



在线全文

四川省三县(市)成年居民肥胖与血脂异常关联研究*

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【摘要】目的 探讨四川省三县(市)成年居民肥胖与血脂异常关联,揭示体质指数(body mass index, BMI)和腰围(waist circumference, WC)与血脂异常风险之间可能存在的非线性剂量-反应关系,为制定精准体重管理策略提供实证依据。**方法** 本研究以四川省三县(市)作为研究现场。在每个县(市)内,采用多阶段整群随机抽样方法抽取社区(乡镇)、家庭及调查对象。调查于2023年开展,共纳入11 561名18岁及以上常住居民。通过二元logistic回归模型分析不同肥胖类型与血脂异常的关联,采用限制性立方样条(restricted cubic spline, RCS)模型,探讨BMI与WC及血脂异常之间的剂量-反应关系,模型优度以AIC值评估。**结果** 研究对象血脂异常检出率29.07%,超重检出率33.50%,肥胖检出率11.95%,腹型肥胖检出率29.79%。Logistic回归分析显示,调整混杂因素后,与正常体重者相比,肥胖[比值比(odds ratio, OR)=1.22, 95%置信区间(confidence interval, CI): 1.05 ~ 1.42]和腹型肥胖(OR=1.23, 95%CI: 1.11 ~ 1.36)与血脂异常呈正相关。性别分层后,女性人群中腹型肥胖与血脂异常之间的关联更为明显(OR=1.36, 95%CI: 1.18 ~ 1.57)。RCS模型进一步揭示, BMI与血脂异常呈J型曲线关系,拐点BMI=24.87 kg/m²; WC与血脂异常呈S型曲线关系,拐点WC=86 cm,提示关联强度随指标增加呈非线性变化。**结论** 四川省三县(市)成年居民中,肥胖、腹型肥胖是血脂异常的独立关联因素,其关联性存在非线性和女性特异性。体重管理策略应重点关注肥胖、腹型肥胖,特别是女性腹型肥胖人群,并以BMI和WC的风险拐点作为早期干预的关键指标。

【关键词】 肥胖 腹型肥胖 血脂异常 体重管理

Association Between Obesity and Dyslipidemia Among Adults in Three Counties (Cities) of Sichuan Province

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[Abstract] Objective To investigate the association between obesity and dyslipidemia among adult residents in three counties (cities) of Sichuan Province, and to reveal the potential non-linear dose-response relationship between body mass index (BMI) and waist circumference (WC) and the risk of dyslipidemia, providing an empirical basis for developing precise weight management strategies. **Methods** This study was conducted in Dujiangyan City, Pujiang County, and Jiange County of Sichuan Province. A multi-stage cluster random sampling method was used to select communities (townships), households, and participants within each county (city). The survey was conducted in 2023 and included 11 561 permanent residents aged ≥18 years. A binary logistic regression model was used to analyze the association between different types of obesity and dyslipidemia. A restricted cubic spline (RCS) model was employed to explore the dose-response relationship between BMI, WC, and dyslipidemia, with the model's goodness of fit assessed by the AIC value. **Results** Among the study subjects, the prevalence of dyslipidemia was 29.07%, overweight was 33.50%, obesity was 11.95%, and abdominal obesity was 29.79%. Logistic regression analysis showed that, after adjusting for

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confounding factors, both obesity (odds ratio [OR] = 1.22, 95% CI: 1.05-1.42) and abdominal obesity (OR = 1.23, 95% CI: 1.11-1.36) were positively associated with dyslipidemia compared to individuals with normal weight. After stratification by gender, the association between abdominal obesity and dyslipidemia was more significant in females (OR = 1.36, 95% CI: 1.18-1.57). The RCS model further revealed that the relationship between BMI and dyslipidemia followed a J-shaped curve, with an inflection point at a BMI of 24.87 kg/m². The relationship between WC and dyslipidemia showed an S-shaped curve, with an inflection point at a WC of 86 cm. This indicates that the strength of the association changes non-linearly as the values of these indicators increase. **Conclusion** Among adult residents of three counties (or cities) in Sichuan Province, obesity and abdominal obesity are independently associated with dyslipidemia, and the association exhibits non-linearity and female specificity. Weight management strategies should focus on individuals with general and abdominal obesity, particularly females with abdominal obesity. The risk inflection points for BMI and WC should be used as key indicators for early intervention.

[Key words] Obesity Abdominal obesity Dyslipidemia Weight management

肥胖已成为我国重大公共卫生问题^[1]。四川作为人口大省,肥胖问题同样严峻。2024年四川省慢性病危险因素监测数据显示,18岁及以上居民超重率为34.58%,肥胖率12.21%,血脂异常率高达35.12%^[2]。大量流行病学证据表明,超重肥胖与血脂异常及心血管疾病等多种慢性病密切相关,且血脂异常又进一步加剧心血管疾病的发生和发展^[3-4]。因此,深入探讨四川省居民超重肥胖与血脂异常之间的关联特征,对于制定精准的体重管理策略、有效减轻慢性病负担具有重要的现实意义。

既往多数研究采用传统的线性分析方法,基于肥胖指标与血脂异常呈线性关系的假设进行分析,而实际上这种关系可能存在非线性模式,线性模型可能遗漏重要的阈值效应^[5];此外,既往研究多关注单一肥胖指标,对一般性肥胖和腹型肥胖与血脂异常关联的系统性比较相对不足^[6],对肥胖与血脂异常关联存在性别差异的机制探讨不充分,缺乏针对性别特异性关联模式的系统分析^[7]。针对上述研究不足,本研究在四川省三县(市)开展大样本调查,创新运用限制性立方样条模型(restricted cubic spline, RCS)深入探索体质量指数(body mass index, BMI)和腰围(waist circumference, WC)与血脂异常的非线性剂量-反应关系。RCS模型作为强有力的统计工具,能够有效表征连续暴露与结局之间的剂量-反应关联,直观地检验关联的线性假设,并最大限度地减少连续变量调整时的残余混杂。同时,本研究结合性别分层分析,系统阐明肥胖与血脂异常关联的性别差异特征,为制定基于风险阈值和性别特异性的精准体重管理策略提供科学依据,助力健康体重管理行动目标实现。

1 资料与方法

1.1 研究对象

以四川省成年居民为研究对象,兼顾区域代表性和

社会经济差异性,根据《2022年四川省国民经济和社会发展统计公报》^[8]选取全省经济水平排名1/21的成都市和排名16/21的广元市作为研究现场。综合考虑两市人口规模及资源配置差异,以“可达性”和“城乡分布均衡”为原则,在成都市选取两个县(市);在广元市选取1个县作为样本点。抽样过程采用多阶段分层整群随机抽样方法:首先,在每个县(市)内根据城乡分布进行分层;其次,在每层中随机抽取10个社区(乡镇)作为初级抽样单元;再次,在每个抽中的社区(乡镇)内抽取400户家庭;最后,采用最近生日法在每个抽中的家庭里选取1名符合条件的成员作为调查对象。调查于2023年6-11月开展。本研究已获得四川大学华西医院生物医学伦理委员会批准(2023年审[1742]号)。

1.2 样本量估计

本研究采用横断面调查样本量计算公式估算所需样本量。以2021年四川省人群健康状况及重点疾病报告的肥胖率(13.83%)^[9]为参考,设定 $p=0.10$ 。置信水平取95%(双侧),因此 $\alpha=0.05$, $u=1.96$ 。采用多阶段抽样,设计效应(deff)取值为2。允许的相对误差(r)设定为15%,则绝对误差 $d=r \times p=0.15 \times 0.10=0.015$ 。预估无应答率为15%。

样本量计算公式为:

$$N = \frac{\text{deff} \times u^2 \times p(1-p)}{d^2}$$

计算所需的基础样本量为:

$$N_{\text{base}} = \frac{2 \times 1.96^2 \times 0.10(1-0.10)}{0.015^2} \approx 3073$$

考虑15%的无应答率,调整后的最终样本量为:

$$N_{\text{final}} = \frac{N_{\text{base}}}{1-0.15} = \frac{3073}{0.85} \approx 3616$$

为达到本研究的检验效能,每县(市)需纳入3 616名研究对象。为保证各县(市)样本量的充足性以及应对潜

在的抽样偏差,本研究在每县(市)各抽取4 000名研究对象,共12 000人。

1.3 调查内容及方法

(1)调查内容:本研究以中国疾病预防控制中心统一制定的《中国慢性病及危险因素监测》(2018年版)^[10]标准问卷为调查工具,涵盖主要慢性疾病的患病、控制情况、家族史、吸烟、饮酒、饮食习惯、身体活动等健康行为信息。调查内容包括基本人口学特征、健康状况、体格检查及实验室检测指标如身高、体重、腰围和血脂等。其中,血脂检查由区县疾控中心组织当地医务人员现场采样,由二级以上医院使用全自动生化分析仪进行分析。该问卷作为国家慢病监测项目通用工具,已在全国范围广泛应用,具有良好的信效度。

(2)诊断标准:本研究采用《中国成人超重和肥胖症预防控制指南》中的判定标准对体重和腹型肥胖进行分类和定义^[11]。BMI $<18.5\text{ kg/m}^2$ 定义为低体重, $18.5\text{ kg/m}^2\leq\text{BMI}<24.0\text{ kg/m}^2$ 为正常体重, $24.0\text{ kg/m}^2\leq\text{BMI}<28.0\text{ kg/m}^2$ 为超重, BMI $\geq 28.0\text{ kg/m}^2$ 为肥胖;男性WC $\geq 90\text{ cm}$ 、女性WC $\geq 85\text{ cm}$ 判定为腹型肥胖。

根据《成人血脂异常诊疗指南(2016)》标准^[12],以下四项血脂指标中的任意出现一项均诊断为血脂异常:血清总胆固醇(total cholesterol, TC) $\geq 6.22\text{ mmol/L}$,血清甘油三酯(triglycerides, TG) $\geq 2.26\text{ mmol/L}$,血清高密度脂蛋白胆固醇(high-density lipoprotein cholesterol, HDL-C) $<1.04\text{ mmol/L}$,或血清低密度脂蛋白胆固醇(low-density lipoprotein cholesterol, LDL-C) $\geq 4.14\text{ mmol/L}$ 。

(3)纳入标准:所有研究对象必须满足以下条件:年龄 ≥ 18 岁,为四川省常住人口或居住时间 ≥ 6 个月;具备基本的理解能力并自愿参与调查;未患有严重急性疾病,能够配合问卷调查、体格检查及血液检测。

(4)排除标准:近1年内患有心肌梗死、脑卒中等严重急性疾病;既往确诊严重精神疾病或认知功能障碍的患者;孕妇、哺乳期女性;无法配合调查或拒绝参与的居民。

1.4 质量控制

研究团队全程质量控制,统一对调查员进行问卷填写、体检操作及偏倚控制培训并考核合格;现场核对调查时间、地点及人员信息;对数据进行逻辑核查、异常值与缺失值处理,连续变量采用分层均值插补,分类变量使用多重回归插补,剔除关键指标如血脂指标缺失或异常值的问卷。

1.5 统计学方法

采用SPSS 26.0进行统计分析。定性资料以频数和百

分比表示,组间比较使用 χ^2 检验;定量资料以 $\bar{x}\pm s$ 表示,组间比较采用独立样本 t 检验。采用二元logistic回归分析血脂异常与超重肥胖的关联,模型1未调整混杂因素,模型2调整了包括年龄、种族、文化程度、职业、婚姻状况及吸烟在内的混杂因素。混杂因素的选择基于现有文献证据和有向无环图(directed acyclic graph, DAG)理论框架^[13-14],初步考虑了与肥胖和血脂异常均可能相关的社会人口学特征和行为因素,包括年龄、种族、文化程度、职业、婚姻状况及吸烟、饮酒、体力活动等情况^[15-16]。其中,饮酒和体力活动因与结局变量的关联未达到统计学显著水平,故未纳入最终模型。比值比(odds ratio, OR)及其95%置信区间(confidence interval, CI)表示关联强度,检验水准取 $\alpha=0.05$ 。为进一步评估剂量-反应关系,采用RCS进行建模,模型优度参照AIC评估。 $P<0.05$ 为差异有统计学意义。

2 结果

2.1 基本情况

共纳入11 561名调查对象,其中男性5 316人(45.98%),女性6 245人(54.02%)。居民平均年龄为(56.80 ± 15.82)岁。超重3 873人(33.50%),肥胖1 381人(11.95%),腹型肥胖3 444人(29.79%)。详见表1。

2.2 血脂异常分布情况

血脂异常3 361人(29.07%),其中高TC 890人(7.70%),高TG 2 160人(18.68%),低HDL-C 861人(7.45%),高LDL-C 540人(4.67%)。采用卡方检验进行单因素分析,结果显示血脂异常的检出率在不同性别、年龄、民族、文化程度、职业、婚姻状况、吸烟状况、BMI分类及腹型肥胖状态之间差异均有统计学意义($P<0.05$)。详见表2、表3。

2.3 不同肥胖类型与血脂异常关联分析

2.3.1 不同肥胖类型与血脂异常的二元logistic回归分析

见表4、表5。多因素logistic回归结果显示,以正常体重人群为参照组,在调整年龄、民族、文化程度、职业、婚姻状况及吸烟等混杂因素后,肥胖(OR=1.22, 95%CI: 1.05 ~ 1.42, $P=0.010$)和腹型肥胖(OR=1.23, 95%CI: 1.11 ~ 1.36, $P<0.001$)与血脂异常呈正相关;超重与血脂异常之间差异无统计学意义(OR=1.03, 95%CI: 0.93 ~ 1.15, $P=0.575$)。

在性别分层分析中,调整混杂因素后,男性肥胖与血脂异常呈正相关(OR=1.55, 95%CI: 1.24 ~ 1.95, $P<0.001$),而超重(OR=0.98, 95%CI: 0.84 ~ 1.14, $P=0.651$)和腹型肥胖(OR=1.07, 95%CI: 0.92 ~ 1.25, $P=0.504$)与血脂异常之

表 1 调查对象的人口学特征统计
Table 1 Demographic characteristics of the survey respondents

Characteristic	Group	Case	Proportion/%
Gender	Male	5 316	45.98
	Female	6 245	54.02
Age/yr.	18-44	2 681	23.19
	45-59	3 668	31.73
	60 and above	5 212	45.08
Ethnicity	Han	9 823	84.97
	Other ethnic groups	1 738	15.03
Education level	Primary school or below	5 101	44.12
	Junior high school	4 226	36.55
	High school/technical school	796	6.89
	College/university and above	1 436	12.42
Occupation	Physical labor	5 305	45.89
	Non-physical labor	6 256	54.11
Marital status	Unmarried	1 092	9.45
	Married	9 236	79.89
	Divorced/separated/widowed/cohabiting	1 233	10.67
Smoking status	Yes	2 176	18.82
	No	9 385	81.18
Body mass index	Underweight	3 807	32.93
	Normal	2 500	21.62
	Overweight	3 873	33.50
	Obesity	1 381	11.95
Abdominal obesity	Yes	3 444	29.79
	No	8 117	70.21
Dyslipidemia	Yes	3 361	29.07
	No	8 200	70.93

表 2 居民血脂异常分布情况
Table 2 Analysis of dyslipidemia among the population

Item	Total/case (%), <i>n</i> = 11 561	Male/case (%), <i>n</i> = 5 316	Female/case (%), <i>n</i> = 6 245	χ^2	<i>P</i>
High TC	890 (7.70)	384 (7.22)	506 (8.10)	3.122	0.077
High TG	2 160 (18.68)	1 015 (19.09)	1 145 (18.33)	1.088	0.279
Low HDL-C	861 (7.45)	454 (8.54)	407 (6.52)	17.050	< 0.001
High LDL-C	540 (4.67)	220 (4.14)	320 (5.12)	6.265	0.012
Dyslipidemia	3 361 (29.07)	1 575 (29.63)	1 786 (28.60)	1.474	0.225

TC: total cholesterol; TG: triglycerides; HDL-C: high-density lipoprotein cholesterol; LDL-C: low-density lipoprotein cholesterol.

间差异无统计学意义; 女性腹型肥胖与血脂异常呈正相关 (OR=1.36, 95%CI: 1.18 ~ 1.57, $P<0.001$); 超重 (OR=1.06, 95%CI: 0.91 ~ 1.22, $P=0.446$) 和肥胖 (OR=1.01, 95%CI: 0.82 ~ 1.23, $P=0.922$) 与血脂异常之间差异均无统

计学意义。
2.3.2 不同肥胖类型与血脂异常的剂量-反应分析
采用RCS模型分析BMI和WC与血脂异常的剂量-反应关系, 结果显示无论在总体人群还是按性别分层后,

表 3 居民基本特征与血脂异常的单因素分析结果

Table 3 Univariate analysis of the association between basic demographic characteristics and dyslipidemia

Characteristic		Dyslipidemia/case (%), $n = 3\,361$	Normal lipid/case (%), $n = 8\,200$	χ^2	P
Gender	Male	1 575 (46.86)	3 741 (45.62)	1.474	0.225
	Female	1 786 (53.14)	4 459 (54.38)		
Age/yr.	18-44	552 (16.42)	2 129 (25.96)	131.999	< 0.001
	45-59	1 093 (32.52)	2 575 (31.4)		
	60 and above	1 716 (51.06)	3 496 (42.63)		
Ethnicity	Han	2 808 (83.55)	7 015 (85.55)	7.482	0.006
	Other ethnic groups	553 (16.45)	1 185 (14.45)		
Education level	Primary school or below	1 695 (50.43)	3 406 (41.54)	107.670	< 0.001
	Junior high school	1 087 (32.34)	3 139 (38.28)		
	High school/technical school	264 (7.85)	532 (6.49)		
	College/university and above	315 (9.37)	1 121 (13.67)		
Occupation	Physical labor	1 678 (49.93)	3 627 (44.23)	31.126	< 0.001
	Non-physical labor	1 683 (50.07)	4 573 (55.77)		
Marital status	Unmarried	239 (7.11)	853 (10.4)	39.344	< 0.001
	Married	2 709 (80.6)	6 527 (79.6)		
	Divorced/separated/widowed/cohabiting	413 (12.29)	820 (10)		
Smoking status	Yes	678 (20.17)	1 498 (18.27)	5.658	0.017
	No	2 683 (79.83)	6 702 (81.73)		
Body mass index status	Underweight	539 (16.04)	1 961 (23.91)	126.155	< 0.001
	Normal	1 090 (32.43)	2 717 (33.13)		
	Overweight	1 214 (36.12)	2 659 (32.43)		
	Obesity	518 (15.41)	863 (10.52)		
Abdominal obesity	Yes	1 196 (35.58)	2 248 (27.41)	76.079	< 0.001
	No	2 165 (64.42)	5 952 (72.59)		

表 4 研究变量及其赋值情况

Table 4 Variable assignment

Variable	Assignment situation
Dyslipidemia	1 = Abnormal, 0 = Normal
Gender	1 = Male, 2 = Female
Age	1 = 18-44 yr., 2 = 45-59 yr., 3 = 60 yr. and above
Ethnicity	1 = Han, 2 = Other ethnic groups
Education level	1 = Primary school or below, 2 = Junior high school, 3 = High school/technical school, 4 = College/university and above
Occupation	1 = Physical labor, 2 = Non-physical labor
Marital status	1 = Unmarried, 2 = Married, 3 = Other (Divorced/separated/widowed/cohabiting)
Smoking status	1 = Yes, 0 = No
Body mass index	2 = $0 < 18.5 \text{ kg/m}^2$ (Underweight), 1 = $18.5 \leq 24 \text{ kg/m}^2$ (Normal weight), 3 = $24 < 28 \text{ kg/m}^2$ (Overweight), 4 = 28 kg/m^2 and above (Obesity)
Abdominal obesity	1 = Yes, 0 = No

表 5 不同肥胖类型与血脂异常的关联分析
Table 5 Analysis of the association between different types of obesity and dyslipidemia

Group	Factor	Model 1		Model 2	
		OR (95% CI)	P	OR (95% CI)	P
Male (n = 5 316)	Normal	1 (Reference)		1 (Reference)	
	Underweight	0.59 (0.49, 0.70)	< 0.001	0.63 (0.52, 0.76)	< 0.001
	Overweight	0.96 (0.83, 1.12)	0.651	0.98 (0.84, 1.14)	0.651
	Obesity	1.56 (1.25, 1.95)	< 0.001	1.55 (1.24, 1.95)	< 0.001
	Abdominal obesity	1.05 (0.90, 1.22)	0.504	1.07 (0.92, 1.25)	0.504
Female (n = 6 245)	Normal	1 (Reference)		1 (Reference)	
	Underweight	0.77 (0.66, 0.91)	0.002	0.86 (0.72, 1.01)	0.071
	Overweight	1.23 (0.97, 1.30)	0.108	1.06 (0.91, 1.22)	0.446
	Obesity	1.07 (0.88, 1.32)	0.472	1.01 (0.82, 1.23)	0.922
	Abdominal obesity	1.46 (0.92, 1.25)	< 0.001	1.36 (1.18, 1.57)	< 0.001
Total	Normal	1 (Reference)		1 (Reference)	
	Underweight	0.66 (0.61, 0.77)	< 0.001	0.75 (0.66, 0.85)	< 0.001
	Overweight	1.06 (0.95, 1.17)	0.304	1.03 (0.93, 1.15)	0.575
	Obesity	1.27 (1.10, 1.47)	0.002	1.22 (1.05, 1.42)	0.010
	Abdominal obesity	1.25 (1.13, 1.39)	< 0.001	1.23 (1.11, 1.36)	< 0.001

OR: odds ratio. Model 1, Unadjusted for confounding factors. Model 2, Adjusted for confounders including age, ethnicity, education level, occupation, marital status and smoking status.

BMI和WC与血脂异常之间均存在非线性剂量-反应关系 ($P<0.001$, $P_{\text{for non-linearity}}<0.001$)。总体人群中,BMI与血脂异常呈“J”型曲线,模型分析设定的四个节点分别为18.73、22.31、24.87、30.10 kg/m²(AIC_{min}=13 733.66)。与此同时,腰围与血脂异常则呈“S”型曲线,模型分析设定的四个节点分别为65、78、86、100 cm(AIC_{min}=13 743.35)。详见图1。

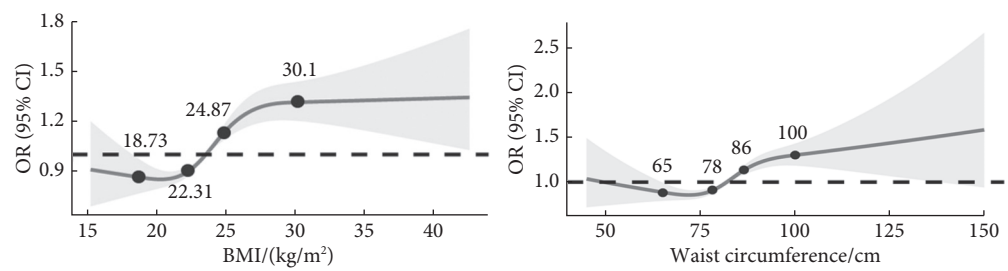


图 1 BMI、WC与血脂异常风险的剂量-反应关系
Fig 1 Dose-response association between body mass index (BMI), waist circumference (WC), and risk of dyslipidemia
OR: odds ratio. The shaded area represents the 95% confidence interval.

在性别分层的RCS模型中,男性BMI与血脂异常呈“J”型曲线,模型分析设定的四个节点分别为19.15、22.66、24.98、29.67 kg/m²(AIC_{min}= 6 391.95)。男性腰围与血脂异常呈近似“L”型曲线,模型分析设定的四个节点分别为68、80、88、100 cm(AIC_{min}= 6 422.94)。女性BMI与血脂异常呈“S”型曲线,模型分析设定的四个节点分别为18.43、22.00、22.47、30.49 kg/m²(AIC_{min}= 7 337.56)。女性腰围与血脂异常呈“U”型曲线,模型分析设定的四个节点分别为63、76、84、98 cm(AIC_{min}= 7 328.90)。详见图2、图3。

3 讨论

本研究结果显示,四川省三县(市)成年居民血脂异常检出率为29.07%,肥胖检出率为11.95%,腹型肥胖检出率为29.79%。在调整多个潜在混杂因素后,与正常

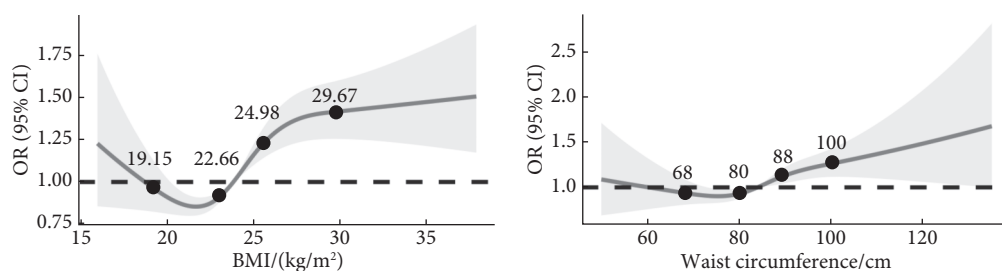


图2 男性人群BMI、WC与血脂异常风险的剂量-反应关系

Fig 2 Dose-response relationship between body mass index (BMI), waist circumference (WC), and dyslipidemia risk in males

OR: odds ratio. The shaded area represents the 95% confidence interval.

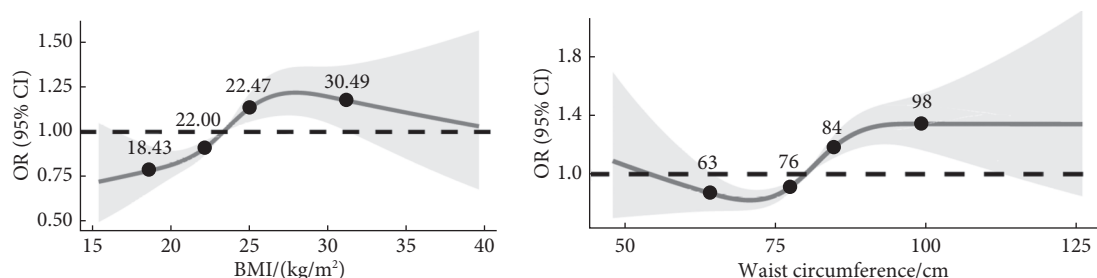


图3 女性人群BMI、WC与血脂异常风险的剂量-反应关系

Fig 3 Dose-response association between body mass index (BMI), waist circumference (WC), and risk of dyslipidemia in females

OR: odds ratio. The shaded area represents the 95% confidence interval.

BMI群体相比,一般性肥胖($\text{BMI} \geq 28.0 \text{ kg/m}^2$)与血脂异常呈正相关($\text{OR} = 1.22$, $95\% \text{ CI}: 1.05 \sim 1.42$, $P = 0.010$),腹型肥胖与血脂异常的关联更为密切($\text{OR} = 1.23$, $95\% \text{ CI}: 1.11 \sim 1.36$, $P < 0.001$)。这一结果与国内外多项研究一致^[17-18],进一步验证了肥胖特别是腹型肥胖在血脂代谢紊乱中的关键作用。

肥胖与血脂异常之间存在复杂的病理生理联系,其核心机制在于脂肪组织功能失调所致的一系列代谢紊乱。肥胖状态下常见的血脂异常特征包括甘油三酯升高、游离脂肪酸增多、HDL-C降低伴HDL功能障碍、LDL-C正常或轻度升高但小而致密LDL颗粒增多及LDL颗粒数量增加,以及载脂蛋白B水平升高^[19]。这种致动脉粥样硬化性血脂谱的形成,是肥胖个体心血管事件风险显著增加的重要原因。脂肪分布模式是决定血脂异常严重程度的关键因素,这也解释了腹型肥胖为何较一般性肥胖具有更强的代谢风险。已有多项研究证实,内脏脂肪组织及上躯干皮下脂肪组织的增加与较高的甘油三酯和较低的HDL-C水平显著相关;而腿部皮下脂肪组织的增多则被认为具有“代谢保护”作用,与较低的甘油三酯水平相关^[20-21]。功能异常的内脏脂肪组织不仅是被动的能量储存库,更是活跃的内分泌器官。一方面,其通过门静脉系统持续释放过量游离脂肪酸及多种脂肪因

子,直接干扰肝脏脂质-葡萄糖代谢并损害血管功能;另一方面,当脂肪储存能力超负荷时,脂质异位沉积至内脏、肝脏、骨骼肌等非脂肪组织,导致生物活性脂质(如脂酰辅酶A、二酰甘油、神经酰胺)积累,触发亚临床炎症和胰岛素抵抗,形成代谢不健康表型^[22-24]。这种由脂肪组织驱动的慢性低度炎症状态,是导致并加剧血脂异常等代谢并发症的关键因素。

值得注意的是,本研究中超重与血脂异常的关联未达到统计学意义($\text{OR} = 1.03$, $95\% \text{ CI}: 0.93 \sim 1.15$, $P = 0.575$)。这一结果反映了超重/肥胖人群的代谢异质性:部分BMI升高的个体表现为“代谢健康型肥胖”表型,保留良好的胰岛素敏感性和脂质稳态。全球疾病负担研究显示,肥胖对健康的影响存在显著的个体差异,相当比例的肥胖个体在代谢指标上仍保持相对健康^[17]。这一差异提示超重个体的代谢风险受脂肪分布、遗传易感性、生活方式等多重因素调控^[25]。因此,临床实践中对超重人群应进行更精细的代谢状态评估,而非仅依赖BMI指标进行风险分层。

本研究进一步利用RCS模型深入探讨了四川省三县(市)成年居民BMI、WC与血脂异常之间的非线性剂量-反应关系,识别出重要的风险阈值特征。结果显示,总人群中BMI与血脂异常之间存在“J”型曲线关系,关键拐

点位于 $BMI = 24.87 \text{ kg/m}^2$ (接近我国成人超重诊断标准 24.0 kg/m^2),提示在此阈值附近风险呈现非线性的快速上升。此外,总人群中WC与血脂异常之间呈现出“S”型曲线关系,关键拐点位于 $WC = 86 \text{ cm}$ (接近我国成年女性腹型肥胖诊断标准 85 cm),当腰围超过此值后关联强度迅速增强,达到极高水平后进入高位平台期。类似的非线性关系已在国内外多项研究中得到验证^[18, 26]。这种非线性特征的生物学基础可能与脂肪分布的动态变化、内脏脂肪积累达到临界阈值后对代谢的级联效应,以及与胰岛素抵抗等代谢综合征组分的协同作用密切相关^[22-24]。拐点的发现为早期预警提供了量化依据,提示当体重或腰围指标接近阈值时,应视其为重要的预警信号并及时采取干预措施。

性别分层分析揭示了本研究的另一重要发现。研究结果显示,四川省三县(市)女性成年居民腹型肥胖与血脂异常呈正相关($OR = 1.36, 95\%CI: 1.18 \sim 1.57, P < 0.001$),男性成年居民肥胖与血脂异常呈正相关($OR = 1.55, 95\%CI: 1.24 \sim 1.95, P < 0.001$)。性别分层RCS分析中,男性BMI与血脂异常呈典型“J”型曲线,风险拐点位于 $BMI = 24.98 \text{ kg/m}^2$,而男性WC与血脂异常则呈近似“L”型曲线。这种“J”型和“L”型响应模式提示,男性的血脂代谢可能对体重增加表现出较强的“阈值效应”,即在达到一定程度后,代谢负担迅速加重,关联强度会快速上升。值得注意的是,男性BMI模型的拟合优度优于WC模型,进一步反映出BMI在评估男性血脂代谢风险时的敏感性可能更强。相比之下,女性的BMI与血脂异常呈“S”型曲线,关联强度在BMI达到 22.00 kg/m^2 后即开始快速升高,WC与血脂异常呈“U”型曲线,拐点出现在 $WC = 84 \text{ cm}$,较我国成年女性腹型肥胖诊断标准($WC \geq 85 \text{ cm}$)高度接近。从模型拟合优度上看,女性WC模型优于BMI模型,提示腰围可能比BMI更能有效捕捉女性血脂异常的风险特征。这种性别差异可能源于体脂分布与代谢机制的本质差异。男性多以内脏脂肪沉积为主,脂肪积聚较早介导血脂紊乱,而女性脂肪主要集中于皮下,在围绝经期前可能对血脂有相对保护作用;然而激素水平变化及脂肪重新分布会显著改变这一平衡。具体而言,女性在围绝经期及绝经后将面临雌激素水平的急剧下降,原有受激素保护的脂肪分布模式被打破,导致脂肪从相对良性的皮下区域(如臀、腿部)重新分布至代谢更为活跃且更具致病性的腹部内脏区域^[27-28],显著增强女性血脂异常风险^[29]。这一生理变化可能解释了女性在中老年阶段腹型肥胖与血脂异常关联增强的机制基础。

基于以上发现,本研究为精准体重管理提供了重要

的实践参考。本研究识别的风险拐点为个体化风险评估提供了量化依据,提示应该在临床决策支持系统中整合BMI和腰围的非线性风险模型,实现基于性别和体型特征的个性化健康管理。女性应重点监测腰围变化(预警值 84 cm),采用减少内脏脂肪的综合干预措施,包括中等强度有氧运动结合抗阻训练、结合间歇性断食或地中海饮食模式等营养干预,并运用基因组学、代谢组学等精准营养技术制定个体化营养配方^[30]。男性则应重点监测BMI变化(预警值 24.98 kg/m^2),通过增加高蛋白摄入结合力量训练优化体成分,根据个体代谢特征调整膳食结构。对于接近风险拐点的个体,无论性别,均应实施强化的生活方式干预和密切的代谢监测^[31],用智能可穿戴设备、移动健康应用等数字营养技术进行实时监测与反馈,以提高干预依从性和效果^[32]。

从公共卫生角度而言,建议将腰围测量和血脂检测纳入常规体检项目,实现对高风险人群的早筛、早诊、早干预。同时,应建立覆盖全生命周期的体重管理体系,对儿童青少年群体建立家校协作机制,通过自我营养管理教育、优化学校和家庭环境等策略,从生命早期预防肥胖相关代谢疾病^[33]。随着人工智能、大数据、精准营养等数字健康技术的快速发展,未来应进一步探索这些创新技术在肥胖及血脂异常防控中的应用,构建覆盖全人群、全生命周期的智慧健康管理体系。

本研究也存在一定的局限性。研究对象来自四川省三个县(市),在一定程度上限制了研究结果的普遍适用性;研究控制了多项混杂因素,但居民详细的膳食习惯、具体的体力活动水平以及相关疾病的家族史等未被测量的协变量可能会对结果产生一定的影响。未来可拓展研究对象范围,并纳入更全面的协变量进行深入分析。

* * *

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利益冲突 所有作者均声明不存在利益冲突

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