

COMPARATIVE EVALUATION OF VISCERAL ORGAN MEASUREMENTS, IN REFERENCE TO BMI AND GENDER AMONG SIALKOT POPULATION

Ahmad Raza ¹, Muhammad Areeb Shahid^{*2}, Shayan Ajmal³, Muhammad Abdullah Dar⁴,
Zubair Ramzan ⁵, Shaher Bano⁶, Zaha Tariq⁷, Messam Shamsi^{*8}

^{1,*2,3,4,5,6,7} Department of Medical Imaging and Ultrasonography, University of Management and Technology, Sialkot Campus, Pakistan.

^{*8} Department of Nutrition Sciences, University of Management and Technology, Sialkot Campus, Pakistan.

¹ahmadraza.sahi99@gmail.com, ²areebshahid007@gmail.com, ³shayanajmal9@gmail.com
⁴abdullahdar721@gmail.com, ⁵zubairramzan319@gmail.com, ⁶shehrrbano224@gmail.com
⁷zahatariq9@gmail.com, ^{*8}messamshamsi2@gmail.com

DOI: <https://doi.org/10.5281/zenodo.22973308>

Keywords

Body Mass Index, Hepatomegaly, Organ Dimensions, Overweight, Ultrasonography

Article History

Received: 18 June 2026

Accepted: 09 September 2026

Published: 26 September 2026

Copyright @Author

Corresponding Author: *
Muhammad Areeb Shahid
Messam Shamsi

Abstract

Background: Excess body weight is a growing global epidemic closely linked to metabolic and structural alterations in abdominal visceral organs. In sonographic research, organ dimensions are crucial for evaluating physiological health. However, localized reference data comparing these dimensions within the Pakistani population remains limited, making it difficult to differentiate normal variation from early pathological enlargement. The main objective is to compare baseline sonographic sizes of the liver, spleen, and kidneys of normal-weight and overweight adults (18-40 years) in the Sialkot region to identify early morphological abnormalities associated with excess body mass, and to assess relationships with biological sex and BMI.

Methods: An observational cross-sectional analysis over three months in Sialkot enrolled 130 healthy participants (65 males, 65 females) aged 18–40 years through convenience sampling. A standardized transabdominal ultrasound measured longitudinal lengths of the liver, spleen, and bilateral kidneys. Height and weight were recorded to calculate and categorize BMI into normal (18.5–24.9 kg/m²) and overweight (25.0–29.9 kg/m²) groups.

Results: Overweight individuals exhibited significantly longer liver (mean difference 0.74 cm, $p < 0.001$) and right kidney (mean difference 0.29 cm, $p = 0.010$) lengths than the normal-weight cohort. Spleen length showed a trend toward enlargement (mean difference 0.26 cm) approaching the statistical significance threshold ($p = 0.064$). BMI showed a significant positive correlation with liver ($r = 0.39$, $p < 0.001$) and right kidney lengths ($r = 0.26$, $p = 0.003$). Gender sub-analysis indicated males possessed significantly larger spleens and bilateral kidneys than females ($p < 0.05$).

Conclusion: This research establishes that subclinical organ visceromegaly, particularly in the liver and right kidney, begins in the overweight category before clinical obesity. Findings highlight the necessity of population-specific

INTRODUCTION

Overweight and obesity have become epidemics worldwide, with 13% of adults being obese and 39% of persons being overweight. (Voon et al., 2021) Surveys in Pakistan also reveal a significant burden, approximately 28% of adults (mean age ~ 38) are overweight or obese, with women more affected than men (~30% vs. 24%). (Asif et al., 2020) Non-alcoholic fatty liver disease (NAFLD), the most common chronic liver disease in the world today, is closely linked to a high body mass index (BMI). (Younossi et al., 2023) Increased weight triggers compensatory renal hyperfiltration in the kidneys, driving systemic metabolic inflammation that can manifest as splenomegaly. (Guan et al., 2024; Kalra et al., 2025) Because these structural responses are highly influenced by localized genetics, diet, and lifestyle, utilizing generalized Western nomograms may lead to the misclassification of early visceral hypertrophy. Consequently, evaluating the baseline sonographic lengths of the liver, spleen, and bilateral kidneys using B-mode imaging across normal and overweight BMI categories and biological sexes is crucial for identifying early morphological adaptations prior to clinical disease.

The abdominal visceral organs, such as the liver, spleen, and kidneys, are vital in maintaining physiological homeostasis. These organs are responsible for regulating metabolism, immune response, and fluid balance, respectively. The morphometric dimensions of these organs are not static. These morphometric dimensions actively fluctuate and are clinical markers of metabolic status and overall health. The liver functions as a biological glucostat to maintain stable systemic energy by regulating blood sugar through glycolysis, glycogenesis, gluconeogenesis, and glycogenolysis. (Soon & Torbenson, 2023) Similar to the liver, the renal system is essential for maintaining the body's fluid balance and metabolic processes. (Imenez Silva & Mohebbi, 2022; Rong et al., 2024) The physical size of the kidney often acts as a direct indicator of its functional ability. (Ahmed Khan et al., 2018) Functionally, the spleen features

two distinct regions: the white pulp and the red pulp. (Omole & Launico, 2026) The spleen helps protect the body from infection. (Kapila et al., 2023)

Anthropometric factors heavily influence the dimensions of these visceral organs. Body weight shows the strongest correlation with organ dimensions, and multivariate analyses consistently identify BMI and BSA as significant positive predictors of organ size. (Huang et al., 2022) The correlation between body mass and organ dimensions is a physiological reality, not just a mathematical trend. To meet the increased metabolic and circulatory demands of a higher BMI, major organs such as the kidneys, liver, spleen, and cardiac tissue enlarge. Consequently, visceral size is a clear indicator of the body adapting to a metabolic burden. When this adaptation progresses to pathological changes like fatty infiltration or hyperfiltration, the enlargement shifts from normal compensation to true pathological visceromegaly. (Kosicka-Noworzyń et al., 2024; Kovesdy et al., 2017)

Dysfunctional adipose tissue signaling and lipid flux play a central role in driving the deterioration of the liver, transforming isolated fat accumulation into active non-alcoholic steatohepatitis (NASH). (Karjoo et al., 2022; Wang et al., 2021) Splenomegaly is associated with overweight status, waist circumference, and fatty liver, serving as an indicator of systemic metabolic inflammation. (Abd El-Aziz et al., 2018; Kalra et al., 2025) An increase in weight alters splenic immune cells, which interact with liver inflammation, exacerbating systemic inflammation (spleen–liver axis). In this axis, the spleen acts as a reservoir for inflammatory monocytes that can migrate to the liver, promoting hepatic inflammation and fibrosis in overweight states. (Brummer et al., 2025; Han et al., 2024; Kalra et al., 2025; Zhang et al., 2023)

An increase in weight also increases the risk and advancement of chronic kidney disease, regardless of diabetes and hypertension. Compensatory hyperfiltration occurs in people with excess body weight to accommodate the

elevated physiological workload and systemic requirements associated with a larger overall mass. (Kovesdy et al., 2017) The main histological feature of obesity-related glomerulopathy (ORG) is thought to be glomerulomegaly, or the abnormal expansion of glomeruli. (Rico-fontalvo et al., 2026) As a highly active endocrine entity, fat tissue directly triggers both the sympathetic nervous system (SNS) and the renin-angiotensin-aldosterone system (RAAS). (Parvanova et al., 2024) A popular, safe, and non-invasive imaging method for evaluating solid intra-abdominal organs such as the kidneys, liver, and spleen is ultrasound. (Ahmed Khan et al., 2018; Ponti et al., 2020)

Organ size measurement is a crucial component of standard ultrasonography exams, as variations in organ dimensions can reveal underlying disease. However, several variables, such as biological sex and overall BMI, can significantly alter these dimensions. A significant portion of values used to assess abdominal organs are derived from populations in Western countries. Because Pakistani people have different body types, lifestyles, and nutritional statuses, these numbers might not be entirely applicable to them. Furthermore, there is a lack of local data, particularly among young adults, comparing organ measurements between normal-weight and overweight people. As a result, it's critical to assess how gender and BMI affect abdominal organ sonographic measures in the community. The main objective of the research is to compare the baseline sonographic sizes of the liver, spleen, and kidneys in normal-weight and overweight adult males and females (18-40 years old) in the Sialkot region. Overall, the study focuses on identifying early morphological abnormalities associated with excess body mass and assessing the relationships between these parameters and biological sex and BMI.

LITERATURE REVIEW

Tiryaki and Aksu (2024) conducted a study in which healthy Turkish adults' normal liver, kidney, and spleen proportions were examined, along with their associations with body mass index (BMI). The study sought to create objective and population-specific standard values for detecting organomegaly because organ dimensions vary in various disorders and

physical examination alone is unreliable. 1,918 healthy persons over the age of 18 (987 females and 931 males) participated in the cross-sectional study. Liver length, liver depth, splenic length, splenic thickness, and all kidney dimensions were measured. All liver, spleen, and kidney parameters were considerably higher in men than in women, according to the data. Significant increases in liver length and depth were linked to an increase in BMI. Splenic thickness shown a strong positive connection with BMI, while differences in splenic length between BMI groups were not statistically significant. The authors came to the conclusion that the established mean standard values will help close the gap in the normal reference data for healthy Turkish individuals and aid doctors in detecting organomegaly. (Tiryaki & Aksu, 2024)

Asghar et al. (2024) conducted an observational analysis within an Islamabad-based private medical facility to evaluate how varying body mass indices influence kidney dimensions among healthy individuals. The authors aimed to produce locally relevant data that could assist clinicians in distinguishing between normal variations in renal volume and pathological changes within the Pakistani population, given that renal volume is a crucial parameter for evaluating renal health and is known to vary with anthropometric indices. In order to assure an appropriate assessment of physiological variability, a total of 310 volunteers, ages 18 to 70, were recruited. Those with concomitant conditions, including diabetes and hypertension, were carefully excluded. Ultrasonography was used to quantify renal volumes in accordance with normal sonographic procedures. The results showed that the mean left renal volume was $95.3 \pm 16.5 \text{ cm}^3$, and the average capacity of the right kidney was recorded at $88.7 \pm 15.7 \text{ cm}^3$. Statistical modeling showed a robust, direct proportionality with BMI for both the right ($r = 0.947$, $P = 0.001$) and left ($r = 0.911$, $P = 0.001$) organs. The authors concluded that as body weight increases, the kidney size directly increases as well. This specific finding perfectly aligns with established trends seen in international studies. These results highlight the influence of body habitus on kidney measures

and provide useful regional reference data. (Asghar et al., 2024)

Shrestha et al. (2021) carried out a prospective, cross-sectional investigation to ascertain standard baseline dimensions for a healthy adult liver. The study sought to develop local reference ranges for the Nepalese population and investigate their association with anthropometric measurements because precise liver size is essential for detecting hepatomegaly, which may not always be clinically evident. 400 people (mean age 48.10 ± 14.86 years) with sonographic results unrelated to liver illness were included in the study. The right midclavicular line was used to measure the liver span. According to the findings, the average longitudinal size of the organ was recorded at 15.05 ± 0.27 cm for men and 14.32 ± 0.29 cm for women. Both height and weight showed a high statistically significant association with liver size (correlation coefficient 0.837 for height; P-value of 0.001). Additionally, liver span and BMI showed a weak but significant association (correlation coefficient 0.316; P-value of 0.001). While women demonstrated a slight age-related statistical link, neither the overall cohort nor the male subgroup exhibited any meaningful relationship tying chronological age to hepatic dimensions (P-value > 0.05). The authors gave reference values for the adult Nepalese population, demonstrating strong positive associations with height and weight, and came to the conclusion that accurate assessment of liver size is crucial in assessing hepatic disorders. (Shrestha et al., 2021)

Ahmed Khan et al. (2018) carried out a multicenter cross-sectional study to ascertain normal liver, spleen, and kidney parameters in people without comorbidities. The study sought to develop baseline measurements for the Pakistani population because traditional bedside methods can yield erroneous estimates of organ size and trustworthy local reference values are crucial to minimize misdiagnosis. There were 2,212 participants over the age of 16 (51.5% men and 48.5% females) who were free of diseases, including diabetes and hypertension. Ultrasound was used to measure organ dimensions. Data analysis revealed a robust, direct statistical link connecting hepatic dimensions with body mass index. The overall

physical dimension of both kidneys was significantly correlated negatively with age, whereas the size of the spleen was significantly positively correlated with age. Males had a larger mean spleen size (10.16 ± 1.72 cm) than females (9.44 ± 1.65 cm). The scientists came to the conclusion that whereas spleen size grew and kidney size decreased with age, BMI was positively connected with liver and kidney size. (Ahmed Khan et al., 2018)

METHODOLOGY

After receiving the required clearances, data collection took place in UMT Sialkot's academic environment and at a private hospital (CareOne Medical Center, Commissioner Road, Sialkot). Before any data collection, informed consent was taken from each participant. Adults of both genders (Male and Female) between the ages of 18 and 40 were usually recruited for studies of normal organ size. Participants were required to fall into standard BMI categories: Healthy baseline mass (18.5 to 24.9 kg/m²) or the elevated weight tier (25.0 to 29.9 kg/m²). Anyone with a known liver, renal, or splenic disease should be excluded. Participants having a history of localized organ pathology (such as liver cirrhosis, renal cysts, hydronephrosis, splenomegaly, hepatic or renal masses) or chronic systemic disorders (such as hypertension, diabetes mellitus) were specifically excluded.

To calculate BMI, height was measured with a standard measuring tape, and weight was measured with a digital scale. A trained sonographer used a real-time B-mode ultrasound machine with a curvilinear transducer (3.5–5.0 MHz) for ultrasound examination. During the scan, the patient was in the supine position. Strict protocols and the same equipment were used to ensure measurement uniformity. A real-time sonographic machine with high resolution, consisting of a 3-5 MHz convex array transducer optimized for transabdominal scanning, was used to image the liver, spleen, and kidneys.

The most recent version of IBM's Statistical Package for the Social Sciences (SPSS) was used to process the collected data and conduct statistical analyses. Standard descriptive methodologies were used to describe the

baseline demographic profiles and physical anthropometric traits. An independent-samples t-test was used to compare the mean sonographic measurements of organs between participants who are of normal weight and those who are overweight across both biological sexes. Pearson's correlation coefficient was used to quantify the association between BMI and abdominal organ measurements. Statistical significance across all executed analytical tests was established whenever the calculated probability fell below the 0.05 margin ($p < 0.05$).

RESULTS

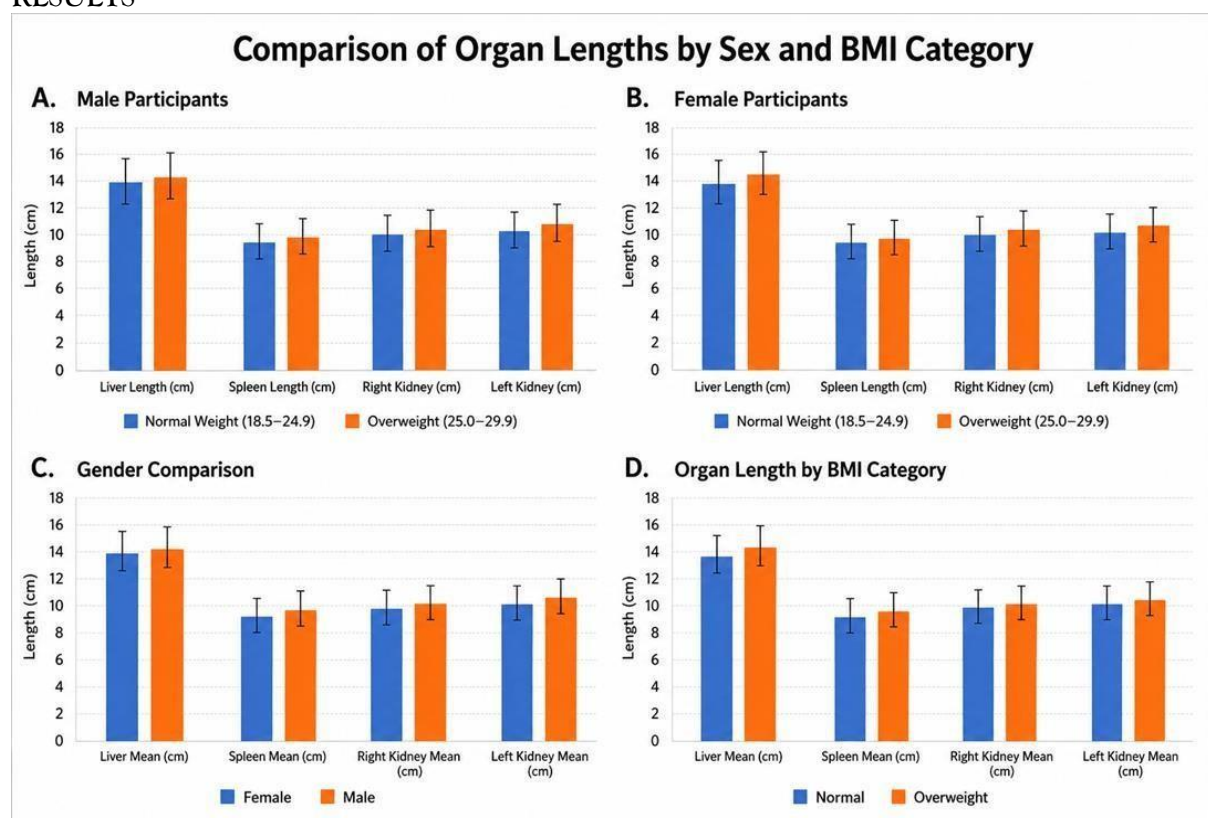


Figure 1: Comparison of mean sonographic organ lengths. (A) Dimensions in male participants by BMI. (B) Dimensions in female participants by BMI. (C) Overall gender comparison. (D) Overall comparison by BMI category. Error bars represent standard deviation.

The interpretation of the given data is that overweight individuals consistently have larger means for organ measures and dimensions across all four measurement scales. Liver length: Overweight individuals have livers approximately 0.74 cm longer than those of normal-weight individuals. The effect size (Cohen's $d = 0.76$) indicates a moderate-to-large clinical effect. Right kidney length: Statistically

A total of 130 apparently healthy adults (65 females, 65 males) aged 18-40 years were enrolled in the study. The study population had a balanced gender distribution with females (50.0%) and males (50.0%). Normal-weight participants comprised 50.8% ($n=66$), and overweight participants, 49.2% ($n=64$). The mean liver length was 14.08 ± 1.02 cm, spleen length 9.61 ± 0.81 cm, right kidney length 10.21 ± 0.65 cm, and left kidney length 10.57 ± 0.80 cm. Consistent with known anatomy, the left kidney was, on average, 0.36 cm longer than the right kidney.

significant difference ($p = 0.010$). Overweight individuals have right kidneys approximately 0.29 cm longer than those of normal-weight individuals. The effect size ($d = 0.46$) indicates a small-to-moderate clinical effect. Spleen length: Borderline non-significant ($p = 0.064$). Splens of overweight individuals are 0.26 centimeters in length and do not meet the conventional significance threshold of 0.05. Left kidney: The

0.23 cm difference was not statistically significant.



Figure 2: Summary of organ length distributions by BMI category. The chart illustrates the minimum, first quartile (Q1), median, third quartile (Q3), and maximum lengths (in cm) for the liver, spleen, and bilateral kidneys across normal-weight and overweight cohorts.

Liver length ($r = 0.39$, $p < 0.001$): A statistically significant, weak-to-moderate positive correlation. Approximately 15.2% of the variability in liver length is explained by BMI. Right kidney length ($r = 0.26$, $p = 0.003$): Statistically significant weak

positive correlation. Approximately 6.8% of the variability in right kidney length is explained by BMI. Spleen and left kidney: Correlations were positive but not statistically significant ($p > 0.05$).

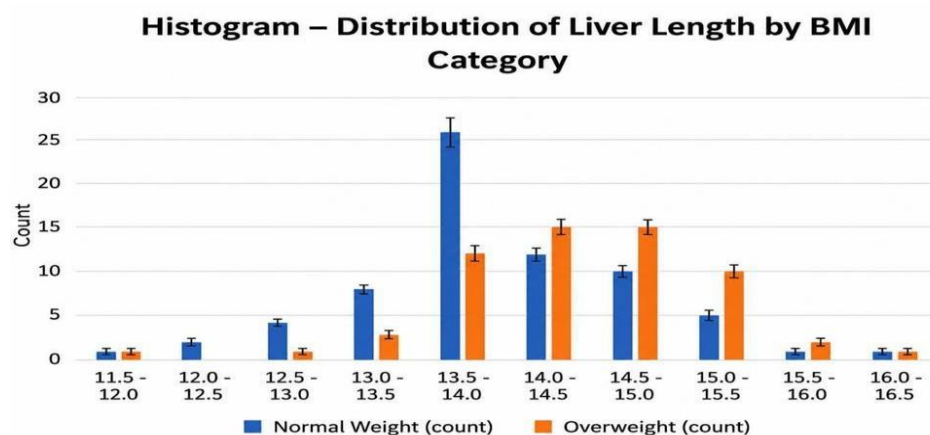


Figure 3: Frequency distribution of liver lengths by BMI category. The histogram demonstrates a rightward shift in liver dimensions among overweight individuals, with a higher frequency of measurements approaching the upper limits of normal (15.0–16.0+ cm).

Males had significantly larger spleens ($p = 0.013$), right kidneys ($p < 0.001$), and left kidneys ($p = 0.003$) compared to females. Liver length was also larger in males, but the difference did not reach statistical significance ($p = 0.149$). Overweight individuals had significantly longer liver length than normal-weight individuals (mean difference = 0.74 , $p < 0.001$, Cohen's $d = 0.76$). The finding of significantly larger liver length in overweight individuals (14.48 ± 0.98 cm vs. 13.74 ± 0.97 cm) is consistent with the existing literature and has important physiological and clinical implications. First, the liver acts as a biological glucostat. (Soon & Torbenson, 2023) Chronic caloric excess leads to increased glycogen synthesis and storage within hepatocytes. Glycogen is osmotically active, and its accumulation causes cellular swelling. This adaptation is initially reversible. Second, the most critical mechanism is non-alcoholic fatty liver disease (NAFLD). Overweight individuals (BMI 25-29.9) frequently develop significant hepatic steatosis. Excess free fatty acids from adipose tissue lipolysis are transported to the liver and esterified into triglycerides. These accumulate as lipid droplets within hepatocytes, causing both hypertrophy (enlargement of individual cells) and an increase in overall organ volume. This study provides sonographic evidence that NAFLD begins in the overweight category, not only in obesity. (Koneru et al., 2022; Younossi et al., 2023) Third, being overweight is associated with low-grade systemic inflammation. Adipose tissue, specifically visceral fat, secretes pro-inflammatory cytokines that contribute to hepatic inflammation and potentially to hepatocyte swelling. (Brummer et al., 2025) The mean liver length in overweight individuals is

14.48 centimeters, approaching the upper limit of normal, 16 centimeters. Several overweight patients exceeded this threshold, indicating subclinical hepatomegaly. This finding has two important clinical implications: (1) weight management interventions should begin in the overweight category, not after obesity develops. (2) Ultrasound screening for NAFLD should be considered in overweight young adults, particularly those with other metabolic risk factors. The present finding aligns closely with previous studies (that reported a positive

correlation between BMI and liver dimension in Pakistani adults. (Ahmed Khan et al., 2018) Another study reported a significant increase in liver length and BMI in Turkish adults. (Tiryaki & Aksu, 2024) Another study reported a significant correlation between BMI and $r = 0.316$ in Nepal (Shrestha et al., 2021). This can be compared with $r = 0.39$ found in this study. Overweight individuals had a significantly longer right kidney length (mean difference = 0.29 cm, $p = 0.010$, Cohen's $d = 0.46$). The finding of a significantly greater right kidney length in overweight individuals (10.37 ± 0.61 cm vs. 10.08 ± 0.65 cm, with a small-to-moderate effect size, $d = 0.46$) supported the hyperfiltration mechanism. Also in the left kidney, a similar trend is observed at 0.23 cm, which is non-significant. This asymmetry is a well-documented physiological norm, resulting from the left kidney having more space to develop due to the smaller spleen relative to the liver, and from the shorter, straighter course of the left renal artery, which provides superior blood flow. (Bhardwaj et al., 2024) Several previous studies have noted asymmetric effects. In the Iranian and Taiwanese populations, BMI correlated more strongly with right renal dimensions in some analyses. (Jabbari et al., 2016; Su et al., 2019) The compensatory hyperfiltration mechanism explained renal enlargement in overweight individuals: excess body weight increases metabolic and circulatory demands, requiring a higher glomerular filtration rate (GFR). (Kovesdy et al., 2017; Martínez-montoro et al., 2022) Afferent arterioles undergo vasodilation, increasing renal plasma flow (RPF) and filtration fraction (FF). (Rico-fontalvo et al., 2026) Over time, this process causes an overall increase in renal length and volume. Additionally, neurohumoral factors contribute. (Ren et al., 2024) Excess visceral and perirenal fat can physically compress the kidneys and stimulate local renin release. Furthermore, these highly active fat tissues directly activate the RAAS system and the sympathetic nervous system. (Hall et al., 2021; Parvanova et al., 2024; Ren et al., 2024) Kidney enlargement in an overweight young female presents an early structural adaptation. If it is sustained this way, it can lead to obesity related glomerulopathy ORG and can eventually lead to focal segmental

glomerular sclerosis (FSGS). (Kataoka, 2023) The right-sided kidney length of an overweight individual is 10.37 centimeters, which remains within the normal range, suggesting that early weight management can reverse these structural changes in the organs.

Spleen length showed a trend toward enlargement in overweight individuals (mean difference = 0.26 cm, $p = 0.064$) that approached but did not reach statistical significance. There is a trend toward enlargement in overweight individuals, with the main difference $d = 0.26$, $P = 0.064$; the effect size (Cohen's d) was small at 0.33. (Brummer et al., 2025) The enlargement of the organ in an overweight individual is explained in the liver access concept by the Brummer study, specifically the spleen. The spleen acts as a reservoir for inflammatory monocytes that can migrate to the liver, promoting hepatic inflammation and fibrosis. Furthermore, increased waist circumference and fatty liver are primary indicators of this systemic metabolic inflammation. (Abd El-Aziz et al., 2018) The splenic alterations may indicate the severity of metabolic disease. (Kalra et al., 2025) Although not statistically significant, the trend toward splenomegaly ($p=0.64$) is clinically notable. The borderline p -value suggests that a larger study would likely confirm significant splenic enlargement. For now, the findings support the concept of systemic metabolic inflammation as an early phenomenon in weight-related diseases, even if the splenic component is less pronounced than hepatic and renal changes.

Males had significantly larger spleens, right kidneys, and left kidneys compared to females. The length of the liver was longer, but not significantly so. Hormones influence physiological factors regardless of gender; for example, testosterone promotes greater lean body mass and larger organ size in most males. Also, differences in body composition: males mostly have greater lean mass, and females have greater fat mass. Females have a smaller baseline body size than men. There is some clinical implementation of gender specific ranges of organ dimensions, which are necessary. Male-derived reference range for female patient could lead to a false positive diagnosis of organomegaly; on the other hand, female-driven

Ranges for the male patient could overlook the enlargement. Due to the limited time available for data collection, a comparatively small sample size ($N=130$) was selected for the study. This limited the study to a cross-sectional design, preventing long-term tracking of organ changes. In addition, the limited cohort size reduced the overall statistical power, preventing confirmation of secondary structural trends, such as borderline splenic enlargement and the smaller, non-significant dimensional increase observed in the left kidney. When you use BMI as a standard in such cases, you cannot differentiate between subcutaneous fat and visceral adiposity, nor account for muscle mass. Therefore, it is impossible to determine if the observed organ enlargement is strictly due to central visceral fat accumulation. Use of Advanced Anthropometrics: future research should compare visceral organ dimensions with the Waist Circumference or the Waist-to-Hip Ratio rather than just BMI. These values provide a more precise representation of central visceral fat, which directly affects abdominal organs.

CONCLUSION

This study evaluated the sonographic dimensions of the spleen, right kidney, liver, and left kidney in almost 130 adults (65 Males and 65 Females) whose ages are within the range of 18 to 40 years old in the Sialkot region; normal weight is $n = 66$, and overweight is $n = 64$ individuals. The null hypothesis (H_0) is that there is no significant difference in organ dimensions between normal-weighted and overweight adults, which was rejected for the liver and the kidney. The alternative hypothesis (H_1) is supported for these organs. Secondary analysis confirmed that males have significantly larger spleens, right kidneys, and left kidneys compared to females. Highlighting the importance of using gender specific reference ranges in clinical sonographic ranges.

Notably, a gender-differentiated sub-analysis revealed a specific pattern indicative of weight-induced visceromegaly. While a non-significant trend towards larger organ dimensions was observed across all measured parameters in overweight males, overweight females showed statistically significant enlargement, especially in liver length. This suggests that early

morphological adaptation to excess weight may differ between sexes, with the female liver potentially showing greater sensitivity to weight-induced hypertrophy.

Overall conclusion: Overweight young adults in the Sialkot region exhibit significant sonographic enlargement of the liver and right kidney compared with normal-weight peers, indicating that subclinical morphological changes in abdominal organs begin in the overweight category (BMI 25-29.9) before the development of obesity (BMI $\geq$ 30). For the Sialkot region, these findings provide essential baseline data and support early weight management and intervention to prevent the progression of irreversible organ pathology.

Declarations

Consent to participate: Written informed consent was obtained from all individual participants included in the study.

Consent for publication: Not applicable.

Conflict of interest: The authors declare that they have no conflicts of interest.

Funding statement: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data availability statement: The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

REFERENCES

Abd El-Aziz, R., Naguib, M., & Rashed, L. A. (2018). Spleen size in patients with metabolic syndrome and its relation to metabolic and inflammatory parameters. *The Egyptian Journal of Internal Medicine*, 30(2), 78-82. https://doi.org/10.4103/ejim.ejim_86_17

Ahmed Khan, S., Yasmeen, S., Adel, H., Adil, S. O., Huda, F., & Khan, S. (2018). Sonographic evaluation of normal liver, spleen, and renal parameters in adult population: A multicenter study. *Journal of the College of Physicians and Surgeons Pakistan*, 28(11), 834-839. <https://doi.org/10.29271/jcpsp.2018.11.834>

Asghar, M., Ziad, A., Raza, F., Malik, M. N., Suhail, B., & Mobeen, M. (2024). Cross-Sectional Study of Ultrasonographic Assessment of Renal Volume and Its Correlation with Basal Metabolic Index. *Journal of Islamabad Medical & Dental College*, 13((Suppl.)), 524-529. [https://doi.org/10.35787/jimdc.v13i\(suppl\).1239](https://doi.org/10.35787/jimdc.v13i(suppl).1239)

Asif, M., Aslam, M., Altaf, S., Atif, S., & Majid, A. (2020). Prevalence and Sociodemographic Factors of Overweight and Obesity among Pakistani Adults. 58-66.

Bhardwaj, S., Singh, A., Kaur, R., & D'cruz, S. (2024). Kidney Dimensions and its Correlation with Anthropometric Parameters in Healthy North Indian Adults. *Indian Journal of Nephrology*, 34(6), 636-642. https://doi.org/10.25259/ijn_12_24

Brummer, C., Singer, K., Renner, K., Bruss, C., Hellerbrand, C., Dorn, C., Reichelt-Wurm, S., Gronwald, W., Pukrop, T., Herr, W., Banas, M., & Kreutz, M. (2025). The spleen-liver axis supports obesity-induced systemic and fatty liver inflammation via MDSC and NKT cell enrichment. *Molecular and Cellular Endocrinology*, 601(January), 112518. <https://doi.org/10.1016/j.mce.2025.112518>

Guan, Y., Wei, X., Li, J., Zhu, Y., Luo, P., & Luo, M. (2024). Obesity-related glomerulopathy : recent advances. *Journal of Leukocyte Biology*, 115(5), 819-839. <https://doi.org/10.1093/jleuko/qiae035>

- Hall, J. E., Mouton, A. J., Silva, A. A., Omoto, A. C. M., Wang, Z., Li, X., & Carmo, J. M. (2021). Obesity , kidney dysfunction , and inflammation : interactions in hypertension. 1859-1876. <https://doi.org/10.1093/cvr/cvaa336>
- Han, C., Zhai, Y., Wang, Y., Peng, X., Zhang, X., Dai, B., & Leng, Y. (2024). Theranostics Intravital imaging of splenic classical monocytes modifying the hepatic CX3CR1 + cells motility to exacerbate liver fibrosis via spleen-liver axis. 14(5). <https://doi.org/10.7150/thno.87791>
- Huang, Y., Zheng, Y., Zhang, C., & Zhong, S. (2022). Ultrasound Assessment of the Relevance of Liver, Spleen, and Kidney Dimensions with Body Parameters in Adolescents. *Computational and Mathematical Methods in Medicine*, 2022. <https://doi.org/10.1155/2022/9150803>
- Imenez Silva, P. H., & Mohebbi, N. (2022). Kidney metabolism and acid-base control: back to the basics. *Pflugers Archiv European Journal of Physiology*, 474(8), 919-934. <https://doi.org/10.1007/s00424-022-02696-6>
- Jabbari, M., Mollazade, R., Ashari, F. E., & Alizadeh, Z. (2016). Normal Renal Dimensions in Iranian Adults Measured by Ultrasound. 13(1), 25-32.
- Kalra, S., Vermaz, S. K., & Kapoor, N. (2025). Obesity And The Spleen. *Journal of the Pakistan Medical Association*, 75(8), 1298-1300. <https://doi.org/10.47391/JPMA.25-63>
- Kapila, V., Wehrle, C. J., & Tuma, F. (2023). Physiology, Spleen. *StatPearls*. <https://www.ncbi.nlm.nih.gov/books/NBK537307/>
- Karjoo, S., Auriemma, A., Fraker, T., & Bays, H. E. (2022). Nonalcoholic fatty liver disease and obesity: An Obesity Medicine Association (OMA) Clinical Practice Statement (CPS) 2022. *Obesity Pillars*, 3(July), 100027. <https://doi.org/10.1016/j.obpill.2022.100027>
- Kataoka, H. (2023). Glomerular hyperfiltration and hypertrophy : an evaluation of maximum values in pathological indicators to discriminate “ diseased ” from “ normal .” 2(July), 21-23. <https://doi.org/10.3389/fmed.2023.1179834>
- Koneru, K., Bhatt, V., Kakrani, A., Edara, M., Reddy, V. T., & Jawade, P. G. (2022). Original Article A study of non - alcoholic fatty liver disease - liver fat score in overweight and obese individuals. <https://doi.org/10.4103/jfmpc.jfmpc>
- Kosicka-Noworzyń, K., Romaniuk-Drapała, A., Sheng, Y. H., Yohn, C., Brunetti, L., & Kagan, L. (2024). Obesity-related drug transporter expression alterations in human liver and kidneys. *Pharmacological Reports*, 76(6), 1429-1442. <https://doi.org/10.1007/s43440-024-00665-7>
- Kovesdy, C. P., Furth, L., & Zoccali, C. (2017). Obesity and Kidney Disease : Hidden. 33-41. <https://doi.org/10.1159/000452965>
- Martinez-montoro, J. I., Morales, E., Tinahones, F. J., Cornejo-pareja, I., & Fernández-garcía, J. C. (2022). Obesity-related glomerulopathy : Current approaches and future perspectives. *December 2021*, 1-15. <https://doi.org/10.1111/obr.13450>
- Omole, A. E., & Launico, M. V. (2026). Anatomy, Abdomen and Pelvis, Spleen. *StatPearls*. <https://www.ncbi.nlm.nih.gov/books/NBK482235/>

- Parvanova, A., Reseghetti, E., Abbate, M., & Ruggerenti, P. (2024). Mechanisms and treatment of obesity-related hypertension – Part 1 : Mechanisms. *Clinical Kidney Journal*, 17(1), 1–
18. <https://doi.org/10.1093/ckj/sfad282>
- Ponti, F., Cinque, A. De, Fazio, N., Napoli, A., Guglielmi, G., & Bazzocchi, A. (2020). *Ultrasound imaging , a stethoscope for body composition assessment*. 10(8), 1699–1722. <https://doi.org/10.21037/qims-19-1048>
- Ren, L., Ju, F., Liu, S., Cai, Y., Gang, X., & Wang, G. (2024). *New Perspectives on Obesity-Associated Nephropathy from Pathophysiology to Therapeutics : Revealing the Promise of GLP-1 RA New Perspectives on Obesity-Associated Nephropathy from Pathophysiology to Therapeutics : Revealing the Promise of GLP-1 RA Therapy*. 8881. <https://doi.org/10.2147/DDDT.S476815>
- Rico-fontalvo, J., Raad-sarabia, M., Rodr, T., Rafael, L., Ramos, C., Sa, P. P., Alexandra, A., Gomez, O., Quintero, J. J., & Daza-arnedo, R. (2026). *In flammatory and lipotoxicity mechanisms in obesity related CKD*. January, 1–9. <https://doi.org/10.3389/fneph.2025.1684004>
- Rong, J., Zhang, Z., Peng, X., Li, P., Zhao, T., & Zhong, Y. (2024). Mechanisms of hepatic and renal injury in lipid metabolism disorders in metabolic syndrome. *International Journal of Biological Sciences*, 20(12), 4783–4798. <https://doi.org/10.7150/ijbs.100394>
- Shrestha, E., Nb, T., & Tayal, A. (2021). *Assessment of Normal Liver Size among Adults by Ultrasonography in Kathmandu Medical College*. 11(2).
- Soon, G. S. T., & Torbenson, M. (2023). *The Liver and Glycogen: In Sickness and in Health*. *International Journal of Molecular Sciences*, 24(7). <https://doi.org/10.3390/ijms24076133>
- Su, H., Hsieh, H., Lee, C., Liao, S., Chu, C., & Id, C. W. (2019). *Reference ranges for ultrasonographic renal dimensions as functions of age and body indices : A retrospective observational study in Taiwan*. 1–17.
- Tiryaki, Ş., & Aksu, Y. (2024). *Ultrasonographic Evaluation of Normal Liver , Spleen , and Kidney Dimensions in a Healthy Turkish Community of Over 18 Years Old Abstract* : 1–11. <https://doi.org/10.2174/1573405620666230522151349>
- Voon, K., Huang, C.-K., Patel, A., Wong, L.-F., Lu, Y.-C., & Hsin, M.-C. (2021). *Conversion of One-Anastomosis Gastric Bypass (OAGB) to Roux-en-Y Gastric Bypass (RYGB) is Effective in Dealing with Late Complications of OAGB: Experience from a Tertiary Bariatric Center and Literature Review*. *Journal of Metabolic and Bariatric Surgery J Metab Bariatr Surg*, 10(1), 32–41. <https://doi.org/10.17476/jmbs.2021.10.1.32>
- Wang, X., Rao, H., Liu, F., Wei, L., Li, H., & Wu, C. (2021). *Recent Advances in Adipose Tissue Dysfunction and Its Role in the Pathogenesis of Non-Alcoholic Fatty Liver Disease*. 1–21.
- Younossi, Z. M., Golabi, P., Paik, J. M., Henry, A., Dongen, C. Van, & Henry, L. (2023). *The global epidemiology of nonalcoholic fatty liver disease (NAFLD) and nonalcoholic steatohepatitis (NASH): a systematic review*. July 2022, 1335–1347. <https://doi.org/10.1097/HEP.0000000000000004>

Zhang, S., Wan, D., Zhu, M., Wang, G., Zhang, C., Kong, G., Geng, J., & Yao, L. (2023). *exacerbate liver fibrosis via spleen –*

liver axis. February 2022, 1612–1629.
<https://doi.org/10.1002/hep.32782>

