

单孔腹腔镜临床应用进展

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摘 要

单孔腹腔镜手术(single incision laparoscopic surgery, SILS)是经脐部单一小切口完成腹部全流程操作的微创术式, 在传统腹腔镜的基础上进一步减少了腹壁创伤, 具有术后疼痛轻、恢复快、并发症少、瘢痕隐蔽美容效果佳等优势, 已广泛应用于普外科、泌尿外科、妇科。但SILS存在器械“筷子效应”、操作三角缺失、视野盲区、学习曲线长等局限, 可弯曲手术器械可改善部分操作难题, 单孔手术机器人凭借多自由度机械臂、3D高清视野大大解决了器械碰撞问题。

关键词

单孔腹腔镜手术, 腹腔镜, 单孔手术机器人, 微创手术

Clinical Advances in Single-Incision Laparoscopic Surgery

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Abstract

Single Incision Laparoscopic Surgery (SILS) is a minimally invasive surgical procedure that completes the entire abdominal operation through a single small umbilical incision. On the basis of conventional laparoscopic surgery, it further reduces abdominal wall trauma and offers advantages

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such as mild postoperative pain, rapid recovery, fewer complications, concealed scars and excellent cosmetic results. It has been widely used in general surgery, urology and gynecology. However, SILS is limited by the “chopstick effect” of instruments, lack of operative triangle, visual blind spots and a long learning curve. Flexible surgical instruments can improve part of the operational difficulties, while single-incision surgical robots have largely solved the problem of instrument collision by virtue of multi-degree-of-freedom robotic arms and 3D high-definition vision.

Keywords

Single Incision Laparoscopic Surgery, Laparoscopic, Single Port Robot, Minimally Invasive Surgery

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1. 引言

1910 年瑞典医生 Jacobaeus [1]首次将膀胱镜经腹部微小切口进入腹腔，同时建立人工气腹，可安全直观地观察腹腔脏器表面，奠定了现代腹腔镜技术的基础。腹腔镜手术的发展经历了三个主要时期：诊断性腹腔镜、手术腹腔镜和现代腹腔镜时代[2]-[4]。随着腹腔镜技术的不断革新与完善，其应用范围日益广泛，目前已成功应用于结直肠癌[5]、胃旁路手术[6]等多种外科手术中。与传统开腹手术相比，腹腔镜手术有着创伤小、切口美观[7]、术后恢复快、并发症少[8]、疼痛轻[9]的特点，符合加速康复外科(enhanced recovery after surgery, ERAS)的理念。随着人们对手术微创和美容效果的需求不断增长、腹腔镜技术和器械的日益完善，SILS 日益受到关注。

2. SILS 定义

SILS 是在传统多孔腹腔镜手术的基础上发展而来，是仅通过脐部单一小切口，置入多通道穿刺器或多器械通道，施行腹腔镜下探查、分离、切除、缝合等全部操作的微创术式。

3. SILS 的优势

SILS 是腹腔镜领域快速发展的重要方向，其在多孔腹腔镜的基础上通过减少切口数量，腹壁手术创伤更小，疼痛轻，伤口感染少，恢复速度更快以及有利于美容的潜在优势[10]。SILS 的切口通常选择在脐部，一般于脐上缘或下缘做 3~5 cm 的切口，置入多孔套管装置进行手术。脐部作为人类天然的疤痕且作为腹壁最薄的部分，若选择脐部作为切口入路，同时术者具备丰富的手术操作及缝合经验，手术切口疤痕可完美隐蔽于脐窝，美容效果更佳[11] [12]。另外 Şentürk 等[13]的研究显示垂直切口比横切口具有更好的美观效果。目前单孔腹腔镜手术已在多个术式中得到应用，如胆囊切除术[14]、腹股沟疝修复[15]、阑尾切除术[16] [17]、结直肠癌[18] [19]、袖状胃切除术[20]、妇科手术[21]以及泌尿外科手术[22]中得到了广泛的应用。

4. 论文格式编排

4.1. 普外科

4.1.1. 胆囊切除术

单孔腹腔镜胆囊切除术(single-incision laparoscopic cholecystectomy, SILC)由 Navarra 等[23]在 1997 年

首次报道,其通过两个经脐套管和三根经腹胆囊固定缝线完成了首例 SILS 手术。作为腹腔镜胆囊切除术(laparoscopic cholecystectomy, LC)在临床上的一种技术创新,已在临床上得到了广泛的应用[24],其适用人群主要为无复杂胆道疾病、既往未接受过大量腹部手术且腹部无明显粘连、除胆道疾病外全身健康状况良好的患者[25]。由于任何位于脐带外的切口必然会留下明显的疤痕,从而削弱该方法的美观优势,因此关于使用 SILC 进行脐外切口的报道很少[26],该手术通常通过一个肚脐处的切口完成。SILC 最常见的悬吊方法是采用圈套式牵开器,并在胆囊与腹壁之间置入 2~3 根经皮缝合线,通过此方法抬高胆囊底部以清晰地暴露 Calot 三角[27],为手术操作创造良好条件。

然而, SILC 在安全性和可行性方面仍然需要进一步的验证,其临床应用中存在的常见问题包括:腹腔镜器械碰撞的可能性增加[28],可替换的器械数量也相对更少[29],操作难度的上升导致手术时间的延长[30]-[32];且由于视野暴露受限、直形器械操作三角关系丧失,其更容易损伤到胆囊管、血管等重要组织;早期 SILC 的切口长度显著高于多切口,其切口疝的发生率显著高于传统的 LC 术式[33],且因脐部位置较深,伤口浆液肿、血肿及伤口感染的发生率也相对更高[34]。

因此,开展 SILC 技术要求术者具备更长的学习曲线,需熟练掌握 SILC 独特的手术视角及操作方式,以缩短手术时间、降低并发症发生率[35]。

4.1.2. 阑尾切除术

急性阑尾炎(acute appendicitis, AA)是外科常见的急腹症,每年每 1000 人中就会发生 1 例[36],自 1983 年 Semm [37]首次介绍了腹腔镜阑尾切除术(laparoscopic appendectomy, LA)后,该术式已逐渐发展成为急性阑尾炎的首选外科治疗方法[38],传统 LA 通常需要 3~4 个切口。随着腹腔镜技术发展以及 SILS 在其他手术中的应用,单切口腹腔镜阑尾切除术(single-incision laparoscopic appendectomy, SILA)应运而生。

与传统 LA 相比, SILA 在疤痕美观度、伤口疼痛程度、术后住院时间、并发症[39]-[42]等方面均体现出显著优势。其临床可行性已被纳入 WSES 指南[43]。随着手术技术的不断成熟, SILA 的应用范围已不再局限于最初的急性单纯性阑尾炎,还成功应用于急性化脓性阑尾炎[40]、坏疽穿孔性阑尾炎[44][45]、阑尾周围脓肿[46]-[48]甚至阑尾肿瘤[49]。Xiao 等[50]的研究还证明了 SILA 对于患有复杂阑尾炎且超重或肥胖的青少年的可行性。

但 SILA 存在一定的技术门槛,多项研究均指出,其手术时间相较于传统 LA 更长;出于安全性考虑,该手术需由高年资、具备扎实腹腔镜操作基础且经过专项培训的医生完成[51]。

4.1.3. 腹股沟疝修复术

腹股沟疝(Inguinal hernia)是临床中最常见的疝类型[52],全球每年有超过 2000 万患者接受腹股沟疝修复手术[53]。患者常常表现出腹股沟区膨胀,并随着时间的发展逐渐扩张,在腹压增高时,腹腔内容物易从腹壁缺损处突出。手术仍然是治疗腹股沟疝的金标准[54]。目前临床常用的治疗方法包括开放修复术、无张力网片修复术及腹腔镜修复术。与传统开放修复术和无张力补片修复术相比,腹腔镜手术具有切口小、术后疼痛轻、恢复速度快等显著优势[55][56]。腹腔镜手术包括经腹前腹膜(TAPP)和全腹膜外(TEP)两种方法,这两种方法均包含 SILS 方法,分别为 SIL-TAPP 和 SIL-TEP。自 2008 年 Cugura 等[57]首次报道首例单切口腹腔镜全腹膜外疝气成形术病例以来,单切口腹腔镜腹股沟疝修复术(single-incision laparoscopic inguinal hernia repair, SIL-IHR)在临床中得到广泛应用。

SIL-IHR 在美容效果、疼痛减轻、缩短治疗周期、降低住院费用、减少腹部创伤等方面相较于传统的 TAPP 术式均有显著优势[58]-[61]。

SIL-IHR 的最佳适应对象为 BMI < 30 kg/m²的原发单侧腹股沟疝患者。禁忌症包括:下腹部手术史(粘连风险)、难复性腹股沟疝、复发性腹股沟疝(相对禁忌)、严重心肺疾病(无法耐受气管插管全麻)[62]。

4.1.4. 其他

随着腹腔镜技术的不断进步, SILS 在普外科领域的应用范围持续扩大, 在肝切除术[63]、胰体尾切除术[64]、结直肠癌[18] [65]、甚至胰十二指肠切除术[66] [67]均有应用。但目前这些术式的临床应用病例数有限, 其安全性和有效性仍需更多多中心、大样本的临床研究进一步验证。

4.2. 妇科

由于阴道是女性的自然腔道, 妇科手术通常采用经阴道术式, 因此 SILS 技术在妇科手术中的应用范围显著小于普外科。主要原因在于 SILS 在做妇科手术时增加了损伤输尿管的风险, 并且其在取标本的困难程度显著高于阴式手术[68]。因此 SILS 通常被应用于良性妇科疾病中[69] [70]。

4.3. 泌尿外科

SILS 在泌尿外科领域的应用始于 2008 年, Desai 等[71]首次报道了经脐无瘢痕单孔肾切除术及肾盂成形术, 为该技术泌尿外科的推广奠定了基础。目前, SILS 在肾上腺切除术[72]、肾脏手术[73]、输尿管手术[74]、膀胱手术[75]等泌尿外科常见手术中均有应用。

在泌尿外科的 SILS 应用中, 我们发现除脐部切口外, 还可选择多种切口降低操作难度、降低并发症的发生水平等, 包括经膀胱 SILS、腰部切口 SILS 等。经膀胱 SILS 的优势在于其通过耻骨联合上方切口, 阴毛和衣物可以掩盖其切口, 并且减少对于肠道的干扰, 适用于膀胱阴道瘘修补、膀胱憩室切除术, 前列腺剜除、前列腺癌根治性切除术等[76]。而腰部切口则离肾脏距离更近, 对于肾脏手术操作更便捷, 而对于肾切除术等需要取较大标本的手术则更容易延长切口, 若切口位置选择得当, 还能进一步将切口隐藏在皮纹中, 从而达到美观的目的。

5. SILS 中的局限性

单孔腹腔镜在临床上应用较多, 但目前仍然存在着许多技术难题需要攻克。

5.1. 手术操作难度高

所有手术器械均通过单一通道进入腹腔, 腹腔镜镜头与操作器械几乎平行进入, 易出现视野盲区, 操作器械之间距离短, 缺乏传统多孔手术的操作三角, 易出现相互干扰的“筷子效应”, 增加了组织分离、止血、缝合等关键操作的难度, 增加了术中出血量, 但随着术者操作经验的增加, 术中出血量可以明显减少。

5.2. 手术时间相对较长

长时间维持单一操作姿势易导致术者疲劳, 进一步影响手术精准度[77]。

5.3. 学习曲线延长

术者首先要掌握传统腹腔镜技术, 然后再逐渐熟悉单孔腹腔镜的器械及操作习惯、器械调整、视野暴露。

5.4. 手术适用范围

初始适用于简单的良性病变、中小型病变, 对于肿瘤根治性手术、腹腔广泛粘连等手术, 操作风险较高, 需要谨慎选择。随着术者的操作熟练, 适应症范围逐步扩大, 由简到繁。

5.5. 设备成本相对高

腹腔镜单孔操作平台、单孔腹腔镜专用器械等费用高于传统腹腔镜器械。

6. SILS 专用器械的研发与临床应用现状

SILS 中,腹腔镜镜头与手术器械必须通过脐部的单一切口进入腹腔,器械间的间距小且相互干扰,形成“筷子效应”,手术难度增加。目前国内外已形成多通道穿刺器、特殊操作器械、辅助牵拉装置等多品类研发体系,且国产器械与进口器械逐步形成互补的临床应用格局。

单孔多通道腹腔镜套管(SILSPort) [78]解决单孔手术中器械碰撞、气密性维持及操作灵活性问题,并且其通过产品迭代优化了通道间距、材料柔性及器械支撑功能。

单孔腹腔镜可弯曲器械分为可调节弯曲器械与预弯曲器械,如头端可弯曲的高清摄像头、曲柄、曲杆或头端可弯曲的手术器械,在进入腹腔后,头端效应器邻近的操作杆可调节成一定的角度,在单孔套管处形成交叉,从而避免器械把手部位在腹腔外的碰撞。在使用可调节弯曲器械时,操作者的双手形成镜面操作,即左手操控的器械在腹腔内视野的右侧,右手操控的器械出现在腹腔内视野的左侧。两者均还原传统腹腔镜的操作三角[79][80]。减少了器械间的相互干扰,改善了视野效果,提升了操作的稳定性和手术的安全性。

为了解决 SILS 术中仅有两把操作器械,无法像传统腹腔镜对组织进行有效牵引,单孔腹腔镜手术牵引暴露装置可协助牵引组织,有利于操作视野暴露和解剖操作[23]。

7. 手术机器人在 SILS 中的应用

相较于传统单孔腹腔镜器械存在的操作局限,单孔手术机器人(single port robot)凭借其独特的结构设计与技术优势,在 SILS 中展现出显著的应用价值。

单孔手术机器人搭载的多自由度机械臂,依托多关节运动构型与运动学冗余设计,可通过灵活的末端位姿调控与力学适配性操作,在狭小腹腔空间内完成多维度旋转、弯曲及精准姿态调整,既从器械运动轨迹层面规避器械间干涉碰撞,又通过重构手术操作三角空间,从力学与运动学维度系统性破解单孔腹腔镜手术固有的“筷子效应”与操作三角缺失难题[81];其搭载的 3D 高清立体视野可将手术区域放大 10~15 倍[82],清晰呈现组织解剖层次[83][84]与血管神经走向,助力术者精准区分病变组织与正常组织边界,有效降低术中副损伤风险;同时,术者可坐姿操控控制台完成手术操作,大幅减轻肢体疲劳,能够更稳定、轻松地实施长时间高难度手术操作[85][86]。

近些年来,随着单孔手术机器人技术的不断成熟与完善,国内外大量学者聚焦于该技术在 SILS 中的临床应用,开展了一系列大样本、多中心的临床研究,通过长期随访与数据汇总,积累了丰富且可靠的循证医学证据,为其临床推广与规范应用提供了坚实的理论与实践支撑。在泌尿外科领域,单孔手术机器人凭借其精准性与微创性的优势,已被广泛应用于多种复杂泌尿外科手术中,成为泌尿外科微创治疗的重要手段,目前已广泛应用于前列腺癌根治术[87]-[89]、肾部分切除术[90][91]、膀胱全切术[92]等复杂术式。

此同时,单孔手术机器人在妇产科领域的应用也日益广泛且成熟[93],依托其精准操作、微创性及灵活性优势,逐步成为妇科微创手术的重要发展方向,相关临床研究也积累了充足的真实循证依据,覆盖妇科良性疾病[94]、恶性肿瘤等多个场景。与在妇科良性疾病治疗中,该机器人可精准开展全子宫切除术[95][96]、双侧输卵管切除术、卵巢肿瘤切除术[97]及子宫肌瘤剔除术[98]等常见术式,该术式仅通过脐部 2.5 cm 左右的小切口即可完成全部操作,不仅术中出血少、术后疼痛轻、恢复速度快,还能有效隐藏手术瘢痕,满足女性患者对体表美观的个性化需求。

在普外科领域,单孔手术机器人的应用同样呈现多元化发展态势,凭借其微创、精准、灵活的核心优势,逐步突破传统单孔腹腔镜手术的操作局限,广泛应用于胃肠外科、肝胆胰外科、小儿普外科等多个亚专科,相关临床研究已积累了丰富的真实循证证据,为复杂普外科手术的微创化发展提供了新路径。

多项临床研究已经证明了其在结直肠癌手术中的显著优势[99]-[102]，包括更清晰的手术视野、更干净的淋巴结清扫以及更高的低位直肠癌保肛率等，为患者生存率及预后提供了良好的保障。同时在良性胆囊疾病的手术中单孔机器人也有广泛的应用[103][104]。

随着 5G 通信技术与人工智能的快速发展，单孔手术机器人远程操控技术被应用于临床中[105]。其通过在医疗发达地区的术者远程操作在偏远地区手术机器人的机械臂，打破了空间地域限制，成为推动优质医疗资源下沉、实现远程精准医疗的重要载体，在临床应用中，单孔机器人远程操控已成功应用于泌尿外科、妇产科、普外科等多个领域，且取得了显著的临床成效[106][107]。

8. 总结与展望

SILS 是腹腔镜技术的重要革新，以脐部为主要入路实现瘢痕隐蔽，兼具疼痛轻、恢复快、并发症少等优势，契合加速康复外科理念，目前已广泛应用于普外科、妇科、泌尿外科等领域，普外科胆囊切除、阑尾切除等术式应用成熟，且逐步拓展至肝、胰等复杂手术，泌尿外科还创新了经膀胱、腰部等多切口入路。但 SILS 仍存在器械“筷子效应”、操作三角丧失、二维视野有盲区等技术局限，部分术式手术时间长、并发症风险较高，对术者操作要求也更为严苛。目前 SILS 专用器械虽已实现多品类临床应用，但仍存在进口器械成本较高、国产专用器械品类有限、缺乏统一操作规范等问题，未来需进一步推进医工融合，结合不同术式需求研发高适配性专用器械，同时完善器械应用的临床循证证据。单孔手术机器人凭借多自由度机械臂、3D 立体视野解决了核心操作难题，远程操控模式还实现了医疗资源跨区域共享。

未来随着 SILS 临床应用范围的进一步扩大，需紧扣其器械平行干涉、操作三角缺失、学习曲线陡峭、复杂术式适配性不足等核心技术瓶颈，聚焦三大方向精准发力：一是深化医工交叉融合，围绕单孔通道的空间约束特性，研发具备多自由度协同操控、防碰撞力学适配的国产专属器械，从硬件端破解“筷子效应”与操作空间重构难题；二是开展面向 SILS 特有术式难点的大样本、多中心临床研究，重点针对结直肠、肝胆等复杂腹部手术场景优化操作流程与组织牵拉策略，基于真实世界证据制定专属临床指南与质控规范，而非沿用传统腹腔镜标准；三是构建贴合 SILS 操作特性的标准化阶梯式培训体系，聚焦单孔下器械协同操控、手眼协调适配等核心技能开展专项训练，针对性缩短术者学习曲线。通过上述针对性突破，推动 SILS 技术摆脱通用微创技术的发展范式，实现标准化、规范化落地，在腹部微创外科领域形成差异化临床优势。

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