DOI: 10.16835/j.cnki.1000-9817.2026209

· 综 述 ·

三体质量指数对儿童青少年体脂及心血管代谢风险预测的研究进展

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【摘要】 儿童青少年肥胖与心血管代谢风险因素密切相关,体质量指数(BMI)是目前应用较为广泛的肥胖评价指标,但存在生长发育期有效性削弱、无法区分脂肪和肌肉等局限性。而三体质量指数(TMI)在青春期数值相对稳定,并能较为特异性地反映体脂含量。本研究系统综述了近年来 TMI 在预测儿童青少年体脂含量及心血管代谢风险因素中的研究进展,表明 TMI 在评估青春期儿童青少年体脂方面具有较好效能,在预测心血管代谢风险方面表现优于或不劣于 BMI;然而 TMI 的预测能力受到年龄、性别和人群差异影响,且尚未建立统一的诊断切点,未来仍需通过前瞻性队列研究等进一步验证 TMI 的预测价值及建立人群的参考界值。

【关键词】 人体质量指数;脂肪组织;心血管系统;儿童;青少年

【中图分类号】 R 179 R 339.3^{+5} R 714.252 【文献标识码】 A 【文章编号】 1000-9817(2026)07-1045-05

Research progress on the prediction of tri-ponderal mass index for body fat and cardiometabolic risks in children and adolescents

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【Abstract】 Obesity in children and adolescents is closely associated with cardiometabolic risk factors. Body mass index (BMI) is currently a widely used indicator for assessing obesity. However, it has limitations, such as reduced validity during growth and development and the inability to distinguish between fat and muscle mass. In recent years, the tri-ponderal mass index (TMI) has gained attention because of its relative stability during adolescence and its ability to more specifically reflect body fat levels. The review systematically summarizes recent research progress on the use of TMI in predicting body fat levels and cardiometabolic risk factors in children and adolescents, indicating that TMI performs well in assessing body fat during adolescence and is superior or non-inferior to BMI in predicting cardiometabolic risk. However, the predictive ability of TMI is influenced by age, sex, and population differences, and unified diagnostic cutoffs have not yet been established. Future prospective cohort studies are needed to further validate the predictive value of TMI and establish population-specific reference cutoffs.

【Keywords】 Body mass index; Adipose tissue; Cardiovascular system; Child; Adolescent

1985—2019 年,中国 7~18 岁儿童青少年超重与肥胖检出率由 1.2%上升至 23.4%,增长约 18 倍;其中肥胖检出率由 0.1%增至 9.6%[1]。研究表明,儿童青少年体脂含量升高与高血糖、血脂异常等心血管代谢风险因素(cardiometabolic risk factors, CMRFs)密切相关,肥胖儿童在成年后发生代谢综合征(metabolic syndrome, MetS)及心血管疾病的风险显著升高[2-6]。因此,通过体脂含量对儿童青少年进行 CMRFs 的筛查与干预,有利于降低成年期心血管代谢疾病的发病及死亡风险。

体质量指数(body mass index, BMI)是评估肥胖的常用指标。儿童青少年生长迅速,年龄、性别及生长速率会影响 BMI 与体脂含量的关系,从而降低其对肥胖判定的准确性[7-9]。此外,儿童 BMI 界值依赖年龄、性别及种族特异性,增加了应用的复杂性,也限制了不同研究结果间的比较[10-11]。近年来,三体质量指数(tri-ponderal mass index, TMI)被用于评估生长发育阶段的体脂水平,TMI 是以体重(kg)除以身高(m)的三次方所得的指数(kg/m^3),其在青春期阶段相对稳定,且应用简便[9]。已有研究表明,TMI 在估算体脂百分比(body fat percentage, BF%)、识别中心性肥胖及预测部分 CMRFs 方面表现优异[12-14]。然而,也有研究显示 TMI 在某些人群中的预测能力并未优于 BMI[15-17]。因此,本文对近年来国内外关于 TMI 预测儿童青少年体脂水平及 CMRFs 方面的研究进展进行系统综述,以期为儿童青少年肥胖及 CMRFs 的早期筛

【基金项目】 十三五科技基础资源调查专项项目(2017FY101100);全民营养科研基金项目(CNS-NNSRG2022-181)

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查与风险评估提供参考依据。

1 TMI 对儿童青少年体脂的预测

1.1 TMI 评估体脂与肥胖 研究显示,TMI 预测 BF% 的准确性优于或不劣于 BMI[14,18-20]。作为筛查工具,TMI 识别肥胖的曲线下面积(area under the curve,AUC)可达 0.96,且误分类率低于国际 BMI 标准[21]。有研究显示 TMI 的 AUC 值高于 BMI[22],且能有效降低肥胖筛查的假阳性率[23]。此外,TMI 估算 BF% 的准确性更高,在青春期男性中尤为突出[9]。一项对我国西藏 8~18 岁儿童青少年的研究显示,TMI 与 BF% 的相关性最强,诊断效能最优,且适用性广、截断值稳定[24]。在生物学机制上,Park 等[25]报道 TMI 与瘦体重的相关性低于 BMI,能更特异地反映体脂变化。Empringham 等[26]对 8~17 岁儿童青少年的研究显示,TMI 与血浆瘦素水平存在独立关联。

然而,TMI 对肥胖预测效能存在一定局限性:相较于结合腰围的指标,TMI 与体脂率之间存在非线性关系,且对全身脂肪的解释度较低[27]。此外,有研究显示 TMI 切点值随年龄和性别变化,在 6~11 岁儿童中的准确性低于 BMI [28]。

1.2 TMI 评估中心性肥胖 中心性肥胖与心血管代谢风险关系更为密切,TMI 在识别此类肥胖方面展现出潜力。对巴西 2~5 岁儿童的研究显示,TMI 筛查中心性脂肪风险的效能高于 BMI,并提出了高灵敏度切点值(14.0 kg/m^3)及最优切点值(16.5 kg/m^3)[29]。一项针对南非 9~13 岁儿童的研究显示,TMI 与反映中心性肥胖指标的腰围身高比(waist-to-height ratio,WHtR)相关,且关联性强于 BMI[30]。对 3 749 名意大利青少年的研究显示,TMI 与 WHtR 的 R^2 值高于 BMI(0.79,0.72),且总体误分类率低于 BMI[31]。Chen 等[17]对 1 587 名 3~17 岁中国儿童的研究显示,TMI 在识别腹部肥胖方面优于 BMI。一项伊朗研究报道,TMI 识别儿童青少年中心性肥胖的准确性优于 BMI,并确定了最优切点值为 13.9 kg/m^3[32]。有研究提到 TMI 和 BMI 一样无法区分身体的脂肪质量和瘦体重质量,可能限制其估计儿童肥胖和超重的准确性[30,33]。

2 TMI 用于儿童青少年的简便性和稳定性

在简便性方面,TMI 与 BMI 相似,均由体重与身高计算得出,但 TMI 无需依赖年龄和性别特异性的百分位数或 Z 评分转换,因此在临床及公共卫生实践中的应用更加简便。在稳定性方面,研究表明 TMI 在儿童期至青春期阶段的数值变化较小。Peterson 等[9]报道,8~17 岁群体中 TMI 均值保持稳定(约 14 kg/m^3),而 BMI 则随年龄增长明显升高。一项针对 5 365 名 6~9 岁中国儿童的研究也显示,TMI 在该年龄段不随年龄增长发生显著变化,而 BMI 呈明显上升趋势[34]。一项针对巴西儿童的研究显示,TMI 的变异系数始终较低(0.09~0.24),而 BMI Z 评分在青春期男生中可达 50.72[23]。另一项研究将 TMI 预测超重/肥胖的界值简化为 4 个,预测效能良好(AUC 值为 0.73~0.98)[35]。Tabib 等[32]对伊朗 6~18 岁儿童研究中提出全年龄段单一 TMI 切点,灵敏度和特异度均较高,支持 TMI 兼具稳定性与简易实用性。

3 TMI 对儿童青少年 CMRFs 的预测

3.1 TMI 对儿童青少年 MetS 的预测 MetS 是一组心脏代谢危险因素聚集的状态[36]。研究显示,TMI 作为 MetS 生长发育与健康监测的预测指标,其效能与 BMI 相当或更优[13,37-40]。有研究指出,TMI 的预测效能可能优于 BMI,尤其在特定性别和青春期[13,39-40]。一项针对韩国 9 749 名 10~20 岁儿童青少年的研究显示,在相同 BMI 分类下,被 TMI 判为超重者的血脂、血压等指标更差[13]。对 3 731 名 7~18 岁伊朗儿童的研究显示,TMI 对 MetS 预测能力优于 BMI,尤其在 11~14 岁女生和 15~18 岁男生中[39]。一项针对中美儿童研究显示,AUC 值为 0.77~0.93,研究确定的性别特异性 TMI 切点在大多数性别、城乡及族裔分层人群中表现出较好一致性[40]。

TMI 对 MetS 预测效能受人群、年龄、性别等因素影响。有研究显示其在 10 岁以上男生中作用突出,而在女生中作用无统计学意义[41]。在预测青春期前肥胖儿童 MetS 时,TMI 的 AUC 值(0.62)低于 BMI(0.70)[42]。对于肥胖儿童青少年,TMI 的总体准确性低于 BMI,且存在性别差异[43]。此外有研究报道,采用更严格的界值时,虽然 TMI 的总误分类率低于 BMI Z 评分,但是其判断的假阴性率较高,联合 WHtR 也未改善[44]。另有部分研究表明 TMI 的预测能力低于 BMI Z 评分、腰围或 WHtR[45-46]。因此,TMI 可作为临床 MetS 预测筛查的辅助指标,在应用时需考虑年龄、性别与肥胖程度等。

3.2 TMI 对儿童青少年高血压的预测 TMI 是评估儿童青少年高血压风险的潜力指标,但受年龄、性别及健康状况等影响。多项研究显示,TMI 在预测青少年高血压方面优于或等效于 BMI。一项针对中国 3~17 岁儿童的研究显示,TMI 与高血压水平及高血压患病风险呈正相关,其效能高于 BMI[17]。一项针对巴西青少年的研究显示,TMI 定义的肥胖状态与高血压患病风险相关[47]。一项中国队列研究指出,TMI 对高血压的预测准确性优于 BMI,该优势在女生及≥16 岁青少年中更显著[48]。Malavazos 等[31]对意大利 12~13 岁青少年的研究显示,TMI 区分超重青少年高血压的判别准确率高于 BMI,且误分类率更低。

部分研究指出 TMI 对血压的预测作用并不优于

BMI。一项芬兰队列研究报道,在 16~20 岁人群中,BMI 预测高血压的 AUC 值(0.58~0.60)高于 TMI(0.56~0.58)[16]。一项对立陶宛 3 710 名 7~18 岁儿童的研究显示,BMI 与高血压的关联强度和预测准确性均高于 TMI[49]。TMI 预测效能存在人群特异性,有研究报道 TMI 在 10 岁以上男性儿童青少年中能更好预测高血压,而在女性和年幼儿童中价值有限[41]。

3.3　TMI 对胰岛素抵抗(insulin resistance, IR)的预测　IR 是高血糖的核心病理环节,空腹血糖受损(impaired fasting glucose, IFG)是 IR 的重要标志之一。现有证据表明,TMI 对儿童青少年 IR 的预测价值与 BMI 大致相当,但存在一定局限。

研究显示,TMI 与 IR 相关指标呈正相关,且预测能力不低于 BMI[44,50-51]。Wang 等[44]报道,TMI 升高与儿童青少年 IFG 风险增加相关。一项病例对照研究显示,TMI 与 IR 相关指标呈正相关[50]。一项对巴西 8~14 岁儿童青少年的研究采用胰岛素抵抗稳态模型作为评估 IR 的指标,结果显示 TMI 与该指标呈正相关,其预测能力与 BMI Z 评分相当[51]。

有部分研究显示 TMI 对 IR 的预测能力并不优于 BMI。一项在拉丁裔儿童中的研究显示,TMI 的 R^2 值和 AUC 值均接近或略低于 BMI[52]。一项队列研究发现,在青春期后期(14~16 岁),TMI 对 IR 的预测能力低于 BMI[16]。一项 20 年随访研究显示,儿童期 TMI 虽与成年后 IR 风险相关[53],但预测效能有限。此外,TMI 的应用存在潜在风险与人群差异。首先,其较宽松的诊断标准可能导致漏诊,建议将 TMI 和 BMI 进行联合使用[54]。对巴西超重青少年研究报道指出,TMI 对 IR 的预测准确性并未优于 BMI,且存在性别差异,对女生敏感性较低[55],而在意大利肥胖青少年中仅与女性参数相关[56]。

TMI 在预测儿童青少年 IR 方面可能与 BMI 相当,但因其稳定、计算简便,可作为大规模筛查的补充工具[44,47]。

3.4　TMI 对儿童青少年血脂异常的预测　多数证据表明 TMI 对儿童青少年血脂异常的预测能力与 BMI 大致相当,且两者在筛查血脂异常上均存在局限性。Ashley-Martin 等[15]研究显示,BMI 和 TMI 对儿童血脂预测准确性较差。一项芬兰对 432 名参与者的研究显示,BMI 与甘油三酯的相关性强于 TMI,但两者对血脂异常的预测效能均处于较低水平[16],可能与体重-身高类指数无法区分脂肪分布的固有缺陷有关。一项对中国儿童的研究显示,TMI 和 BMI 对血脂异常的判别能力均较差[17]。伊朗一项对 7~18 岁儿童青少年的研究显示,TMI 的预测效能表现出性别特异性(仅在男性中与甘油三酯关联性较强),整体的效能有限且难以独立全面评估血脂谱[45]。

然而部分研究揭示了 TMI 的独特优势。首先,TMI 能够识别被 BMI 掩盖的代谢风险亚组。例如,在 BMI 相同的韩国青少年中,TMI 超重者血脂水平更差,提示其可能更敏感[13]。其次,TMI 与特定血脂异常风险相关。一项针对韩国 10~20 岁儿童青少年研究显示,TMI 定义的超重和肥胖与血脂异常风险相关[37],超重者高甘油三酯血症风险增加 2.55 倍,肥胖者风险增加 4.12 倍,且高密度脂蛋白胆固醇降低风险亦显著升高。另一项巴西 12~17 岁儿童青少年的研究显示,TMI 定义的肥胖男生的高胆固醇血症和高甘油三酯血症患病风险升高,肥胖女生的高甘油三酯血症风险亦显著升高[47]。综上,TMI 在血脂异常筛查中的表现未达理想水平,但在揭示隐性风险、筛查特定血脂指标中可能具有优势。

4　小结与展望

综上所述,TMI 是评估儿童青少年体脂与心血管代谢风险的一个极具潜力的简便工具。其在青春期的数值稳定性与使用的简易性是相对 BMI 的核心优势。TMI 在预测体脂含量及识别部分 CMRFs 方面在不同研究中仍存在一定差异,其表现可能受到年龄、性别、种族及人群特征等影响。此外,目前关于 TMI 的诊断界值尚未统一,这在一定程度上限制了其在临床及公共卫生领域的广泛应用。未来研究可聚焦以下内容:开展前瞻性队列研究验证 TMI 对儿童青少年长期心血管代谢结局的预测能力,探索 TMI 与腰围等指标联合应用价值、建立人群优化切点及筛查策略,以提升对于肥胖及心血管代谢风险识别能力。

利益冲突声明　所有作者声明无利益冲突。

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收稿日期:2026-02-04　**修回日期**:2026-03-14　**本文编辑**:顾璇

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收稿日期:2026-03-17　**修回日期**:2026-04-21　**本文编辑**:王苗苗