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Низкодозная компьютерная томография органов грудной клетки в диагностике COVID-19: обзор литературы

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АННОТАЦИЯ

Обоснование. Повышение числа исследований компьютерной томографии во время пандемии COVID-19 актуализировало задачу снижения лучевой нагрузки на пациента, так как воздействие радиационного излучения достоверно связано с повышением риска развития онкологических заболеваний. В работе отделений лучевой диагностики даже в условиях пандемии должен соблюдаться принцип минимальной дозы облучения при максимальном уровне качества диагностики — ALARA (as low as reasonably achievable), предложенный Международной комиссией по радиационной защите.

Цель — систематизация данных о возможностях снижения лучевой нагрузки при диагностике поражения лёгких при COVID-19 методом компьютерной томографии.

Материалы и методы. Проведён анализ релевантных отечественных и зарубежных источников литературы в научных библиотеках PubMed и eLIBRARY по запросам «low dose computed tomography COVID-19» и «низкодозная компьютерная томография COVID-19», опубликованных в период с 2020 по 2022 год. Публикации включались в обзор после оценки их соответствия теме обзора путём анализа названия и абстракта. Списки литературы также были проанализированы на предмет выявления пропущенных при поиске статей, попадающих под критерии включения.

Результаты. Изучение опубликованных результатов исследований позволило обобщить современные данные о лучевой диагностике поражения лёгких при COVID-19 и использовании компьютерной томографии, а также определить возможные варианты снижения дозы лучевой нагрузки.

Заключение. Представлены способы уменьшения лучевой нагрузки при компьютерной томографии органов грудной клетки и сохранения высокого качества диагностического изображения, потенциально достаточного для надёжного выявления признаков COVID-19. Снижение дозы облучения является оправданным подходом к получению актуальной диагностической информации, сохраняющим возможности внедрения технологий продвинутого компьютерного анализа в клиническую практику.

Ключевые слова: компьютерная томография; низкодозная компьютерная томография; обзор литературы; COVID-19; диагностика COVID-19.

Как цитировать

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Low-dose computed tomography in COVID-19: systematic review

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ABSTRACT

BACKGROUND: The increased number of computed tomography scans during the COVID-19 pandemic has emphasized the task of decreasing radiation exposure of patients, since it is known to be associated with an elevated risk of cancer development. The ALARA (as low as reasonably achievable) principle, proposed by the International Commission on Radiation Protection, should be adhered to in the operation of radiation diagnostics departments, even during the pandemic.

AIM: To systematize data on the appropriateness and effectiveness of low-dose computed tomography in the diagnosis of lung lesions in COVID-19.

MATERIALS AND METHODS: Relevant national and foreign literature in scientific libraries PubMed and eLIBRARY, using English and Russian queries "low-dose computed tomography" and "COVID-19," published between 2020 and 2022 were analyzed. Publications were evaluated after assessing the relevance to the review topic by title and abstract analysis. The references were further analyzed to identify articles omitted during the search that may meet the inclusion criteria.

RESULTS: Published studies summarized the current data on the imaging of COVID-19 lung lesions and the use of computed tomography scans and identified possible options for reducing the effective dose.

CONCLUSION: We present techniques to reduce radiation exposure during chest computed tomography and preserve high-quality diagnostic images potentially sufficient for reliable detection of COVID-19 signs. Reducing radiation dose is a valid approach to obtain relevant diagnostic information, preserving opportunities for the introduction of advanced computational analysis technologies in clinical practice.

Keywords: computed tomography; low-dose computed tomography; literature review; COVID-19; COVID-19 diagnosis.

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胸部低剂量计算机断层扫描在COVID-19诊断中的应用：文献综述

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简评

论证。在COVID-19大流行期间，计算机断层扫描检查数量的增加使减少病人的辐射量的任务成为现实，因为暴露于辐射与增加癌症风险有着可靠的联系。国际放射防护委员会提出的在最高诊断质量下的最小辐射剂量原则——ALARA（as low as reasonably achievable），在辐射诊断部门的工作中应该得到遵守，即使在大流行的情况下。

目的是整理关于通过计算机断层扫描诊断COVID-19肺部病变时减少辐射暴露的潜力的数据。

材料和方法。对PubMed和eLIBRARY科学图书馆中2020年至2022年期间发表的的国内外相关文献进行了分析，搜索查询包括“low dose computed tomography COVID-19”和“низкодозная компьютерная томография COVID-19”（低剂量计算机断层扫描COVID-19）。通过分析标题和摘要评估其与综述主题的相关性后，将出版物纳入综述。还对参考文献列表进行了分析，以确定搜索中遗漏的符合纳入标准的文章。

结果。对已发表的研究进行了，研究已发表的科学著作允许总结关于目前COVID-19肺部病变的辐射诊断和计算机断层扫描的使用的数据，并确定减少辐射剂量的可能方法。

结论。介绍了在胸部计算机断层扫描过程中减少辐射量并保留高质量诊断图像的方法，这些图像可能足以可靠地检测COVID-19的症状。减少辐射剂量是获得现实诊断信息的一种有道理的方法，保留将先进计算机化分析技术引入临床实践的可能性。

关键词：计算机断层扫描，低剂量计算机断层扫描，文献综述，COVID-19，COVID-19诊断。

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论证

在撰写本文章时（2022年12月22日），新型冠状病毒感染COVID-19的病例数达到6.5亿[1] 。通过包括早期诊断在内的综合措施，可以预防和减少疾病的传播，因此，预防和减少死亡病例[2] 。

实验诊断的主要方法是逆转录-聚合酶链反应。在冠状病毒大流行的第一波高峰期，这种方法的缺点暴露无遗：假阳性率高，可用性有限，结果耗时长[1]。同时，在胸部计算机断层扫描（CT扫描）上有COVID-19症状的患者可能会收到假阴性结果[2]。

根据俄罗斯[3]和国际[3] 建议，COVID-19相关肺炎的放射诊断方法包括X射线摄影和CT扫描。对于胸部X射线摄影来说，对病毒性肺炎诊断的灵敏性较低[4]，因此CT扫描在COVID-19相关肺炎及其并发症的诊断中起着重要的作用[5]。

在大流行期间，CT扫描的广泛使用造成了与对人群的高辐射暴露有关的问题[6, 7]。在住院期间，在短时间内进行2-6次CT扫描，以评估疾病的进展，因为CT扫描有明显的变化退缩趋势是出院的标准之一[3]。对于疑似COVID-19的病人，可以在门诊进行1-2次CT扫描，以检测疾病的症状[8, 9]。

辐射暴露确实增加癌症风险[10]。即使在大流行的情况下，国际放射防护委员会（International Commission of Radiological Protection）提出的在最高诊断质量下的最小辐射剂量原则——ALARA（as low as reasonably achievable，ICRP），在辐射诊断部门的工作中应该得到遵守[11]。在2020年3月，Z.Kang等人提出使用低剂量计算机断层扫描（LDCT）作为冠状病毒肺炎表现的放射诊断的第一阶段[6]。2020年4月举行的“COVID-19与胸部CT扫描：协议和剂量优化”（«COVID-19 and Chest CT: Protocol and Dose Optimization»）网络研讨会也强调了患有COVID-19时使用LDCT的重要性，来自100个国家的1633名与会者参加了研讨会。在视频会议过程中发现了，55%的机构使用标准协议（CTDIvol 5-10 mGy），43%的机构使用低剂量协议（CTDIvol <5 mGy），2%的机构使用高剂量协议（CTDIvol >10 mGy）[12]。然而，即使粗略地研究一下放射科医师的工作站，也会发现有很多对辐射暴露有影响的扫描参数[13]，同时不同的协议设置和辐射剂量之间的关系可能并不明显，特别是取决于所研究的病理过程。

本文献综述的目的是整理关于通过计算机断层扫描诊断COVID-19诱发的肺部病变时减少辐射暴露的潜力的数据。

材料和方法

对PubMed和eLIBRARY科学图书馆中2020年至2022年期间发表的的国内外相关文献进行了分析，搜索查询包括“low dose computed tomography COVID-19”和“низкодозная компьютерная томография COVID-19”（COVID-19低剂量计算机断层扫描）。

通过分析标题和摘要，评估出版物与综述主题的相关性后，将其纳入综述。原始研究和荟萃分析被纳入综述，而文献综述、临床病例和会议论题都被排除。此外，还对参考文献列表进行了分析，以确定可能在2020年之前发表的与CT扫描时减少辐射暴露的一般原则有关的相关研究。如果发现有类似的文章，则将最新的研究纳入综述。

结果和讨论

共分析了45篇外国作者的文章和5篇国内作者的文章。最后的搜索日期是2022年12月22日。

减少辐射剂量的方法

根据文献综述，减少辐射暴露的方法可分为基于硬件和基于软件的方法。前者包括管电压、管电流、间距系数、X射线束过滤；后者包括重建过滤器、切片厚度和迭代重建。

硬件方法。管电压（tube potential，kVp）与辐射暴露呈非线性关系[14]。F.Zarb等人[15]显示，管电压降低14-17%会导致辐射剂量降低32-38%。另一方面，降低管电压会增加非对比度CT的噪声：根据一个模型研究的结果，这些参数相互之间的关系是-1.3（负一点三）的幂[16]。同时，在对比度增强算法研究中，降低管电压可以改善图像质量，并显著减少辐射暴露[17]。

管电流（tube current，mAs）与辐射暴露呈线性关系[18]。例如，管电流减少50%会导致有效剂量减少50%[17]，同时，信噪比与电流的平方根成反比[19]。

多层螺旋CT扫描仪的间距系数对辐射暴露几乎没有影响[20]。随着间距系数的增加，信噪比下降，断层扫描仪会自动增加管电流以防止图像质量下降[21]。

X射线束过滤是以吸收不穿过患者组织并无法到达探测器的低能量光子而使用的，因此使用额外的锡过滤器可以显著降低当进行CT扫描时的辐射暴露[22]，但需要额外的费用来改造扫描仪。

软件方法。重建过滤器（convolution kernel）的选择对辐射量没有影响，但对信噪比

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[1] 世界卫生组织。新型冠状病毒（COVID-19）情况。访问方式：https://who.sprinklr.com。

[2] 美国疾病控制和预防中心。2019年冠状病毒病（COVID-19）。访问方式：https://www.cdc.gov/coronavirus/2019-ncov/index.html。

[3] 世界卫生组织。COVID-19中胸部影像学的使用：快速建议指南[2020年6月11日]。访问方式：https://apps.who.int/iris/handle/10665/332336。

有影响，强调或消除不同器官或结构的像素之间的差异[23]。

低的切片厚度会降低图像质量，同时对遗漏小病理变化的风险产生积极影响，因此可以优化切片厚度：例如，评估肺部结节的厚度为2毫米[24]。

然而，减少噪声的主要方法是迭代重建的使用，与标准数据重建技术相比，迭代重建允许进行更低辐射剂量和类似信噪比的CT研究[25]。一个有希望的方向是使用神经网络进行图像重建[26，27]。

根据所查阅的文献，可以得出以下的结论：为了减少辐射量，降低管电流是有合理的，同时，为了优化信噪比，使用消除相邻像素之间差异（软组织）的重建过滤器和迭代重建是有合理的。

低剂量计算机断层扫描在COVID-19诊断中的应用

文献综述的结果表明，COVID-19没有单一的、清楚确定的低剂量协议（表1[28-54]）。研究发现，减少剂量主要是通过改变管电压和管电流、使用迭代重建和锡过滤器来实现的。综述中包括的一些研究指出了在结果表述方面的方法缺陷：没提到剂量测定指标（CTDI、DLP、SSDE、有效剂量），而且样本量很小。

有趣的是，在优化扫描协议的过程中，要改变的参数的选择对于不同的临床任务是通用的。例如，在用于肺癌筛查的LDCT中，不同的作者小组也改变了管电流[55，56]，尽管如此，开发专门的LDCT协议应从研究模型对象开始，以选择最佳的减少辐射量的方法。例如，在V.A.Gombolevsky等人的关于LDCT用于COVID-19诊断的研究[57]中，使用了一个带有加厚板的模型，同时自动管电流控制系统（Sure Exposure 3D）的设置水平足以检测到磨砂玻璃磨玻璃样病灶，并最大限度地减少辐射暴露（SD=36）。图1显示从模型研究中选择的协议与标准CT和肺癌筛查LDCT的比较。

要考虑到，开发的任何专门低剂量协议都需要临床验证并与金标准的比较。例如，已经对开发的COVID-19的NDCT协议进行了临床试验，使用作为参照测试的标准CT[28]。所开发协议的临床图像的例子可以在图2和图3中找到。

低剂量计算机断层扫描的局限性

根据Y.K. Kim等人的研究[58]，由于脂肪组织吸收X射线，在常规实践中，肥胖（身体质量指数>25）作为进行中胸部LDCT的限制。然而，专家之间对COVID-19严重程度进行评估的一致性的研究结果表明情况并非如此[59]。

根据经验，LDCT的另一个常见限制是图像噪声增加对人工智能系统性能的负面影响，包括密度测定分析中肺气肿指数的计算[60]，以及亚实性肺结节的影像学分析[61]。扫描协议对定量分析的影响可以通过使用相对指数来减少，如使用受到COVID-19影响的肺组织百分比[62]，或通过特殊算法将数据归一化[63]。

结论

本文介绍了如何减少在胸部计算机断层扫描过程中的辐射量并保持高质量的诊断图像，这些

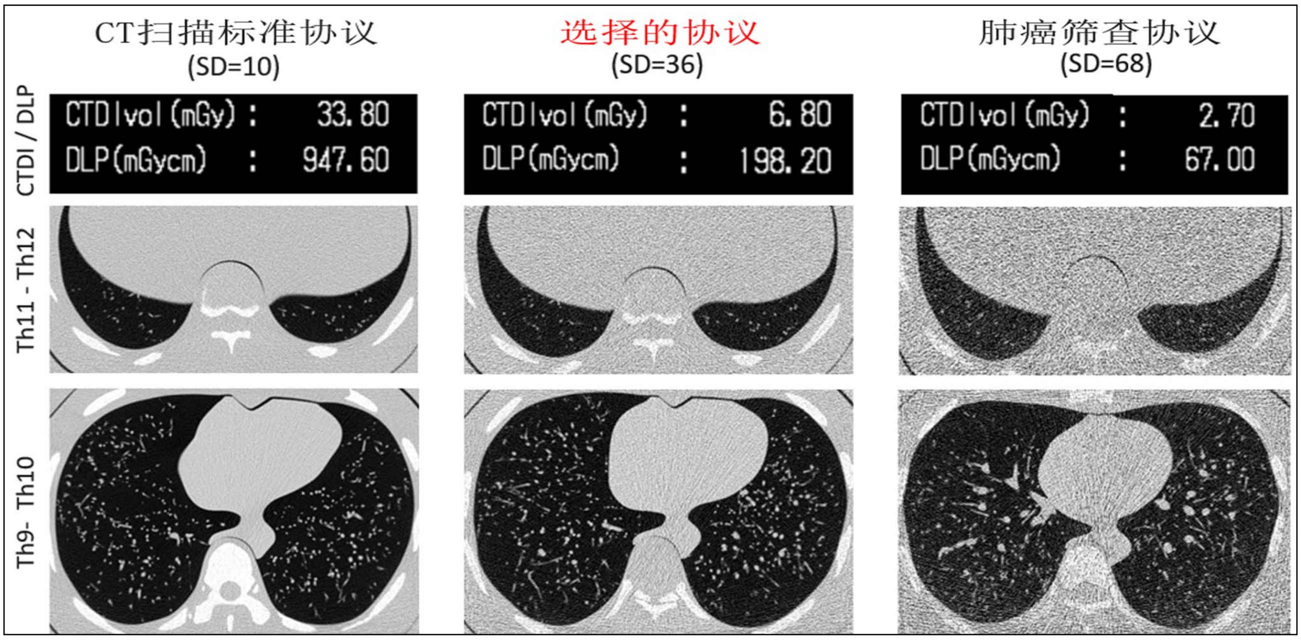

图1。COVID-19专门的低剂量CT扫描协议（SD=36）与标准CT扫描和用于肺癌筛查低剂量CT扫描的比较。辐射暴露信息和肺下部和中部区域水平的轴向模型断层图。用于肺癌筛查的低剂量计算机断层扫描是根据卫生条例预防措施的辐射暴露限制开发的，并且具有最低的信噪比。为COVID-19制定的低剂量计算机断层扫描协议考虑到磨玻璃样的密度测试特性，同时大幅降低辐射暴露。

表1。根据文献综述，低剂量计算机断层扫描在COVID-19诊断中的参数

作者、年，参考	管电压，kVp	管子电流，mAs	平均辐射剂量，mSv	切片厚度，mm	重建过滤器	迭代重建的使用
Blokhin等人 (2022) [28]	120	10-500，噪声水平36（SD）	3	1	FC51, FC07	没有
Filatova等人 (2020) [29]	100/110	40-120	1,27	1	-	是
Afshar等人 (2022) [30]	110	20	1-1,5	2	D40s	-
Fukumoto等人 (2022) [31]	120	20-25	CTDI 1.3 mGy	5	Lung and soft tissue	-
Bieba等人 (2022) [32]	取决于重量	取决于重量	-	1和3	-	-
Barrio等人 (2022) [33]	100/150	类人的电流调制系统	-	1	Br32 B160	-
Thieß等人 (2022) [34]	100	10-100	0,53	0,5和0,625	Fc01 Fc85	是
Greffier等人 (2021) [35]	100/120	10	0,2	1	I30f，mediastinal, I50f, lung images	是
Karakas等人 (2021), [36]	80	40	0,18	5	lung	是
Julie等人 (2021) [37]	120	45	-	1,2	-	-
Desmet等人 (2021) [38]	80-140	20-30	0,64	0,6	-	-
Aslan等人 (2021) [39]	80	35-50	0,2856	3	lung	是
Stoleriu等人 (2021) [40]	120	40-113	35-100 mGy×cm 0.78-2.91 mGy	1,25	Medium Soft	是
Bai等人 (2021) [41]	120	120-380	1,21±0,10	1,25	Standard	是
Agostini等人 (2021) [42]	100	95	0,39	1,5	Sharp	是
Zali等人 (2021) [43]	100-120	50-100	-	1-3	-	-
Argentieri等人 (2021) [44]	80	20	0,219	2	Sharp	-
Leger等人 (2020) [45]	120	45	0,49	1,2	-	-
Hamper等人 (2020) [46]	100	20-120	0,5	0,625-1	Lung	是
Li等人 (2020) [47]	120	30	1,22±0,14	1	-	是
Dangis等人 (2020) [48]	100	20	0,56	1	Lung (150f)	是
Radpour等人 (2020) [49]	100-120	50-100	-	1-3	-	-
Kang等人 (2020) [6]	80-100	10-25	0,203	0,6	-	是
Tofighi等人 (2020) [50]	100	40	2,03	-	-	没有
Tabatabaei等人 (2020) [51]	120	30	1,8	3	-	-
Schulze-Hagen等人(2020) [52]	80	35	1,7	1和3	170f 130f	-
Zhao Yue等人 (2020) [53]	100	50	1,5	1	-	-
Castelli等人 (2020) [54]	120	45	0,47	1,2	-	-

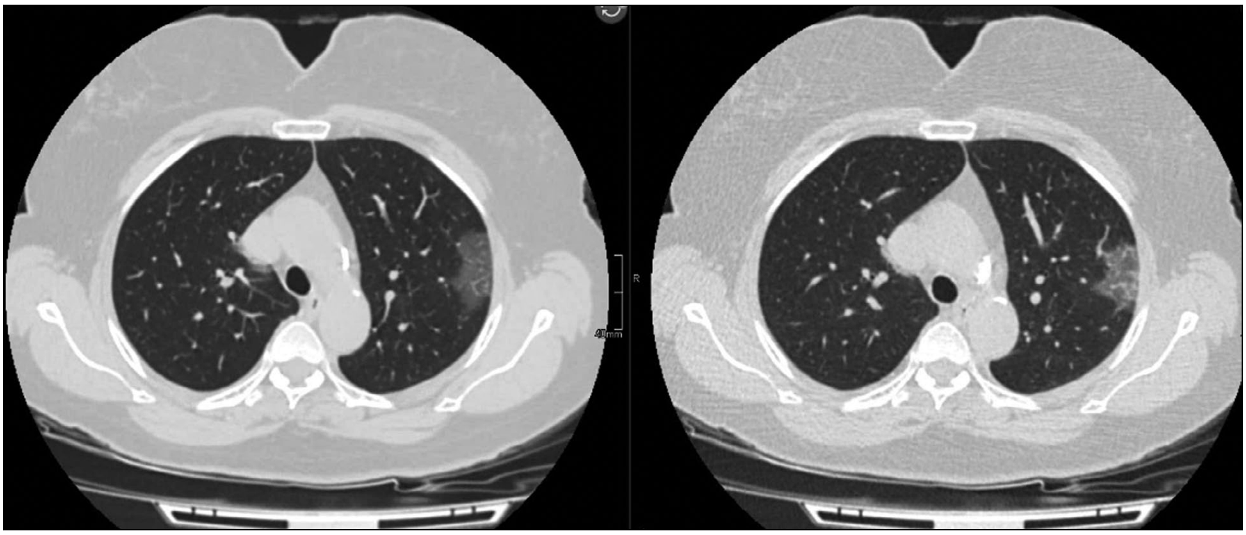

图2。减少了5倍的辐射量。患者，59岁，身体质量指数为29 kg/m²。带软组织过滤器的计算机断层扫描（有效剂量为9.7 mSv），带软组织过滤器的低剂量计算机断层扫描（有效剂量为2.1 mSv）。左肺上叶有一个末梢磨玻璃样病灶。

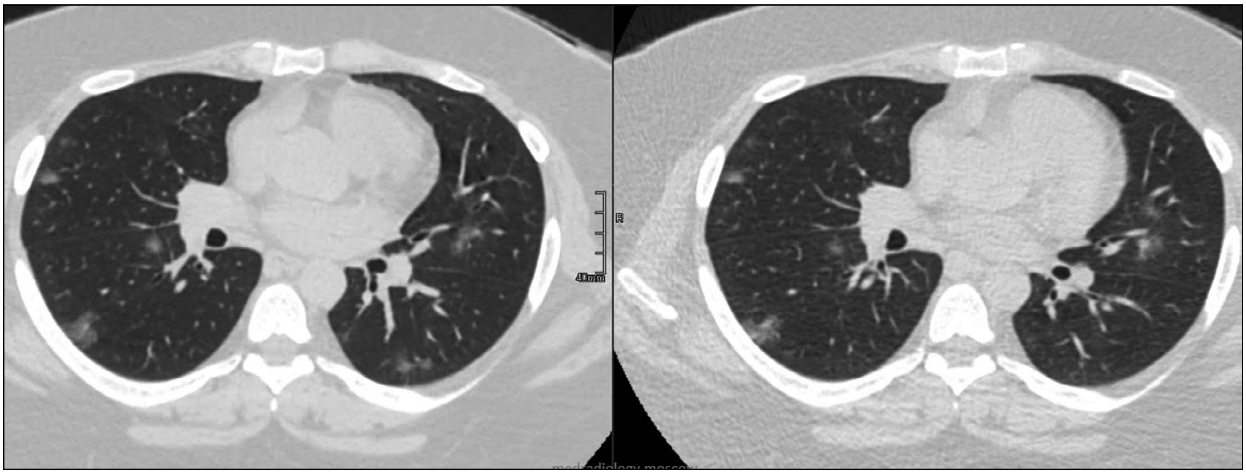

图3。减少了1.5倍的辐射量。患者，44岁，身体质量指数为46 kg/m²。带软组织过滤器的计算机断层扫描（有效剂量为15.3 mSv），带软组织过滤器的低剂量计算机断层扫描（有效剂量为10.5 mSv）。双肺末梢磨玻璃样病灶。

图像可能足以可靠地检测COVID-19的症状。虽然没有单一的方法来优化扫描协议，但减少辐射剂量是一种有道理的方法，允许获得实现的诊断信息，并保留将先进计算机化分析技术引入临床实践的可能性。

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