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基于中西医临床病证特点的骨骼肌损伤动物模型评价

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【摘要】 骨骼肌损伤(skeletal muscle injury,SMI)在临床实践中较为常见,中西医对其病理机制和治疗策略存在不同的理解和方法。开发能够体现中西医临床特征的 SMI 动物模型,对于深入研究其发病机制和探索有效的治疗方法具有重要意义。本文从 SMI 的中西医病因病机、诊断标准、辨证分型出发,对现有动物模型的构建方法、特点及其与中西医病症的吻合度进行了综合评价。结果显示,重物坠落打击模型与中西医病症的吻合度最高,其中西医吻合度为 69.6%,中医吻合度为 49.4%;其次是运动诱导模型,西医吻合度为 49.8%,中医吻合度为 44.1%;而化学刺激和缺血再灌注模型的吻合度最低。总体而言,本文涉及的 SMI 动物模型在西医吻合度上优于中医吻合度,且现有模型难以与中医辨证分型精准对应。因此,构建能够准确反映中西医病证特点及中医证型的动物模型仍是未来研究的重要方向。

【关键词】 骨骼肌损伤;动物模型;中西医病证结合
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Evaluation of skeletal muscle injury animal models based on characteristics of Chinese and western medicine clinical syndromes

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【Abstract】 Skeletal muscle injury (SMI) is relatively common in clinical practice, and there are different understandings and approaches to its pathogenesis and treatment strategies between Chinese and western medicine.

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The development of animal models of SMI that can reflect the clinical characteristics of Chinese and western medicine is of great significance to the in-depth study of its pathogenesis and the exploration of effective treatment method. In this paper, starting from the Chinese and western medical etiology and pathogenesis, diagnostic criteria, and identification and typing of SMI, we conducted a comprehensive evaluation of the construction method and characteristics of the existing animal models and their compatibility with Chinese and western medical conditions. The result showed that the heavy falling blow model had the highest degree of agreement with Chinese and western medical conditions, with 69.6% of Chinese and Western medical agreement and 49.4% of Chinese medical agreement; followed by the exercise-induced model, with 49.8% of western medical agreement and 44.1% of Chinese medical agreement; and chemical stimulation and ischemia/reperfusion models had the lowest degree of agreement. Overall, the animal models of SMI involved in this paper were better than the Chinese medical model in terms of western medical agreement, and the existing models were difficult to correspond accurately with the Chinese medical diagnosis and typing. Therefore, the construction of animal models that can accurately reflect the characteristics of Chinese and western medicine and Chinese medicine patterns is still an important direction for future research.

【Keywords】 skeletal muscle injury; animal model; combination of Chinese and western medicine evidence and disease

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骨骼肌损伤(skeletal muscle injury,SMI)涵盖了如运动创伤、肌肉劳损、炎症等多种病因导致的肌肉结构和功能损害,是常见的临床疾病[1]。该病以剧烈疼痛、肌肉痉挛、僵硬及皮下瘀斑等为主要临床表现[2-3],因损伤后患者日常活动未完全受限,因此,常被患者忽视易导致严重的并发症。SMI 属软组织损伤的一种特殊类型,归属于中医“筋伤病”的范畴。近年来,中医药在治疗 SMI 方面取得了较大的成就。中医认为 SMI 病机多与气血瘀滞、经络不通、肝肾亏虚等因素有关[4-5],通过中药、针灸、推拿等多种手段辨证论治取得了良好的疗效[6-7],如何更深入的理解中医药治疗 SMI 的机制,使中医药治疗 SMI 更加科学化,对推动中医药现代化意义重大。

动物模型在探索人类疾病的发生机制和评估治疗效果方面发挥着关键作用。开发能够体现中西医临床特征的 SMI 动物模型,对于深入理解 SMI 的病理生理机制以及为中西医结合的临床治疗策略提供理论支持具有重要意义。本文以 SMI 的中西医临床表现为基础,对 SMI 的中西医诊断标准及中医证候分型进行了系统整理和总结,并对现有的 SMI 动物模型的构建方法、实验动物的选择以及与临床的吻合度进行了深入分析,旨在为构建符合 SMI 临床特征的动物模型及开展相关药物治疗研究提供实验数据支持和研究方向指导。

1 SMI 的病因病机

1.1 SMI 西医病因病机

西医将本病归属于软组织损伤的范围[8],认为其病因主要为外力撞击引起的撞击伤、挫伤或运动过度导致的拉伤及扭伤等从而引起的骨骼肌的肌肉、肌腱或筋膜的过度挤压或拉伸损,从而导致骨骼肌的功能障碍[9],依据其临床特点可将其分为[10]:轻度(Ⅰ级):仅有部分肌纤维的损伤,伴有轻微的水肿和不适,伴有少量或没有力量损失或运动受限;中度(Ⅱ级):造成肌肉更大的损伤,并伴有明显的收缩能力功能丧失,可在受伤后的 2 ~ 3 d 内形成轻微的局部血肿,并伴有瘀斑;重度(Ⅲ级):延伸到肌肉整个横截面的损伤,导致肌肉功能几乎完全丧失和剧烈疼痛,伴整个损伤部位的、明显的瘀斑。肌肉损伤后遵循恒定的愈合过程启动修复程序:(1)炎症期:包括破坏,其特征是肌原纤维撕裂和随后坏死,在撕裂肌肉中产生的空间形成血肿以及炎症细胞的增殖;(2)修复期:包括修复和重塑,吞噬坏死组织,肌原纤维再生并伴随结缔疤痕组织的产生,以及血管的新形成和神经生长;(3)重塑期:包括重塑、再生肌原纤维的成熟、疤痕组织的收缩和重组以及肌肉功能能力的恢复[11]。

1.2 SMI 中医病因病机

中医将 SMI 归属于“筋伤病”范畴,受跌打、

撞击、挤压、扭转及牵拉等外力损伤致脉络破损，血溢脉外，停滞局部形成瘀血；经络是气血运行的通道，联络脏腑肢节，气血瘀滞严重时可使经络痹阻，气血不能正常濡养筋脉肌肉，易出现肢体麻木、活动受限等症。或因过度劳累、长期劳损以致腠理疏松风寒湿邪趁虚而入，阻碍气血运行，气血运行不通，聚于局部出现肿胀、疼痛；亦或因年老体衰、肝脾肾亏虚，肝肾亏虚，精血不足，不能滋养筋骨，脾胃虚弱，气血生化不足，肌肉失养收外力因素影响易出现损伤。临床症状表现为局部疼痛、肿胀、活动受限[5]。因此，中医治疗本病时，重视气血辨治，同时兼顾“辨因祛邪”，同时注重中医治疗筋伤病的三期辨证的治则，因外力所致气滞血瘀者早期以活血化瘀为主、中后期可以舒筋活络为主；因劳损内因所致气血失养、筋脉痹阻者在早期以活血、补血祛邪为主、中期后补血舒筋为主，以促进损伤的骨骼的修复，恢复其功能[5]。

2　SMI 中西医诊断标准

2.1　西医诊断标准

西医学主要依据症状、体征及辅助检查对其进行诊断。参考《临床诊疗指南 · 创伤学分册》[12]、《中药新药临床研究指导原则》[13]及《肌肉损伤-生理病理学、诊断、治疗和临床表现》[14]中关于肌肉软组织损伤的诊断依据，拟定 SMI 的西医诊断标准，详见表 1。

2.2　中医分型与诊断标准

参照“十四五”规划教材《中医筋伤学》[15]和《中医骨伤科常见病诊疗指南(2012 版)》[16]及《中药新药临床研究指导原则》[13]，SMI 的常见证型总结如下：气血瘀滞证、气血虚损证、寒湿痹阻证、邪热阻络证、气虚湿阻证、经脉痹阻证及血不濡筋证七类，具体详见表 2。

3　SMI 动物模型分析

3.1　模型动物

动物种类的选择查阅相关文献表明，SMI 模型动物种类以大鼠、小鼠及兔为主[17-21]。大鼠及兔常用骨骼肌挫伤模型及运动诱导的 SMI 模型的建模；小鼠常用于化学及负重游泳运动诱导的 SMI 动物模型建模。在动物模型雌雄性别的选择上，因雌雄动物间的差异性，导致两者在损伤后的恢复及相关检测指标可能存在一定的差异性[22]，故多数的动物实验研究以雄性动物为主。鼠、兔的下肢骨骼肌与上肢相比较，其肌肉发达、体积较大且血供丰富，且造模时下肢位置容易固定，适合进行损伤后肌群病理变化的观察和模型构建操作，大小鼠常选择腓肠肌，兔则多以股四头肌作为目标肌群进行模型构建。

3.2　观察指标

SMI 动物模型的观察指标包括以下 4 个方面：(1)损伤症候评分：肿胀(下肢周长、湿重比)、青紫、瘀血、跛行、疼痛(热板实验、机械性痛觉过

表 1　SMI 西医诊断标准

Table 1　Western medicine diagnostic criteria for SMI

项目 Items	表现 Manifestations
临床表现 Clinical manifestations	①损伤肌肉部位肿胀、疼痛；②初期见青紫瘀斑、血肿，后期可见瘀斑消退或成黄褐色；③邻近关节活动受限，活动时疼痛症状加重；④局部触诊压痛明显；⑤局部可触及硬结、条索状隆起或空虚感；⑥肌肉抗阻力检查示阳性 ① Swelling and pain in the injured muscle area, ② bruises and hematomas in the early stage, and the ecchymosis fades or turns yellowish-brown in the later stage, ③ restriction of movement of neighboring joints and aggravation of pain symptoms when moving, ④ localized tenderness on palpation is obvious, ⑤ localized hard knots, striated elevation or emptiness can be palpated, ⑥ muscle resistance test is positive
实验室检查 Laboratory tests	①损伤早期见中性粒细胞、IL-6 升高；②血凝 D-二聚体轻度升高；③肌肉损伤标志物：CK、LDH 部分患者见升高 ① Neutrophils and IL-6 are elevated in the early stage of injury, ② mild elevation of hemagglutination D-dimer, ③ muscle damage markers: CK, LDH is elevated in some patient
影像学检查 Imaging tests	① X 线检查见骨骼肌附着部位无骨折、脱位及骨病；②MRI 检查见损伤区域水肿，部分肌束连续性中断，局部见部分不规则撕裂等；③肌骨超声见损伤部位回声异常、血流增多、肌肉增厚及肌纤维结构欠清楚 ① X-ray examination of the attachment site of skeletal muscle without fracture, dislocation and bone disease, ② MRI examination, see the damage area edema, part of the muscle bundle continuity interruption, local part of the irregular tear, ③ musculoskeletal ultrasound shows abnormal echogenicity, increased blood flow, muscle thickening and unclear structure of muscle fibers in the damaged area

表 2 SMI 中医诊断标准

Table 2 Diagnostic criteria for SMI in Chinese medicine

序号 No.	证型 Pattern of evidence	症状 Symptoms	舌脉 Tongue and pulse manifestations
1	气血瘀滞证 Qi and blood stasis syndrome	伤肢刺痛,痛处固定、拒按;肿胀;肢体或躯干活动受限;躯体或四肢局部见青紫瘀斑或血肿 Tingling in the injured limb, with fixed pain and refusal to be pressed, swelling, limitation of limb or trunk movement, localized bruises and petechiae or hematomas on the trunk or limbs	舌质紫暗,或有瘀斑,脉弦涩 Dark purple tongue, possibly with petechiae, and a wiry, rough pulse
2	气血虚损证 Qi and blood deficiency syndrome	劳累后见肌肉酸痛,或隐隐作痛,缠绵不已;患处肌肉萎缩;屈伸活动无力;少寐多梦,自汗盗汗,头晕目眩,心悸气短,面色苍白,少气懒言、神疲乏力 Muscle aches and pains after exertion, or vague and lingering pains, atrophy of the affected muscles, weakness in flexion and extension, little sleep and dreams, spontaneous sweating and night sweating, dizziness, palpitation, shortness of breath, pale face, little breath and laziness, fatigue	舌淡,苔白,脉细无力 Pale tongue, white coating, and thready, weak pulse
3	寒湿痹阻证 Cold-hygroscopic paralytic obstruction syndrome	局部沉重冷痛或酸楚重坠胀痛,得温通减,遇冷加剧;肌肉关节屈伸活动不利;局部肿胀反复,时重时轻 Localized heavy cold pain or aching and swelling pain, reduced by warmth and aggravated by cold, muscle and joint flexion and extension activities are unfavorable, localized swelling is repeated, sometimes heavy, sometimes light	舌淡胖,苔白滑,脉沉弦或滑 Pale, enlarged tongue with a white slippery coating, and a deep, wiry or slippery pulse
4	邪热阻络证 Evil-heat obstruction syndrome	患处肿胀,损伤周围持续性疼痛;局部皮温升高、燥热,可见高热恶寒;局部肌肉僵硬,关节强直;患处按之可触及索状,硬结 Swelling of the affected area and persistent pain around the injury, localized elevated skin temperature, heat inflammation, visible high fever and malignant cold, localized muscle stiffness and joint ankylosis, cord-like, hard nodules can be touched when the affected area is pressed	舌质红,脉弦数 A red tongue and a wiry, rapid pulse
5	气虚湿阻证 Qi deficiency and dampness obstruction syndrome	患处见反复性肿胀、局部压痛;自觉肢体沉重,遇劳更甚;面色无华,纳呆,少气懒言、神疲乏力 Recurrent swelling and localized tenderness in the affected area, consciousness of heaviness of the limbs, worse in case of exertion, face is colorless, dull, breathless and lazy, fatigue	舌淡胖有齿痕,苔白滑或腻,脉细无力或濡 Pale, enlarged tongue with tooth marks, white slippery or greasy coating, and thready, weak or soft pulse
6	经脉痹阻证 Meridian paralysis and obstruction	患肢或局部麻木、感觉减退;肢体末端皮肤爪甲苍白、干枯、冰凉、或伴皮肤干燥、脱屑;肢体关节活动受限,屈伸不利;局部疼痛,可伴见肿胀,自觉肢体关节沉重,活动不灵 Numbness and loss of sensation in the affected limbs or localized areas, skin and claw nails at the ends of the limbs are pale, dry and cold, or accompanied by dry and flaky skin, restricted movement of joints of the limbs, unfavorable flexion and extension, localized pain, may be accompanied by swelling, consciously heavy limb joints, inactivity	舌淡苔少或有瘀斑,脉弦涩或弦细 Pale tongue with little coating or petechiae, and a wiry, rough or wiry, thready pulse
7	血不濡筋证 Blood failing to moisturize the tendons pattern	伤后日久未愈,患肢或局部酸痛、隐痛,时轻时重屈伸不利,肌萎筋缓,活动欠力,恢复迟缓,迁延不愈;常伴有面色无华、头晕眼花等血虚症状 Affected limb or local area presents with lingering soreness and dull pain that persists over time, varying in intensity, accompanied by limited flexion and extension, muscle atrophy and tendon laxity, weakness during movement, and delayed recovery that becomes chronic, it is often accompanied with blood deficiency signs such as a lusterless complexion, dizziness, and blurred vision	舌淡苔少,脉细 Pale tongue with little coating, and a thready pulse

敏、冷异常性痛);(2)行为学指标(步幅测量、旋转实验、旷场实验、步态分析、平衡木测试);(3)生化指标:常选用损伤肌肉的组织匀浆液检测炎症因子(白细胞介素-6(interleukin-6, IL-6)、前列

腺素 E2(prostaglandin E2, PGE2)、肿瘤坏死因子-α(tumor necrosis factor-α, TNF-α)、白细胞介素-1β(interleukin-1β, IL-1β)、神经生长因子(nerve growth factor, NGF))、氧化应激标志物(超氧化物歧化酶(superoxide dismutase, SOD)、过氧化氢酶(catalase, CAT)、丙二醛(malondialdehyde, MOD)、一氧化氮(nitric oxide, NO))及肌肉损伤因子(肌酸激酶(creatine kinase, CK)、肌酸激酶-MM 型(creatine kinase-muscle/muscle type, CK-MM)、乳酸脱氢酶(lactate dehydrogenase, LDH))的表达水平;(4)组织学评估:通过苏木素-伊红(HE)染色后电镜下观察损伤肌肉的形态变化。通过 Masson 染色观察损伤肌肉肌胶原纤维变化。TUNEL 染色观察实验动物损伤组织细胞焦亡情况。通过甲苯胺蓝染色观察肥大细胞脱颗粒。通过免疫荧光、组化观察损伤肌肉中 Pax7、MyoD、MyoG 标志物的表达。

3.3　动物模型与临床病证吻合情况

本文以中西医诊断标准及中医证候表现为基础,现对 SMI 常见动物模型造模方法及模型特点进行归纳总结,参照《中医药动物模型评价新方法》[23],设定 SMI 动物模型的评价标准(详见表 3),对常见动物模型进行吻合度分析(详见表 4)。

表 3　SMI 动物模型评价标准

Table 3　Evaluation criteria of SMI animal model

项目 Items	评价标准 Evaluation standard
中医诊断标准 Diagnostic criteria of Chinese medicine	主证(A):①伤肢疼痛、麻木;②伤处肿胀;③伤肢活动障碍;④患肢肌肉萎缩;⑤舌脉符合中医辨证标准 次证(B):⑥伤处见青紫瘀斑;⑦肢体皮温异常改变;⑧面色无华、眩晕心悸;⑨少气懒言神疲乏力;⑩肢体沉重、僵硬或强直;⑪遇寒或劳累后症状加重 Primary evidence (A): ① pain and numbness of the injured limb, ② swelling of the injured limb, ③ impaired movement of the injured limb, ④ muscle atrophy of the affected limb, ⑤ tongue and pulse in accordance with the Chinese medicine diagnosis standard Secondary evidence (B): ⑥ bruises and ecchymosis at the injured place, ⑦ abnormal change of skin temperature of the limb, ⑧ colorlessness, dizziness and palpitation, ⑨ lack of breath and laziness, fatigue, ⑩ heaviness, stiffness or straightness of the limb; symptoms are aggravated when exposed to cold or after exertion
西医诊断标准 Diagnostic criteria of western medicine	Ⅰ类指标(C):①肿胀;②疼痛、压痛或麻木;③瘀斑、血肿;④活动受限、抗阻力检查阳性;⑤可触及硬结、条索状隆起或空虚感 Ⅱ类指标(D):⑥X 线检查见骨骼肌附着部位无骨折、脱位及骨病;⑦MRI 检查见损伤区域水肿,部分肌束连续性中断,局部见部分不规则撕裂等;⑧肌骨超声见损伤部位回声异常、血流异常、肌肉增厚及肌纤维结构欠清楚;⑨病理检查见肌纤维断裂、损伤周围炎性细胞浸润或纤维增生 Ⅲ类指标(E):⑩血清炎性指标异常:如中性粒细胞、IL-6 升高;⑪血凝 D-二聚体升高;⑫肌肉损伤标志物:CK、LDH 升高 Class Ⅰ index (C): ① swelling, ② pain, pressure or numbness, ③ petechiae, hematoma, ④ restriction of movement, positive anti-resistance test, ⑤ palpable hard knots, striated elevations or a feeling of emptiness Class Ⅱ index (D): ⑥ X-ray examination shows that there is no fracture, dislocation or bone disease at the attachment site of skeletal muscle, ⑦ MRI examination shows that the damaged area is edematous, the continuity of some muscle bundles is interrupted, and some irregular tears are seen locally, ⑧ ultrasound of muscle and bone shows that the damaged area has abnormal echogenicity, blood flow abnormality, muscle thickening and the structure of the muscle fibers is not clear, ⑨ pathological examination of muscle fiber breaks, inflammatory cell infiltration or fibroplasia around the injury Class Ⅲ index (E): ⑩ abnormal serum inflammatory indexes: e. g. elevated neutrophils, IL-6, ⑪ elevated hemagglutination D-dimer, ⑫ muscle injury markers: elevated CK, LDH

注:参照《中医药动物模型评价新方法》[23],设定 SMI 动物模型的评价标准,对评价标准进行量化加权,公式如下:中医吻合度 = N × 60 /(100 × A) + M × 40 /(100 × B)(其中 A、B 分别为主证、次证数,N、M 分别为与主证、次证吻合数);西医吻合度 = N × 60 /(100 × C) + M × 30 /(100 × D) + P × 10/(100 × E)(其中 C、D、E 为Ⅰ、Ⅱ、Ⅲ级指标数,N、M、P 分别为与Ⅰ、Ⅱ、Ⅲ级指标吻合数)。

Note. With reference to *New evaluation methods for animal models in Chinese medicine*[23], the evaluation criteria for the SMI animal model were established, and the criteria were quantitatively weighted using the following formulas: Chinese medicine consistency score = N × 60 / (100 × A) + M × 40 / (100 × B) (where A and B represent the number of primary and secondary symptoms, respectively; N and M represent the number of symptoms consistent with the primary and secondary symptoms, respectively); Western medicine consistency score = N × 60 / (100 × C) + M × 30 / (100 × D) + P × 10 / (100 × E) (where C, D and E represent the number of level Ⅰ, Ⅱ and Ⅲ indicators, respectively; N, M and P represent the number of indicators consistent with level Ⅰ, Ⅱ and Ⅲ indicators, respectively).

表 4 SMI 动物模型与临床病证吻合情况

Table 4 Consistency between the SMI animal model and clinical syndromes

动物模型 Animal model	动物种类 Animal species	造模方法 Modeling method	模型特点 Model characteristics	临床吻合度 Clinical consistency
骨骼肌撞击损伤模型[17,24-26] Skeletal muscle impact injury model[17,24-26]	SD 大鼠、Wistar 大鼠、C57BL/6 小鼠、新西兰兔、日本大耳兔 SD rats, Wistar rats, C57BL/6 mice, New Zealand rabbits, Japanese rabbits	动物麻醉后使用砝码沿 PVC 管坠落打击造模,可依据 W = m × g × h(W: 势能,m : 质量(kg),h: 距离(m),g = 9.8 N/kg)计算打击势能的大小,确定砝码坠落的高度及质量 After anesthesia, a weight was dropped along the PVC pipe to create a model, and the size of the potential energy of the blow could be calculated based on W = m × g × h (W: potential energy, m: mass (kg), h: distance (m), g = 9.8 N/kg) to determine the height of the weight and mass of the weight dropped	优点:操作相对简单;造模时间短;急性 SMI 与慢性 SMI 均可使用此方法。实验结果的重复性较高;接近临床实际损伤。模拟骨骼肌的损伤程度的大小损伤程度可调节 缺点:难以精确控制损伤变量;当重物落在骨骼肌上时,重物存在反弹,造成骨骼肌“二次打击” Advantages: operation is relatively simple, the modeling time is short, both acute SMI and chronic SMI can use this method. Results are highly reproducible, close to the actual clinical injury. The size of the injury can be adjusted to simulate the degree of injury to the skeletal muscle Disadvantages: it is difficult to control the damage variables accurately, when the weight falls on the skeletal muscle, there is a rebound of the weight, resulting in a “second blow” to the skeletal muscle	符合西医指标中的①②③④⑦⑨⑩⑫,吻合度为 69.6%。符合中医诊断标准:①②③⑥⑦,吻合度为 49.4% It meets ①②③④⑦⑨⑩⑫ of the western medicine index, and the degree of agreement is 69.6%. It meets the diagnostic criteria of Chinese medicine: ①②③⑥⑦, and the degree of agreement is 49.4%
		小型气动生物冲击机 Small pneumatic bio-impact machine blow	优点:较为精准地控制对腓肠肌的冲击力度和损伤程度。能将冲击力量集中于腓肠肌特定部位;使用小型气动生物冲击机操作相对简单 缺点:需要专门的小型气动生物冲击机等设备,设备购置和维护成本较高;不同的动物肢体周径存在一定差异,可能造成组织损伤程度存在一定差异 Advantages: more precise control of the impact strength and degree of damage to the gastrocnemius muscle, it is possible to focus the impact force on specific areas of the gastrocnemius muscle, it is relatively simple to use a small pneumatic biopercussion machine Disadvantages: requires specialized equipment such as a small pneumatic biopercussion machine, which is costly to purchase and maintain, the circumference of the limb varies from animal to animal, which may result in some variation in the degree of tissue damage	
长时间周期性运动诱导模型[19,27-30] Prolonged cyclic exercise induction model[19,27-30]	C57BL/6J 小鼠、Wistar 大鼠、SD 大鼠、BALB/c 小鼠、ICR 小鼠 C57BL/6J mice, Wistar rats, SD rats, BALB/c mice, ICR mice	在-16°的跑台,以 16 m/min 的速度,连续运动 90 min/d,每周 6 d,共计造模时间为 28 d Running platform at -16°, at a speed of 16 m/min, continuous exercise of 90 min/d, 6 d per week, a total of 28 d of modeling time 在 28 ~ 33 ℃的水温中,并在动物尾部负重其自重 5% ~ 8%的铅坠,每周 5 d,造模时间约为 4 ~ 8 周 Water temperature was 28 ~ 33 ℃ and the animals were loaded with a lead mass of 5% ~ 8% of their own mass on their tails for 5 d per week, with a modeling time of approximately 4 ~ 8 weeks	优点:能够较好地模拟真实运动损伤,该模型可以在不同的实验动物个体上重复诱导出 SMI,实验结果的稳定性和可靠性较高。实验操作相对简单,易于掌握,成本也相对较低 缺点:长时间周期性运动可能引起其他生理系统的变化,这些变化可能会干扰对 SMI 的研究 Advantages: it can better simulate the real sports injury, the model can repeatedly induce SMI on different individual experimental animals, and the stability and reliability of the experimental results are high. Experimental operation is relatively simple and easy to master, and the cost is relatively low Disadvantages: prolonged periodic exercise may cause changes in other physiological systems, and these changes may interfere with the study of SMI	符合西医指标中的④⑦⑧⑨⑩⑫,吻合度为 49.8%。符合中医指标中的③⑦⑨⑪,吻合度为 44.1% It meets ④⑦⑧⑨⑩⑫ in the indicators of western medicine, and the degree of agreement is 49.8%. It meets ③⑦⑨⑪ in the indicators of Chinese medicine, and the degree of agreement is 44.1%

续表 4

动物模型 Animal model	动物种类 Animal species	造模方法 Modeling method	模型特点 Model characteristics	临床吻合度 Clinical consistency
化学诱导模型[31-34] Chemically induced models[31-34]	日本白兔、Wistar 大鼠、Sirt2 KO 小鼠、野生型 C57BL/6J 小鼠 Japanese white rabbits, Wistar rats, Sirt2 KO mice, wild-type C57BL/6J mice	通过使用氯化钡、蛇毒毒素等化学物质肌内注射在大小鼠的目标肌群内来诱导骨骼肌发生损伤 Skeletal muscle damage is induced by intramuscular injection of barium chloride, snake venom toxin, and other chemicals into target muscle groups in mice and rats	优点:实验过程相对简单,易于实施。损伤的机制相对明确;诱导 SMI 稳定性高,实验结果的重复性强;能精确地控制 SMI 的程度与特定病理状态 缺点:与自然损伤存在差异;化学试剂在诱导 SMI 可能存在全身毒性与潜在的炎症反应 Advantages: procedure is relatively simple and easy to perform. Mechanism of injury is relatively clear, the stability of the induced SMI is high and the results are reproducible, the degree of SMI and the specific pathologic state can be precisely controlled Disadvantages: there are differences with natural damage, chemical reagents in the induction of SMI may have systemic toxicity and potential inflammatory reaction	符合西医指标中的①④⑨⑫,吻合度为 34.8%。符合中医指标中的②③⑦,吻合度为 30.7% It meets ① ④ ⑨ ⑫ of the indicators of western medicine, and the degree of agreement is 34.8%. It meets ② ③ ⑦ in the indicators of Chinese medicine, and the degree of agreement is 30.7%
缺血-再灌注诱导模型[35-38] Ischemia-reperfusion induction model[35-38]	新西兰兔、SD 大鼠、Wistar 大鼠 New Zealand rabbit, SD rat, Wistar rat	SMI 缺血-再灌注诱导模型是通过对供应骨骼肌的血管进行夹闭造成缺血,而后恢复血流灌注以引发 SMI SMI ischemia-reperfusion induction model involves ischemia by clamping the blood vessels supplying the skeletal muscle, and then restoring perfusion to induce SMI	优点:观察骨骼肌在不同缺血时长和再灌注时长下的损伤程度和病理生理变化规律,时间因素可控;实验结果的可重复性高,便于不同研究团队之间进行对比研究和结果验证 缺点:手术操作难度大,操作过程要求精细,造模过程中血管痉挛、血栓形成等影响模型的稳定性和可靠性;长时间的缺血和再灌注过程可能会引发全身炎症反应等并发症,进一步干扰 SMI 的研究 Advantages: to observe the degree of damage and pathophysiological changes of skeletal muscle under different ischemia and reperfusion durations, the time factor can be controlled, the reproducibility of the experimental results is high, which makes it easy for different research teams to conduct comparative studies and validate the results Disadvantages: the difficulty of surgical operation, the operation process requires fine, vascular spasm and thrombosis during the modeling process affects the stability and reliability of the model, the prolonged ischemia and reperfusion process may trigger complications such as systemic inflammatory response, which further interferes with the study of SMI	符合西医指标中的③⑧⑩⑨⑫,吻合度为 33.6%;符合中医指标中的⑥⑦⑩,吻合度为 20.1% It meets ③ ⑧ ⑩ ⑨ ⑫ of the indicators of western medicine, and the degree of agreement is 33.6%. It meets ⑥ ⑦ ⑩ in the indicators of Chinese medicine, and the degree of agreement is 20.1%

注:根据相关文献对吻合度评级:低吻合度:西医吻合度≤ 40%,中医吻合度≤ 40%;中吻合度:西医吻合度> 40%且< 60%,中医吻合度> 40%且< 60%;高吻合度:西医吻合度≥ 60%,中医吻合度≥ 60%。

Note. According to the relevant literature on the grading of compatibility. Low compatibility. Western medicine compatibility ≤ 40 % and Chinese medicine compatibility ≤ 40 %. Moderate compatibility. Western medicine compatibility > 40 % and < 60 %, Chinese medicine compatibility > 40 % and < 60 %. High compatibility. Western medicine compatibility ≥ 60 % and Chinese medicine compatibility ≥ 60 %[39].

4　讨论与展望

SMI 是常见损伤性疾病,中医药对于 SMI 损伤具有悠久的历史,中医药辨证论治 SMI 具有满意的疗效,SMI 动物模型的构建与评价是连接基础研究与临床应用的关键环节对于深入研究其损伤后的病理过程以及修复再生机制,对于促进肌肉的修复和再生具有极其重要的意义。中西医结合治疗 SMI 的方法在临床中越来越得到普遍的应用。因此,探索符合中西医病证特点的造

模方法越来越受到关注。

现阶段的 SMI 动物模型主要以构建西医临床病理变化为主,缺乏对中医证候的反映,目前主要采用重物坠落、运动诱导、化学诱导模型及缺血再灌注损伤方法进行模型的构建。本研究基于中西医临床病证特点的 SMI 动物模型,结果显示,目前重物坠落损伤动物模型的吻合度高,分别为西医 69.6%,中医 49.4%,它能最大限度的模拟临床中 SMI 损伤的病理发生过程,重物坠落打击后伤肢出现的不同程度的青紫、瘀血、肿胀、跛行、触痛及功能障碍等表现与中医“血瘀证”或“瘀滞证”具有较高一致性。此模型对于常用于探讨 SMI 损伤的发病与病理过程的演变及药物干预后损伤肢体肿胀、疼痛及活动变化等研究,也是中药及复方内服及外用的首选模型。其次是运动诱导法吻合度为中,西医为 49.8%,中医 44.1%,运动诱导 SMI 模型主要通过长时间的诱导动物在有坡度的跑台或力竭游泳来实现,长时间高强度运动也是造成 SMI 的常见原因,运动诱导模型与这类损伤的发病机制相符合是此类研究的理想动物模型。造模成功后出现的动物体质量下降、神情疲倦、反应迟钝等表现与中医学中气血亏虚证的表现相符。力竭游泳造模时,模型动物长时间在低温水中运动[40],这种与中医学寒湿痹阻证的发病相符。此外,多数力竭游泳的模型中大鼠尾部系有铅坠,造模结束的标准是动物力竭,即沉水后 10 s 内无法自主上浮至水面,这与中医学气虚湿阻证的机制相符。化学诱导法与缺血-再灌注动物模型的吻合度均为低吻合度。化学诱导法通常使用心脏毒素等药物进行肌内注射,诱导局部出现红肿、热痛、渗出等症状,这些症状与湿热内侵阻络的病理机制相似。此模型常用于 SMI 后肌肉的病理变化过程的常用模型,此外化学刺激法也是研究药物对 SMI 的细胞实验中细胞损伤模型的常见诱导方法。缺血-再灌注损伤造模法也是 SMI 模型制备的主要方法之一,通过采用束缚环捆扎动物近端血管,造成骨骼肌一定时间的缺血。在造模过程中,动物的趾掌会变得苍白,局部皮肤青紫、皮温发凉,患肢活动明显受限。解开束带恢复血供后,动物的趾掌会恢复红润温暖[41]。通过多普勒激光检测下肢血流情况发现,缺血-再灌注损伤会导致下肢微血管血流显著减少,这一病理机制与中医的经脉痹阻证的机制相似。虽然 SMI 相关的动物实验研究中将其作为 SMI 的常用模型之一,但此模型诱导方法与临床中骨筋膜室综合征的发病机制类似,存在与 SMI 的病理机制不符等情况,是否能作为 SMI 的动物模型仍需进一步的研究。

这些模型在模拟临床损伤病理和中医证候特征方面各具优势,在模型与证候吻合度的客观评价方面,当前仍面临中西医指标体系融合的难题。现代医学偏向于采用微观层面的病理指标(如肌纤维结构改变、炎症因子表达等),而中医学则侧重于依据望闻问切获取的宏观证候表现(如舌脉特征、神态行为和疼痛反应等)。建立综合统一的量化评价框架有必要引入多组学技术(如蛋白质组学、代谢组学),通过系统分析“证候—生物标志物”之间的关联机制,从而提升模型评价的整体性和可比性。因此,系统评估不同模型在病理表现、证候吻合度以及复合损伤模拟能力方面的合理性与科学性,对推进中西医结合研究具有重要作用。

展望未来,基于中西医临床病证特点的 SMI 动物模型研究领域充满了无限的机遇与广阔的发展前景。同时,蛋白质组学和代谢组学等新兴组学技术的发展,为深入研究中医证候的物质基础提供了强大的技术支持。通过对不同中医证候状态下动物体内蛋白质和代谢产物的全面分析,能够揭示出隐藏在证候背后的关键生物标志物和代谢通路,进而为建立更加精准、科学的中医证候动物模型奠定坚实的基础。

参 考 文 献(References)

[1] SHU L Z, ZHANG X L, DING Y D, et al. From inflammation to bone formation: the intricate role of neutrophils in skeletal muscle injury and traumatic heterotopic ossification [J]. Exp Mol Med, 2024, 56(7): 1523-1530.

[2] BAI H, LIU L, LUO Z, et al. Advancements in two-dimensional nanomaterials for regenerative medicine in skeletal muscle repair [J]. Mater Today Bio, 2025, 33: 101924.

[3] OWENS D J, TWIST C, COBLEY J N, et al. Exercise-induced muscle damage: what is it, what causes it and what are the nutritional solutions? [J]. Eur J Sport Sci, 2019, 19(1): 71-85.

[4] 何敏. 伤科跌打胶囊治疗急性软组织损伤的效果及对患者生活质量的影响观察[J]. 内蒙古中医药, 2025, 44(5): 5-7.
HE M. Observation on the effect of Shangke Dieda capsule on acute soft tissue injury and its influence on patients' quality of life[J]. Nei Mongol J Tradit Chin Med, 2025, 44(5): 5-7.

[5] 黄桂成, 王拥军. 中医骨伤科学(5 版)[M]. 北京: 中国中医药出版社; 2021.
HUANG G C, WANG Y J. Orthopedics and traumatology of traditional Chinese medicine (5th ed)[M]. Beijing: China Press of Traditional Chinese Medicine; 2021.

[6] 黄于婷, 林煜也, 张国俊, 等. 电针诱导巨噬细胞极化促进大鼠骨骼肌急性损伤修复的机制研究[J]. 中国针灸, 2025, 45(6): 791-800.
HUANG Y T, LIN Y Y, ZHANG G J, et al. Mechanism of electroacupuncture-induced macrophage polarization in promoting acute skeletal muscle injury repair in rats[J]. Chin Acupunct Moxibust, 2025, 45(6): 791-800.

[7] 蒋军文, 覃丽雯, 沈仰峰. 基于 Nrf2/ARE 通路探究五味子多糖对运动性疲劳小鼠骨骼肌线粒体自噬的影响[J]. 中国比较医学杂志, 2025, 35(6): 65-73.
JIANG J W, QIN L W, SHEN Y F. Based on Nrf2/ARE pathway, the effect of *Schisandra chinensis* polysaccharide on mitochondrial autophagy of skeletal muscle in exercise-induced fatigue mice was explored[J]. Chin J Comp Med, 2025, 35(6): 65-73.

[8] 国家创伤医学中心, 中华医学会疼痛学分会, 中国医师协会创伤外科医师分会, 等. 急性闭合性软组织损伤诊疗与疼痛管理专家共识[J]. 中华医学杂志, 2021, 101(21): 1553-1559.
National Center for Trauma Medicine, Pain Society of Chinese Medical Association, Trauma Surgeons Branch of Chinese Medical Doctor Association, et al. Expert consensus on diagnosis, treatment and pain management of acute closed soft tissue injury[J]. Nat Med J Chin, 2021, 101(21): 1553-1559.

[9] JÄRVINEN M J, LEHTO M U. The effects of early mobilisation and immobilisation on the healing process following muscle injuries[J]. Sports Med, 1993, 15(2): 78-89.

[10] FERNANDES T L, PEDRINELLI A, HERNANDEZ A J. Muscle injury-physiopathology, diagnosis, treatment and clinical presentation[J]. Rev Bras Orgop, 2015, 46(3): 247-255.

[11] LIU J, SAUL D, BÖKER K O, et al. Current methods for skeletal muscle tissue repair and regeneration[J]. Biomed Res Int, 2018, 2018: 1984879.

[12] 中华医学会. 临床诊疗指南-创伤学分册[M]. 北京: 人民卫生出版社; 2007.
Chinese Medical Association. Clinical guidelines-traumatology[M]. Beijing: People's Health Publishing House; 2007.

[13] 郑筱萸. 中药新药临床研究指导原则——试行[M]. 北京: 中国医药科技出版社; 2002.
ZHENG X Y. Guidelines for clinical research of new Chinese medicines: a trial[J]. Beijing: China Medical Science and Technology Press; 2002.

[14] SANTANNA J P C, PEDRINELLI A, HERNANDEZ A J, et al. Lesão muscular: fisiopatologia, diagnóstico e tratamento[J]. Rev Bras Ortop (Sao Paulo), 2022, 57(1): 1-13.

[15] 周红海, 于栋. 中医筋伤学[M]. 北京: 中国中医药出版社; 2021.
ZHOU H H, YU D. Traumatology of traditional Chinese medicine[M]. Beijing: China Press of Traditional Chinese medicine; 2021.

[16] 中华中医药学会. 中医骨伤科常见病诊疗指南[M]. 北京: 中国中医药出版社; 2012.
Chinese Society of Traditional Chinese Medicine. A guide to the diagnosis and treatment of common diseases in Chinese orthopedics and traumatology[M]. Beijing: China Press of Traditional Chinese Medicine; 2012.

[17] LIU J, LIAO Z, WANG J, et al. Research on skeletal muscle impact injury using a new rat model from a bioimpact machine[J]. Front Bioeng Biotechnol, 2022, 10: 1055668.

[18] BRASIL L J, MARRONI N, SCHEMITT E, et al. Effects of pulsed radiofrequency on a standard model of muscle injury in rats[J]. Anesth Pain Med, 2020, 10(1): e97372.

[19] WANG Y, SUN Y, YANG C, et al. Sodium salicylate ameliorates exercise-induced muscle damage in mice by inhibiting NF-κB signaling[J]. J Orthop Surg Res, 2023, 18(1): 967.

[20] DU T, ZHOU L, LIU J, et al. Effectiveness of microwave therapy combined with berberine /GelMA via COX-2/IL-1β pathway to treat skeletal muscle injury: an *in vivo* study in rats[J]. Int J Nanomedicine, 2025, 20: 5509-5527.

[21] ZHANG W, PENG Q, ZHANG X, et al. Vitamin a promotes the repair of mice skeletal muscle injury through RARα[J]. Nutrients, 2023, 15(17): 3674.

[22] WANG Y, CHEN M, GAO Y, et al. Effect of one-time high load exercise on skeletal muscle injury in rats of different genders: oxidative stress and mitochondrial responses[J]. Acta Cir Bras, 2022, 37(8): e370805.

[23] 田硕, 曹利华, 苗明三, 等. 基于临床中西医病症特点的中医药动物模型评价新方法[J]. 中药药理与临床, 2017, 33(6): 165-169.
TIAN S, CAO L H, MIAO M S, et al. A new method for the

evaluation of animal models used in traditional Chinese medicine based on the clinical characteristics of Chinese and western medicine [J]. Pharmacol Clin Chin Mater Med, 2017, 33(6): 165-169.

[24] SOUSA FILHO L F, BARBOSA SANTOS M M, DOS PASSOS MENEZES P, et al. A novel quercetin/β-cyclodextrin transdermal gel, combined or not with therapeutic ultrasound, reduces oxidative stress after skeletal muscle injury [J]. RSC Adv, 2021, 11(45): 27837-27844.

[25] TIAN X, GAO Z, YIN D, et al. 17beta-estradiol alleviates contusion-induced skeletal muscle injury by decreasing oxidative stress via SIRT1/PGC-1α/Nrf2 pathway [J]. Steroids, 2023, 191: 109160.

[26] WANG S, HUANG S, XU X, et al. Effects of radial extracorporeal shock wave with different frequencies on acute skeletal muscle injury in rabbits [J]. Sci Rep, 2024, 14(1): 21276.

[27] DA COSTA SANTOS V B, CORREA J C M, CHIEROTTI P, et al. Cold water immersion or LED therapy after training sessions: effects on exercise-induced muscle damage and performance in rats [J]. Lasers Med Sci, 2019, 34(5): 991-999.

[28] HOU Z, WANG Z, ZHANG J, et al. Effects of cannabidiol on AMPKα2/HIF-1α/BNIP3/NIX signaling pathway in skeletal muscle injury [J]. Front Pharmacol, 2024, 15: 1450513.

[29] CHEN X, XUE Y, JIA G, et al. Antifatigue effect of naringin on improving antioxidant capacity and mitochondrial function and preventing muscle damage [J]. Exp Biol Med, 2022, 247(19): 1776-1784.

[30] PARK K H, PARK C I, SEO J W, et al. Anti-fatigue effect of an enzymatically derived deer velvet extract through muscle damage recovery and improvement of antioxidant levels [J]. J Ethnopharmacol, 2025, 337: 118965.

[31] SIKORSKA M, DUTKIEWICZ M, ZEGROCKA-STENDEL O, et al. Beneficial effects of β-escin on muscle regeneration in rat model of skeletal muscle injury [J]. Phytomedicine, 2021, 93: 153791.

[32] PABLOS A, CECA D, JORDA A, et al. Protective effects of foam rolling against inflammation and notexin induced muscle damage in rats [J]. Int J Med Sci, 2020, 17(1): 71-81.

[33] LEE E J, LEE M M, PARK S, et al. Sirt2 positively regulates muscle regeneration after notexin-induced muscle injury [J]. Exp Mol Pathol, 2022, 127: 104798.

[34] BRONISZ-BUDZYŃSKA I, KOZAKOWSKA M, PODKALICKA P, et al. The role of Nrf2 in acute and chronic muscle injury [J]. Skelet Muscle, 2020, 10(1): 35.

[35] 张卫林, 曹礼庭, 蒋冰蕾, 等. CEUS 参数评估兔骨骼肌缺血再灌注后肌肉活力 [J]. 中国医学影像技术, 2019, 35(5): 646-650.
ZHANG W L, CAO L T, JIANG B L, et al. CEUS parameters in evaluation of muscle viability after ischemia-reperfusion in rabbit skeletal muscles [J]. Chin J Med Imag Technol, 2019, 35(5): 646-650.

[36] 申震, 朱付平, 刘天举, 等. 桃红四物液对肢体缺血-再灌注损伤大鼠骨骼肌细胞凋亡的影响研究 [J]. 辽宁中医杂志, 2018, 45(3): 631-633, 672-673.
SHEN Z, ZHU F P, LIU T J, et al. Effects of Taohong Siwu liquid on skeletal muscle apoptosis of rats with limb ischemia reperfusion injury [J]. Liaoning J Tradit Chin Med, 2018, 45(3): 631-633, 672-673.

[37] ZHANG Y, LI H, WANG M, et al. Vagus nerve stimulation attenuates acute skeletal muscle injury induced by ischemia-reperfusion in rats [J]. Oxid Med Cell Longev, 2019, 2019: 9208949.

[38] DE CARVALHO E G, CORSINI W, DE ALMEIDA HERMES T. Severe muscle damage after a short period of ischemia and reperfusion in an animal model [J]. Surgery, 2023, 174(2): 363-368.

[39] 苗明三, 马林纳, 彭孟凡, 等. 中医药动物模型研究现状 [J]. 中国比较医学杂志, 2022, 32(1): 141-146.
MIAO M S, MA L N, PENG M F, et al. Animal model research and applications in traditional Chinese medicine [J]. Chin J Comp Med, 2022, 32(1): 141-146.

[40] 吴丽君, 王佳怡, 毕翔宇. 虾青素通过 mTOR-ULK1 自噬通路对大鼠运动性骨骼肌损伤影响的研究 [J]. 山东体育学院学报, 2024, 40(3): 114-126.
WU L J, WANG J Y, BI X Y. Effect of astaxanthin on exercise-induced skeletal muscle damage in rats through AMPK/mTOR/ULK1 autophagy pathway [J]. J Shandong Sport Univ, 2024, 40(3): 114-126.

[41] 刘宗义, 朱付平, 李武平. 桃红四物汤对大鼠肢体缺血-再灌注损伤骨骼肌长链非编码 RNA H19、核因子 κB-p65 表达的影响 [J]. 陕西中医, 2022, 43(9): 1163-1169.
LIU Z Y, ZHU F P, LI W P. Effects of Taohong Siwu decoction on expression of LncRNA H19 and NF-κB-p65 in skeletal muscle of rats with limb ischemia-reperfusion injury [J]. Shaanxi J Tradit Chin Med, 2022, 43(9): 1163-1169.

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