·临床研究·

基于左心室整体纵向应变及心肌做功探讨甘油三酯-葡萄糖指数与亚临床左心室功能障碍的相关性研究

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[摘　要]　**目的**:探讨甘油三酯-葡萄糖(triglyceride-glucose,TyG)指数与亚临床左心室收缩功能障碍的独立关联,分析其对左心室整体纵向应变(global longitudinal strain,GLS)及左心室做功指数的影响。**方法**:纳入2024年8月—2025年2月收治的103例患者,采集患者临床参数、生化指标及超声心动图数据,计算TyG指数。通过GE EchoPAC工作站获取GLS及左室做功参数,包括整体做功指数(global work index,GWI)、整体有用功指数(global constructive work,GCW)、整体无用功指数(global wasted work,GWW)和整体做功效率指数(global work efficiency,GWE),采用多因素Logistic回归分析TyG指数与左室功能异常的独立关联。绘制受试者工作特征(receiver operating characteristic,ROC)曲线评估TyG指数对左心室功能障碍的预测效能,计算曲线下面积(area under the curve,AUC)、最佳截断值、灵敏度及特异度。**结果**:高TyG指数组与低TyG指数组相比,高血压(67.31% *vs.* 43.14%)、糖尿病(42.31% *vs.* 7.84%)及高脂血症(34.62% *vs.* 3.92%)患病率显著升高(*P*均<0.05)。GLS绝对值(−17.60±2.65 *vs.* −19.82±2.12)、GWI[(1 672.33±308.58)mmHg% *vs.*(1 932.31±280.26)mmHg%)及GCW[(1 999.46±324.11)mmHg% *vs.*(2 299.20±323.32)mmHg%]均显著降低(*P*均< 0.001)。调整年龄、性别、BMI、血压、血脂等混杂因素后,TyG指数升高仍为GLS降低(OR=2.982,95%CI:1.182~7.522,*P*=0.021)、GWI降低(OR=3.168,95%CI:1.302~7.706,*P*=0.011)及GCW降低(OR=2.836,95%CI:1.250~7.309,*P*=0.021)的独立危险因素。ROC曲线显示出TyG指数对GLS、GWI及GCW降低的预测效能,AUC分别为0.725、0.697、0.683。**结论**:TyG指数升高与GLS及心肌做功能力下降独立相关,是亚临床左心室功能障碍的潜在生物标志物,提示其在代谢性心血管疾病早期风险评估中的临床应用价值。

[关键词]　甘油三酯-葡萄糖指数;左心室整体纵向应变;左室做功指数;亚临床左心功能障碍;代谢紊乱

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Association between triglyceride-glucose index and subclinical left ventricular dysfunction: a study based on left ventricular global longitudinal strain and myocardial work

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[**Abstract**]　**Objective**: To investigate the independent association between the triglyceride-glucose(TyG)index and subclinical left ventricular(LV)systolic dysfunction,and to analyze its impact on left ventricular global longitudinal strain(GLS)and myocardial work indices. **Methods**: A total of 103 patients admitted from August 2024 to February 2025 were enrolled. Clinical parameters,biochemical indicators,and echocardiographic data were collected,and the TyG index was calculated. GLS and LV myocardial work parameters,including global work index(GWI),global constructive work(GCW),global wasted work(GWW),and global work efficiency(GWE)were obtained using GE EchoPAC software. Multivariate logistic regression analysis was employed to assess the independent association between the TyG index and impaired LV function. Receiver operating characteristic(ROC)curves were plotted to evaluate the predictive efficacy of the TyG index for LV dysfunction,calculating the area under the curve(AUC),optimal cutoff value,sensitivity,and specificity. **Results**: Compared to the low-TyG group,the high-TyG group exhibited significantly higher prevalence

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rates of hypertension（67.31% *vs.* 43.14%），diabetes（42.31% *vs.* 7.84%），and dyslipidemia（34.62% *vs.* 3.92%）（all $P < 0.05$）. The absolute values of GLS（−17.60 ± 2.65 *vs.* −19.82 ± 2.12），GWI（1 672.33 ± 308.58 *vs.* 1 932.31 ± 280.26 mmHg%），and GCW（1 999.46 ± 324.11 *vs.* 2 299.20 ± 323.32 mmHg%）were significantly lower in the high TyG group（all $P < 0.001$）. After adjusting for age，sex，body mass index（BMI），blood pressure，dyslipidemia，and other confounders，an elevated TyG index remained an independent risk factor for reduced GLS（OR=2.982，95% CI：1.182−7.522，P=0.021），reduced GWI（OR=3.168，95% CI：1.302−7.706，P=0.011），and diminished GCW（OR=2.836，95% CI：1.250−7.309，P=0.021）. ROC curve analysis demonstrated the predictive efficacy of the TyG index for reduced GLS，GWI，and GCW，with AUC values of 0.725，0.697，and 0.683，respectively. **Conclusion：** An elevated TyG index is independently associated with reduced GLS and myocardial work capacity，serving as a potential biomarker for subclinical LV dysfunction and highlighting its clinical utility in early risk assessment for metabolic cardiovascular diseases.

［**Key words**］ triglyceride-glucose index；left ventricular global longitudinal strain；myocardial work indices；subclinical left ventricular dysfunction；metabolic disorders

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近年来，代谢紊乱与心血管疾病之间的关联备受关注。胰岛素抵抗（insulin resistance，IR）作为代谢综合征的核心病理生理机制，已被证实与动脉粥样硬化、心肌肥厚及心力衰竭密切相关[1-2]。然而，传统代谢指标（如空腹血糖、血脂）对早期心血管损害的预测价值有限，尤其在亚临床心功能障碍的识别中敏感性不足。甘油三酯-葡萄糖（triglyceride-glucose，TyG）指数作为一种基于空腹甘油三酯（triglyceride，TG）和血糖（fasting plasma glucose，FPG）计算的复合指标，因其简便、低成本且与胰岛素抵抗高度相关，逐渐成为代谢性心血管风险评估的热点工具[3-5]。目前研究多聚焦于TyG指数与动脉僵硬度、冠状动脉病变的关联[6]，而其对亚临床左心室功能障碍的影响尚未充分阐明。亚临床左心室功能障碍是心力衰竭的前驱阶段，其特征性表现为左心室整体纵向应变（global longitudinal strain，GLS）及心肌做功指数的异常，此类指标通过超声心动图新技术（如心肌应变和压力-应变环分析）可精准量化[7-8]。尽管已有研究表明代谢异常（如肥胖、糖尿病）与左室重构相关[9]，但TyG指数是否独立于传统危险因素直接参与心肌功能损害，其机制仍不明确。

本研究通过整合代谢标志物与先进超声心动图技术，旨在探讨TyG指数升高是否与左心室整体应变及做功能力下降独立相关。本研究不仅为代谢异常与早期心功能损害的关联提供新证据，也为心血管高危人群的早期筛查策略提供了潜在生物标志物和干预靶点。

1 对象和方法

1.1 对象

本研究为横断面研究，纳入2024年8月—2025年2月就诊于江苏省中医院的103例患者。纳入标准：①年龄≥18岁；②无明确左心室收缩功能障碍，左室射血分数（left ventricular ejection fraction，LVEF）正常；③临床资料完整。排除标准：①严重心律失常；②先天性心脏病或心脏瓣膜病；③急性感染或恶性肿瘤；④妊娠期或哺乳期女性。所有参与者签署知情同意书，研究经医院伦理委员会批准（批准文号2024NL-161-02）。

1.2 方法

1.2.1 临床参数

记录患者年龄、性别、身高、体重、血压、腰围等基础信息，计算体重指数（body mass index，BMI）和体表面积（body surface area，BSA）。

1.2.2 生化指标

采集空腹静脉血，检测TG、FPG、尿素氮、血清肌酐等指标，计算TyG指数：TyG指数=ln［空腹TG（mg/dL）×FPG（mg/dL）/2］。

1.2.3 超声心动图检查

采用GE Vivid E95彩色多普勒超声仪，由1名经验丰富的超声医师按照美国超声心动图协会指南进行图像采集。使用EchoPAC 203软件进行脱机分析，通过心肌自动功能成像模式追踪心肌运动轨迹，计算左室GLS绝对值。输入肱动脉血压，通过心肌做功分析模式获取以下参数：左室整体做功指数（global work index，GWI）：压力-应变环面积，反映左室整体做功；左室整体有用功指数（global constructive work，GCW）：收缩期心肌有效做功；左室整体无用功指数（global wasted work，GWW）：心肌不同步或无效收缩的能耗；左室整体做功效率指数（global work efficiency，GWE）：GCW/（GCW+GWW）×100%。

1.3　统计学方法

所有统计分析均采用SPSS 22.0软件完成。连续性变量首先通过Shapiro-Wilk检验评估数据分布的正态性。符合正态分布的计量资料以均数±标准差($\bar{x} \pm s$)表示，组间比较采用独立样本t检验；非正态分布数据则以中位数（四分位数）[$M(P_{25}, P_{75})$]表示，组间差异分析采用Mann-Whitney U检验。分类变量以频数（百分比）表示，组间比较采用卡方(χ^2)检验，若理论频数<5则使用Fisher精确概率法。采用Pearson相关分析评估正态分布变量间的线性关联，非正态分布变量则使用Spearman秩相关分析。为探讨TyG指数与左心室功能障碍的独立关联，以左心室功能异常为因变量，TyG指数为自变量，构建多因素Logistic回归模型。GLS界值选取依据中国及美国超声心动图学会指南推荐的亚临床功能障碍标准[7-8,10]。由于心肌做功参数（GWI、GCW）缺乏统一诊断界值，本研究以队列中位数作为分组依据，旨在通过数据驱动方式最大化暴露组与非暴露组的效应对比。模型协变量的选择基于临床意义及单因素分析结果，逐步调整人口学变量（年龄、性别）、人体测量学参数（BMI、BSA）、血流动力学相关变量（收缩压、舒张压）以及代谢指标。多重共线性通过方差膨胀因子（variance inflation factor，VIF）评估（VIF<5视为无显著共线性），模型拟合优度采用Hosmer-Lemeshow检验验证($P > 0.05$提示模型拟合良好)。为评估TyG指数对左心室功能障碍的预测效能，绘制受试者工作特征（receiver operating characteristic，ROC）曲线，计算曲线下面积（area under the curve，AUC）、最佳截断值、灵敏度及特异度。所有假设检验均为双侧检验，$P < 0.05$为差异有统计学意义。

2　结　果

2.1　基线特征与TyG指数分组差异

根据TyG指数中位数将患者分为高TyG指数组（≥8.72，n=52）与低TyG指数组（<8.72，n=51）。高TyG指数组与低TyG指数组患者比较，高血压（67.31% *vs.* 43.14%，P=0.014）、糖尿病（42.31% *vs.* 7.84%，$P < 0.001$）及高脂血症（34.62% *vs.* 3.92%，$P < 0.001$）的患病率显著升高，体重[(76.19±15.17)kg *vs.*(65.47±13.50)kg，$P < 0.001$]、BMI[(26.45±3.22)kg/m² *vs.*(23.86±3.75)kg/m²，$P < 0.001$]及BSA[(1.86±0.22)m² *vs.*(1.73±0.19)m²，P=0.002]也显著升高。此外，高TyG指数组相比低TyG指数组代谢紊乱更严重，FPG、TG、总胆固醇（total cholesterol，TC）、高密度脂蛋白胆固醇（high-density lipoprotein cholesterol，HDL-C）、低密度脂蛋白胆固醇（low-density lipoprotein cholesterol，LDL-C）比较，差异均有统计学意义（表1）。

2.2　超声心动图参数对比

超声心动图分析（表2）显示，TyG指数升高与亚临床左心室功能损害存在显著关联。高TyG指数组患者GLS绝对值显著低于低TyG指数组（−17.60±2.65 *vs.* −19.82±2.12，$P < 0.001$），表明其心肌纵向收缩功能受损。在左室做功参数中，高TyG指数组与低TyG指数组比较，GWI[(1 672.33±308.58)mmHg% *vs.*(1 932.31±280.26)mmHg%，$P < 0.001$]及GCW[(1 999.46±324.11)mmHg% *vs.* 2 299.20±323.32)mmHg%，$P < 0.001$]均显著降低，提示心肌有效收缩效率下降。然而，两组间GWW[(110.63±73.33)mmHg% *vs.*(105.08±48.60)mmHg%，P=0.652]及GWE[(93.90±3.48)% *vs.*(94.84±1.91)%，P=0.093]差异无统计学意义，说明心肌无效能耗与能量转化效率未受TyG指数显著影响。TyG指数对应的GLS与左室心肌做功牛眼图见图1。

此外，高TyG指数组患者舒张功能参数E/e’显著升高(9.20±2.21 *vs.* 8.17±1.98，P=0.014)，提示左室舒张功能异常。其他结构性参数中，高TyG指数组与低TyG指数组比较，左房内径[(34.58±4.21)mm *vs.*(32.29±4.18)mm，P=0.007]、室间隔厚度[(10.17±1.41)mm *vs.*(9.29±1.27)mm，P=0.010]、左室后壁厚度[(9.38±0.99)mm *vs.*(8.88±0.91)mm，P=0.009]及相对室壁厚度[(0.398±0.045)mm *vs.*(0.372±0.047)mm，P=0.007]均显著增加，反映潜在心肌肥厚倾向。值得注意的是，两组LVEF虽均在正常范围，但高TyG指数组略低于低TyG指数组[(66.28±4.12)% *vs.*(67.78±3.54)%，P=0.049]，进一步支持TyG指数升高与亚临床心功能损害的关联（表2）。

2.3　GLS、GWI及GCW潜在风险因素的相关性检验

Pearson相关分析表明，TyG指数与GLS绝对值降低呈显著正相关(r=0.490，$P < 0.001$)，与GWI(r=−0.432，$P < 0.001$)及GCW(r=−0.431，$P < 0.001$)呈显著负相关。年龄增长、男性与GLS绝对值降低显著负相关($P < 0.001$)，与GWI/GCW升高显著正相关($P < 0.05$)。身高与GWI/GCW呈显著负相关($P < 0.01$)。体重、BMI、BSA升高与GLS绝对值降低显著正相关($P < 0.001$)，与GWI/GCW降低显著负相关($P < 0.01$)。舒张压升高与GLS绝对值降低显著正相关($P < 0.05$)，收缩压和舒张压升高均与

表1 高TyG指数与低TyG指数患者的临床参数对比

Table 1 Comparison of clinical parameters between patients with high and low TyG index

Clinical parameters	Total(n=103)	High TyG(n=52)	Low TyG(n=51)	$t/Z/\chi^2$	P
Age(years, $\bar{x} \pm s$)	52.52 ± 14.50	53.10 ± 14.15	51.94 ± 14.97	0.403	0.688
Male[n(%)]	61(59.22)	35(67.31)	26(50.98)	2.842	0.092
Height(cm, $\bar{x} \pm s$)	167.34 ± 8.66	168.25 ± 9.15	166.41 ± 8.11	1.078	0.284
Weight(kg, $\bar{x} \pm s$)	70.88 ± 15.28	76.19 ± 15.17	65.47 ± 13.50	3.789	<0.001
BMI(kg/m^2, $\bar{x} \pm s$)	25.17 ± 3.71	26.45 ± 3.22	23.86 ± 3.75	3.759	<0.001
BSA(m^2, $\bar{x} \pm s$)	1.79 ± 0.21	1.86 ± 0.22	1.73 ± 0.19	3.221	0.002
SBP(mmHg, $\bar{x} \pm s$)	127.25 ± 16.63	128.98 ± 14.94	126.11 ± 15.78	0.948	0.345
DBP(mmHg, $\bar{x} \pm s$)	81.25 ± 11.02	82.38 ± 12.44	80.10 ± 9.34	1.053	0.295
TyG index($\bar{x} \pm s$)	8.72 ± 0.65	9.24 ± 0.42	8.20 ± 0.34	13.782	<0.001
FPG(mmol/L, $\bar{x} \pm s$)	5.71 ± 1.84	6.37 ± 2.29	5.04 ± 0.78	3.920	<0.001
TG(mmol/L, $\bar{x} \pm s$)	1.62 ± 0.98	2.26 ± 0.98	0.96 ± 0.31	8.976	<0.001
TC[mmol/L, $M(P_{25}, P_{75})$]	4.71(4.20,5.41)	5.13(4.51,5.82)	4.43(4.05,4.94)	4.023	<0.001
HDL-C[mmol/L, $M(P_{25}, P_{75})$]	1.11(0.98,1.25)	1.06(0.95,1.19)	1.15(1.03,1.31)	−2.851	0.004
LDL-C[mmol/L, $M(P_{25}, P_{75})$]	3.14(2.64,3.63)	3.39(2.81,3.89)	2.94(2.56,3.35)	3.022	0.003
ALT[U/L, $M(P_{25}, P_{75})$]	24.35(16.21,40.47)	25.17(17.08,41.16)	23.78(15.19,39.47)	0.612	0.345
AST[U/L, $M(P_{25}, P_{75})$]	26.56(18.11,36.11)	25.53(17.11,35.34)	27.13(19.19,39.87)	−0.156	0.671
SCR[μmol/L, $M(P_{25}, P_{75})$]	50.06(35.11,75.61)	52.55(36.11,78.18)	49.78(34.11,72.39)	0.221	0.551
BUN[mmol/L, $M(P_{25}, P_{75})$]	6.90(5.23,10.11)	6.81(5.07,10.05)	7.01(5.56,10.21)	−0.197	0.687
K^+(mmol/L, $\bar{x} \pm s$)	4.03 ± 0.42	3.95 ± 0.43	4.11 ± 0.41	−1.980	0.050
Na^+(mmol/L, $\bar{x} \pm s$)	139.72 ± 2.91	140.25 ± 3.02	139.17 ± 2.77	1.896	0.061
Cl^-(mmol/L, $\bar{x} \pm s$)	103.58 ± 3.63	103.97 ± 3.82	103.17 ± 3.41	1.143	0.256
Ca^{2+}(mmol/L, $\bar{x} \pm s$)	2.29 ± 0.16	2.28 ± 0.15	2.31 ± 0.17	−0.969	0.335
Hypertension[n(%)]	57(55.33)	35(67.31)	22(43.14)	6.086	0.014
T2DM[n(%)]	26(25.24)	22(42.31)	4(7.84)	16.207	<0.001
Dyslipidaemia[n(%)]	20(19.42)	18(34.62)	2(3.92)	15.503	<0.001
Smoking history[n(%)]	22(21.36)	12(23.07)	10(19.61)	0.183	0.669
Drinking history[n(%)]	34(33.01)	18(34.61)	16(31.37)	0.126	0.723

BMI: body mass index; BSA: body surface area; SBP: systolic blood pressure; DBP: diastolic blood pressure; TyG index: triglyceride-glucose index; FPG: fasting plasma glucose; TG: triglyceride; TC: total cholesterol; HDL-C: high-density lipoprotein; LDL-C: low-density lipoprotein; ALT: alanine aminotransferase; AST: aspartate aminotransferase; SCR: serum creatinine; BUN: blood urea nitrogen; T2DM type 2 diabetes mellitus.

GWI/GCW升高显著正相关($P < 0.01$)。此外,TG、FPG、TC、LDL-C升高及HDL-C降低均与GLS绝对值降低显著正相关($P < 0.05$),与GWI/GCW降低显著负相关($P < 0.05$,表3)。

2.4 TyG指数对左室功能障碍的独立预测价值

GLS是评估亚临床心肌功能障碍的敏感指标。基于国际及国内权威指南、共识[8,11],对于男性患者,左室GLS<17%(绝对值)为事件"1",左室GLS≥17%(绝对值)为事件"0";对于女性患者,左室GLS<18%(绝对值)为事件"1",左室GLS≥18%(绝对值)为事件"0"。由于心肌做功参数(GWI、GCW)尚无统一诊断截点,本研究采用队列中位数作为分组界值。当GWI≤1 829 mmHg%赋值为事件"1",当GWI>1 829 mmHg%赋值为事件"0";当GCW≤2 153 mmHg%赋值为事件"1",当GCW>2 153 mmHg%赋值为事件"0"。多因素Logistic回归分析显示,在逐步调整年龄、性别、BMI、BSA、血压、血脂等代谢因素后,TyG指数升高仍与左室功能障碍独立相关:GLS绝对值<17%(男)、<18%(女):调整后OR=2.982(95%CI:1.182~7.522,P=0.021);GWI≤1 829 mmHg%:调整后OR=3.168(95%CI:1.302~7.706,P=0.011);GCW≤2 153 mmHg%:调整后OR=2.836(95% CI:1.250~7.309,P=0.021,表4)。

2.5 TyG指数预测GLS、GWI及GCW降低的ROC结果

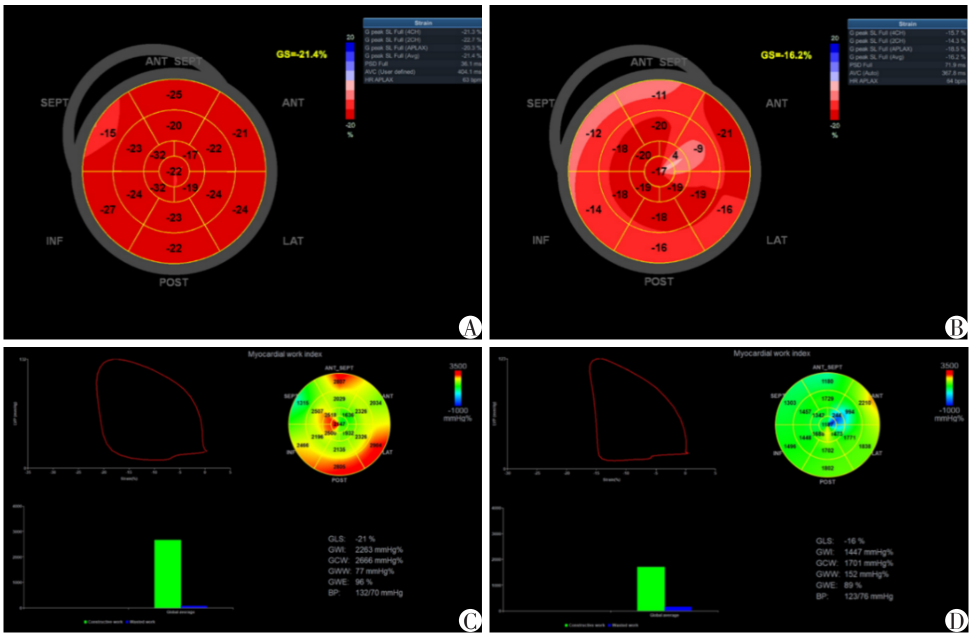
TyG指数是预测GLS降低的独立危险因素,

表2 高TyG指数与低TyG指数患者的超声心动图参数对比

Table 2 Comparison of echocardiographic parameters between patients with high and low TyG index ($\bar{x} \pm s$)

Echocardiographic parameters	Total(n=103)	High TyG(n=52)	Low TyG(n=51)	t/z	P
LAD(mm, $\bar{x} \pm s$)	33.45 ± 4.33	34.58 ± 4.21	32.29 ± 4.18	2.763	<0.01
LVD(mm, $\bar{x} \pm s$)	47.17 ± 3.80	47.19 ± 3.62	47.16 ± 4.00	0.047	0.963
LVEF(%, $\bar{x} \pm s$)	67.02 ± 3.90	66.28 ± 4.12	67.78 ± 3.54	−1.989	0.049
Septal thickness(mm, $\bar{x} \pm s$)	9.74 ± 1.41	10.17 ± 1.41	9.29 ± 1.27	3.322	<0.05
Posterior wall thickness(mm, $\bar{x} \pm s$)	9.14 ± 0.98	9.38 ± 0.99	8.88 ± 0.91	2.676	<0.01
GLS(%, $\bar{x} \pm s$)	−18.70 ± 2.64	−17.60 ± 2.65	−19.82 ± 2.12	4.678	<0.01
GWI(mmHg%, $\bar{x} \pm s$)	1 801.06 ± 321.21	1 672.33 ± 308.58	1 932.31 ± 280.26	−4.474	<0.01
GCW(mmHg%, $\bar{x} \pm s$)	2 147.87 ± 355.59	1 999.46 ± 324.11	2 299.20 ± 323.32	−4.698	<0.01
GWW[mmHg%, $M(P_{25}, P_{75})$]	100.23(60.02, 153.00)	101.51(61.76, 155.32)	98.02(58.91, 150.98)	0.410	0.357
GWE(%, $\bar{x} \pm s$)	94.37 ± 2.84	93.90 ± 3.48	94.84 ± 1.91	−1.694	0.093
E(m/s, $\bar{x} \pm s$)	0.71 ± 0.18	0.68 ± 0.20	0.74 ± 0.16	−1.657	0.101
A(m/s, $\bar{x} \pm s$)	0.77 ± 0.17	0.78 ± 0.18	0.77 ± 0.16	0.330	0.742
E/A	0.96 ± 0.34	0.91 ± 0.33	1.01 ± 0.35	−1.437	0.154
Septale'(cm/s, $\bar{x} \pm s$)	7.33 ± 2.56	6.48 ± 2.00	8.20 ± 2.80	−3.586	<0.01
Laterale'(cm/s, $\bar{x} \pm s$)	10.55 ± 3.28	9.62 ± 3.08	11.51 ± 3.23	−3.047	<0.01
E/e'($\bar{x} \pm s$)	8.69 ± 2.15	9.20 ± 2.21	8.17 ± 1.98	2.495	<0.05
LVMI(g/m^2, $\bar{x} \pm s$)	85.67 ± 14.08	86.43 ± 12.84	84.90 ± 15.34	0.547	0.585
RWT($\bar{x} \pm s$)	0.39 ± 0.05	0.40 ± 0.05	0.37 ± 0.05	2.762	<0.01

LAD: left atrialdimension; LVD: left ventricularend diastolic dimension; LVEF: left ventricular ejection fraction; GLS: global longitudinal strain; GWI: global work index; GCW: global constructive work; GWW: global wasted work; GWE: global work efficiency; LVMI: left ventricular mass index.



A: LV GLS(−21.4%) corresponding to a low TyG index(TyG=7.8). B: LV GLS(−16.2%) corresponding to a high TyG index(TyG=9.0). C: LV pressure-strain loop curve corresponding to a low TyG index(TyG=7.8). D: LV pressure-strain loop curve corresponding to a high TyG index(TyG=9.0).

图1 TyG指数对应的左心室GLS与左室心肌做功牛眼图

Figure 1 Representative left ventricular GLS and myocardial work polar maps stratified by TyG index

AUC=0.725(95% CI: 0.622~0.828，最佳截断值为8.656，特异度为60.6%，灵敏度为75%，P < 0.001，图2A)。TyG指数是预测GWI降低的独立危险因素，AUC=0.697(95% CI: 0.595~0.799，最佳截断值为8.656，特异度为68.6%，灵敏度为69.2%，P=0.001，图2B)。TyG指数是预测GCW降低的独立危险因素

表3 GLS、GWI及GCW的潜在风险因素的相关性检验

Table 3 Correlation analysis of potential risk factors with GLS，GWI，and GCW

Clinical parameters	GLS		GWI		GCW	
	r	*P*	*r*	*P*	*r*	*P*
TyG	0.490	<0.001	−0.432	<0.001	−0.431	<0.001
Age	−0.299	0.002	0.268	0.006	0.196	0.047
Sex	−0.458	<0.001	0.308	0.002	0.299	0.002
Height	0.444	<0.001	−0.281	0.004	−0.280	0.004
Weight	0.542	<0.001	−0.371	<0.001	−0.380	<0.001
BSA	0.528	<0.001	−0.358	<0.001	−0.365	<0.001
BMI	0.426	<0.001	−0.314	0.001	−0.324	0.001
SBP	0.169	0.088	0.475	<0.001	0.531	<0.001
DBP	0.235	0.017	0.285	0.004	0.313	0.001
TG	0.403	<0.001	−0.369	<0.001	−0.360	<0.001
FPG	0.344	<0.001	−0.232	0.018	−0.251	0.011
TC	0.291	0.003	−0.261	0.008	−0.252	0.011
HDL-C	−0.232	0.018	0.217	0.027	0.208	0.035
LDL-C	0.270	0.006	−0.240	0.015	−0.235	0.017

AUC=0.683（95%CI为0.580~0.787，最佳截断值为8.656，特异度为66.7%，灵敏度为67.3%，*P*=0.001，图2C）。

3 讨 论

本研究通过横断面分析揭示了TyG指数与亚临床左心室功能障碍的独立关联，表明TyG指数升高与GLS降低、左室整体做功指数（GWI、GCW）下降显著相关。这一发现为代谢紊乱与早期心血管功能损害的病理生理机制提供了新的证据，并提示TyG指数可作为亚临床左心室功能障碍的潜在生物标志物，具有重要的临床意义。

TyG指数作为胰岛素抵抗的替代指标，近年来已被多项研究证实与动脉粥样硬化、心肌肥厚及心

表4 TyG指数与GLS、GWI及GCW相关参数的多因素Logistic回归分析

Table 4 Multivariate logistic regression analysis of TyG index with GLS，GWI，and GCW parameters

Parameter	Model	*B*	OR	95%CI	*P*
TyG-GLS	Model 1	1.487	4.424	1.875−10.438	0.001
	Model 2	1.421	4.143	1.790−9.588	0.001
	Model 3	1.128	3.089	1.317−7.245	0.010
	Model 4	1.167	3.212	1.281−8.049	0.013
	Model 5	1.092	2.982	1.182−7.522	0.021
TyG-GWI	Model 1	1.227	3.411	1.626−7.154	0.001
	Model 2	1.216	3.372	1.580−7.196	0.002
	Model 3	1.210	3.354	1.482−7.591	0.004
	Model 4	1.200	3.321	1.382−7.985	0.007
	Model 5	1.153	3.168	1.302−7.706	0.011
TyG-GCW	Model 1	1.139	3.125	1.512−6.458	0.002
	Model 2	1.123	3.074	1.468−6.441	0.003
	Model 3	1.026	2.789	1.280−6.007	0.010
	Model 4	1.106	3.023	1.250−7.309	0.014
	Model 5	1.042	2.836	1.169−6.882	0.021

Model 1：crude model（unadjusted for any confounding factors）；Model 2：adjusted for age and sex；Model 3：Model 2 covariates+body mass index（BMI）and body surface area（BSA）；Model 4：Model 3 covariates+systolic blood pressure（SBP）and diastolic blood pressure（DBP）；Model 5：Model 4 covariates+metabolic indicators such as TC，LDL-C，and HDL-C.

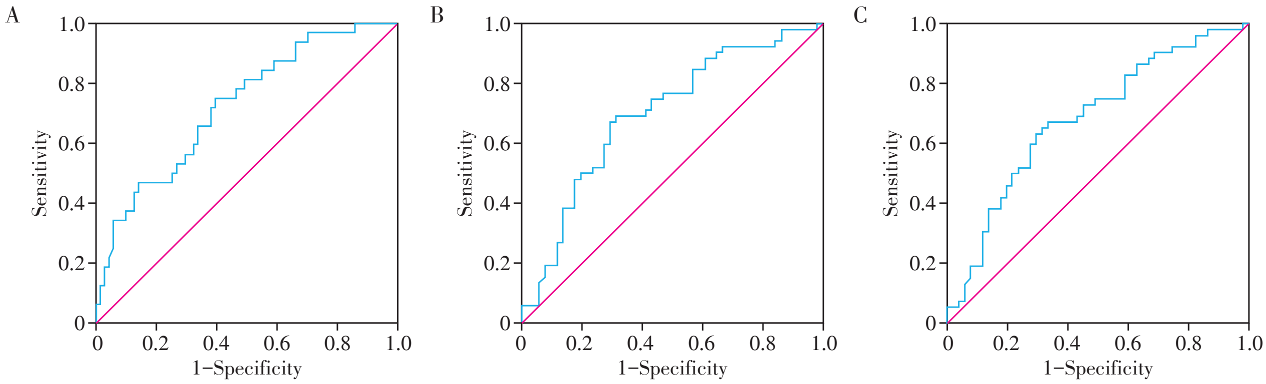


图2　TyG预测GLS（A）、GWI（B）及GCW（C）降低的ROC曲线分析

Figure 2　ROC curves of TyG index for predicting reduced GLS（A），GWI（B），and GCW（C）

血管事件风险密切相关[4,12]。本研究进一步扩展了其应用范围，首次系统评估了TyG指数与左心室整体应变及做功参数的关系。结果显示，高TyG指数组患者的GLS、GWI及GCW显著低于低TyG指数组，且在多因素调整后，TyG指数升高仍为亚临床左室功能障碍的独立危险因素。这一结果与Zhang等[13]的横断面研究一致，其发现TyG指数升高与左室舒张功能异常相关，但本研究进一步通过心肌做功参数（GWI、GCW）量化了收缩功能的亚临床损害，揭示了代谢异常对心肌力学特性的直接影响。

目前评价左心室收缩功能的参数有LVEF、室壁运动积分指数等，但这些参数受图像质量、观测者主观性影响较大，易出现测量误差。大量研究证实斑点追踪技术（speckle tracking echocardiography，STE）具有较高的重复性和准确性[14-15]，能先于传统超声心动图检测出早期心功能的亚临床改变[16]，但易受后负荷的影响。无创压力应变技术（pressure strain loop，PSL）作为近年来超声心动图的新技术，可无创、定量评价心肌收缩功能及心肌做功。PSL是在斑点追踪的基础上，通过GLS与无创袖臂血压相结合得出左室心肌做功各项参数，这些参数包括GWI、GCW、GWW及GWE。该技术能够克服后负荷的影响，客观准确地评估左心室整体及局部做功情况，优于传统的LVEF及斑点追踪技术，为临床左心功能的评估提供了新方法[17]。

TyG指数与左心室功能障碍的关联可能通过以下机制实现：①代谢紊乱介导的心肌损伤。高TyG指数反映的糖脂代谢异常可激活氧化应激和炎症通路，促进心肌纤维化及线粒体功能障碍[18-19]，导致心肌应变能力下降。此外，游离脂肪酸的过度积累（脂毒性）可能直接损害心肌细胞膜完整性，干扰钙离子稳态，从而降低左室收缩效率[20-21]。②胰岛素抵抗的直接作用。IR状态下，心肌细胞对葡萄糖的摄取受限，转而依赖脂肪酸β-氧化供能，这一过程不仅增加活性氧生成，还可导致能量代谢失衡，进而降低心肌做功效率[22-23]。本研究结果中GWI及GCW的显著下降可能与此机制密切相关。③血流动力学负荷与心肌重构。高TyG指数组患者合并高血压、肥胖的比例更高，提示容量负荷增加和室壁应力升高可能通过心肌肥厚及间质纤维化加重心功能损害[24]。然而，即使调整血压和BMI后，TyG指数仍与亚临床左室功能障碍独立相关，提示其作用机制部分独立于传统血流动力学因素。

本研究的创新性在于整合代谢标志物（TyG指数）与超声心动图新技术（心肌应变及做功分析），为亚临床左心功能障碍的早期识别提供了新思路。相比传统LVEF，GLS及心肌做功参数对细微心功能变化的敏感性更高[11,17]，而TyG指数作为一种简便、低成本的代谢指标，可联合超声技术用于高危人群的筛查。例如，本研究发现对于TyG指数≥8.656的个体，即使LVEF正常，也需警惕亚临床左心功能异常，并早期启动生活方式干预或代谢管理，以延缓心力衰竭进展。

本研究存在以下局限性：①样本量较小且为单中心横断面研究，难以明确TyG指数与左室功能障碍的因果关系，未来需通过多中心队列研究验证其纵向关联；②未纳入饮食结构、体力活动及降糖/降脂药物使用等潜在混杂因素，可能影响结果的准确性；③GWI与GCW的异常界值采用队列中位数而非临床金标准。未来需通过大样本队列建立心肌做功参数的诊断截点，并与心血管硬终点事件关联验证。

综上所述，本研究发现TyG指数升高是亚临床左心室功能障碍的独立危险因素，为代谢性心血管疾病的早期风险评估提供了新依据，潜在支持在临

床实践中将TyG指数纳入心血管风险分层体系,以优化高危人群的管理策略。

利益冲突声明:

所有作者声明无利益冲突。

Conflict of Interests:

All authors declare no conflict of interests.

作者贡献声明:

陈超负责试验设计、数据收集、数据分析、论文撰写全过程深度参与;陶炜伟负责部分样本数据分析;陆美娟负责少部分样本数据分析;何安霞负责数据分析指导及论文撰写指导;刘加宝参与制定研究计划、论文撰写以及对整个研究工作负责。

Author's Contributions:

CHEN Chao was deeply involved in the whole process of experiment design, data collection, data analysis, and paper writing; TAO Weiwei was responsible for part of sample data analysis; LU Meijuan was responsible for a small part of sample data analysis; HE Anxia was responsible for guidance in data analysis and paper writing; LIU Jiabao participated in research planning, paper writing, and oversaw the entire research work.

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