Men) or >88 cm (Women). (Adjusted for South Asians: >90 cm M; >80 cm W).
2. **Triglycerides:** ge 150 mg/dL.
3. **HDL Cholesterol:** <40 mg/L (Men) or <50 mg/dL (Women).
4. **Blood Pressure:** Age 130/85 mmHg.
5. **Fasting Glucose:** ge 100 mg/dL.

7. Statistical Analysis

Data were analyzed using **SPSS Version 26.0**. Continuous variables were expressed as Mean ± SD, and categorical variables as frequencies/percentages.

● **Pearson's/Spearman's Correlation:** Used to determine the relationship between VAI and HS grades.

- **One-way ANOVA:** Used to compare VAI across different grades of steatosis.
- **ROC Curve Analysis:** Conducted to determine the sensitivity and specificity of VAI in predicting MetS.
- A **p-value < 0.05** was considered statistically significant.

Results

A total of **450 participants** (242 males, 208 females) with a mean age of **44.8 ± 10.2 years** completed the study across the three centers. The data reveals a significant interplay between visceral adiposity, hepatic fat accumulation, and metabolic risk factors.

1. Baseline Characteristics and Prevalence of Metabolic Syndrome

Based on the NCEP-ATP III criteria (adjusted for South Asians), **42.2% (n=190)** of the study population met the criteria for Metabolic Syndrome (MetS). The most prevalent components were increased waist circumference (58.4%) and low HDL cholesterol (51.1%).

Parameter	MetS Group (n=190)	Non-MetS Group (n=260)	p-value
Age (years)	48.2 ± 8.4	41.5 ± 11.3	<0.05
BMI (kg/m^2)	28.6 ± 4.1	23.4 ± 3.8	<0.001
Waist Circumference (cm)	96.4 ± 7.2	82.1 ± 9.5	<0.001
Systolic BP (mmHg)	138 ± 12	122 ± 10	<0.001
Fasting Glucose (mg/dL)	112 ± 18	94 ± 12	<0.001

2. Ultrasonographic Findings: Hepatic Steatosis (HS)

Radiological assessment identified Hepatic Steatosis in **54.6% (n=246)** of the total cohort. The distribution of HS grades was as follows:

- **Grade 0 (Normal):** 45.4% (n=204)
- **Grade I (Mild):** 28.2% (n=127)
- **Grade II (Moderate):** 18.2% (n=82)
- **Grade III (Severe):** 8.2% (n=37)

Among participants diagnosed with MetS, the prevalence of HS was significantly higher (**78.9%**) compared to the non-MetS group (**36.9%**), with a $p < 0.001$.

3. Correlation between VAI and Hepatic Steatosis

The **Visceral Adiposity Index (VAI)** showed a progressive increase corresponding to the severity of hepatic steatosis.

- Subjects with **Grade 0** had a mean VAI of **1.8 ± 0.6**.
- Subjects with **Grade III** had a mean VAI of **5.2 ± 1.4**.

Spearman's rank correlation coefficient revealed a **strong positive correlation** (r = 0.72, p < 0.001) between VAI scores and the radiological grade of fatty liver.

4. Predictive Accuracy of VAI vs. BMI

Receiver Operating Characteristic (ROC) curve analysis was performed to evaluate the ability of VAI and BMI to predict Metabolic Syndrome.

- **VAI:** The Area Under the Curve (AUC) was **0.88 (95% CI: 0.84–0.92)**.
- **BMI:** The AUC was **0.74 (95% CI: 0.69–0.79)**.

VAI demonstrated significantly higher sensitivity (84%) and specificity (79%) than BMI in identifying individuals at high metabolic risk within this industrial urban population.

5. Multi-Center Comparison

While the prevalence of MetS was slightly higher in the **Ahmedabad** cohort (44.5%) compared to the **Durgapur** cohort (40.2%), the correlation between VAI and Hepatic Steatosis remained consistent across all three centers, suggesting that visceral adiposity is a universal driver of liver fat regardless of specific regional industrial variations.

Discussion

The findings of this multi-center study, conducted across the industrial hubs of **Durgapur and Ahmedabad**, provide a comprehensive look into the metabolic health of the modern Indian urban workforce. By correlating physiological markers (**Visceral Adiposity Index**), radiological evidence (**Hepatic Steatosis**), and community health outcomes (**Metabolic Syndrome**), we have established a robust framework for understanding how fat distribution—rather than just total body mass—governs systemic disease.

1. The Superiority of VAI over Conventional Anthropometry

One of the most significant observations in our study is the superior predictive power of the **Visceral Adiposity Index (VAI)** compared to **Body Mass Index (BMI)**. While BMI remains the most widely used screening tool in clinical practice, our results (AUC 0.88 for VAI vs. 0.74 for BMI) align with the growing consensus that BMI is an inadequate marker for South Asian phenotypes.

The "Asian Indian Phenotype" is characterized by lower BMI but higher abdominal fat, higher visceral fat, and greater insulin resistance. This is often referred to as the **"Thin-Fat" Indian**. In our cohort, many individuals categorized as "overweight" or even "normal weight" by BMI standards exhibited high VAI scores and Grade II hepatic steatosis. This suggests that the VAI—which incorporates waist circumference, triglycerides, and HDL—captures the **metabolic function** of adipose tissue rather than just its volume.

Physiologically, visceral fat is more cellular, vascular, and innervated than subcutaneous fat. It has a higher turnover of free fatty acids (FFAs) and is more sensitive to lipolytic stimuli. The portal vein drains visceral fat directly into the liver, exposing the hepatocytes to high concentrations of FFAs and pro-inflammatory adipokines. This "portal theory" explains why VAI serves as a more direct proxy for liver health and metabolic risk than peripheral measurements.

2. Hepatic Steatosis: The Sentinel of Metabolic Dysfunction

Our study found a remarkably high prevalence of **Hepatic Steatosis (HS)** at 54.6%. The fact that nearly 80% of participants with Metabolic Syndrome (MetS) also had ultrasound-proven fatty liver confirms that HS is not merely a comorbidity but the **hepatic manifestation of MetS**.

The radiological grading of HS showed a linear correlation with VAI. As VAI scores increased, the echogenicity of the liver increased, indicating a transition from simple steatosis to more advanced stages of lipid accumulation. From a **Radio-diagnosis** perspective, ultrasonography proved to be an invaluable non-invasive tool. Although liver biopsy remains the gold standard for diagnosing Non-Alcoholic Steatohepatitis (NASH), it is impractical for large-scale screening in industrial populations. Our findings suggest that a "High VAI + Positive USG" model could serve as a highly effective, non-invasive screening protocol to identify high-risk individuals before they progress to irreversible cirrhosis or cardiovascular events.

3. The Industrial Urban Influence: Durgapur and Ahmedabad

The geographical focus on Durgapur and Ahmedabad provides critical context for these results. Both cities are characterized by heavy industrial activity (steel, chemicals, and manufacturing). The workforce in these sectors often faces a "double burden":

1. **Occupational Sedentary Stress:** Many workers, particularly those in administrative or monitoring roles, experience prolonged sitting, which is a known risk factor for reduced lipoprotein lipase activity and increased visceral fat deposition.
2. **Environmental and Lifestyle Factors:** Urban industrial life often correlates with high-calorie "street food" consumption, disrupted circadian rhythms due to shift work, and high levels of ambient air pollution. Recent studies have suggested that fine particulate matter ($PM_{2.5}$) can trigger systemic inflammation and oxidative stress, further exacerbating insulin resistance.

The consistency of our results across both West Bengal and Gujarat suggests that the metabolic impact of the industrial urban lifestyle is a national phenomenon in India, transcending regional dietary differences.

4. Biochemical Interplay and Lipid Paradoxes

Our results highlighted that **Hypertriglyceridemia** and **Low HDL-C** were the most common biochemical abnormalities. In the South Asian context, this "atherogenic dyslipidemia" is more prevalent than high LDL-C.

The physiological link between hepatic steatosis and dyslipidemia is centered on the overproduction of Very Low-Density Lipoproteins (VLDL). When the liver is overloaded with fat (as seen in our Grade II and III HS subjects), it increases the secretion of large, triglyceride-rich VLDL particles. These particles interact with HDL, leading to its rapid clearance and resulting in the low HDL levels observed in over 50% of our MetS group. This biochemical cycle explains why VAI—which includes TG and HDL in its formula—is so effective at predicting the radiological presence of fatty liver.

5. Clinical and Public Health Implications

The integration of **Physiology, Radiology, and Community Medicine** in this study points toward a necessary shift in occupational health policy. Currently, most industrial health check-ups focus on lung function (Spirometry) and basic blood work. Our study advocates for:

- **Routine Metabolic Profiling:** Moving beyond BMI to include VAI calculations in annual employee health records.
- **Targeted Ultrasound Screening:** Implementing abdominal USG for any employee with a VAI score above a specific threshold (e.g., >2.5).
- **Lifestyle Interventions:** Given that HS is reversible in its early stages through weight loss and exercise, early detection through the VAI-USG correlation could save the healthcare system significant costs related to future diabetes and heart disease management.

6. Limitations and Future Directions

While our study is strengthened by its multi-center design and multidisciplinary approach, certain limitations exist. First, as a cross-sectional study, we cannot definitively establish a temporal cause-and-effect relationship between VAI and the onset of HS. Second, ultrasonography, while practical, has limited sensitivity when hepatic fat infiltration is less than 20–30%.

Future research should focus on longitudinal tracking of these industrial cohorts to see if reducing VAI through targeted interventions leads to a regression in HS grades. Additionally, investigating the role of specific inflammatory markers (like CRP or Adiponectin) alongside VAI could further refine the predictive model.

Conclusion

This study concludes that the **Visceral Adiposity Index** is a powerful, low-cost physiological marker that correlates strongly with the radiological severity of **Hepatic Steatosis**. In the industrial urban landscape of modern India, where the "Thin-Fat" phenotype is prevalent, relying on BMI alone is no longer sufficient. By combining the metabolic insights of VAI with the diagnostic clarity of ultrasonography, clinicians and public health experts can better identify, stratify, and manage the growing wave of Metabolic Syndrome in the workforce. The liver, viewed through the lens of radiology, serves as a window into the systemic metabolic health of the individual, and the VAI provides the key to unlocking that information.

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