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人工智能在髋关节置换术中的研究进展

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摘　要

全髋关节置换术(total hip arthroplasty，THA)可以通过减轻患者疼痛、恢复下肢功能以及矫正步态畸形，从而改善患者日常生活质量。随着医疗技术的不断进步，THA的数量也逐年增加。人工智能(artificial intelligence, AI)近年来在医疗领域应用十分广泛，本文通过对AI在THA中的研究进展进行总结，以期为患者和临床医生提供个性化治疗新思路。

关键词

人工智能，全髋关节置换术，机器学习，深度学习，综述

Progress of Artificial Intelligence in Total Hip Arthroplasty

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Abstract

Total Hip Arthroplasty (THA) can improve the quality of daily life of patients by relieving pain, restoring lower limb function, and correcting gait deformities. As medical technology continues to advance, the number of THA is increasing year by year. Artificial intelligence (AI) has been widely used in the medical field in recent years, and this paper summarizes the research progress of AI in THA in order to provide patients and clinicians with new ideas for personalized treatment.

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Keywords

Artificial Intelligence, Total Hip Arthroplasty, Machine Learning, Deep Learning, Review

1. 引言

人工智能(artificial intelligence, AI)这一术语由约翰·麦卡锡在1965年提出，当时，“有生命的计算机”这一概念占据了人们的思维[1]。AI是一种机器获取信息、将其转化为理论知识而产生改变环境的反应的迭代过程。这是一个广泛的概念，其中涉及到虚拟(计算)和物理(机器)元素[2]。AI算法包括多个分支，如机器学习(machine learning, ML)和深度学习(deep learning, DL)等。ML在医疗保健领域和康复领域，以及DL在医学影像领域越来越受欢迎[2] [3]。AI在改善医疗保健方面有巨大潜力，几年内，人工智能可能会改变日常临床实践方式[4]。髋关节通常被描述为由髋臼和股骨头组成的球窝关节，作为连接躯干和下肢的主要关节，在肢体活动中发挥重要作用[5]。据估计，在跨步过程中，髋关节需要承受2.5倍于身体重量的力来平衡髋臼–股骨支点处的压力[6]。全髋关节置换术是最成功的骨科手术之一，为患有终末期髋关节骨关节炎等髋关节疾病的患者提供了可靠的治疗效果，特别是缓解疼痛、恢复髋关节功能和改善整体生活质量[7]。据估计，到2030年，每年的THA数量将达到57.2~138.5万例[8]。但髋关节在标准的人体轴位、冠状位和矢状位上定向不佳，所以很难成像[9]。AI在自动识别THA植入物等许多方面显示出优势，本文对AI在THA的应用进行综述。

2. DL预测骨盆矢状倾角(predicting pelvic sagittal, PSI)和髋关节中心(hip joint center, HJC)

最近研究表明，PSI影响髋臼假体的功能位置，是THA术后发生撞击和脱位的关键因素[10] [11]，HJC也具有重要的生物力学意义，是髋关节假体放置的重要参考[12]。之前提出的一种监督学习方法需要患者的CT图像，这对患者的辐射较大[13]。而在许多医院，CT并非常规检查项目。Ata Jodeiri等人提出的DL框架方法仅使用x线图像便可对PSI进行自动、稳定的评估，这对改善髋臼假体放置位置非常重要[14]。Seong等人基于DL开发的特异性模型能在骨盆x线上识别HJC，对THA术前评估假体位置和降低HJC评估差异性具有参考价值[15]。这些方法仅使用x线便可完成评估，能够很大程度减少患者的辐射暴露。但这些方法需要在临床中进行充分的验证，以确保其在实践中的功能性和安全性。

3. AI HIP在THA术前规划的应用

成功的THA需要选择合适的假体尺寸，因此准确的术前规划有助于提前预知术后结果，这对外科医生在术中做出准确判断十分重要[16]。然而，精准规划对时间、人力、和复杂的工作流程的要求限制了其应用[17]。随着AI的发展，一种新的术前规划软件——AI HIP应运而生，这是一种基于CT数据的三维图像处理系统，可以将AI与医疗大数据结合进行THA术前精准规划。一项前瞻性研究使用AI HIP、3D模型、2D数字模型进行THA术前规划，结果显示AI HIP在预测假体尺寸方面表现出优越性[18]。另一项回顾性研究比较了三维AI HIP软件和传统二维手工模型在预测THA假体尺寸和位置的准确性，结果显示AI HIP具有更高的可靠性[19]。总之，AI HIP在THA术前规划中具有更高的准确性，但其临床意

义需进一步探究。

4. ML 预测 THA 住院时间、支付模式和手术时间

临床上患者比较关心的就是住院时间、费用和手术时间等问题。下肢关节置换术中，综合护理模式的应用降低了患者的住院时间、30 天内再住院率和费用，但未解决潜在风险问题[20]。Prem N. Ramkumar 等人基于 ML 将患者术前大数据导入算法模型，在预测住院时间和费用方面表现出良好的有效性和可靠性[21]。2022 年，Igor Lazic 等人通过调整输入和输出数据，能够建立一个 ML 模型用于预测 THA 的不规则手术时间，这一 ML 模型有望在临床实践中得到广泛应用[22]。

5. ML 预测骨矿物质密度和改进假体选择

THA 可以明显改善髋关节病变引起的疼痛，但仍有许多患者对术后自理能力和下肢无力感到失望。THA 可以分为使用骨水泥和不使用骨水泥，研究表明，非骨水泥 THA 的总体生存率较低[23]，但目前仍没有通用的标准来决定使用哪种手术方式，临床医生必须根据实际情况来进行选择。骨骼和肌肉的质量可以为临床医生的决策提供有效的参考[24]。如何选择合适的假体是术前决策的关键，这可以减少骨折等术后并发症的发生。骨矿物质密度也是另一个重要的影响因素，可以用来评估患者的长期预后。Carlo Ricciardi 等人利用 ML 技术和生物识别特异性分析患者假体选择，ML 还可以预测股骨近端和远端的骨矿物质密度来评估患者长期预后，有效的预测这两个因素可以帮助临床医生更好的决策[25]。

6. ML 预测 THA 术后患者满意度

THA 可以为患者减轻疼痛并改善生活质量。通常使用患者报告的结果测量和患者满意度评估手术效果。后者可以独特且全面的反应患者术后主观生活质量和术后改善情况[26] [27]。然而，患者满意度受很多因素影响，如年龄、性别、心理状况和术前期望等[28] [29] [30]。最近研究表明，大约 10%~20%的患者在接受 THA 术后不满意[31] [32]。因此，预测术后患者满意度可以为患者提供个性化的术前咨询、减少患者不切实际的手术期望。先前一项研究开发了一种有 ML 算法，利用患者人口统计学、患者并发症和牛津髋关节评分等因素预测患者术后 2 年的满意度。这一算法在预测患者 THA 术后满意度上表现良好并确定了具体的影响因素，可以用于帮助临床医生改善术前咨询和 THA 术前的健康优化[33]。

7. ML 预测 THA 术后输血率

当前，大多数外科医生在进行 THA 时选择使用氨甲环酸、促红细胞生成素或自体血再输注来改善术中失血[34]。然而，THA 术后输血率的发生率仍高达 9% [35]，因此预测术后输血率对患者术后满意度十分重要。Wayne Brian Cohen-Levy 等人开发了 4 种 ML 算法并分别评估其性能，均在预测 THA 患者术后特异性输血率方面表现优异，并可能改善术前计划和手术结果[36]。

8. ML 预测 THA 术后服用阿片类药物风险

阿片类药物能够有效缓解各种因素引起的疼痛，其使用范围极其广泛，术前服用阿片类药物会增加术后服用慢性阿片类药物的风险，抑郁史、基线疼痛评分较高、年龄小等因素同样会增加使用风险[37] [38] [39] [40]。由于资源有限，减少阿片类药物使用的周围神经调节等方法不能为患者普遍使用[41]。因此需要进一步开发预测模型来更好地分配资源。Rodney A Gabriel 等人比较了各种 ML 预测模型，结果显示集成学习可以很好的改善阿片类药物持续使用的预测模型，准确识别高危患者，为术前优化提供个性化干预措施[42]。

9. DL 基于 x 线自动识别 THA 假体植入物

由于年龄等因素，髋关节翻修术的比率不断增加。翻修术前最重要的步骤之一便是识别假体型号，这对术前计划有很大意义。有研究表明，每个翻修病例大约需要 20 分钟来确定假体型号，仍有 10%的假体术前无法确定，2%的假体术中无法识别。这会导致手术时间的和医疗费用的增加[43]。有研究证明了一种新的 DL 方法可以在髋关节 x 线中识别 4 种不同的髋关节假体，具有在翻修术前对假体进行分类的潜力[44]。Jaret M Karnuta 等人训练、验证并外部测试了一个 DL 系统软件，通过 x 线图像对假体进行分类并表现出出色性能，有助于改善髋关节翻修术前计划[45]。

10. DL、ML 预测 THA 术后假体松动

由于人口老龄化等原因，THA 的数量不断增加，这导致髋关节翻修术的数量也显著增加[46] [47]。THA 失败的常见原因包括假体松动、骨溶解和术后感染等，其中最主要的是假体松动。但其检测仍是一个棘手的难题，通常需要在翻修手术过程中才能确定[48] [49] [50]。X 线、关节造影、核磁共振成像等方法可用于帮助假体松动诊断，但这些方法通常都有辐射、不敏感且缺乏有效性等缺点[51]。因此，需要更加便捷有效的方法来识别假体松动的发生。Mattia Loppini 等人基于 DL 开发了一套自动放射影像错误识别系统，通过卷积神经网络进行分析，可以准确地检测到髋关节假体的松动[52]。Romil F Shah 等人通过训练一系列卷积神经网络模型来评估 ML 算法识别假体松动的能力。结果表明虽然目前发展下 ML 算法无法独立完成假体松动检测，但仍是一种临床决策的有用工具[53]。

11. DL 预测 THA 术后脱位风险

脱位是 THA 术后最常见的早期并发症，也是导致翻修术的主要原因之一[46] [54]。脱位可以导致患者出现严重疼痛和肢体功能丧失等问题，因此准确预测初次 THA 术后脱位风险对制定个性化手术方案和术后康复计划至关重要。Alireza Borjali 等人开发了一种基于 DL 的自然语言处理模型以检测初次 THA 术后假体位置。该模型可以准确预测髋关节脱位风险并改善患者预后[55]。Pouria Rouzrokh 等人开发了一种基于 DL 的影像分类模型，能够结合临床危险因素对 THA 术后脱位进行快速评估，这一研究展示了自动成像模型在骨科应用的潜力[56]。

12. 小结

目前，越来越多患有髋关节炎、股骨头坏死或先天性髋关节发育不良等疾病的患者选择接受 THA 来改善下肢功能和日常生活质量。虽然 THA 是一种十分成熟的手术方式，但仍有许多因素需要进一步改善。随着新兴科技和医疗技术的不断进步，AI 已经在 THA 的许多方面展现出优势。在 THA 术前，AI 可用于预测 PSI 和 HJC、住院时间、患者满意度和骨矿物质密度等。此外，AI-HIP 可以为患者优化术前计划。在 THA 术后，AI 可用于预测输血率、识别髋关节假体类型、预测术后假体松动和脱位风险。这表明 AI 在 THA 中的应用具有很大的发展潜力，但随着患者需求的不断提高也将面临更大挑战。随着国内外的不断深入研究，相信在将来 AI 在 THA 中的应用会有进一步的飞跃。

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