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在线全文

早发型2型糖尿病患者代谢特征及微血管并发症预测模型*

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【摘要】 **目的** 本文旨在探讨早发型2型糖尿病（early-onset type 2 diabetes mellitus, EOT2DM）患者的代谢特征，并建立微血管并发症的风险预测模型。**方法** 回顾性收集2020年4月–2024年4月入院治疗的980例2型糖尿病患者，根据诊断年龄将患者分为两组：早发组（诊断年龄<40岁，n=265）和晚发组（诊断年龄≥40岁，n=715），比较两组间代谢指标的差异。进一步将早发组患者根据微血管并发症发生情况分为并发症组（n=142）和无并发症组（n=123），收集并比较两组患者的基线特征、代谢参数及实验室指标。采用多因素logistic回归分析确定微血管并发症的独立危险因素，并构建列线图预测模型。通过受试者工作特征（recciver operating characteristic, ROC）曲线评估模型的判别能力，采用校准曲线和Hosmer-Lemeshow检验评价模型的校准度，同时绘制决策曲线分析（decision-curve analysis, DCA）评估模型的临床实用性。**结果** 与晚发组相比，早发组患者表现出更显著的代谢异常，包括更高的体质量指数（body mass index, BMI）、糖尿病家族史比例、糖化血红蛋白（glycosylated hemoglobin, HbA1c）水平、总胆固醇（total cholesterol, TC）、甘油三酯（triglyceride, TG）、低密度脂蛋白胆固醇（low-density lipoprotein cholesterol, LDL-C）、甘油三酯-葡萄糖指数（triglyceride glucose Index, TyG）和乳酸脱氢酶（lactate dehydrogenase, LDH）水平（均P<0.05），但病程较短且高密度脂蛋白胆固醇（high density lipoprotein cholesterol, HDL-C）水平较低（P<0.05）。多因素分析显示，收缩压（systolic arterial pressure, SBP）、总胆红素（total bilirubin, TBIL）、HDL-C、LDL-C、TyG和LDH是EOT2DM患者发生微血管并发症的独立影响因素。基于这些因素建立的预测模型为：Log(P)=－19.915+0.017×SBP－0.136×TBIL－1.241×HDL-C+0.684×LDL-C+0.769×TyG+0.050×LDH。ROC曲线下面积（area under the curve, AUC）为0.864（95%置信区间：0.820～0.907），Hosmer-Lemeshow检验显示良好的拟合优度（χ^2=10.286, P=0.246），DCA曲线斜率亦均接近1。**结论** 基于收缩压、TBIL、HDL-C、LDL-C、TyG和LDH建立的列线图预测模型对微血管并发症具有良好的预测效能，可为临床风险分层和个体化干预提供参考依据。

【关键词】 早发型2型糖尿病 微血管并发症 代谢特征 风险预测 列线图模型

Metabolic Characteristics of Patients With Early-Onset Type 2 Diabetes Mellitus and a Risk Prediction Model for Microvascular Complications

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[**Abstract**] **Objective** To investigate the metabolic characteristics of patients with early-onset type 2 diabetes mellitus (T2DM) and to develop a risk prediction model for microvascular complications. **Methods** A retrospective study was conducted on 980 T2DM patients admitted for treatment between April 2020 and April 2024. Based on age at diagnosis, the patients were divided into two groups, an early-onset T2DM group (age at diagnosis < 40 years, n = 265) and a late-onset T2DM group (age at diagnosis ⩾ 40 years, n = 715). Differences in metabolic indicators between the two groups were compared. Patients in the early-onset group were further divided into a complication subgroup (n = 142) and a non-complication subgroup (n = 123) based on the presence or absence of microvascular complications. Data on baseline characteristics, metabolic parameters, and laboratory indicators were collected and compared between the two groups. Multivariate logistic regression analysis was used to identify independent risk factors for microvascular complications, and a nomogram prediction model was constructed. The model's discriminative performance was assessed using receiver operating characteristic (ROC) curves, and its calibration was evaluated using calibration curves and the Hosmer-Lemeshow test. Decision curve analysis (DCA) was also performed to assess the model's clinical utility. **Results** Compared with the late-onset group, patients in the early-onset group exhibited more pronounced metabolic

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abnormalities, including higher body mass index (BMI), proportion of family history of diabetes mellitus, glycated hemoglobin (HbA1c) levels, total cholesterol (TC), triglycerides (TG), low-density lipoprotein cholesterol (LDL-C), triglyceride-glucose index (TyG), and lactate dehydrogenase (LDH) levels (all $P < 0.05$), along with a shorter disease duration and lower levels of high-density lipoprotein cholesterol (HDL-C) ($P < 0.05$). According to a multivariate analysis, systolic blood pressure (SBP), total bilirubin (TBIL), HDL-C, LDL-C, TyG, and LDH were identified as independent risk factors for microvascular complications in patients with early-onset T2DM. A predictive model based on these factors was established as the follows, $\mathrm{Log}(P) = -19.915 + 0.017 \times \mathrm{SBP} - 0.136 \times \mathrm{TBIL} - 1.241 \times \mathrm{HDL\text{-}C} + 0.684 \times \mathrm{LDL\text{-}C} + 0.769 \times \mathrm{TyG} + 0.050 \times \mathrm{LDH}$. The area under the ROC curve (AUC) was 0.864 (95% CI, 0.820-0.907), and the Hosmer-Lemeshow test indicated good model fit ($\chi^2 = 10.286$, $P = 0.246$). The slope of the DCA curve was also close to 1. **Conclusion** The nomogram prediction model based on SBP, TBIL, HDL-C, LDL-C, TyG, and LDH demonstrates good predictive performance for microvascular complications and can provide a reference for clinical risk stratification and individualized intervention.

[Key words] Early-onset type 2 diabetes mellitus Microvascular complications Metabolic characteristics Risk prediction Nomogram model

2型糖尿病(type 2 diabetes mellitus, T2DM)是一种全球流行的代谢性疾病,对公共卫生构成重大挑战[1]。过去,T2DM主要影响中老年人群中(患病率约11.6%),然而近年来,早发型T2DM(诊断年龄< 40岁)的发病率显著上升,日益受到学界关注[2]。与晚发型T2DM相比,早发型患者在病理生理机制、代谢特征及并发症进展方面均表现出显著差异。现有证据表明,早发型T2DM患者更早出现严重的代谢紊乱,包括胰岛素抵抗增强、脂质代谢失调和肥胖倾向等[3]。这些代谢异常可加速微血管并发症(如糖尿病视网膜病变、肾病和神经病变)的发生发展,成为导致患者不良预后的关键因素[4-5]。因此,早期识别并进行干预显得尤为重要。

目前,T2DM的临床管理主要依赖血糖监测,然而,鉴于代谢调控的复杂性,单一血糖指标难以全面反映疾病进展。研究发现,除血糖控制外,脂代谢异常、胰岛素敏感性降低及慢性炎症状态等均与微血管并发症风险显著相关[6]。因此,系统评估早发型T2DM患者的代谢特征,并阐明其与微血管并发症的关联机制,对于优化个体化治疗策略具有重要临床价值。列线图作为一种多因素预测工具,能够整合关键风险因素的权重,提供可视化的风险评估模型[7]。基于此,构建早发型T2DM微血管并发症的列线图预测模型,有望实现风险分层、早期干预和精准化管理。

本研究拟通过系统分析早发型T2DM患者的代谢特征,探究其与微血管并发症的关联性,并建立列线图预测模型,以期为临床实践提供可靠的决策支持工具,最终改善患者预后并降低并发症负担。

1 资料与方法

1.1 研究对象

回顾性收集2020年4月–2024年4月在入院治疗的980例T2DM患者,根据国际糖尿病联盟(IDF)年龄分层标准[8],以40岁为界将患者分为两组:早发组(诊断年龄< 40岁,n= 265)和晚发组(诊断年龄≥40岁,n= 715)。纳入标准:①符合T2DM诊断标准[9];②微血管并发症诊断参考《基层糖尿病微血管病变筛查与防治专家共识(2021年版)》[10];③具有完整糖尿病病史记录且病程≥1年。排除标准包括:①合并其他严重疾病(如急性或慢性肝肾功能不全、恶性肿瘤、心脏病等);②1型糖尿病、妊娠期糖尿病或其他代谢性疾病(如胰岛素抵抗综合征);③基础代谢数据或微血管并发症评估数据缺失者。本研究方案经医院伦理委员会审核批准(批件号:2024KY0117-KS002),豁免知情同意,全程遵循《赫尔辛基宣言》伦理准则[11]。

1.2 方法

1.2.1 临床资料收集

收集早发组、晚发组患者的人口学特征(包括年龄、糖尿病病程、糖尿病家族史)及人体测量学参数(身高、体质量),并采用标准化流程进行代谢指标检测:所有受试者禁食8 h后,于晨间采集肘静脉血5 mL进行实验室分析,具体包括:(1)采用高效液相色谱法(HPLC)定量检测糖化血红蛋白(glycosylated hemoglobin, HbA1c);(2)应用全自动生化分析仪测定空腹血糖(fasting plasma glucose, FPG,己糖激酶法)和餐后2 h血糖(two hours postprandial blood glucose, 2 h PG);(3)血脂谱检测:总胆固醇(total cholesterol, TC)(胆固醇氧化酶法)、高密度脂蛋白胆固醇(high density lipoprotein cholesterol, HDL-C)和低密度脂蛋白胆固醇(low-density lipoprotein cholesterol, LDL-C)(均采用直接清除法)、甘油三酯(triglyceride, TG)(酶比色法),并据此计算甘油三酯-葡萄糖指数(triglyceride glucose index, TyG);(4)同时检测血清肌酐(serum

creatinine, SCr)和乳酸脱氢酶(lactate dehydrogenase, LDH)水平。

1.2.2 回顾性队列设计与模型构建

基于微血管并发症发生状态,将早发型T2DM患者(n= 265)分为并发症组(n= 142)与无并发症组(n= 123)。比较两组间基线资料、代谢及实验室指标差异,通过多因素logistic回归筛选独立预测因子,构建微血管并发症列线图预测模型。

依据多因素分析样本量标准(变量数的10 ~ 20倍),考虑10%的脱落率,本研究所需的最小样本量为: n= (20×10)/(1—10%)= 222,最终本研究纳入265例早发型患者。

1.3 统计学方法

SPSS 26.0分析数据。正态分布数据以$\bar{x} \pm s$表示,组间比较采用独立样本t检验;计数资料以例数(%)表示,组间比较采用χ^2检验;通过多因素logistic回归分析方法筛选早发型T2DM患者微血管并发症的独立危险因素;采用R语言、rms程序包建立列线图预测模型,采用受试者工作特征(recciver operating characteristic, ROC)曲线下面积(area under the curve, AUC)及95%置信区间(confidence interval, CI)评价列线图的区分度,绘制校正曲线以及进行Hosmer-Lemeshow拟合优度检验,进行决策曲线分析(decision-curve analysis, DCA)评估模型净获益值。P< 0.05为差异有统计学意义。

2 结果

2.1 早发型与晚发型T2DM患者临床特征比较

在性别分布、收缩压(systolic blood pressure, SBP)、舒张压(diastolic blood pressure, DBP)、同型半胱氨酸(homocysteine, Hcy)、总胆红素(total bilirubin, TBIL)、FPG及2 h PG水平的差异均无统计学意义(均P> 0.05)。然而,早发型组体质量指数(body mass index, BMI)、家族史比例、HbA1c以及TC、TG、LDL-C、TyG、LDH高于晚发组,病程与HDL-C水平低于晚发组(均P< 0.05)。见表1。

表 1　早发与晚发T2DM患者临床特征比较

Table 1　Comparison of clinical characteristics between patients with early-onset and late-onset T2DM

Indicator	Early-onset group (n = 265)	Late-onset group (n = 715)	t/χ^2	P
Age/yr., $\bar{x} \pm s$	34.35 ± 4.84	50.32 ± 8.16	29.960	< 0.001
Sex/case (%)			2.789	0.095
Male	177 (66.79)	436 (60.98)		
Female	88 (33.21)	279 (39.02)		
BMI/(kg/m^2), $\bar{x} \pm s$	25.11 ± 3.23	24.65 ± 3.08	2.049	0.041
Course of disease/year, $\bar{x} \pm s$	7.12 ± 3.41	8.72 ± 3.86	5.943	0.000
Family history/case (%)	137 (51.70)	275 (38.46)	13.902	0.000
Systolic blood pressure/mmHg, $\bar{x} \pm s$	134.64 ± 21.12	137.22 ± 21.36	1.685	0.092
Diastolic blood pressure/mmHg, $\bar{x} \pm s$	81.99 ± 12.98	80.43 ± 13.05	1.665	0.096
Hcy/(μmol/L), $\bar{x} \pm s$	9.28 ± 1.60	9.16 ± 1.51	1.087	0.277
TBIL/(μmol/L), $\bar{x} \pm s$	16.16 ± 3.71	16.34 ± 3.62	0.782	0.435
HbA1c/%, $\bar{x} \pm s$	9.38 ± 2.44	8.69 ± 2.35	4.040	0.000
FPG/(mmol/L), $\bar{x} \pm s$	9.30 ± 3.31	8.92 ± 2.76	1.810	0.071
2 h PG/(mmol/L), $\bar{x} \pm s$	14.56 ± 4.59	14.35 ± 4.60	0.635	0.526
TC/(mmol/L), $\bar{x} \pm s$	4.69 ± 1.54	4.26 ± 1.23	4.627	0.000
TG/(mmol/L), $\bar{x} \pm s$	1.70 ± 0.82	1.33 ± 0.67	7.210	0.000
HDL-C/(mmol/L), $\bar{x} \pm s$	0.98 ± 0.26	1.13 ± 0.34	6.510	0.000
LDL-C/(mmol/L), $\bar{x} \pm s$	2.68 ± 0.85	2.51 ± 0.82	2.854	0.004
TyG ($\bar{x} \pm s$)	9.15 ± 0.38	8.68 ± 0.26	21.989	0.000
Scr/(μmol/L), $\bar{x} \pm s$	65.78 ± 12.99	65.07 ± 13.44	0.741	0.459
LDH/(U/L), $\bar{x} \pm s$	255.36 ± 38.96	216.84 ± 35.66	14.642	0.000

BMI: body mass index; Hcy: homocysteine; TBIL: total bilirubin; HbA1c: glycosylated hemoglobin; FPG: fasting plasma glucose; 2 h PG: two hours postprandial blood glucose; TC: total cholesterol; TG: triglyceride; HDL-C: high density lipoprotein cholesterol; LDL-C: low-density lipoprotein cholesterol; TyG: triglyceride glucose index; Scr: serum creatinine; LDH: lactate dehydrogenase. 1 mmHg = 0.133 kPa.

2.2 早发型T2DM患者微血管并发症组与非并发症组基线特征比较

并发症组与非并发症组患者年龄、性别、学历、婚姻状况、BMI、糖尿病病程、舒张压、Hcy、HbA1c、2 h PG、TC、Scr差异无统计学意义(均$P>0.05$)。但居住地分布、糖尿病家族史比例、收缩压、TBIL、HDL-C、LDL-C、TyG以及LDH组间具有统计学意义(均$P<0.05$)。见表2。

2.3 logistic回归分析早发型T2DM微血管并发症的危险因素

以微血管并发症状态(发生组=1,未发生组=0)为因变量,将单因素分析中差异显著的变量〔居住地(农村=1,城市=2),家族史(有=1,无=0),收缩压、TBIL、HDL-C、LDL-C、TyG、LDH均为连续变量以原始值代入〕作为协变量纳入二元logistic回归模型。结果显示,以下6项指标是早发型T2DM患者微血管并发症的独立危险因素(均$P<0.05$)。最终预测模型的logit(P)表达式为Log(P)= −19.915+0.017×收缩压−0.136×TBIL−1.241×HDL-C+0.684×LDL-C+0.769×TyG+0.050×LDH。见表3。

2.4 列线图模型建立及验证

基于logistic回归分析结果,构建早发型T2DM微血管并发症风险预测列线图(图1)。ROC曲线下面积为0.864(95%CI: 0.820 ~ 0.907),见图2;校准曲线显示预测概

表 2 早发T2DM患者基线与临床资料对比

Table 2 Comparison of baseline and clinical data in patients with early-onset T2DM

Indicator	Occurrence group (n = 142)	Non-occurrence group (n = 123)	t/χ^2	P
Age/yr., $\bar{x}\pm s$	34.02 ± 4.06	34.49 ± 4.19	1.573	0.116
Sex/case (%)			3.354	0.067
Male	108 (76.06)	81 (65.85)		
Female	34 (23.94)	42 (34.15)		
BMI/(kg/m^2), $\bar{x}\pm s$	24.99 ± 3.03	25.31 ± 3.12	0.846	0.399
Course of disease/year, $\bar{x}\pm s$	7.03 ± 3.21	7.15 ± 3.07	0.310	0.757
Educational attainment/case (%)			5.832	0.054
College and above	43 (30.28)	26 (21.14)		
High school/Middle school	34 (23.94)	45 (36.59)		
Junior high school and below	65 (45.77)	52 (42.28)		
Place of residence/case (%)			9.134	0.003
Rural	83 (58.45)	49 (39.84)		
Urban	59 (41.55)	74 (60.16)		
Marital status/case (%)			1.689	0.430
Married	82 (57.75)	79 (64.23)		
Single	27 (19.01)	23 (18.70)		
Widowed	33 (23.24)	21 (17.07)		
Family history/case (%)	81 (57.04)	48 (39.02)	8.565	0.003
Systolic blood pressure/mmHg, $\bar{x}\pm s$	133.57 ± 20.68	126.31 ± 21.47	2.800	0.006
Diastolic blood pressure/mmHg, $\bar{x}\pm s$	82.89 ± 11.69	83.94 ± 12.88	0.696	0.487
Hcy/(μmol/L), $\bar{x}\pm s$	9.26 ± 1.47	9.43 ± 1.55	0.915	0.361
TBIL/(μmol/L), $\bar{x}\pm s$	15.02 ± 3.16	16.88 ± 3.56	4.506	0.000
HbA1c/%, $\bar{x}\pm s$	9.45 ± 2.63	9.27 ± 2.34	0.585	0.559
2 h PG/(mmol/L), $\bar{x}\pm s$	15.08 ± 4.43	14.17 ± 4.12	1.723	0.086
TC/(mmol/L), $\bar{x}\pm s$	4.78 ± 1.10	4.59 ± 1.06	1.426	0.155
HDL-C/(mmol/L), $\bar{x}\pm s$	0.92 ± 0.38	1.13 ± 0.41	4.325	0.000
LDL-C/(mmol/L), $\bar{x}\pm s$	2.83 ± 0.91	2.37 ± 0.80	4.339	0.000
TyG ($\bar{x}\pm s$)	9.18 ± 0.52	8.97 ± 0.45	3.488	0.001
Scr/(μmol/L), $\bar{x}\pm s$	63.97 ± 10.90	66.45 ± 11.08	1.833	0.068
LDH/(U/L), $\bar{x}\pm s$	265.37 ± 21.36	241.75 ± 23.61	8.549	0.000

The abbreviations are explained in the note to Table 1.

表 3　logistic回归分析早发型T2DM微血管并发症的危险因素

Table 3　Logistic regression analysis of risk factors for microvascular complications in patients with early-onset T2DM

Factor	*B*	SE	Wald	*P*	Odds ratio (95% CI)
Place of residence	−0.350	0.551	0.404	0.525	0.705 (0.239-2.075)
Family history	0.663	0.558	1.411	0.235	1.941 (0.650-5.793)
Systolic blood pressure	0.017	0.008	4.752	0.029	1.017 (1.002-1.032)
TBIL	−0.136	0.048	7.841	0.005	0.873 (0.794-0.960)
HDL-C	−1.241	0.414	8.982	0.003	0.289 (0.128-0.651)
LDL-C	0.684	0.198	11.949	0.001	1.982 (1.345-2.922)
TyG	0.769	0.331	5.391	0.020	2.157 (1.127-4.127)
LDH	0.050	0.008	36.672	0.000	1.052 (1.035-1.069)
Constant	−19.915	4.131	23.243	0.000	

The abbreviations are explained in the note to Table 1. *B*: partial regression coefficifent; SE: standard error.

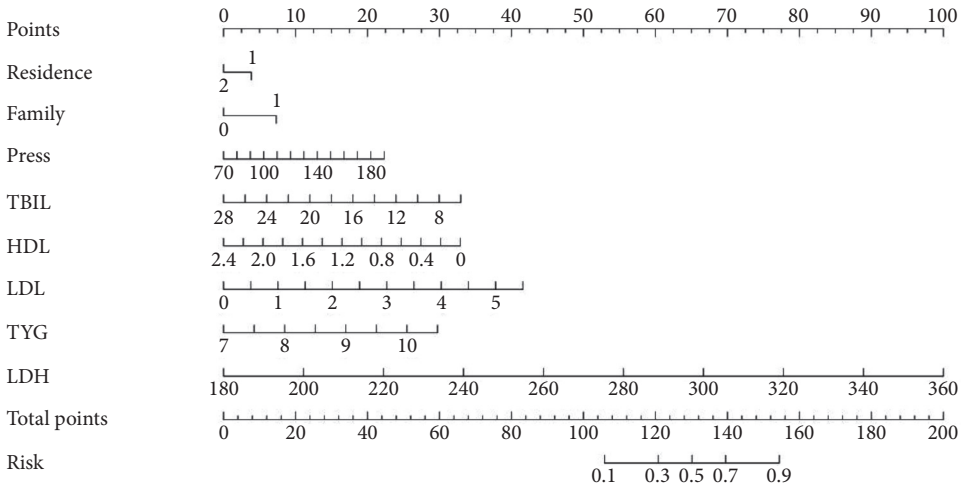

图 1　基于logistic回归分析构建早发型T2DM微血管并发症风险预测列线图

Fig 1　Constructing a risk prediction curve for microvascular complications in early-onset type 2 diabetes mellitus based on logistic regression analysis

The abbreviations are explained in the note to Table 1.

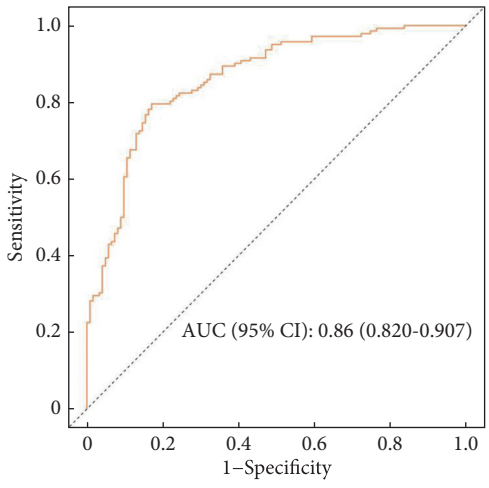

图 2　风险预测模型预测早发型T2DM患者微血管并发症的ROC曲线

Fig 2　ROC curve for the risk prediction model of microvascular complications in patients with early-onset T2DM

AUC: area under curve.

率与实际概率高度吻合(图3); Hosmer-Lemeshow拟合度检验(χ^2= 10.286, *P*= 0.246)证实模型校准误差无统计学意义。预测模型的DCA曲线斜率接近1, 亦进一步证实了列线图模型的预测效能(图4)。

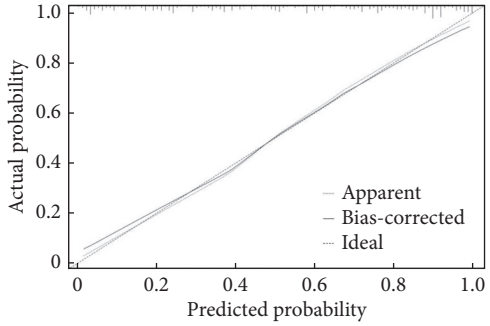

图 3　风险预测模型预测早发型T2DM患者微血管并发症的校准曲线

Fig 3　Calibration curve of the risk prediction model for microvascular complications in patients with early-onset T2DM

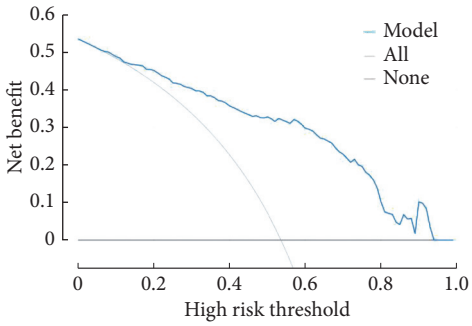

图 4 风险预测模型预测早发型T2DM患者微血管并发症的决策分析曲线

Fig 4 Decision analysis curve for the risk prediction model of microvascular complications in patients with early-onset T2DM

3 讨论

T2DM患者在疾病早期即表现出显著的血糖波动和微血管损伤特征，同时伴有进行性β细胞功能减退，这一病理过程导致患者对外源性胰岛素治疗的依赖性显著增加[12]。临床观察表明，若血糖控制不佳，此类患者微血管并发症的发生时间明显提前，其严重后果包括但不限于视力丧失、终末期肾病需透析治疗、外周血管病变导致截肢等，最终造成显著的致残率和死亡率上升[13]。基于这一临床背景，本研究系统分析了早发型T2DM患者的代谢特征谱，并构建了微血管并发症的风险预测模型，以期早期识别高危患者并指导临床干预。

本研究结果显示，早发型T2DM组与晚发型组患者的BMI、糖尿病家族史比例、HbA1c水平，以及TC、TG、LDL-C、TyG和LDH水平均明显高于晚发型组；而糖尿病病程和HDL-C水平则明显低于晚发型组。这些发现提示早发型T2DM患者具有独特的代谢特征，其可能的病理生理机制包括：早发型患者BMI显著升高，肥胖作为胰岛素抵抗的重要诱因，迫使胰岛β细胞代偿性增加胰岛素分泌以维持血糖稳态。长期代谢压力最终导致β细胞功能进行性衰退，这可能是早发型糖尿病发生的关键机制[14-15]。其次，较高的家族史比例凸显了遗传因素在早发型T2DM发病中的重要作用，这一发现与宋江南等[16]等的研究结果一致，提示对于有糖尿病家族史的年轻人群，应实施更积极的早期筛查和生活方式干预策略。另外，早发型患者表现出更显著的β细胞功能衰退和胰岛素抵抗，这种双重缺陷导致长期慢性高血糖状态，反映在HbA1c水平的显著升高[17]。胰岛素抵抗状态引发脂肪组织分解增加、肝脏甘油三酯合成亢进以及脂蛋白代谢障碍，最终形成以高TG、高LDL-C和低HDL-C为特征的致动脉粥样硬化性血脂谱[18]。

本研究通过多因素分析确定了收缩压、TBIL、HDL-C、LDL-C、TyG以及LDH为早发型T2DM患者微血管并发症的危险因素。这些指标通过不同病理生理机制参与微血管病变的发生发展。升高的SBP与慢性高血糖产生协同效应。高血糖通过晚期糖基化终末产物改变血管壁结构，而高血压则施加持续的机械应力，共同导致血管内皮细胞损伤、功能障碍及通透性增加，最终促进微血管并发症的发生[19-20]。血清TBIL作为内源性抗氧化剂，其水平降低将削弱对血管内皮的抗氧化保护，使内皮细胞更易受到氧化应激损伤[21-23]。同时，低水平HDL-C会减弱其抗炎和抗氧化功能，进一步损害内皮细胞的修复能力[24-25]。此外，升高的LDL-C，尤其是氧化型LDL，可直接损伤血管内皮，激活炎症反应[26]。

为了检验微血管并发症的危险因素的预测价值，本研究利用R软件绘制了列线图预测模型并展现出良好的预测效能，ROC曲线下面积达到0.864（95%CI：0.820～0.907），且校准曲线显示预测概率与实际概率高度吻合（Hosmer-Lemeshow检验P> 0.05）。同时，DCA曲线斜率接近1，亦进一步证实了列线图模型的预测效能。模型参数分析表明，家族史阳性、收缩压升高、LDL-C和TyG指数增高以及LDH水平上升是微血管并发症的独立危险因素，而TBIL和HDL-C水平降低则具有保护作用。这些发现提示，在临床实践中对早发型T2DM患者进行微血管并发症风险评估时，应当综合考虑血压、血脂谱（包括LDL-C、HDL-C和TyG指数）、LDH及TBIL等多维度指标，实施个体化的综合管理策略。

综上所述，本次研究构建的T2DM患者发生微血管并发症的列线图模型为临床提供了可视化的风险评估工具，有助于早期识别高风险患者并指导个体化干预。但作为一项回顾性研究，本研究仍存在以下局限性，未系统纳入高血压、肥胖等共病对代谢特征的干扰，可能混淆模型中糖尿病特异性标志物的效应，且研究样本量较小，可在后续的研究中适当扩大样本量，建立针对早发型人群的长期队列，整合多组学数据，并通过外部验证提升模型的普适性与临床转化价值。

* * *

作者贡献声明 王艳艳负责论文构思、数据审编、调查研究和初稿写作，江华负责论文构思、经费获取、研究方法和验证，吕欣、荆丹清和刘佳佳负责正式分析和审读与编辑写作，王聪、赵悦和魏泳钰负责数据审编和调查研究，郑蕾负责正式分析、监督指导、验证、可视化和审读与编辑写作。所有作者已经同意将文章提交本刊，且对将要发表的版本进行最终定稿，并同意对工作的所有方面负责。

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