

本文亮点:

- (1) 回顾瘢痕激光治疗的发展历史及基本机制,提出以“早期褪红、规律干预、动态评估、安全有效的参数设置及联合或序贯治疗”为核心的临床策略。
- (2) 分析瘢痕激光治疗在成本控制与评估标准化方面的挑战,并展望个体化精准诊疗新模式的建立。

Highlights:

- (1) This paper reviewed the developmental history and fundamental mechanisms of scar laser therapy, proposing a core clinical strategy centered on "early erythema reduction, regular intervention, dynamic evaluation, safe and effective parameter setting, and combined or sequential therapy".
- (2) The challenges in cost control and standardization of evaluation criteria in scar laser therapy were analyzed, providing a perspective on the establishment of a new paradigm for individualized precision diagnosis and treatment.



瘢痕激光治疗的临床策略

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【摘要】 瘢痕的形成与演变是一个涉及炎症反应、血管新生及胶原沉积等多环节的复杂过程,可对患者外观、功能及心理健康产生长期影响。在瘢痕治疗中,尽管点阵激光、血管靶向激光、强脉冲光等已被广泛应用,但临床仍缺乏相对统一的治疗策略。该文基于笔者团队十余年临床实践,回顾瘢痕激光治疗的发展历史及基本机制,提出以“早期褪红、规律干预、动态评估、安全有效的参数设置及联合或序贯治疗”为核心的临床策略,以供临床参考;同时对瘢痕激光治疗的未来发展方向进行展望。

【关键词】 瘢痕; 激光疗法; 早期干预; 联合治疗

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Clinical strategies for scar laser therapy

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【Abstract】 The formation and evolution of scars is a complex process involving multiple stages, including inflammation, angiogenesis, and collagen deposition, which exerts long-term impacts on patients' appearance, function, and mental health. Although fractional lasers, vascular-targeted lasers, and intensive pulsed light have been widely utilized in scar management, a standardized clinical strategy remains to be established. Based on over a decade of clinical experience of our team, this paper reviews the developmental history and fundamental mechanisms of scar laser therapy. It proposes a core clinical strategy centered on "early erythema reduction, regular intervention, dynamic evaluation, safe and effective parameter setting, and combined or sequential therapy" to provide a reference for clinical practice. Furthermore, the paper discusses future perspectives in scar laser therapy.

【Key words】 Cicatrix; Laser therapy; Early intervention; Combination therapy

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瘢痕是创伤、手术、烧伤等皮肤损伤修复过程中的常见并发症,其发生率高,临床表现复杂,对患者的生理功能、外观美学以及心理健康均造成不同程度的影响。因此,如何有效预防和治疗瘢痕,一直是整形外科、烧伤科、皮肤科及康复医学科等多学科关注的重点。

传统的瘢痕干预方法包括压力疗法、药物注射、手术切除及放射治疗等,但疗效有限且瘢痕易复发。随着光电医学技术的发展,激光治疗逐渐成为瘢痕管理的一线策略^[1-2]。瘢痕激光治疗以选择性光热作用和点阵光热分解作用为核心机制,通过靶向作用于瘢痕中的血管、胶原及表皮结构,实现褪红、改善质地、软化瘢痕及促进胶原有序排列的目的。点阵激光、脉冲染料激光(pulsed dye laser, PDL)以及强脉冲光等在瘢痕治疗中的广泛应用,显著提高了治疗的有效性和患者的满意度。

然而,瘢痕激光治疗仍存在诸多挑战,包括激光的干预时机,激光参数的选择,疗效与安全性的平衡,以及不同人群的个体化差异等。本文将回顾瘢痕激光治疗的发展历史和临床应用,总结现有实践经验,探讨目前瘢痕激光治疗中的一些关键问题和治疗策略,并探索未来发展方向,为临床医师和基础研究者提供参考。

1 瘢痕激光治疗的发展简史

1960 年 Maiman^[3]研制出第 1 台红宝石激光器,这标志着医学激光时代的开启。激光最初主要用于治疗皮肤血管性病变和色素性疾病^[4]。剥脱性激光以二氧化碳激光(波长 10 600 nm)^[5]和铷激光(波长 2 940 nm)^[6]为代表,其主要机制是通过汽化表皮和真皮浅层,实现皮肤表面的磨削和重塑,同时也可诱导真皮胶原变性、重排和新生,从而改善皮肤的质地和平整度^[7]。鉴于剥脱性激光具有真皮重塑的作用,其应用范围被进一步拓展至瘢痕整复领域。受限于当时的技术条件,二氧化碳激光和铷激光多采用连续输出模式,热损伤范围大,术后恢复期长,且常伴随色素异常、感染等并发症^[8-9]。这些问题在很大程度上限制了连续输出模式的剥脱性激光在瘢痕整复中的应用。

2004 年 Manstein 等^[10]提出的“点阵光热分解”理论,为瘢痕激光治疗开创了新的模式。该理论的核心是“微热损伤区(microthermal zone, MTZ)”,即点阵激光作用于靶组织,在其中产生很多大小一

致、排列均匀的三维柱状热损伤带^[11]。点阵激光的热损伤激活了皮肤的创伤修复机制,MTZ 周围的正常组织迅速迁移至受损区域,从而加速愈合进程。基于这一原理的点阵二氧化碳激光和点阵铷激光,不仅实现了瘢痕表皮的重塑与真皮胶原的再生,还显著缩短了术后恢复期,降低了红斑与色素沉着等不良反应的发生率。

近 10 年来,临床医师和研究者都逐渐认识到瘢痕的形成涉及血管新生、黑色素代谢及胶原重塑等多个病理生理过程。瘢痕激光治疗理念已从单一汽化剥脱转向多波长光/激光的序贯或联合治疗,该类疗法已成为目前国内外科指南所推荐的方案^[1,12-13]。综合考量瘢痕厚度、血管密度、皮肤类型等因素,选择合适的激光类型、治疗参数和治疗周期,实现个体化、精准化治疗是瘢痕激光治疗的目标。

2 瘢痕激光治疗的基本原理

激光在皮肤瘢痕治疗中的应用主要基于“选择性光热作用”和“点阵光热分解作用”原理。瘢痕是一种以血管异常和胶原结构紊乱为主要特征的异常组织状态,激光治疗瘢痕的核心目标不是单纯的瘢痕组织汽化剥脱,而是对瘢痕的形成和重塑过程进行调控。早期及增生期瘢痕常伴随血管扩张与新生,以血红蛋白为主要靶基的激光(如 PDL^[14])可通过选择性光热作用改善血管结构,减轻瘢痕的充血和炎症反应,抑制 Fb 过度活化,从而抑制瘢痕的进一步发生发展。剥脱性及非剥脱性点阵激光通过在真皮内产生可控的热损伤,诱导胶原的变性、降解与再生,并促进胶原纤维重新排列,实现瘢痕厚度、硬度及弹性的逐步改善^[15]。因此,瘢痕激光治疗并非单一靶点或单一机制的作用,而是通过对血管、炎症及胶原重塑等过程的多方位调控,从而对瘢痕组织进行修复和重塑。

3 瘢痕激光治疗的临床实践和治疗策略

3.1 尽早干预、按周期规律治疗、动态评估治疗终点

瘢痕激光治疗的最佳干预时机一直是临床争议的焦点之一。传统观点认为,激光治疗需待瘢痕组织稳定后(通常 6 个月以上)方可进行。近年来,大量临床实践和循证研究均提示:激光干预不应该只局限于瘢痕成熟后,而应在创面上皮化后尽早启动^[16-21]。

Davari 等^[22]采用 PDL 治疗手术切口瘢痕,并比较不同起始时间干预的疗效差异。结果显示,早期 PDL 治疗(拆线后 1 个月内,尤其在拆线当天或 1 周内开始)较延迟治疗(拆线后 2 个月及以上)在改善血管分布和色泽方面效果更好,同时所需治疗的次数更少,患者的满意度更高。在一项纳入 221 例烧伤瘢痕患者的回顾性研究中,研究者根据患者首次接受点阵二氧化碳激光治疗的时间分组,最早干预时间为伤后 1 个月内。结果显示,所有患者经治疗后温哥华瘢痕量表各项评分均显著下降,其中伤后 1 个月内行点阵二氧化碳激光干预组改善最为显著,尤其是在色素沉着与瘢痕厚度方面[评分分别由(2.0±0.6)、(2.9±1.0)分降至(1.7±0.8)、(2.6±1.1)分]^[23]。在儿童烧伤瘢痕的治疗中,早期激光干预也是安全有效的^[24]。

在早期干预的基础上,瘢痕激光治疗通常需要多次、分阶段进行,以适应瘢痕在炎症、增生与重塑不同阶段的动态变化。治疗周期方面,建议以每 4 周 1 次的间隔实施血管靶向类激光如波长 585~595 nm 的 PDL、波长 532 nm 的磷酸钛氧钾晶体激光及窄谱强脉冲光等治疗,逐步减少瘢痕的血液灌注^[25];建议以每 6~8 周 1 次的间隔实施剥脱性点阵激光治疗,以留出足够的组织重塑与胶原重排时间^[26-27]。

由于个体差异,患者对瘢痕激光治疗的反应并不完全一致,因此目前尚无统一推荐的疗程方案,无法预设治疗的次数或时间。既往临床研究多以温哥华瘢痕量表^[28]与患者和观察者瘢痕评估量表^[29]评分的显著改善作为判定治疗终点的指标^[30]。因此,在临床实践中建议在患者接受 3~5 次激光治疗后,结合客观量表和主观症状,对疗效进行综合评估,重点观察:(1)瘢痕外观,包括颜色、厚度、表面形态等是否呈稳定趋势;(2)患者主观满意度与功能改善是否达到预期;(3)连续治疗后是否仍存在进一步改善空间等。若连续多次治疗后改善逐步减少或进入平台期,则可考虑暂停治疗,延长观察周期,避免过度治疗。

激光治疗可在瘢痕的各个阶段中应用。对于无明显功能障碍的成熟期或陈旧性瘢痕,经专科医师评估后,亦可通过激光治疗来改善其外观及质地^[31-32]。

3.2 褪红是早期瘢痕激光干预的重要目标

早期瘢痕常表现为红色、充血及轻度增厚,处

于炎症与血管新生最活跃的阶段。从病理生理角度看,创伤后的炎症期内,损伤组织会释放多种趋化因子和血管活性介质;随后进入增生期,VEGF 等持续上调,诱导微血管新生,引发局部红斑与组织增厚,促进瘢痕增生。血管密度与瘢痕增生程度呈正相关,其变化直接决定瘢痕的色泽与活跃程度^[33-34]。创面愈合后 1 个月内血管密度迅速上升,2~6 个月到达高峰期^[35],而瘢痕的成熟常伴随血管密度的显著降低,因此对早期瘢痕进行激光干预,积极褪红,可以有效抑制瘢痕血管新生,预防瘢痕增生,主动调控瘢痕的发展进程。

以血管为靶基的激光治疗,是早期瘢痕褪红干预的优先选择^[36-37]。PDL 的波长与血红蛋白吸收峰高度重叠,能够有效封闭血管,改善红斑外观^[35]。强脉冲光覆盖 400~1 200 nm 波段,具有与激光相似的特征,能通过选择性光热作用原理,同时作用于氧合血红蛋白与黑色素,有效改善瘢痕潮红和色素沉着^[38]。窄谱强脉冲光是对传统强脉冲光的精准化迭代,将能量集中于波长 500~600 nm 或 550~650 nm 的窄谱区间,提高了血管的靶向性^[39],在降低血管密度的同时也能缓解瘙痒等症状^[40]。此外,光子技术通常采用大光斑设计,适用于范围较大、潮红伴色素沉着的早期瘢痕^[41-42]。波长 532 nm 的磷酸钛氧钾晶体激光在瘢痕治疗中的应用较少,但其也具有与其他褪红激光类似的作用^[43-44]。

以血管为靶基的激光和光子,其作用不仅限于“血管封闭”,还能通过提高 Fb 活性、调控胶原纤维及弹性纤维重塑,从而加速瘢痕的成熟和平整化^[45-47]。因此,积极开展激光褪红干预,可实现对瘢痕过度血管化、炎症反应与组织重塑的多重调控。

3.3 “中低扫描密度,中等能量密度”的点阵激光治疗诱导瘢痕重塑

点阵激光是治疗瘢痕的另一重要手段,其通过产生 MTZ 启动瘢痕的修复和重塑。与血管靶向激光不同,点阵激光无明确的终点反应,且点阵激光 MTZ 的深度、直径及周围的热凝固带范围等形态特征及相应的生物学效应是由不同的激光参数(能量密度、扫描密度、脉冲宽度及光斑直径等)共同决定的,因此点阵激光参数设置相对复杂。

能量密度与激光的穿透深度和消融宽度呈正比^[48];扫描密度决定了单位治疗面积内 MTZ 的比例^[10],高扫描密度可增强瘢痕改善效果,但红斑与炎症持续时间更长;脉冲宽度则影响 MTZ 汽化与凝

固的比例^[49-50],短脉冲宽度的剥脱效应强,而长脉冲宽度能增加热凝固,有利于胶原重塑但热损伤范围也相应扩大。必须强调的是,高能量密度、高扫描密度、长脉冲宽度的综合效应会导致热量累积、创面愈合延迟、色素脱失及色素沉着^[51],甚至可能造成进一步的瘢痕增生或恶化^[52]。

目前瘢痕点阵激光治疗尚缺乏统一的参数标准体系。基于临床实践验证,笔者推荐以“中低扫描密度,中等能量密度”为起始,进行多次、分阶段治疗,并在随访过程中对参数进行动态调整。临床上,点阵激光参数设置应以瘢痕厚度为核心依据,激光治疗深度通常为瘢痕厚度的 50%~75%^[53]。以 UltraPulse 超脉冲二氧化碳点阵激光治疗仪为例,若瘢痕厚度 < 2 mm,建议采用 Deep FX 模式:5% 的扫描密度,12.5~20.0 mJ/cm² 的能量密度;若瘢痕厚度为 2~5 mm,建议采用 SCAAR-FX 模式:1% 的扫描密度,60.0~80.0 mJ/cm² 的能量密度,同时联合应用糖皮质激素。针对厚度 > 5 mm 的瘢痕或瘢痕疙瘩,建议优先考虑糖皮质激素瘢痕内注射治疗。

3.4 多模式联合或序贯治疗的重要性

瘢痕的发生与发展是一个涉及炎症反应、Fb 活化、胶原沉积及血管生成等多因素、多环节的复杂过程,因此单一治疗手段往往难以兼顾疗效与安全性。近年来的临床研究和实践均表明,多模式联合或序贯治疗已成为瘢痕管理的重要趋势^[54]。例如,在早期红色瘢痕阶段,采用 PDL 抑制血管活性,减轻炎症与充血,再配合点阵激光改善表面质地和胶原重塑^[55-57]。在增生性瘢痕和瘢痕疙瘩中,点阵激光联合糖皮质激素或 5-氟尿嘧啶局部注射,可以在降低药物总剂量的同时提高治疗效果,减少不良反应^[58]。此外,手术修复和硅酮类敷料^[59]都可以与激光技术相整合,协同提升患者瘢痕的功能与美观度。在儿童等特殊人群中,合理的联合策略能够有效提升患儿及其家属的依从性^[60]。

多模式联合或序贯治疗不仅是技术叠加,更是精准评估、个体化干预的体现,可根据瘢痕的阶段、类型和患者特点制订动态组合方案,从而实现最优的治疗效果。

4 挑战与展望

激光治疗能够有效改善瘢痕的质地和色泽,提升患者的整体生活质量,具有积极的临床价值。然而,瘢痕激光治疗通常需多次干预,设备成本、耗材

费用及患者时间投入较高(从数月到数年不等),其成本效益比在不同瘢痕类型、人群及医疗环境中差异明显。目前有关瘢痕激光治疗的研究多集中于疗效与安全性的评价,对经济学指标及长期获益的系统分析相对不足,这是未来需要关注的挑战之一。基于长期的临床实践,对于在功能或外观上造成明确影响的瘢痕,笔者仍建议在权衡成本的前提下,采取早期、多次、分阶段的激光干预,以减少后续手术治疗及长期护理的综合负担。

目前瘢痕激光治疗的循证医学证据仍以小样本研究、回顾性分析及专家经验为主,不同研究在评价体系、随访周期及结局指标方面存在差异,限制了结果的横向比较。不同类型的瘢痕对激光治疗的反应存在显著个体差异,这导致研究设计在统一入组标准、参数设置和疗效评价方面面临挑战。未来有必要开展多中心、标准化的前瞻性研究,引入统一的疗效评价体系,以提高证据等级。

展望未来,为实现个性化和精准化的激光治疗,需要不断探求激光与皮肤或瘢痕组织间相互作用的生物学效应,从而进一步优化治疗参数;此外,无创或微创成像技术在评估瘢痕血流灌注等临床指标方面的应用日益成熟^[34],为瘢痕的诊断、治疗监测及预后评估提供了更客观的依据。未来,笔者期待能通过构建“个体化光学模型”,为瘢痕激光治疗提供更优化、更精准的治疗方案。

利益冲突 所有作者声明不存在利益冲突

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