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·循证研究·

# 气道廓清技术在重症康复应用的文献计量分析

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**摘要**

**目的** 分析气道廓清技术(ACT)在重症康复中应用的研究现状、热点和发展趋势。

**方法** 检索建库至2024年12月31日Web of Science核心合集数据库中的相关文献。使用CiteSpace VI 6.2.R3 和VOSviewer 1.6.19 对纳入文献的发文趋势、国家、机构、作者、期刊、关键词、共被引文献进行可视化分析。

**结果** 共纳入文献2 189篇，发文量总体呈稳定输出趋势。美国是发文量最多的国家，University of Toronto是发文量最多的机构，Paolo Pelosi是最高产的作者。当前研究的热点关键词包括mechanical ventilation和acute respiratory distress syndrome，近年来的突现关键词是electrical impedance tomography和mechanical insufflation-exsufflation。

**结论** 近年来，ACT在重症康复的应用愈发广泛。研究热点包括对呼吸衰竭和肺部损伤患者的气道廓清管理。机械吸入-呼出排痰技术，采用电阻抗断层成像、驱动压检测等辅助技术为气道廓清障碍患者提供指导性治疗方案可能是该领域的未来研究趋势。

**关键词** 气道廓清；呼吸康复；重症康复；文献计量学

## Application of airway clearance techniques in critical care rehabilitation: a bibliometric analysis

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**Abstract**

**Objective** To analyze the research status, hotspots and development trends of the application of airway clearance techniques (ACT) in critical care rehabilitation.

**Methods** Relevant literatures up to December 31st, 2024 were retrieved from the Web of Science Core Collection database. CiteSpace VI 6.2.R3 and VOSviewer 1.6.19 were used to perform bibliometric analysis, including annual publication volume, countries, institutions, authors, journals, keywords and co-cited references.

**Results** A total of 2 189 publications were included, showing an overall stable output trend over time. The United States

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was the country with the highest publication, the University of Toronto was the most productive institution, and Pelosi Paolo was the most prolific author. The hottest keywords included mechanical ventilation and acute respiratory distress syndrome. The bursting keywords were electrical impedance tomography and mechanical insufflation-exsufflation.

**Conclusion** ACT have been widely used in critical care rehabilitation in recent years, especially for the management of airway clearance in patients with respiratory failure and lung injury. It may focus on the use of mechanical insufflation-exsufflation, and assistive technologies such as electrical impedance tomography and driving pressure detection to guide treatment for patients with airway clearance disorders in the future.

**Keywords**: airway clearance; respiratory rehabilitation; critical illness rehabilitation; bibliometric

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## 0 引言

重症医学的快速发展显著提高重病患者的生存率[1]。然而许多患者在经历监护室内有创机械通气后，常出现肺不张、肺部感染和获得性肌无力等并发症，导致长期卧床、活动能力受限和生活质量下降[2-5]。气道廓清技术(airway clearance techniques, ACT)作为一种辅助清除气道分泌物的外部手段，可在危重症患者管理中发挥重要作用[6]。

文献计量学是一种基于系统文献指标的分析方法，兼具定量与定性的分析价值[7-8]。CiteSpace作为常用的文献计量工具，能够对数据进行可视化处理，有助于整体把握特定领域的研究热点与发展趋势[9-10]。目前，关于ACT在重症医学中的应用已积累了大量研究。部分研究也探讨了其在囊性纤维化、脑损伤等疾病中的疗效和发展动态[11-14]，本研究基于Web of Science (WOS)核心合集数据库，运用CiteSpace和VOSviewer软件，对ACT在重症康复中的研究现状、研究热点和未来趋势进行可视化分析。

## 1 资料与方法

### 1.1 数据来源与检索策略

检索WOS数据库建库至2024年12月31日相关文献。

检索式：(airway clearance technique OR airway clearance physiotherapy OR chest physiotherapy OR cough training OR forced cough OR active cycle breathing technique OR autonomic drainage OR postural drainage OR positive end pressure OR oscillatory positive expiratory pressure OR high-frequency chest wall oscillation) AND (critical care medicine)

纳入标准：①文献类型仅包括论著和综述；②语言仅限于英文。

排除标准：①文献类型为会议摘要、社论材料、信函及修订；②重复发表或无法获取全文。

### 1.2 数据处理

将检索到的文献转换为.txt格式，采用CiteSpace VI 6.2.R3进行数据转化、清洗，系统自动去除重复文献。

### 1.3 数据分析

采用CiteSpace VI 6.2.R3和VOSviewer 1.6.19对纳入文献进行可视化分析。包括发文量、国家、机构、作者、期刊分布和文献共被引分析。

## 2 结果

最终纳入2 189篇文献。

### 2.1 发文量

自2002年以来，每年发文量虽然有波动，但年发文量均在70篇以上，总体呈稳定输出趋势。见图1。

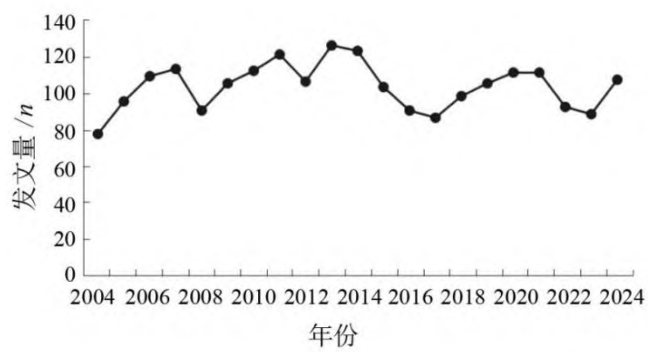



**图1 年发文量**

**Figure 1 Annual publications**

**2.2** 国家/地区

文献来自79个国家。以国家为节点类型，采用VOSviewer 1.6.19筛选发文量超过5篇的43个国家/地区。见图2。美国以831篇发文量居首，且中心性最高(0.13)。见表1。

**2.3** 机构

以机构为节点类型，共有2 759家机构发表ACT相关文章。排名前10位的机构发文量共计1 337篇。其中约有40%来自美国，包括Massachusetts General Hospital、Harvard University、Harvard University Medical Affiliates和Harvard Medical School。见表2。

**2.4** 作者

以作者为节点类型，共10 866名作者参与ACT的研究，Paolo Pelosi是本领域最为活跃的研究者，累计发文量72篇。其中8名作者发文量超过35篇文章。见表3。

**表1　发文量排名前10的国家**

**Table 1　Top ten countries by number of publications**

| 排名 | 国家 | 发文量/$n$ | 篇均被引频次 | H指数 | 中心性 |
|---|---|---|---|---|---|
| 1 | USA | 831 | 71.62 | 120 | 0.13 |
| 2 | Italy | 379 | 72.92 | 82 | 0.01 |
| 3 | France | 321 | 89.72 | 85 | 0.02 |
| 4 | Canada | 247 | 102.54 | 72 | 0.01 |
| 5 | Germany | 242 | 93.40 | 71 | 0.02 |
| 6 | Spain | 189 | 84.81 | 60 | 0.03 |
| 7 | Brazil | 187 | 66.86 | 54 | 0.03 |
| 8 | Australia | 147 | 81.92 | 53 | 0.09 |
| 9 | Netherlands | 134 | 60.31 | 48 | 0.01 |
| 10 | England | 133 | 118.44 | 46 | 0.04 |

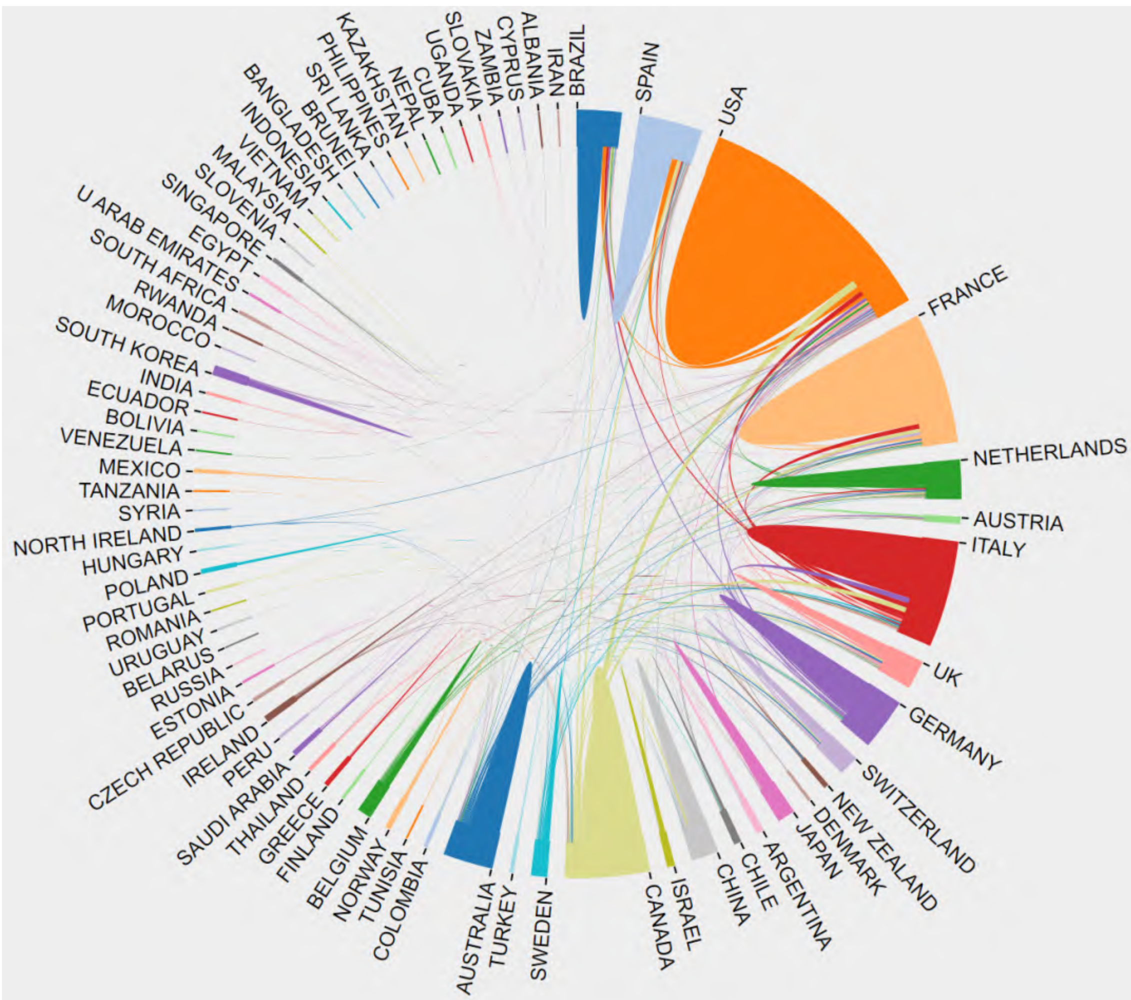



**图2　活跃国家/地区图谱(VOSviewer)**

**Figure 2　Map of active countries/regions (VOSviewer)**

表2 发文量排名前10的机构

Table 2 Top ten institutions by number of publications

| 排名 | 机构 | 发文量/*n* | 篇均被引频次 | H指数 | 中心性 |
|---|---|---|---|---|---|
| 1 | University of Toronto (Canada) | 183 | 120.54 | 64 | 0.06 |
| 2 | Institut National De La Sante Et De La Recherche Medicale Inserm (France) | 169 | 57.12 | 55 | 0.02 |
| 3 | Assistance Publique Hopitaux Paris Aphp (France) | 164 | 122.01 | 67 | 0.07 |
| 4 | Harvard University (USA) | 162 | 124.64 | 64 | 0.03 |
| 5 | Harvard University Medical Affiliates (USA) | 145 | 134.20 | 61 | 0.03 |
| 6 | University of Milan (Italy) | 116 | 83.57 | 48 | 0.03 |
| 7 | Saint Michaels Hospital Toronto (Canada) | 106 | 124.97 | 45 | 0.06 |
| 8 | Massachusetts General Hospital (USA) | 104 | 150.76 | 53 | 0.04 |
| 9 | Harvard Medical School(USA) | 96 | 87.08 | 45 | 0.03 |
| 10 | Universidade De Sao Paulo (Brazil) | 92 | 63.64 | 41 | 0.07 |

表3 发文量排名前10的作者

Table 3 Top ten authors by number of publications

| 排名 | 作者 | 国家 | 作者机构 | 发文量/*n* | 总被引次数/*n* | 年均被引频次 | H指数 |
|---|---|---|---|---|---|---|---|
| 1 | Paolo Pelosi | Italy | University of Genoa | 72 | 5186 | 246.95 | 37 |
| 2 | Laurent Brochard | Canada | Saint Michaels Hospital Toronto | 70 | 7440 | 354.29 | 40 |
| 3 | Luciano Gattinoni | Germany | University of Gottingen | 61 | 7991 | 380.52 | 39 |
| 4 | Antonio Pesenti | Italy | University of Milan | 44 | 5113 | 340.87 | 31 |
| 5 | Davide Chiumello | Brazil | Ospedale San Paolo | 40 | 3893 | 185.38 | 27 |
| 6 | Samir Jaber | France | Universite de Montpellier | 39 | 3958 | 197.90 | 29 |
| 7 | Robert M Kacmarek | USA | Massachusetts General Hospital | 39 | 4277 | 203.67 | 27 |
| 8 | Patricia R M Rocco, | Brazil | Universidade Federal do Rio de Janeiro | 36 | 1317 | 62.71 | 22 |
| 9 | Jordi Mancebo | Spain | Hospital of Santa Creu i Sant Pau | 35 | 3830 | 182.38 | 24 |
| 10 | John J Marini | USA | University of Minnesota Twin Cities | 35 | 6142 | 279.18 | 22 |

**2.5** 关键词

**2.5.1** 共现分析

关键词共现分析显示，频次排名前3的分别是mechanical ventilation、end-expiratory和acute respiratory distress syndrome。见图3。

**2.5.2** 密度分析

关键词密度可视化展示研究的整体结构并且突出重要研究领域[15]。图中mechanical ventilation、end-expiratory pressure和acute lung injury在研究中关注度高且常关联出现。见图4。

**2.5.3** 聚类分析

关键词聚类分析得到4个聚类，分别代表4大类研究热点领域：黄色聚类代表气道廓清障碍病理生理机制，蓝色聚类代表气道廓清障碍并发症的支持策略，绿色聚类代表ACT治疗原理与评估手段，红色聚类代表ACT在重症监护室(intensive care unit, ICU)的应用。见图3。

**2.5.4** 突现分析

关键词突现指关键词在一段时间内被频繁引用，反映该时期的热点研究[16-17]。自2004年以来，共识别出15个突现词。其中，pulmonary function和alveolar recruitment于2004年成为早期热点。而electrical impedance tomography、Coronavirus disease 2019和mechanical insufflation-exsufflation在2020年成为近期热点。突现强度最高的早期关键词为driving pressure (15.11)和tidal volume ventilation (10.68)。见图5。

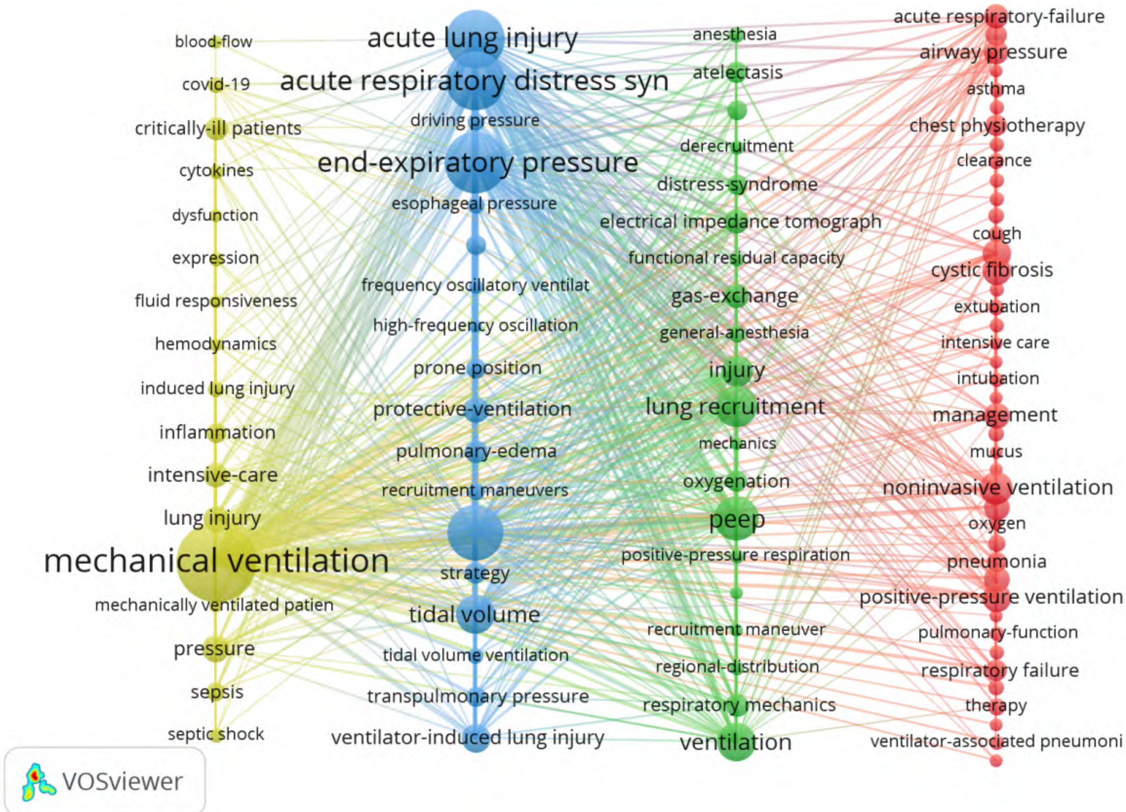



**图3　关键词共现图谱(VOSviewer)**

**Figure 3　Co-occurrence map of keywords (VOSviewer)**

**2.6** 文献共被引

以被引文献为节点，得到包含1 253个节点，5 636条线和16个聚类的网络。见图6。表4总结了有关共同引用参考文献聚类的一般信息。

**2.7** 期刊和期刊共被引

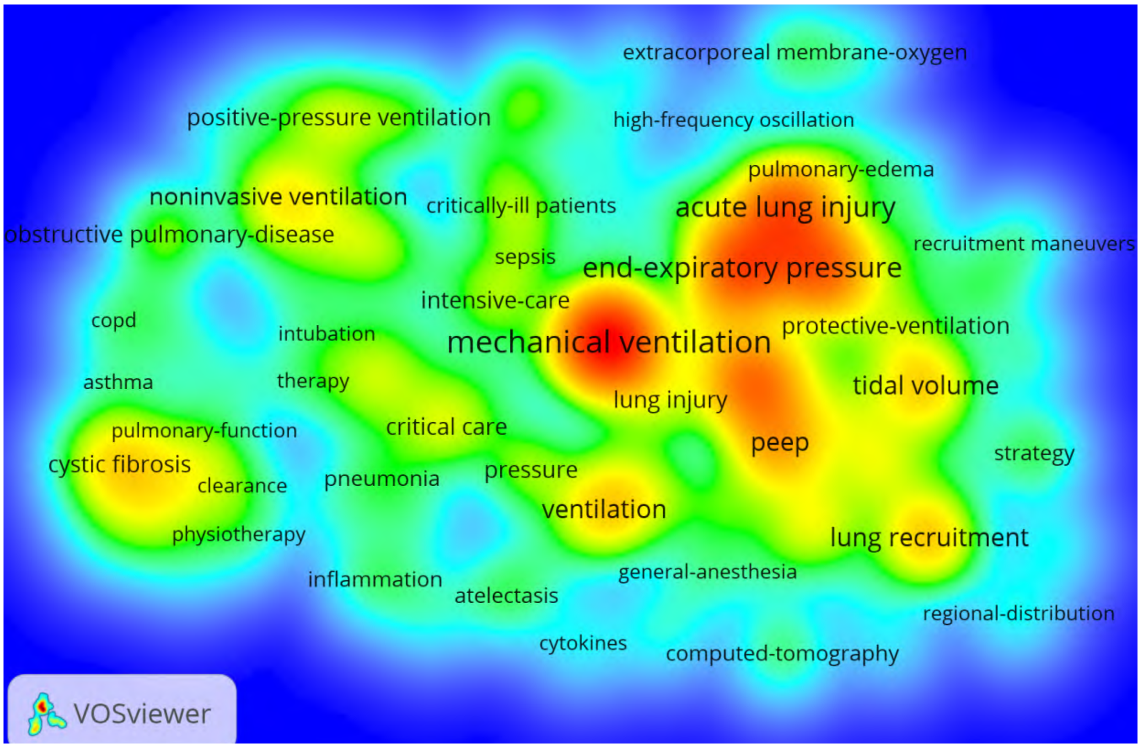
以期刊作为节点类型，共涉及37种期刊，前10名最活跃的期刊发表论文占总文献的79.85% (1 748篇)。*Respiratory Care* (313篇)是最活跃的期刊，其次是 *Critical Care Medicine* (271篇)和 *Critical Care* (261篇)。见表5。

共被引期刊是由研究人员一起引用的期刊，通常反映一个研究领域的基础，是文献计量分析中最重要的指标之一。*New England Journal of Medicine* 影响因子最高(IF = 158.5)。*American Journal of Respiratory and Critical Care Medicine* (1 722次)在联合引用期刊中排名第一，其次是 *Critical Care Medicine* (1 552次)和 *Intensive Care Medicine* (1 461次)，这表明这些期刊在重症康复领域的ACT研究中得到了更高的认可。见表6。

**3** 讨论

**3.1** 研究现状

本研究纳入的文献来自79个国家的2 759个机构，发表于37种同行评审期刊，共有71 391篇参考文献。年发文量和年引用次数均显示该领域研究产出保持稳定。美国发文量最多(831篇)。美国、加拿大和西班牙之间的密切合作对ACT在重症康复应用做出了重大贡献。但发文量排名前10的国家中心性整体偏低，未来需加强跨国合作。在前10所顶尖院校中，大部分来自美国，如Massachusetts General Hospital、Harvard University和Harvard University Medical Affiliates。作者方面，Paolo Pelosi和Laurent Brochard发文较多，共被引频次较高，表明其团队可作为潜在合作者。此外，排名前10的共被引期刊包含影响因子较高的期刊，如 *New England Journal of Medicine* (IF = 158.5)，JAMA (IF = 120.7)和 *Intensive Care Medicine* (IF = 38.9)，研究人员可将上述期刊作为重要的参考文献来源。




注：颜色越接近红色，代表该关键词出现频率越高，研究关注度也越大；而颜色偏向绿色或蓝色，则说明关键词在研究中出现频率较低。

**图4　关键词密度图谱(VOSviewer)**

**Figure 4　Density map of keywords (VOSviewer)**

| Keywords | Year | Strength | Begin | End |
|---|---|---|---|---|
| alveolar recruitment | 2004 | 8.39 | **2004** | 2011 |
| pulmonary function | 2004 | 8.15 | **2004** | 2008 |
| lower infection point | 2004 | 7.42 | **2004** | 2008 |
| cytokines | 2004 | 6.58 | **2004** | 2009 |
| mucociliary clearance | 2005 | 7.99 | **2005** | 2009 |
| support ventilation | 2004 | 7.01 | **2005** | 2011 |
| cystic fibrosis | 2004 | 7.62 | **2007** | 2009 |
| tidal volume ventilation | 2004 | 10.68 | **2013** | 2017 |
| high frequency oscillation | 2014 | 6.70 | **2014** | 2021 |
| esophageal pressure | 2010 | 7.32 | **2015** | 2017 |
| driving pressure | 2016 | 15.11 | **2016** | 2024 |
| extracorporeal membrane oxygenation | 2010 | 8.23 | **2016** | 2021 |
| electrical impedance tomography | 2005 | 9.32 | **2020** | 2024 |
| coronavirus disease 2019 | 2020 | 8.29 | **2020** | 2022 |
| mechanical insufflation-exsufflation | 2020 | 6.66 | **2020** | 2024 |

**2004-2024**

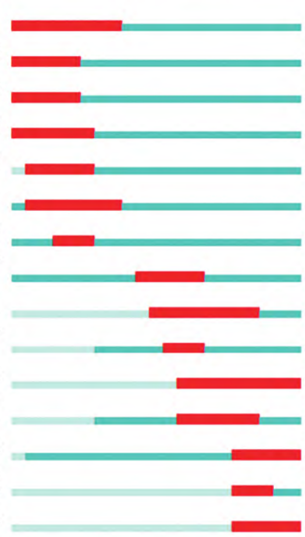


**图5　突现关键词(CiteSpace)**

**Figure 5　Bursting keywords (CiteSpace)**

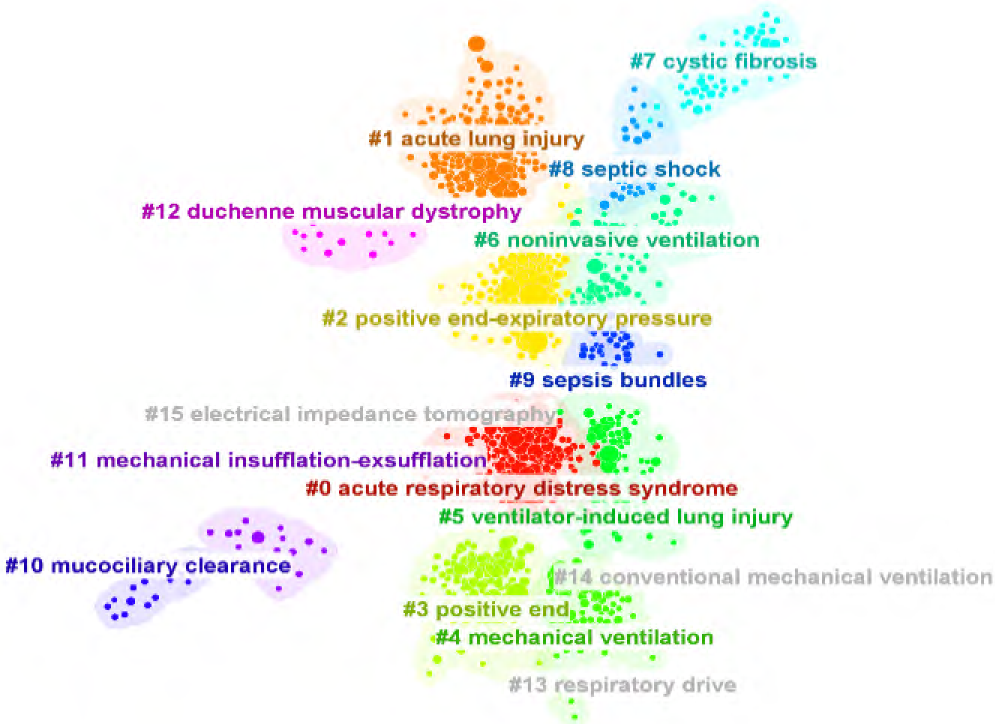



图6 被引文献共现图谱(CiteSpace)

Figure 6 Co-occurrence map of references (CiteSpace)

表4 共被引参考文献集的基本信息

Table 4 Basic information of the co-cited reference clusters

| 序号 | 标签 | 大小 | 轮廓值 | 年份 |
|---|---|---|---|---|
| 0 | acute respiratory distress syndrome | 192 | 0.831 | 2014 |
| 1 | acute lung injury | 173 | 0.939 | 2002 |
| 2 | positive end-expiratory pressure | 149 | 0.862 | 2007 |
| 3 | positive end | 141 | 0.918 | 2019 |
| 4 | mechanical ventilation | 103 | 0.879 | 2020 |
| 5 | ventilator-induced lung injury | 89 | 0.875 | 2014 |
| 6 | noninvasive ventilation | 72 | 0.924 | 2007 |
| 7 | cystic fibrosis | 53 | 0.969 | 2004 |
| 8 | septic shock | 36 | 0.987 | 2004 |
| 9 | sepsis bundles | 30 | 0.985 | 2009 |
| 10 | mucociliary clearance | 16 | 0.999 | 2011 |
| 11 | mechanical insufflation-exsufflation | 16 | 0.997 | 2017 |
| 12 | duchenne muscular dystrophy | 12 | 0.994 | 2008 |
| 13 | respiratory drive | 9 | 1.000 | 2020 |
| 14 | conventional mechanical ventilation | 9 | 0.995 | 2014 |
| 15 | electrical impedance tomography | 7 | 0.989 | 2012 |

### 3.2 研究概况

#### 3.2.1 重症患者气道廓清障碍病理生理机制

健康人拥有用于清除肺部吸入颗粒的多种生物学机制，如黏液纤毛清除、咳嗽反射和肺泡巨噬细胞的作用[18]。健康黏液向病理性黏液的转变涉及多种机制，包括炎症反应、细胞因子的作用。这些机制共同影响黏液的水合作用和生化成分，具体表现为黏蛋白的过量产生、炎性细胞浸润导致的黏液成分改变(如黏附性增强)，以及支气管血管通透性增加所引发的盐和水分异常[19-20]。

重症患者可能因为人工气道的建立，导致气道廓清能力下降，例如呼吸机使用不当导致的呼吸机相关性肺损伤。气道在刺激、感染等情况下发生炎症反应，引起肺泡内大量炎性因子表达，造成肺泡上皮细胞不同程度受损，通透性增加，进而诱发肺水肿。病原菌能促进炎症因子的释放，加剧肺组织损伤程度[21-23]。重症患者常出现气道廓清障碍，涉及黏液分泌过度、纤毛清除功能受损、人工气道对咳嗽反射的抑制效应以及呼吸肌功能衰退导致的咳嗽效能降低。

#### 3.2.2 气道廓清障碍并发症及支持策略

急性肺损伤(acute lung injury, ALI)是以肺泡上皮

**表5　发文量排名前10的期刊**

**Table 5　Top ten journals by number of publication**

| 排名 | 期刊 | 发文量/*n* | IF |
|---|---|---|---|
| 1 | *Respiratory Care* | 313 | 2.4 |
| 2 | *Critical Care Medicine* | 271 | 7.7 |
| 3 | *Critical Care* | 261 | 8.8 |
| 4 | *American Journal of Respiratory and Critical Care Medicine* | 208 | 19.3 |
| 5 | *Chest* | 201 | 9.5 |
| 6 | *Intensive Care Medicine* | 197 | 27.1 |
| 7 | *Current Opinion in Critical Care* | 93 | 3.5 |
| 8 | *Journal of Critical Care* | 73 | 3.2 |
| 9 | *Pediatric Critical Care Medicine* | 67 | 4.0 |
| 10 | *Annals of Intensive Care* | 64 | 5.7 |

**表6　引用频次排名前10的期刊**

**Table 6　Top ten journals by citation frequency**

| 排名 | 被引期刊 | 频次 | IF |
|---|---|---|---|
| 1 | *American Journal of Respiratory and Critical Care Medicine* | 1722 | 24.7 |
| 2 | *Critical Care Medicine* | 1552 | 8.8 |
| 3 | *Intensive Care Medicine* | 1461 | 38.9 |
| 4 | *Chest* | 1446 | 9.6 |
| 5 | *New England Journal of Medicine* | 1417 | 158.5 |
| 6 | *JAMA* | 1052 | 120.7 |
| 7 | *Journal of Applied Physiology* | 986 | 3.3 |
| 8 | *Critical Care* | 972 | 15.1 |
| 9 | *Anesthesiology* | 933 | 8.8 |
| 10 | *European Respiratory Journal* | 867 | 24.3 |

细胞和肺毛细血管内皮细胞通透性增加为主要特征的异质性综合征，常进展为急性呼吸窘迫综合征(acute respiratory distress syndrome, ARDS)，两者属于肺损伤发生发展的伴随状态[24-25]。ALI/ARDS常导致肺水肿和通气血流比例失调，特别是肺内分流显著增加，从而诱发严重的低氧血症。

机械通气是纠正缺氧的主要措施[26]。呼气末正压通气(positive end-expiratory pressure breathing, PEEP)是最常用的呼吸模式，它能扩张萎缩的肺泡，纠正通气/血流比，增加功能残气量和肺顺应性，有利于氧通过呼吸膜弥散[27-28]。

**3.2.3** ACT治疗原理与评估手段

ACT主要包括手动技术和设备辅助技术(呼气末正压和振荡呼气正压)，可以改善黏膜纤毛清除率。手动技术包括体位引流、手动扣拍和手动振动。体位引流通过重力作用促进气道内黏液移动，从而改善排痰效果。扣拍技术旨在松解残留分泌物，操作者以空杯状手型，在受累肺叶区域进行有节奏的叩击。手动振动是通过双手施加振荡力量于下胸壁，在深吸气末对胸壁施加适度压力，并在呼气末期平稳摆动胸壁，以促进肺部分泌物排出。

在应用振荡呼气正压技术时，一般患者可选择背心式高频胸壁振荡设备，而危重患者多采用胸带式装置[29]。

呼气末正压和振荡呼气正压被推荐用于有慢性阻塞性肺疾病、支气管扩张症和囊性纤维化患者的ACT，因为它们比传统物理治疗更有效。治疗效果取决于所选设备、阻力设置和患者执行情况[27,30-31]。一项随机对照试验显示，振荡呼气正压组50% (12/24)痰量减少，而自主引流组24% (6/25)痰量减少。

**3.2.4** ACT在ICU的应用

自20世纪60年代末首个ICU成立以来，重症监

护医学迅速发展，目前超过90%的患者可在初始危及生命的疾病中存活[32]。然而，ICU患者因长期卧床和行动受限，极易出现神经肌肉萎缩和身体多器官损伤[33]。物理治疗对重建身体功能、提高生活质量具有关键作用[34-35]。积极活动和康复可以改善肌力，提高功能独立性，并减少谵妄发生，特别在入住ICU初期[36-37]。加强多学科团队协作，有助于实施有效物理治疗，优化患者管理，并制定个体化治疗方案[38-39]。ACT是呼吸康复的重要组成部分，ICU患者需要恢复和锻炼呼吸肌，同时调整适宜的正压通气参数。此外，运动锻炼也可以促进气道廓清，改善呼吸功能。对于重症患者，若状况允许，应提倡将气道廓清项目与早期活动相结合，以加速患者肺功能和呼吸肌肉功能恢复[40]。

### 3.3 研究热点

机械通气与ALI一直是该领域的研究热点。共被引文献揭示了该领域发展中发挥关键作用的核心文献及研究趋势[41]。聚类分析显示，聚类#0 acute respiratory distress syndrome排名第一，这可能与2019年以来新型冠状病毒病(coronavirus disease, COVID-19)持续流行有关。COVID-19可诱发ARDS，约5%的患者需入住ICU；其病死率达30%~60%，使得ICU的患者流量阶段性增长[42]。

自2012年《急性呼吸窘迫综合征柏林新定义》发布后，随着ARDS研究的深入及COVID-19的全球流行，学界考虑扩大定义，以更好地指导ARDS的临床诊治[43]。根据2023年修订的ARDS全球定义，ARDS是一种由肺炎、非肺部感染性炎症、创伤、输血、烧伤、误吸或休克等易感危险因素诱发的急性弥漫性炎症性肺损伤[44]。既往柏林定义使用氧分压/吸入气体氧含量($PaO_2/FiO_2$)进行ARDS诊断和严重程度的评估，但动脉血气的可及性在资源有限的环境中并不一致，因而建议使用$PaO_2/FiO_2 \leqslant 300$ mmHg或经皮血氧饱和度($SpO_2$)/$FiO_2 \leqslant 315$ (若$SpO_2 \leqslant 97\%$)识别低氧血症患者，有助于早期诊断与干预。

改善呼吸困难与低氧血症是治疗COVID-19相关ARDS的关键[45]，71%的COVID-19诱发ARDS危重患者需要有创机械通气纠正气体交换异常。机械通气旨在恢复足够的气体交换，同时限制呼吸机相关肺损伤风险[46]。在ARDS期间，适当的通气管理是可调控的生存率影响因素之一[42]。除机械通气外，ACT是ARDS的重要辅助疗法。肺内叩击通气是一种高频通气模式，可叠加在自发呼吸上，减轻呼吸肌负荷，促进分泌物排出，提高氧合，并降低迟发性肺炎风险[47]。此外，手法过度通气等ACT方法有助于预防气道堵塞和肺萎缩，显著改善ARDS患者肺部感染和呼吸能力，降低ICU并发症[47]。上述发现为当前ALI/ARDS的治疗策略提供了参考依据。

### 3.4 新兴趋势和未来研究方向

#### 3.4.1 电阻抗成像技术(electrical impedance tomography, EIT)

EIT是一种基于生物电阻抗原理的功能成像技术。胸部EIT通过微电压在胸腔气体内产生微电流，通过呼吸阻抗的变化，测量肺部气体的动态和立体成像[48-49]。该技术可用于比较ACT疗效，例如高频胸壁震荡改善肺不张[50]。目前ICU机械通气患者的气道廓清评估主要依赖临床经验、听诊结果以及影像学检查。听诊敏感性与特异性有限，X线和CT检查则存在辐射暴露、费用较高及转运风险等问题[51-52]。近年来，EIT已逐步发展为一种成熟的肺部监测工具[48,53]。它利用生物阻抗所携带的生理和病理信息，实现床旁无创、无放射性且连续动态的实时监测，并进行功能化成像[54]。肺部成像可明确识别患者现存的气胸、肺间质综合征、肺实变和肺不张、胸腔积液等疾病。它可以精准定位肺部问题，提供目标导向性气道廓清方案。它还可以为机械通气患者实施以EIT技术为主导的呼吸管理护理策略，如联合振动排痰、辅助咳嗽，促进痰液的排出和肺复张。此外，它可以通过图像实时评估这些干预措施的效果。Eronia等[55]发现由EIT引导的个性化PEEP滴定可行，并能准确反映局部肺通气特性。

#### 3.4.2 机械吸入-呼出(mechanical insufflation-exsufflation, MI-E)排痰技术

MI-E排痰技术通过模拟正常咳嗽时吸气和呼气的压力变化，促进气道分泌物排出[56-57]，在慢性呼吸系统疾病和神经肌肉性疾病患者中的疗效和安全性已得到验证[58-59]。MI-E可提高机械通气患者痰液清除效率和肺顺应性[60-62]。未来MI-E在ICU的应用应关注参数个体化设置以及与手法治疗的联合应用方案。

#### 3.4.3 驱动压

驱动压是关键词中爆发强度最高的指标。驱动压是驱动整个呼吸系统扩张的直接动力，是死亡的强有力预测因素[63]。其计算方式有两种：对于机械通气患者，呼吸肌不做功，驱动压=气道平台压($P_{plat}$)—

PEEP；驱动压也可以表现为潮气量和呼吸系统顺应性的商[64]。允许合适的驱动压是肺部保护性通气的主要考虑因素。俯卧位通气通过扩张背部肺区、降低胸膜压力，改善经肺压力分布，增加开放肺单元，使所有肺单元的压力更加均匀，从而有助于调整驱动压[65]。同时，该体位可借助重力促进分泌物引流，增强气道廓清效果[66]，进一步改善肺部顺应性并降低驱动压。对于重症COVID-19患者，胸壁按压亦可通过分散经肺压力、扩张剩余肺单元，提高总呼吸顺应性，从而降低驱动压[65]。肺保护性机械通气概念已延伸至术中患者呼吸管理，其中PEEP是关键组成部分。PEEP过低可导致肺泡萎陷和肺不张，过高则会引起气道压升高、肺过度膨胀和血流动力学紊乱，故采用合适的PEEP至关重要[67]。适当PEEP可以防止肺泡塌陷，保持肺泡开放，减少剪切伤。驱动压可以影响PEEP水平的变化，当呼吸系统的顺应性最大(最低驱动压)时所测的PEEP为呼吸机滴定参数的最佳值[68]。

驱动压与ARDS患者生存率密切相关[67]。潮气量、PEEP或平台压本身与生存率无直接关联，仅当其变化引起驱动压下降时才与生存率有所联系。与传统通气策略相比，使用低驱动压和低PEEP的机械通气可显著降低病死率，改善肺顺应性和呼吸功能，从而在源头上预防气道廓清障碍的发生[42]。

**3.5** 局限性

本研究文献仅来源于WOS数据库，且限于英文，可能存在选择偏倚；分析时段固定，未能纳入最新发表的研究成果。未来应进一步拓展分析范围，以增强结果的广泛性和代表性。

## 4 结论

ACT在重症康复中的应用研究发文量总体保持稳定，未来研究可更多聚焦于借助EIT、MI-E和驱动压监测等技术，为气道廓清障碍患者提供指导性、个体化的康复治疗方案。

利益冲突声明：所有作者声明不存在利益冲突。

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