

Review Article

Artificial Intelligence and Its Potential Application in Advancing Hip Osteoarthritis Care

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Abstract

Background: Hip joint osteoarthritis remains an incurable disabling health condition.

Aim: To examine what trends exist in the realm of Artificial Intelligence [AI] applications to hip osteoarthritis.

Methods: An in-depth literature review focusing on hip osteoarthritis and selected artificial intelligence association's themes was conducted.

Results: Artificial intelligence is being widely studied and applied in the realms of hip osteoarthritis diagnoses and surgical factors and approaches, but less so in the clinical and deterministic spheres.

Conclusion: Future expanded research efforts that integrate the features of the whole joint and person-environment factors and their association with favorable and unfavorable hip osteoarthritis outcomes are needed and are likely to prove promising and save immense human and service costs.

Keywords: Arthroplasty; Artificial Intelligence; Deep Learning; Diagnosis; Hip Osteoarthritis; Machine Learning; Outcomes; Pathology; Prevention; Surgery

Introduction

Osteoarthritis, a painful disabling joint disorder, often impacting one or both hip joints adversely commonly induce a high degree of progressive functional and social disability is almost all aging populations. Although deemed incurable with no definitive cause and despite its seemingly low priority when compared for example to heart disease, an increasing number of dedicated researchers, research teams and clinicians continue to strive to better understand the origins of

the disease and if possible, to pinpoint how to alleviate its distressful life limiting features and immense costs and demands on shrinking resources. In the face of the immense costs of hip osteoarthritis, a very common disease site among older populations and one where there is growing need to reduce its burden including the need for better hip surgery outcomes, can the realm of what is known as artificial Intelligence (AI) that has already shown much promise in multiple spheres, similarly help to advance this high demand hip osteoarthritis field of endeavor. At the same time, can a parallel mode of technology known as Machine Learning (ML) further advance this basic set of understandings gleaned from large data sets given that osteoarthritis is now considered a disease involving multiple evolving biochemical and cellular alterations of multiple joint tissues and joint structures, not just a single tissue. Its manifestation may also vary within or across the affected joint or joints, or individual cases, hence a need for the emergence of personalized data sets that represent the individual case and that can be compared to generalized facts, appears highly warranted [1]. As well, current data sets based on past observational data, limited samples and uncertain measurement properties may not adequately represent the clinical picture of an individual case without the addition of ML approaches.

In this regard, in light of the growing population of older adults living to higher ages and shrinking rather than expanding health budgets along with the aging or resignation of many in the health care fields who cannot be readily replaced, can AI help to uncover more preventive as well as treatment solutions to counter hip osteoarthritis?

As per Yao, et al., it appears a better understanding of the nature of the complex pathological features, signaling pathways and key molecules involved in mediating or moderating hip osteoarthritis may be crucial for advancing therapeutic target design and drug development [1].

In addition to the possible ease of being able to categorize and differentiate the various hip osteoarthritis disease subsets more decisively Haeberle, et al., conclude that various forms of AI and ML are well placed to expand upon multiple orthopedic surgery frontiers and others [2]. For example, with the development of AI technology, a device known as the AI HIP is shown to be a highly reliable form of planning software based on AI technology that can quickly and automatically identify the morphology of the key hip bones. It can automatically match the optimal prosthesis size that may be needed for a given hip surgical candidate [3].

In view of these possibilities and the very severe impact of hip joint osteoarthritis on the lives of many older adults no matter where they reside and the fact the disease symptoms do not always correlate well with commonplace radiographic staged disease classifications, it thus seems plausible to examine if researchers are pursuing this line of inquiry in diverse ways so as to advance more accurate disease profiling. The rationale for considering the possible importance of AI at all stages of osteoarthritis disease, including surgery, is its enormous human burden and the fact age and a 'wear and tear' theory is often not a factor in explaining either the presence of the disease, or why the disease may manifest on one side of the body but not the other. The after care of the hip osteoarthritis case may also be less supportive and available in many cases in 2023, where younger family members have to work and cannot provide persistent care.

Patients may also benefit from more accurate interpretations of their symptoms because of the strong possibility that AI can integrate data from biochemical tests, as well as radiographic and muscle based structural features, plus biomechanical test data and health records in real time that may prove highly valuable in fostering timely efficacious evidence-based solutions.

Approach and Rationale

Using the PUBMED, PubMed Central and Google Scholar data bases deemed to house salient representative data and the terms artificial intelligence, machine learning and hip osteoarthritis clinically oriented articles dating largely from the most recently studied period and specifically related to the context of hip osteoarthritis biomechanics, functional challenges and diagnoses were sought. Articles on hip dysplasia, knee osteoarthritis and rheumatoid arthritis were excluded. As well, articles that discussed proposed studies were excluded. Since AI is not well developed as a tested science in this realm and is largely exploratory at present, all forms of information were deemed relevant. The focus was on articles extending from mid-2021-2023 as several reviews on prior data are available. For example, in a current scoping review published in 2022 and designed to uncover how various aspects of AI may advance hip osteoarthritis preventive and therapeutic care, this review included 2021 data, with 12 related to diagnosis, 7 to prediction, 4 to phenotyping, 12 to severity and 11 to progression. The number of patients included ranged from 18 to 5749. Overall, 35% of the articles described the use of Deep Learning (DL) and 74% imaging analyses. Only a small total of the articles involved hip osteoarthritis and most involved the same cohort. Data and source codes were described as publicly available respectively in 54% and 22% of the articles. External validation was provided in only 7% of the articles. This shows that there is a long way to go to employing large data sets to solve osteoarthritis dilemmas and that the disease at the hip, while common and highly disabling, is vastly understudied [4].

Nich, et al., report how AI/ML systems could facilitate data-driven personalized care for patients, while Farrow, et al., is proposing AI can serve as a first step toward delivering an automated solution for arthroplasty selection using routinely collected health care data [5,6]. Following appropriate external validation and clinical testing, this could substantially improve the proportion of referred patients that are selected to undergo surgery, with a subsequent reduction in waiting time for arthroplasty appointments.

Archer, et al., agree that AI-based software has been shown to demonstrate reliable radiological assessment of patients with hip joint disease with significant interpretation-related time savings [7]. AI also appears to have the potential to serve as a prognostic indicator of hip joint osteoarthritis severity [8].

Search Results

Key Findings

Among multiple applications and reports of AI, ML and Deep Learning (DL) published since 2019, or even before that, (Fig. 1), Lalehzerian, et al., conclude that since its inception AI has been of immense diagnostic benefits in various realms of orthopedics [9]. With the attributes of accuracy and speed, AI and similar systems can flag the most critical features of hip osteoarthritis patients and discern who needs immediate attention, while reducing the amount of human error involved in this process, as well as the strain on medical professionals and systems, while improving care. In addition, novel therapy approaches based on AI such as digital physiotherapy can also produce better health outcomes after hip replacement surgery if this is required than standard approaches [10]. Thus, while the identification of osteoarthritis at a stage where it is potentially reversible remains elusive, there is hope that fewer cases will suffer over time and that other AI technologies may be able to close this gap [11].

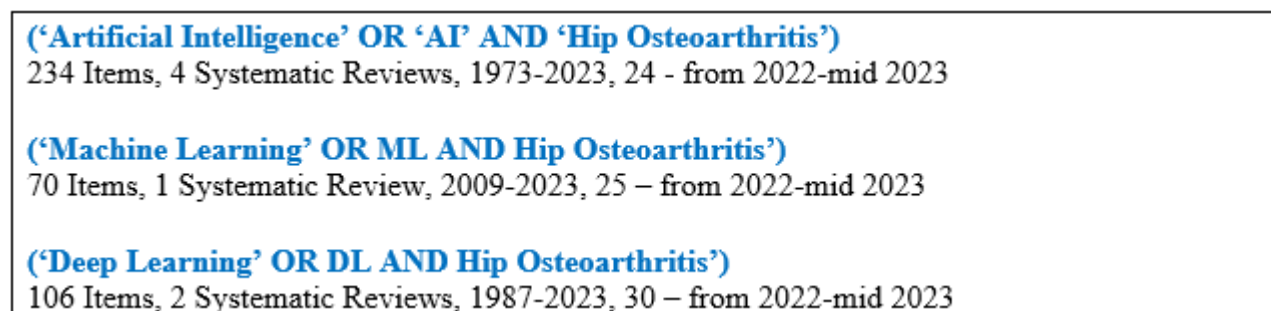


Figure 1: Overview of PUBMED search as of June 26, 2023 showing many years of interest in the AI realm and possible hip osteoarthritis applications. Numbers though are generally overestimates because articles that do not discuss hip osteoarthritis are classified as such.

It is also apparent that although there are very few topical papers on Machine Learning (ML) that discuss hip osteoarthritis specifically, as opposed to knee osteoarthritis, or osteoarthritis in general and that have been published since 2021, current research published between 2022-2023 continues to reveal a very promising role for ML plus multitask Deep Learning (DL) models as regards their ability to reliably assess radiographic features of hip osteoarthritis. This may not only be useful clinically, but useful in large epidemiologic studies wherein a detailed structural assessment of osteoarthritis still relies on expert radiologists’ readings [12].

Gebre, et al., who developed and compared Deep Learning (DL) models designed to detect hip osteoarthritis using clinical Computerized Tomography (CT) scans concluded that CT-based summary images termed CT-AT and that resemble radiographs can be used to accurately detect the same information as standard radiographic hip osteoarthritis approaches [6]. In addition, in the absence of large training data, a reliable DL model can be optimized by combining CT-AP and X-ray images.

To go beyond the conventional hip osteoarthritis diagnostic approach done by assessing X-ray images manually, Xue, et al., elected to explore the diagnostic value of DL for improving hip osteoarthritis diagnoses [14]. Using a deep Convolutional Neural Network (CNN) in which the network was trained and tested on 420 hip radiographs designed to automatically diagnose hip osteoarthritis, results showed excellent sensitivity (95.0%) as well as high specificity (90.7%), with an accuracy of 92.8% when compared to that of chief physicians. The CNN model performance was also comparable to that of an attending physician with 10 years of experience. The results of this study strongly indicated that DL has considerable potential in the field of intelligent medical image diagnosis and practices for fostering hip osteoarthritis diverse clinical predictions.

In this regard, Chen, et al., noted DL algorithms can also be used to detect anomalies in medical images, as well as the presence of hip osteoarthritis and can thereby predict the need for further surgery to replace the diseased hip joint [15]. Moreover, in

another important realm, Nuech, et al., who elected to determine if gait kinematics specific to knee versus hip osteoarthritis can be distinguished using wearable sensors and statistical parametric mapping and whether disease-related gait deviations are associated with patient reported outcome measures showed this approach to have considerable potential [16]. As a result, the researchers concluded that if applied to large cohorts, this method of assessment could represent a major advancement in the realms of future research on musculoskeletal diseases such as hip osteoarthritis.

Sibert, et al., indicate further that ML techniques are forms of AI that can analyze big data and recognize different patterns that might relate to different types of pathology [17]. Their research showed data collected from on-line self-reports related to hip complaints can differentiate between basic hip pathologies, while the addition of radiological scores for osteoarthritis further improves these outcomes.

Ramkumar, et al., found a preliminary ML algorithm they tested had excellent construct validity, reliability and responsiveness properties in the context of hip joint surgery for osteoarthritis [18]. This system was deemed helpful because it allows for a risk-based personalized estimate of several complex elective hip surgery outcomes and processes to be generated collectively. Crawford, et al., too have developed an additional ML algorithm that could save immense costs as well as time because it can identify potential surgical candidates for hip joint arthroplasty without an in-person evaluation or physical examination [19]. It is also able to help direct the appropriate next steps for patients with osteoarthritis while improving the efficiency of identifying eligible and needy surgical candidates.

Dorraki, et al., describe a novel network analytic methodology for using microcomputed tomography images of human trabecular bone point that can provide for a novel description of bone microstructure in hip osteoarthritis and that may help to further describe the nature of this syndrome and how surgery might be modulated advantageously [20]. In other areas, such as drug development, AI is helping to provide insights into key molecular influences in various disease processes and to possibly highlight attractive drug targets or to accelerate translation of their benefits [21].

Clinically, Biebl, et al., have demonstrated that an app called the Motion Coach is non inferior to physiotherapist evaluations and was valid for all investigated exercises and subgroups and that could be very helpful in a time of health constraints [22]. In addition, as Chen, et al., describe, an AI planning tool can be used to significantly reduce the time and manpower required to conduct any desirable detailed preoperative plans, with more accuracy than any traditional planning method [23]. The software tool AI-HIP has also been shown to yield excellent reliability for predicting the component size and implant position in primary total hip arthroplasty, while Jang, et al., report a ML model that can predict 10-year total hip arthroplasty surgery risk more accurately than standard methods by using Deep Learning (DL) radiographic measurements [24,25]. The model weights predictive variables in concordance with clinical total hip arthroplasty pathology assessments and appears very valuable in aiding patients and clinicians to augment shared decision-making.

Additional Observations and Clinical Implications

Despite their many attributes, it is believed many ML models commonly tend to show ‘black box’ characteristics and, therefore, may exhibit a lack of transparency, interpretability and trustworthiness that can limit their practical application in clinical contexts. To overcome these limitations, a device known as ‘Explainable Artificial Intelligence’ has shown promising results. This was concluded after completion of a study examining the influence of different input representations on a trained model for accuracy and interpretability, as well as clinical relevancy using this approach, for example in the context of addressing individual pathologic gait patterns [26]. Zhang, et al., too has shown that certain ML algorithms are able to demonstrate fair discriminative ability in predicting patient satisfaction after total hip arthroplasty surgery [27]. However, in another related study, it was shown that appraisal cognitions are likely to be very important hip arthroplasty surgery outcome predictors and should not be ignored [28].

Other possible improvements that can be made to extend current systems are data that can reveal the nature of the movement-related joint loading attributes of varying degrees of hip joint osteoarthritis as well as healthy joint loading. Moreover, examining various functional attributes in the patients’ natural environment, rather than the lab, may provide for greater ecological validity and opportunities to develop large data sets of movement data to intervene on mitigating hip osteoarthritis. In this regard,

inertial sensors currently show promise for remote monitoring, risk assessment and intervention delivery in individuals with hip and knee osteoarthritis. Future opportunities remain to validate these sensors in real-world settings across a range of activities of daily living and to optimize sensor placement and data analysis approaches [29]. A joint loading device developed using an iterative design process, has been deemed to have favorable impacts in the realm of efforts to develop a personalized joint loading predictive device. Using this along with imaging, improved network performance, and cartilage cellular and muscle structural and functional measures may add considerably to its clinical utility [30-33].

Discussion

Hip joint osteoarthritis and its consequences are of immense concern in all aging societies. Although many advances have been made in this realm, securing an early hip osteoarthritis diagnosis, while desirable, currently remains elusive, thus treatments are largely those devoted to end stage disease situations. Some of the other challenges in this realm are that the more extensive focus of its consequences rarely calls for a more holistic disease understanding, even though the disease is now considered to involve multiple joint tissues. Treatments are currently largely directed towards reducing pain via pharmacologic approaches or surgery or both with no universally observable functional disease reversal. In this present review that examined possible advances in hip osteoarthritis knowledge and interventions and AI associations, most common was the use of AI for validating radiological features and their predictive implications. In this regard, many reports show various diagnostic scanning and other hip images obtained through radiography can be even more accurately captured and interpreted than the present standard approaches by using one or more forms of AI. Indeed, as of 2022 and described in this report there has been a notable uptake in the development and validation of AI techniques used to perform texture analysis and predict osteoarthritis progression through various forms of imagery, in particular [34]. The use of AI for fostering surgical success, as well as enhancing the understanding of some aspects of osteoarthritis joint pathology and biomechanics has also been advanced, even though very few articles focus on other forms of medical management to improve function and mobility. The use of AI to better depict the natural history of severe osteoarthritis of the hip and how this differs from a milder clinical picture is however, not evident despite its implications, but if captured over time may enable more timely decisive benefits to many. Qualitative data, often neglected in systematic reviews or quantitative research, for example patient pain experiences and beliefs, as well as daily functional loading estimates on the hips that may be very salient outcome predictors of hip osteoarthritis, regardless of treatment modality, are also not well covered in the current AI, ML or DL osteoarthritis thematic and implications realms. Prevalence data and the relationship of socio demographics, disease symptoms, bone, vascular, muscle and radiographic changes that may greatly enhance osteoarthritis understandings and outcomes have not been stressed to date, despite the immense computing promise of AI systems and samples studied are often the same in various reports or exclude outliers, high aged adults, those with certain diseases and those with no health provider. As such, it can be concluded that until more inclusive insightful studies are forthcoming, the immense potential of AI will remain limited as far as hip osteoarthritis advancement is concerned. Moreover, its current usage will remain limited in light of the small number of robust studies published to date and their limited attention to multiple features of hip determinants and their heterogeneity. In addition, very few guiding studies currently pinpoint how predictors of surgical complications, inflammatory correlates, pain attributes and experiences, cognitive, behavioral and muscle influences, including the role of comorbid health conditions and hip joint shape among other factors determine the disease course with any certainty [35]. In addition, even among diagnostically themed publications that are most favored, along with surgical themes of study, Korneev, et al., identified two problems that block the full integration of AI into the routine of an orthopedic physician, including those who are involved in hip osteoarthritis care [36]. The first of these is related to the insufficient amount, variety and quality of data for training and validation and testing of AI models in almost any sphere. The second problem is the rarity of rational evaluation of models (and possible failure to differentiate hip osteoarthritis subgroups) which is why their real quality cannot always be evaluated. The role of disease stage as assessed by clinical markers over extended time frames and features of pain catastrophizing and self-efficacy could possibly help improve the ability to discern what is needed in a broader sense to improve overall life quality and reduce pain. The quality of the prevailing data has also been questioned as well as its generalizability [4]. Radiographs alone may also be poorly correlated with disease disability markers such as pain. We thus agree with Nich, et al., 2022, that it is not yet possible to employ AI/ML with great confidence as a standalone approach in advancing hip osteoarthritis clinical or surgical practices, or overall etio pathogenic features. Since osteoarthritis is considered a disease of the whole joint, its diagnosis and prediction of its advancement as well as its implications must be more ably based on the state of the whole joint as well as the person-environmental factors that often underpin many hip osteoarthritis outcomes, such as obesity [5]. It can also be argued that the sole focus of intervening in osteoarthritis based on radiography may fail to afford insights into its presence

early on simply based on clinical findings that meet disease criteria. As a result, it appears, even if AI has greatly improved clinical decision-making, identification of hip and knee implants to predict clinical outcomes and complications following a reconstruction procedure of these joints AI may still fail to yield desired functional outcomes if features such as psychosocial and medical history factors that may have potent indirect influences on surgical outcomes are overlooked or the disease is only identified when severe [37]. As well, a lack of information on those diverse factors that converge to produce osteoarthritis of the hip joint may further limit the optimal mapping of AI/ML systems with any anticipated disease prognosis and a possible more efficacious data-driven personalized care solution for the hip osteoarthritis case that can result in increased mobility and function. For example, perhaps more access to kinetic analyses and their implications can be studied to better understand mobility issues, along with surface electromyography to detail motor synergies and motor unit signaling attributes and records of joint pain frequency that align with radiographic measures and disease severity [38-40]. It is also anticipated that the accurate evaluation of cartilage cell status and organization can specifically increase the objectivity of imaging evaluations as well as highlighting possible regeneration opportunities and how any alterations align with the clinical presentation of hip osteoarthritis [32,41,42]. In the interim, it is concluded that AI is a tool of immense promise, but its utility depends on the insightful input of large data sets that have been carefully devised and can be adequately aggregated and are based on inclusive diverse samples collected over time with validated procedures. Extending the AI data base beyond its overwhelming use in advancing structural diagnoses and applying its potential to reveal key upstream and downstream osteoarthritis determinants, including disease bio-molecular and neuromuscular interactions can have the potential to greatly enhance a provider's understandings, as well as patient's and an emergent mutually agreeable treatment decision. In the interim, research endeavors that can truly represent a comprehensive clinical picture including patient-based voices and practice-based evidence must not be ignored, but more intentionally sought in a unified, inclusive, equitable and robust manner.

Conclusion

Although this current overview is clearly limited in multiple ways and may not be all inclusive, it appears that it is safe to conclude that:

1. The degrees of disablement among many older adults in all parts of the world who require various forms of pain relief and functional support due to hip osteoarthritis is growing and remains a public health challenge of immense proportions.
2. The disease, while largely impervious to the sole application of various drugs and other modalities, may yet be impacted favorably by concomitant or independent efforts of hip replacement surgery and advances in general in the realm of artificial intelligence.
3. To extend its largely diagnostic benefits that are clearly established, researchers can greatly help to advance this line of inquiry urgently needed to allay suffering and health costs by concerted efforts to study the nature of hip osteoarthritis sub group features in the context of large varied samples of vulnerable younger and older individuals with and without hip osteoarthritis in a careful comprehensive manner over time.
4. How the biochemical and molecular as well as kinetic and cognitive aspects of the disease can be better discerned and correlated with the status of all surrounding joint components and functional indicators as well as radiographic measures when using advanced technology including radionuclide scintigraphy will likely prove revealing and is strongly indicated.
5. Until more research is forthcoming, the application of carefully construed hip osteoarthritis pathogenic factors, its remediable origins, including social factors and interventions that do not neglect human prowess and skills and the role of cognitions appear desirable and hold great promise.
6. Efforts to obtain robust reliable biomechanical data among large diverse cohorts at multiple disease stages that are noninvasive and compared to those with wearable measures that might alter proprioception are highly recommended before home based wearable measures can be deemed meaningful.

Conflict of Interest

The author has no conflict of interest to declare.

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