Cross-Sectional Study

The Association Between the Triglyceride-Glucose Index and Its Combination with Obesity Metrics and Adult Spinal Pain: A Cross-Sectional Study

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Background: Spinal pain, particularly low back pain, poses a significant health and economic burden, contributing to widespread disability and economic costs. Emerging evidence suggests a connection between spinal pain and metabolic conditions, such as insulin resistance and obesity. When combined with obesity metrics, the triglyceride-glucose (TyG) index, a reliable marker for insulin resistance, may provide enhanced predictive value for metabolic syndrome and related health outcomes. However, the association of the TyG index with spinal pain remains underexplored.

Objectives: This study explores the connection of the TyG and TyG-obesity metrics (TyG-WC, TyG-WHtR, and TyG-BMI) to spinal pain. The analysis relies on data collected through the National Health and Nutrition Examination Survey from 1999 to 2004.

Study Design: A cross-sectional study was conducted on 31,126 NHANES participants aged ≥20 years.

Methods: Weighted multivariable logistic regression models were utilized to evaluate the associations of the TyG index and TyG-obesity metrics with spinal pain outcomes. Restricted cubic spline analysis was employed to assess dose-response relationships, and receiver operating characteristic (ROC) analysis quantified the predictive accuracy of these indicators.

Results: Higher levels of the TyG index and TyG-obesity metrics (TyG-WC, TyG-WHtR, and TyG-BMI) were strongly linked to a greater occurrence of spinal pain and associated functional impairments (P trend < 0.001). Among these indicators, TyG-WC demonstrated the greatest predictive value for spinal pain (OR 1.70; 95% CI 1.53-1.89), whereas TyG-WHtR showed the most effective diagnostic performance across various spinal pain outcomes (AUC: 0.647; 95% CI 0.635-0.659). The associations demonstrated both linear and nonlinear trends, emphasizing the complex interplay between metabolic factors and spinal pain.

Limitations: This study's cross-sectional design means that temporal relationships cannot be established, thus limiting causal inference. Additionally, self-reported data may introduce bias, and residual confounding cannot be fully excluded.

Conclusions: This research work highlights the potential of the TyG and TyG-obesity metrics as valuable tools for predicting and diagnosing spinal pain and associated functional limitations. Incorporating these metabolic markers into clinical assessments could enhance early detection and intervention strategies for individuals at risk of spinal pain.

Key words: Triglyceride-glucose index, spinal pain, metabolic syndrome, obesity metrics, NHANES

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Spinal pain, particularly low back pain (LBP), has been identified as the leading global cause of disability. In 2020, the number of individuals affected by this condition exceeded 619 million, and this figure is projected to rise to 843 million by 2050, a development driven largely by the aging global population (1). This condition limits mobility, interferes with daily activities and often leads to chronic disability, reducing individuals' ability to work and increasing early retirement rates (2). The economic burden associated with spinal pain is considerable, with estimates indicating that it costs the health care system approximately $134.5 billion annually in the United States alone (3). Spinal pain refers to pain originating from the spine and can involve the axial skeleton (e.g., bones in the back and neck) or extend to the extremities. The pain may result from a variety of causes, including mechanical issues like muscle strain, ligament injuries, spinal fractures, disc herniation, and conditions like spinal stenosis. Non-mechanical causes such as arthritis (e.g., ankylosing spondylitis), infections, and tumors affecting the spine can also lead to spinal pain (4,5). Recent studies have commenced an investigation into the relationship between spinal pain and metabolic conditions. A number of studies have indicated that chronic spinal pain is correlated with a range of metabolic disorders, including obesity, diabetes mellitus, (DM) and cardiovascular disease (6,7).

The triglyceride-glucose (TyG) index is widely acknowledged as a reliable indicator for assessing insulin resistance and its relationship with metabolic syndrome (MetS). This indicator has demonstrated a substantial link to both the onset and progression of MetS (8). Obesity is a widespread global issue, strongly linked to health complications such as insulin resistance, impaired glucose tolerance, and metabolic disorders. These conditions contribute significantly to the development and exacerbation of various illnesses (9). High levels on the TyG index and TyG-obesity metrics have been associated with insulin resistance, elevated uric acid levels, MetS, DM, and fatty liver disease (10,11). Studies suggest that a combination of the TyG index and obesity metrics may offer better predictive value than the TyG index alone (12).

Despite growing interest in the correlation between TyG index and MetS, the connection that TyG and its obesity-related markers may have to spinal pain in adults remains unclear. This knowledge gap motivated us to undertake the present study. This study hypothesizes that a higher TyG index in adults may correlate with a greater likelihood of experiencing spinal pain and functional impairments. The investigation seeks to explore this relationship utilizing data obtained from the National Health and Nutrition Examination Survey (NHANES) online database (www.cdc.gov/nchs/nhanes/index.html).

Methods

Study Design and Population Selection

This cross-sectional analysis included 31,126 individuals from the NHANES database, collected from 1999 to 2004, with the selection of patients shown in Fig. 1. Individuals were excluded if they: (a) were under 20 years old, (b) lacked data on the TyG and its obesity-related indicators, and (c) had no recorded outcomes for spinal pain or functional limitations. The National Center for Health Statistics Research Ethics Review Board granted approval for the NHANES protocol, with all patients offering their written consent after being fully informed.

Defining TyG and Its Combination with Obesity Metrics

The TyG index, which quantifies insulin resistance, is calculated based on fasting glucose and triglyceride measurements. Patients' fasting blood glucose (FBG) and triglyceride levels were obtained from blood samples provided by those individuals. Measurements of height, waist circumference (WC), and body weight were collected during their physical examinations. From these figures, the body mass index (BMI) and waist-to-height ratio (WHtR) were calculated. Patients were then divided into 4 quartile groups (Q1, Q2, Q3, Q4) according to the TyG index and TyG-obesity metrics. The Q1 quartile group was used as the control group for comparison.

The calculations for the TyG index and its variants, TyG-WC, TyG-WHtR, and TyG-BMI, were performed using the following equations: (a) WHtR = WC (cm)/height (cm); (b) BMI = body weight (kg)/height^2 (m^2); (c) TyG = ln [triglycerides (mg/dl) × FBG (mg/dl)/2]. For the composite indices, the TyG index was multiplied by each of the following: WC for TyG-WC, WHtR for TyG-WHtR, and BMI for TyG-BMI.

Spinal Pain and Associated Activity Limitations

From the "Miscellaneous Pain" survey, 3 pain-related binary outcomes related to were extracted. Patients

reported whether they had experienced persistent pain in the neck, in the low back, or in the low back that spread below the knee and lasted for at least an entire day within the last 3 months. Additionally, the "Medical Conditions" survey collected self-reported medical diagnoses of arthritis and rheumatism, conditions often associated with spinal pain, by inquiring, "Has a doctor ever told you that you had arthritis or rheumatism?" A "yes" response to any of those questions was considered a positive result for spinal pain.

The "Physical Functioning" questionnaire was used to assess limitation outcomes, following the disability classification framework outlined by the Institute of Medicine (13). Patients aged 60 and older were invited to fill out the questionnaire, while those aged 20 to 59 were included only if they had previously indicated physical limitations caused by long-term physical, mental, or emotional health conditions (Suppl. File 1, Section 1). The patients were asked to assess their capacity to carry out 19 different activities without the use of special equipment, selecting from options labeled"Unable,""Much difficulty,""Some difficulty,"or "No difficulty" (Suppl. File 1, Section 2). Whenever patients indicated any level of difficulty, they were prompted to specify the underlying condition or health issue contributing to their challenges or need for assistance (Suppl. File 1, Section 3). Those who indicated that their limitations were due to back or neck problems, arthritis, or rheumatism were considered to have positive outcomes for those respective limitation outcomes (5).

Assessment of Covariates

The patients'races and ethnicities were classified into 4 distinct categories: Mexican Hispanic, non-Hispanic White, non-Hispanic Black, and other. Socioeconomic status was determined by 2 factors: family income (less than $20,000; $20,000–54,999; greater than $55,000 USD) and educational level (college degree or above; high school diploma; less than a high school diploma) (14). Marital status was divided into 3 groups: widowed, divorced or separated, married or living with a partner, and never married. The identification of comorbidity was facilitated by the "Medical Conditions" questionnaire, which encompassed a range of diseases including but not limited to chronic bronchitis, emphysema, congestive heart failure, coronary artery disease, hypertension, DM, myocardial infarction, liver disease, and cancer. A comorbidity index variable classified patients according to the number of coexisting conditions (0, 1, or > 1) (5). Clinical data were collected from NHANES laboratory records and included fasting glucose, HbA1c, triglycerides (TG), liver enzymes (alanine transaminase [ALT], aspartate transaminase [AST], and gamma-glutamyl transferase [GGT]), blood urea nitrogen (BUN), creatinine (Cr), uric acid (UA), calcium, albumin, and globulin.

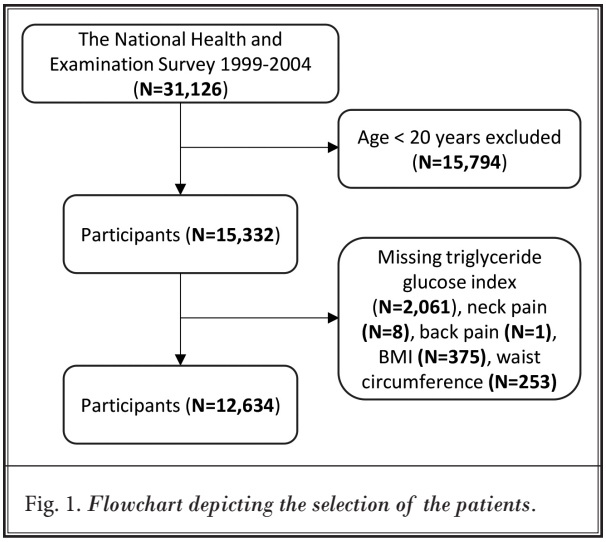

Fig. 1. *Flowchart depicting the selection of the patients.*

Statistical Analysis

The raw data downloaded from the NHANES database, which were organized and used for the analysis in this article, can be found in Suppl. File 2. Conforming to the protocols established by the Centers for Disease Control and Prevention (CDC), all statistical analyses were conducted. Those analyses accounted for the intricate, multistage, stratified probability sampling design of the NHANES, which included the use of sample weights, clustering, and stratification. Continuous data were depicted as mean values along with 95% confidence intervals (CI), whereas categorical data were presented as percentages. The patients'baseline characteristics were summarized across quartiles of the TyG and TyG-obesity metrics. Variance homogeneity was assessed, and Bonferroni post-hoc tests were conducted subsequently. Weighted, multivariable logistic regression models were applied to examine the relationship that the TyG and TyG-obesity metrics had to spinal pain, with findings expressed as odds ratios (OR) with 95% CI. Three predictive models were developed in accordance with the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines (15). The unadjusted model was created without any covariates being adjusted. Model I accounted for

demographic and socioeconomic variables such as gender, age, ethnicity, education level, marital status, and household income. Model II incorporated additional adjustments for comorbidities, albumin, globulin, ALT, AST, GGT, BUN, Cr, UA, and calcium.

The linear or nonlinear dose-response relationship between the TyG index and spinal pain was investigated using restricted cubic spline (RCS) analysis. This analysis was controlled for the variables that were also included in Model I. To mitigate the influence of outliers, 3-6 nodes were made to eliminate the most extreme 5% of the data values. The presence of nonlinearity was determined by using likelihood ratio testing. To evaluate diagnostic performance, receiver operating characteristic (ROC) curve analysis was conducted, and the area under the curve (AUC) was used to measure the model's predictive accuracy. The statistical analyses were performed utilizing the EmpowerStats (www.empowerstats.net, X & Solutions, Inc.) and R 4.2.2 software programs.

Results

Table 1 in the main body of this paper and Table S1-S3 in Suppl. File 3 demonstrate the patient characteristics based on quartiles of TyG and TyG-obesity metrics. Patients with elevated levels on the TyG index and in TyG-obesity metrics tended to be male, older, and non-Hispanic White, and they also had lower levels of educational attainment, income, and albumin. In addition, patients who showed elevated values of these metrics were likelier to be married or cohabitating and to produce greater measurements in height, BMI, and WC. Furthermore, patients in these quartiles showed an increased prevalence of comorbid conditions, elevated quantities of liver enzymes (ALT, AST, and GGT), higher levels of BUN, Cr, UA, calcium, and globulin, and a greater incidence of spinal pain and associated functional limitations.

The univariate analysis (Suppl. File 3: Table S4) revealed that gender, age, race, income, marital status, educational level, comorbidities, and multiple biochemical profile indicators were risk factors for spinal pain and associated functional limitations. Moreover, the risk was found to be elevated by TyG and high BMI and WC, highlighting the impact of MetS on spinal pain and associated functional limitations.

Fig. 2 illustrates the associations between the TyG index and TyG-obesity metrics, and spinal pain across various models. Comprehensive details of these relationships are available in Suppl. File 3: Table S5-S8. In accordance with the guidelines of the STROBE statement, the outcomes of unadjusted, partially adjusted, and fully adjusted analyses are presented concurrently. After accounting for covariates, the findings revealed significant positive correlations of TyG and TyG-obesity metrics with spinal pain and related functional limitations (P trend < 0.001), except for the lack of a significant link between TyG-WC and neck pain.

Regarding total spinal pain, TyG-WC demonstrated the strongest predictive capacity (OR = 1.70, 95% CI = 1.53-1.89), with TyG-WHtR (OR = 1.61, 95% CI = 1.57-1.66) as the second strongest predictor. Respectively, for neck pain, TyG had the strongest correlation (OR = 1.12, 95% CI = 1.09-1.16), followed by TyG-BMI (OR = 1.11, 95% CI = 1.07-1.14) and TyG-WC (OR = 1.11, 95% CI = 0.96-1.28). For LBP, TyG-WC had the strongest correlation (OR = 1.72, 95% CI = 1.54-1.91), followed by TyG-WHtR (OR = 1.52, 95% CI = 1.48-1.56). For LBP spreading down either leg below the knee, TyG-WC showed the strongest correlation (OR = 2.06, 95% CI = 1.71-2.48), with TyG-WHtR (OR = 1.86, 95% CI = 1.77-1.95) as the second strongest predictor. As for arthritis and rheumatism, TyG-WC again demonstrated the greatest predictive capacity (OR = 2.20, 95% CI = 1.91-2.54), followed by TyG-BMI (OR = 2.16, 95% CI = 2.08-2.24). For total limitations from spinal pain, TyG-WC demonstrated once more the strongest correlation (OR = 2.35, 95%CI = 2.02–2.74), slightly surpassing TyG-WHtR (OR = 2.28, 95%CI = 2.1-2.38). Meanwhile, for limitations caused by back or neck problems, TyG-WHtR showed the strongest correlation (OR = 2.06, 95% CI = 1.96-2.17), slightly surpassing TyG-WC (OR = 2.04, 95% CI = 1.69-2.48). Finally, for limitations from arthritis or rheumatism, TyG-WC demonstrated the strongest correlation (OR = 2.84, 95% CI = 2.36-3.43), followed by TyG-WHtR (OR = 2.59, 95% CI = 2.45-2.73).

In Fig. 3, we utilized RCS analysis to model and visually represent the relationships between TyG-obesity metrics and spinal pain. Following the incorporation of all covariates into Model I, a linear association was identified between the TyG-obesity metrics and both spinal and neck pain (P for overall < 0.001 and P for nonlinearity > 0.05). Likewise, LBP was observed to have linear associations with between TyG-WC, TyG-WHtR, and TyG-BMI, as was the presence of arthritis or rheumatism in patients who LBP spread down either leg below the knee (P for overall < 0.001 and P for nonlinear > 0.05). Similarly, TyG-WC and TyG-WHtR also had linear correlations with both limitations caused by back or neck problems and limitations caused by arthritis or rheumatism (P for overall < 0.001 and P for nonlinear

Table 1. *Baseline characteristics according to TyG quartiles: NHANES, 1999–2004*[a].

	TyG (n = 12,634)				
	Q1 ≤ 8.16 n = 3158	**8.16 < Q2 ≤ 8.58 n = 3159**	**8.58 < Q3 ≤ 9.03 n = 3155**	**Q4> 9.03 n = 3162**	***P*-Value**
General Characteristics					
Male, %	39.12	45.92	51.65	58.94	< 0.0001
Age, years	39.87 ± 14.70	45.59 ± 16.96	48.38 ± 16.91	50.56 ± 15.81	< 0.0001
Non-Hispanic white, %	69.54	72.13	73.92	73.38	< 0.0001
College graduate or above, %	61.45	54.65	51.19	47.04	< 0.0001
Married/living with partner, %	60.05	61.25	63.36	65.84	< 0.0001
> 550,000 annual family income, %	36.44	34.30	32.19	29.42	< 0.0001
Standing height, cm	168.63 ± 9.71	168.67 ± 10.05	169.03 ± 10.26	169.79 ± 10.20	< 0.0001
BMI, kg/m^2	25.42 ± 5.43	27.50 ± 5.97	29.44 ± 6.37	30.36 ± 5.90	< 0.0001
Waist circumference, cm	87.87 ± 13.47	94.57 ± 14.52	100.39 ± 14.68	104.33 ± 14.17	< 0.0001
Comorbidities, %					< 0.0001
1	15.87	18.65	17.43	19.10	
> 1	2.75	3.58	3.67	5.63	
Biochemistry Profile					
Albumin, g/L	43.83 ± 3.32	43.34 ± 3.36	43.14 ± 3.58	43.15 ± 3.40	< 0.0001
ALT, U/L	22.50 ± 24.53	24.58 ± 16.64	26.85 ± 24.62	31.85 ± 47.38	< 0.0001
AST, U/L	23.91 ± 20.55	24.44 ± 16.59	25.18 ± 21.20	26.39 ± 14.63	< 0.0001
Blood urea nitrogen, mmol/L	4.47 ± 1.54	4.71 ± 1.75	4.90 ± 1.93	5.16 ± 2.20	< 0.0001
Calcium, mmol/L	2.36 ± 0.09	2.37 ± 0.10	2.37 ± 0.10	2.38 ± 0.10	< 0.0001
GGT, U/L	22.13 ± 31.11	25.80 ± 30.41	30.23 ± 33.08	42.82 ± 70.51	< 0.0001
Uric acid, umol/L	284.38 ± 76.40	308.83 ± 79.67	334.83 ± 83.08	353.75 ± 87.00	< 0.0001
Creatinine, umol/L	71.27 ± 24.48	74.23 ± 33.42	76.43 ± 39.12	79.97 ± 43.07	< 0.0001
Globulin, g/L	29.45 ± 4.33	30.05 ± 4.16	30.19 ± 4.27	30.41 ± 4.17	< 0.0001
Clinical Outcome					
Spinal Pain, %	48.55	53.58	55.75	60.73	< 0.0001
a. Neck pain, %	21.46	19.51	19.94	24.01	< 0.0001
b. Low back pain, %	35.38	39.39	39.77	44.14	< 0.0001
c. Low back pain spreading down either leg below knee, %	8.33	9.15	11.26	13.42	< 0.0001
d. Arthritis/rheumatism, %	14.33	21.12	25.02	29.76	< 0.0001
Limitations from Spinal Pain, %	10.11	13.97	18.32	24.24	< 0.0001
a. Limitations from back or neck problem, %	6.65	8.11	10.70	14.88	< 0.0001
b. Limitations from arthritis /rheumatism, %	5.69	9.97	12.30	16.11	< 0.0001

[a]mean ± SD for continuous variables: *P*-value was calculated by weighted linear regression model. % for categorical variables: *P*-value was calculated by weighted chi-square test.

> 0.05). All TyG index levels involving limitations from spinal pain exhibited nonlinear associations, as did TyG with LBP and arthritis or rheumatism with LBP spreading down either leg below the knee (*P* for overall < 0.001 and *P* for nonlinear < 0.05).

ROC analysis was employed for the comparison of multiple predictors, the results of which demonstrated that TyG-WHtR showed the strongest diagnostic performance for nearly all forms of spinal pain and associated activity limitations, as illustrated in Fig. 4A-H. Suppl. File 3: Table S9 provide further detailed information. The AUC was utilized to facilitate a comparison of the accuracy of multiple diagnostic indicators.

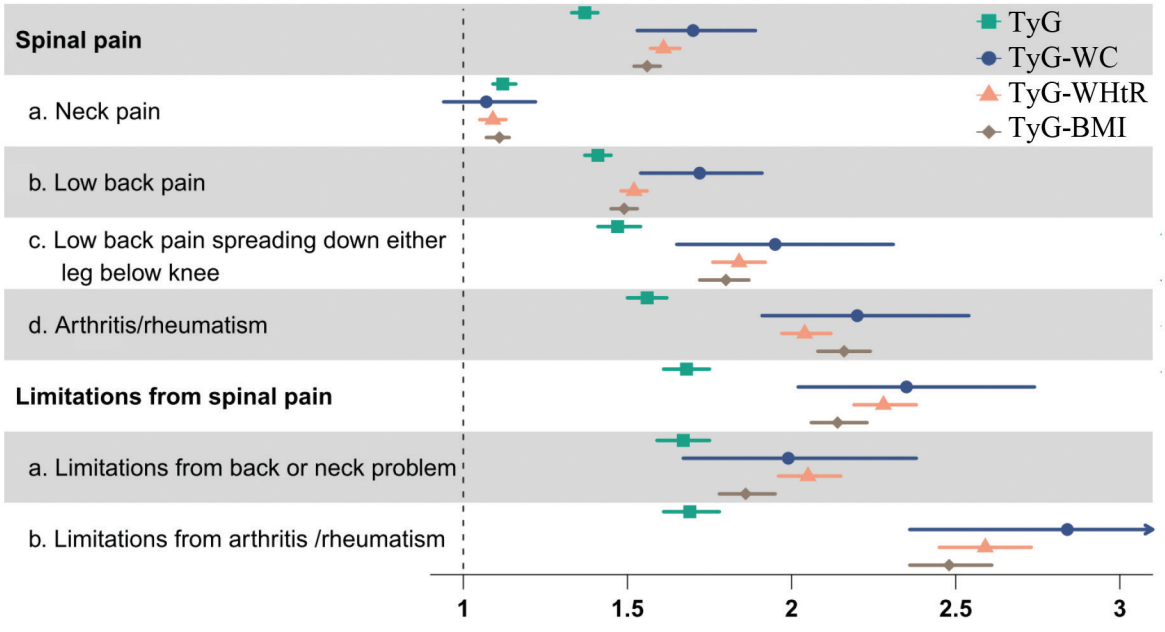

Fig. 2. *Forest plot of the TyG-obesity metrics with spinal pain and associated functional limitations calculated using multivariate logistic regression models. The adjustments involved the covariables selected in the full binomial logistic regression model. The data presented were selected from Model Adjust I and the Q4 group. The specific data can be found in the attached spreadsheet. The Q1 quartile group was used as the control group for comparison.*

For total spinal pain, TyG-WHtR exhibited the strongest diagnostic performance (AUC = 0.582, 95% CI = 0.572-0.591), with TyG-WC (AUC = 0.571, 95% CI = 0.561-0.581) exhibiting the second strongest. As a predictor for neck pain, TyG and TyG-WHtR demonstrated the best diagnostic accuracy (AUC = 0. 520, 95% CI = 0.507-0.533), followed by TyG-BMI (AUC = 0.518, 95% CI = 0.505-0.530). For LBP, TyG-WHtR showed the best diagnostic performance (AUC = 0.555, 95%CI = 0.545-0.565), with TyG-WC closely behind (AUC = 0.552, 95% CI = 0.542-0.563). For LBP spreading down below the knee of either leg, TyG-WHtR again showed the top diagnostic capability (AUC = 0.591, 95% CI = 0.575-0.607), slightly surpassing TyG-WC (AUC = 0.582, 95% CI = 0.567-0.598). For arthritis or rheumatism, TyG-WHtR demonstrated the best diagnostic performance (AUC = 0.635, 95% CI = 0.624-0.646), with TyG-WC (AUC = 0.615, 95% CI = 0.604-0.626) coming second. For total limitations from spinal pain, TyG-WHtR showed the best diagnostic ability (AUC = 0.647, 95% CI = 0.635-0.659), surpassing TyG-WC (AUC = 0.624, 95% CI = 0.612-0.636). For limitations caused by back or neck problems, TyG-WHtR again demonstrated the top diagnostic capacity (AUC = 0.617, 95% CI = 0.602-0.633), with TyG-WC (AUC = 0.608, 95% CI = 0.593-0.624) exhibiting the second strongest performance. Finally, regarding limitations due to arthritis or rheumatism, TyG-WHtR exhibited the best diagnostic performance (AUC = 0.662, 95% CI = 0.649-0.675), with TyG-WC in second place (AUC = 0.630, 95% CI = 0.616-0.643).

Discussion

This study evaluated the relationship that TyG and TyG-obesity metrics (TyG-WC, TyG-WHtR, and TyG-BMI) had to spinal pain and the functional limitations associated with it. The results revealed that elevated TyG and TyG-obesity metrics were significantly associated with an increased prevalence of spinal pain and the aforementioned limitations, with linear or nonlinear trends depending on specific conditions. Among the metrics, TyG-WHtR and TyG-WC exhibited the strongest predictive capacities for spinal pain and associated functional limitations. Additionally, TyG-WHtR showed superior diagnostic accuracy across various forms of spinal pain, as confirmed through ROC analysis. These results underscore the potential of the TyG and TyG-obesity metrics as predictive and diagnostic tools for spinal pain and its associated limitations.

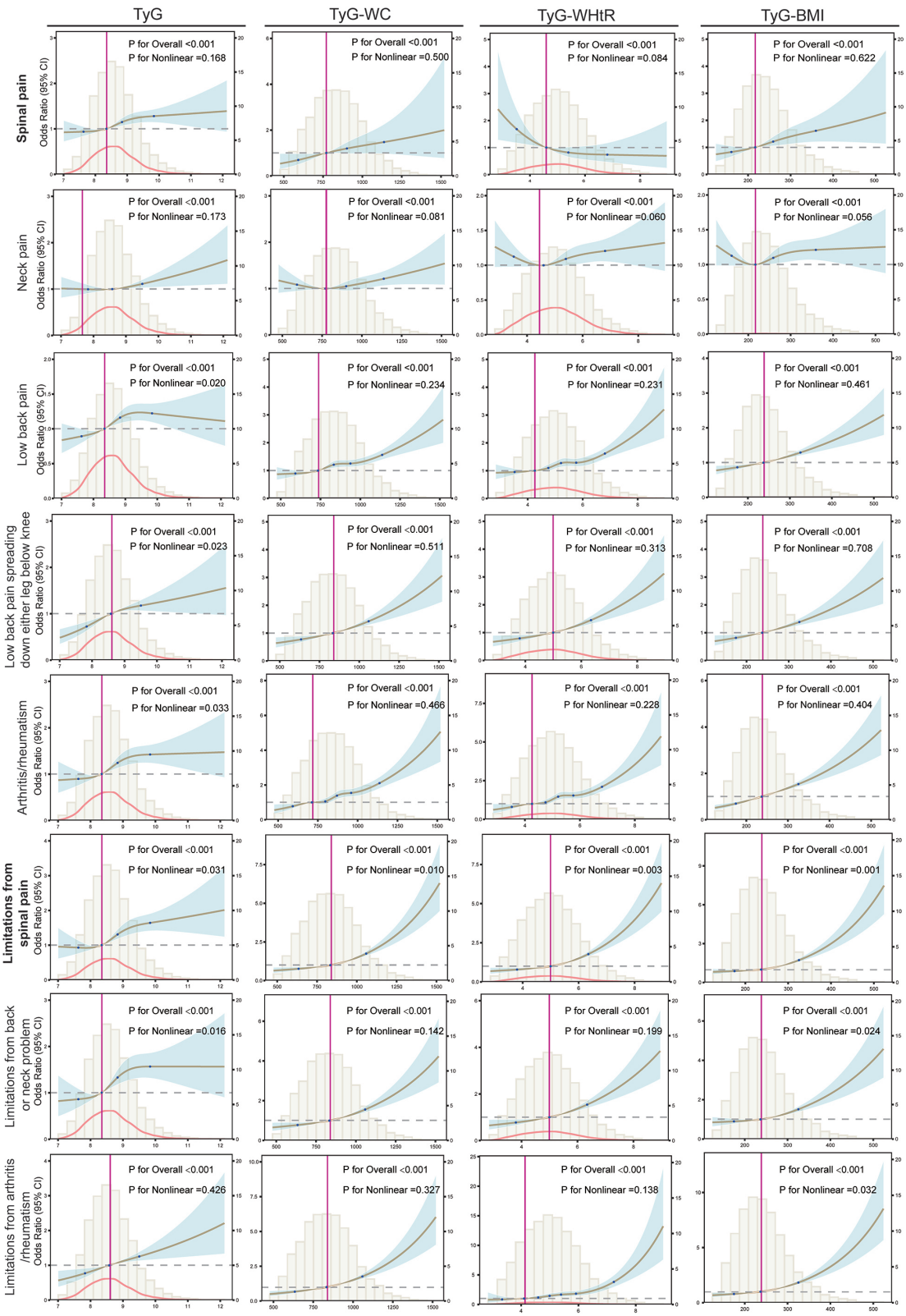

Fig. 3. *RCS analysis after adjustment for the covariables on the association that TyG-obesity metrics and spinal pain had with related functional limitations. The solid dark yellow lines represent the central estimates, while the blue-shaded areas denote the 95% CI.*

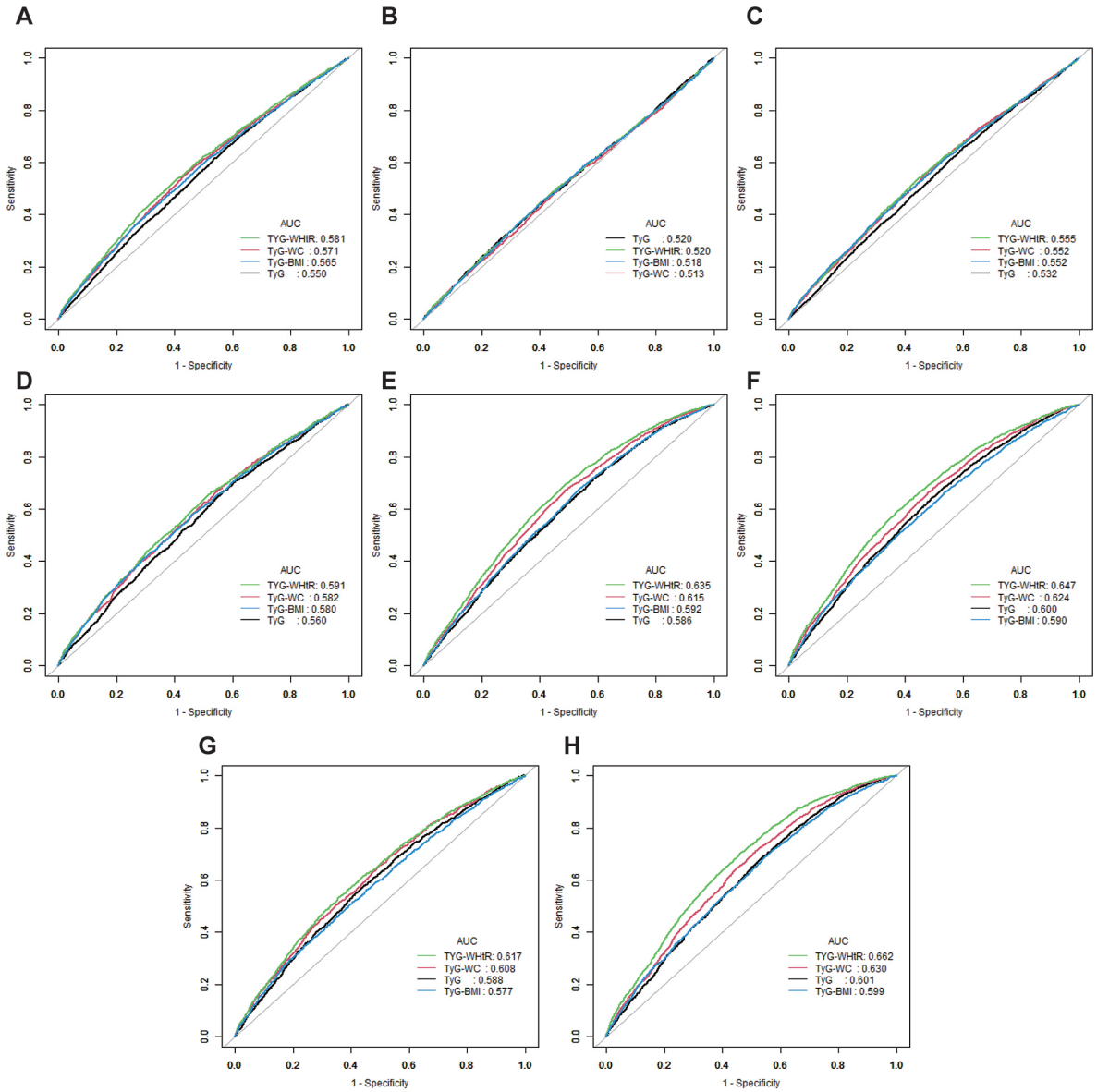

Fig. 4. *ROC analysis was conducted to facilitate a comparison of multiple predictors. The results are presented as AUC. The figure depicts the ROC-AUC curves of the TyG-obesity metrics in relation to spinal pain (A-E) and associated activity limitations (F-H).*

The connection between individual components of MetS and spinal pain has been investigated widely, yet the findings remain inconsistent. For instance, 2 community-based cross-sectional studies conducted in Japan found a significant link between MetS and LBP, but this association was observed exclusively in women (16,17). Conversely, Huang et al (18), using data from the China Health and Retirement Longitudinal Study, reported a reduced prevalence of LBP among patients with MetS, although the co-occurrence of MetS and depressive symptoms elevated the risk of LBP significantly. When specific components of MetS are examined, hypertension has been suggested as a potential protective factor against LBP (19). In contrast, DM has been linked consistently to a higher prevalence and greater severity of both neck pain and LBP, underscor-

ing its negative impact on spinal pain outcomes (20). Despite these findings, limited research has explored the combined effects of MetS components on spinal pain within population-based studies, highlighting a critical gap in the literature. Our study innovatively incorporates the TyG index into research on spinal pain, integrating the index with obesity metrics to provide a deeper understanding of the relationship between MetS and spinal pain.

Prior research examining the association between MetS and neck pain has yielded inconsistent results (21-23). Some researchers suggest that the association between LBP and MetS may be confounded by obesity, a well-established risk factor for DM. As a non-weight-bearing region, neck pain offers a unique perspective in this context, since its symptoms are less likely to be directly influenced by weight-bearing mechanisms (24). Furthermore, differences in socioeconomic status, sociodemographic factors, and educational attainment may play a role in the observed associations between MetS and spinal pain. Utilizing multivariate regression analysis, our study highlighted the multifactorial nature of this complex relationship.

This study has several notable strengths. Primarily, it utilized data from the NHANES online database, providing a comprehensive and representative sample of the U.S. population. During the analyses, appropriate NHANES sample weights were applied, enhancing the generalizability of the findings. Moreover, adjustments for covariates were made to reduce the influence of potential confounders, enhancing both the reliability and generalizability of the findings to broader populations.

Limitations

The limitations of this study must be recognized. Firstly, a cross-sectional study captures data at a single point in time, limiting its ability to establish temporal relationships between exposure and outcome variables. Unlike longitudinal studies, which track changes over time and allow for causal inference, cross-sectional designs provide only a snapshot of associations. As a result, observed correlations may be influenced by reverse causation or confounding factors, making it impossible to determine whether the exposure precedes the outcome. Therefore, while cross-sectional studies are valuable for hypothesis generation and epidemiological insights, they inherently preclude definitive conclusions about causality. Secondly, the data on spinal pain and its associated limitations were obtained exclusively from self-reported sources, which may have been susceptible to biases in recall, information, or social desirability, potentially leading to underreporting or overreporting. Finally, while extensive adjustments were made for numerous potential confounders in the multivariate analyses, it was not possible to completely rule out residual confounding from unmeasured or unidentified variables.

Conclusion

This study underscores the significant relationship that the TyG index and TyG-obesity metrics (TyG-WC, TyG-WHtR, and TyG-BMI) have to various forms of spinal pain and its associated limitations. Elevated levels of these indicators were found to be strongly associated with an increased prevalence of spinal pain, particularly LBP and arthritis and rheumatism, as well as with limitations arising from these conditions. Notably, TyG-WC demonstrated the highest predictive capacity for spinal pain and related limitations across multiple models, including univariate, adjusted, and ROC analyses. Furthermore, TyG-WHtR was identified as the best diagnostic indicator for various types of spinal pain and functional limitations, including those stemming from arthritis or rheumatism. The findings emphasize the importance of incorporating metabolic and obesity-related indicators in assessing the risk of spinal pain and functional impairment, highlighting these indicators' potential utility in clinical settings for early identification and intervention in at-risk populations.

Ethics Approval and Consent to Participate

The National Center for Health Statistics Ethics Review Board approved the NHANES research program, and all patients provided written informed consent upon enrollment.

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Availability of Data and Materials

The data that supports the findings of this study are available in the supplementary material of this article.

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SUPPLEMENTARY MATERIAL

Questions utilized to identify functional limitations in the NHANES dataset from 1999 to 2004

Section 1. *Physical, mental emotional limitations*.

Does a physical, mental or emotional problem now keep [you/SP[1]] from working at a job or business?
[Are you/is SP] limited in the kind or amount of work [you/s/he] can do because of a physcial, mental or emotional problem?
Because of a health problem, [do you/does SP] have difficulty walking without using any special equipment?
[Are you/is SP] limited in any way because of difficulty remembering or because [you/s/he] experience[s] periods of confusion?
[Are you/is SP] limited in any way in any activity because of a physical, mental or emotional problem?

[1] SP : Survey Participant

If YES, to any previous question OR age > 60 years, then:

Section 2. *Difficulties doing certain activities because of a health problem*.

1-Walking for a quarter mile
2-Walking up ten steps
3-Stooping, crouching, kneeling
4-Lifting or carrying
5-Doing house chores
6-Preparing meals
7-Walking between rooms on same floor
8-Standing up from armless chair
9-Getting in and out of bed
10-Using fork, knife, drinking from cup
11-Dressing yourself
12-Standing for long periods
13-Sitting for long periods
14-Reaching up over head
15-Grasping/holding small objects
16-Going out to shopping, movies, or sporting events
17-Participating in social activities
18-Doing things to relax at home or for leisure
19-Pushing or pulling large objects

If difficulty with any above question, then:

Section 3. *What condition or health problem causes [you/sp] to have difficulty with or need help with these activities?*

***10-Arthritis/rheumatism**
***11-Back or neck problem**
12-Birth defect
13-Cancer
14-Depression/anxiety/emotional problem
15-Other developmental problem (such as cerebral palsy)
16-Diabetes
17-Fractures, bone/joint injury
18-Hearing problem
19-Heart problem
20-Hypertension/high blood pressure
21-Lung/breathing problem
22-Mental retardation
23-Other injury
24-Senility
25-Stroke problem
26-Vision/problem seeing
27-Weight problem
28-Other impairment/problem
77-Refused
99-Don't know
. - Missing