Review

# Utilizing Artificial Intelligence for the Diagnosis, Assessment, and Management of Chronic Pain

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## ABSTRACT

Chronic pain is a prevalent condition and the leading cause of work absenteeism worldwide. This condition involves persistent pain lasting more than three months, significantly impacting the quality of life and social interactions of patients. While the causes of chronic pain can often remain unknown, no definitive cure exists for the various known causes. Furthermore, the evaluation and prediction of pain can be challenging, particularly in unconscious patients receiving care in the intensive care unit. Subjective measures and traditional methods are typically employed for diagnosis, assessment, and treatment to identify the most effective approach. However, recent advancements in Artificial Intelligence (AI) and other computer science fields have revolutionized the medical domain, offering a novel and promising avenue for enhancing pain management. This review provides an overview of the potential benefits, limitations, and prospects associated with the role of AI in the diagnosis, assessment, and management of chronic pain.

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## Keyword

Artificial Intelligence; Machine Learning; Artificial Neural Networks; Deep Learning; Pain Management; Pain Assessment

## Introduction

The potential ability of Artificial Intelligence (AI) in medicine has become recently increasingly prominent to enhance the precision and effectiveness of diagnosis and treatment in various fields of medicine [1-3].

Chronic pain has a significant negative impact on the quality of life and social activities of the patients [4, 5]. Improving patient outcomes needs accurate diagnosis, comprehensive assessment, and effective management [6].

Pain research has extensively used AI and Machine Learning (ML) techniques to develop algorithms to assess and control pain effectively [7]. Advanced technologies have shown a remarkable level of agreement with on-site assessments performed by medical professionals and brought notable benefits in terms of consistency, repeatability, efficiency, and cost-effectiveness [8]. AI learns from experience, which treatment modalities best improve outcomes while conserving the clinician's time,

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potentially improving patient outcomes, and reducing the burden on the healthcare system. Additionally, these approaches may be more affordable and accessible than human-based interventions, making them more feasible for all healthcare organizations [9]. The use of AI in chronic pain management is an exciting development that holds great promise for the future of healthcare [2, 10]. In this review, we explore the clinical application of AI models to diagnose, assess, and manage chronic pain disorders, their limitations, and challenges, and future direction.

## AI-Based Diagnosis of Pain Disorders

AI helps clinicians understand the primary cause and final diagnosis by analyzing vast amounts of patient data, including medical records, imaging studies, and genetic information [11]. Additionally, ML algorithms can identify patterns and risk factors associated with chronic pain [12, 13], such as low back pain, a prevalent condition that often requires Magnetic Resonance Imaging (MRI) for accurate diagnosis [14-16]. However, early diagnosis can be challenging [16]. Soin et al. demonstrated that AI can assist in decision-making for spinal pain, with software-generated diagnoses using patient data with a 72% accuracy rate [17].

The potential of AI in exploring the automatic detection, classification, and location of spinal diseases, is immense. With the ability to analyze large amounts of data quickly and accurately, AI can transform the way spinal diseases are diagnosed and treated, leading to better patient outcomes [17-21].

However, it is crucial to carefully select an appropriate AI model that possesses acceptable validity when it comes to assisting in clinical diagnosis [11]. The values of accuracy, sensitivity, and specificity may not reflect the behavior of the method in a real-world environment. Therefore, careful consideration and validation are necessary before implementing AI in clinical practice [22].

AI-based diagnosis of pain disorders has the potential to improve patient outcomes and revolutionize the healthcare industry. However, it is essential to ensure that AI models are appropriately validated and integrated into clinical practice to ensure their efficacy and safety [13, 23, 24].

Artificial Neural Networks (ANNs) have emerged as powerful tools for diagnosing and predicting the severity of painful conditions based on medical imaging [24-26]. The ANNs form the fundamental framework of DL algorithms and have exhibited promising outcomes in the identification of early signs of knee osteoarthritis using X-ray images. This advancement has the potential to revolutionize the diagnostic and treatment approaches for this debilitating condition [24].

ANNs coupled with MR image processing have significantly reduced radiologists' workload and improved diagnoses' accuracy. These algorithms can detect subtle changes in anatomy associated with diseases, such as spinal conditions, much faster and more accurately than a human radiologist [27, 28].

Additionally, ANNs can analyze large patient datasets to identify potential correlations between symptoms, diagnose conditions, and ultimately predict the most suitable treatment options for each patient, resulting in improved patient outcomes by ensuring that they receive the most effective and timely treatment [29, 30].

Besides their application in diagnosing pain conditions, ANNs have also demonstrated effectiveness in predicting the risk of multiple co-occurring symptoms, such as pain, depression, and lack of well-being, within a specific timeframe. This capability can be particularly valuable in proactive symptom management, enabling healthcare providers to intervene, before escalating symptoms to severe and debilitating levels. Consequently, utilizing ANNs in this manner has the potential to enhance patient outcomes [30].

ANNs have been helpful in diagnosing facial pain syndromes, such as trigeminal neuralgia, and also in predicting the success rate of interventions [31, 32]. Also, DL develops spontaneous pain indicators and evaluates the efficacy of analgesics in real-time. ANNs have also classified pathological pain into either neuropathic or nociceptive subtypes. This has the potential to improve the accuracy of pain diagnosis and lead to more effective treatments [29, 33].

ANNs have displayed promising potential in pain diagnosis and management. Through ongoing research and development in this field, there is a strong possibility of achieving substantial enhancements in patient outcomes and overall quality of life. The continued exploration of ANNs' capabilities in pain-related applications holds great promise for advancing the field and improving the well-being of individuals suffering from pain conditions [34].

Regression models are a set of methods that utilize ML algorithms to automatically detect patterns and predict outcomes based on input data [35]. In the context of pain research, regression models have the potential to help the diagnosis, classification, and management of pain [36, 37]. These models can predict pain occurrence, probability, volatility, and management response via a logistic regression model. Regression models rely on large and diverse datasets to effectively train the ML algorithms and can analyze various types of data, such as patient demographics, medical history, pain symptoms, and treatment outcomes. The ability of regression models to analyze patient data leads to offering personalized and adaptive pain management strategies, resulting in their primary advantages [36, 38].

Several studies have demonstrated the potential of regression models in pain research [37-41], with successful predictions of imaging no-shows, pain severity in patients with primary Sjögren syndrome [39] or juvenile idiopathic arthritis [40], and postoperative discomfort following implant surgery [37]. However, these models have their limitations, requiring large and diverse datasets to be effective, and incomplete or biased data may lead to inaccurate predictions. Additionally, AI regression models cannot capture the complexity of pain experiences, such as the subjective nature of pain perception [41].

Natural Language Processing (NLP) is increasingly used in pain diagnosis to capture relevant information from verbal descriptions of chronic pain and extract and process textual features for various tasks related to pain diagnosis [42]. These techniques have been applied to transcribe verbal descriptions of chronic pain to capture relevant information that would otherwise not be accessible [42, 43].

A pain lexicon was developed to assist in subsequent NLP tasks and employed to extract information from longitudinal clinical records for pain status monitoring and the identification of new pain phenotypes [44]. As an example, recent studies showed NLP and ML can accurately classify migraine headaches versus cluster headaches [45, 46]. This technology can improve the accuracy of diagnoses and reduce the risk of misdiagnosis, leading to better patient outcomes [47].

## AI-Based Pain Assessment

Clinicians face challenges in assessing chronic pain due to the absence of a specific device or method to objectively measure pain severity. Instead, healthcare providers rely on patient self-reporting as the primary means of assessing pain intensity [48]. Nevertheless, the integration of data from wearable devices, electronic health records, and mobile applications into AI algorithms holds the potential to enhance pain assessment and facilitate the development of personalized treatment plans. This technology can effectively predict and detect various types of pain by analyzing patients' physiological data [49, 50].

Physiological data-based pain estimation models have primarily focused on identifying the presence or absence of pain rather than exploring the pain features used for diagnosis and treatment [51-53]. However, there is a potential for non-invasive and objective pain measurements through biosensors coupled with ML algorithms. Traditional medical devices, such as electrocardiographs, pulse plethysmographs, electroencephalographs, thermometers, and vital sign monitoring systems, can measure physiological data for pain estimation models [52, 54, 55]. Additionally, AI-based devices can sense motion signals, eye movements, facial expressions, and skin conductance to detect pain status in healthy subjects and quantify acute and chronic pain using ML algorithms [54-56].

Different ML models, such as ANNs, linear regression, support vector regression, Support Vector Machines (SVMs), random forest, adaptive boosting, and extreme gradient boosting, are built using extracted features. However, studies showed SVM and DL are more accurate models for the classification of pain [57, 58]. Probabilistic models, such as Gaussian Naive Bayes (GNB) classifiers and hidden Markov models (HMMs), can help clinicians assess pain levels with patient self-reports by analyzing physiological information from individuals with chronic pain, including respiration rate, pulse rate, oxygen level, body temperature, and blood pressure [59].

On the other hand, using physiological data for pain assessment has limitations due to the variability of pain perception among individuals [51]. Furthermore, pain often occurs in settings where it may be difficult to collect physiological data. Wearable devices and mobile applications help overcome this challenge, but patients may be hesitant to share personal health information, and data collection methods must be transparent and secure [49, 60]. Thus, careful study design and collaboration across disciplines are necessary to address these challenges [13].

## AI-Based Pain Management

AI has the potential to optimize treatment plans and improve therapeutic outcomes and can analyze large datasets containing patient information, treatment responses, and outcomes to identify patterns and optimize treatment recommendations [13]. Moreover, AI-based decision-making support systems can assist healthcare providers in making informed decisions regarding pain management. These systems can analyze patient data, clinical guidelines, and medical literature to provide evidence-based recommendations for treatment options, such as medication dosages and potential interactions, improving the quality and safety of pain interventions [61].

AI-based interventions can also personalize treatment plans based on patient needs, recognizing exercises for self-management of low back pain for instance. Reinforcement learning algorithms can be used to develop personalized Cognitive-Behavioral Therapy (CBT) for pain management services that automatically adapt to each patient's unique and changing needs [61-64]. In addition, personalizing CBT interventions increases access and reduces costs for patients [13, 62, 65]. AI-supported psychotherapy can target services based on patient feedback, and pain treatment becomes increasingly effective as it interacts with patients [64].

Moreover, AI-powered tools, such as Virtual Reality (VR) and mobile applications, can play a significant role in delivering personalized interventions, including CBT, physical therapy exercises, and medication adherence support. These technologies have the capability to differentiate between healthy individuals and patients, enabling more efficient allocation of clinical resources and increased accessibility to effective pain management services [63, 66, 67].

Furthermore, AI and ML algorithms are being integrated into VR therapy systems to provide an immersive and individualized pain management experience. These systems can dynamically adjust VR environments and stimuli based on real-time patient data, such as pain intensity and emotional state, to optimize pain relief and enhance the overall therapeutic effect [66].

Integrating ML-based pain management interventions into existing clinical workflows can be achieved by using a user-centered design approach to address real-world clinical pain points and configuring them in a clinically actionable way. The user-centered design toolkit consists of four questions covering solvable pain points, the unique value of ML, the actionability pathway, and the model's reward function [68]. These models are also being developed to identify patients who require more attention and calibrated follow-up programs in telemedicine-based cancer pain management [65].

Common Machine Learning (ML) methods utilized in pain interventions encompass Logistic Regression, Regularized Logistic Regression, Naive Bayes Classifier, Artificial Neural Networks (ANNs), Random Forest, and Gradient-Boosted Trees. The effectiveness of these ML algorithms is closely tied to factors, such as the volume of processed information, optimization of hyper-parameters, and the specific class of algorithms employed. By appropriately managing these elements, ML techniques can significantly contribute to improving pain interventions and optimizing patient outcomes [69, 70].

It is important to note that while these examples showcase the potential of ML and AI in pain treatment, their implementation and efficacy may vary depending on specific applications and healthcare settings.

Table 1 summarizes the common applications of AI models in specific pain conditions.

# Discussion

## Limitations and Challenges

Although, AI exhibits promising potential in managing chronic pain, it presents limitations and challenges. The use of AI in pain management increases ethical concerns, including the preference of some patients for human interaction over AI-based interventions, potentially leading to dehumanization [82]. There are also concerns regarding the reliability and validity of AI-based approaches to replace human interaction and empathy in pain management [82].

Moreover, AI algorithms have bias, leading to inaccurate pain assessment and treatment. Therefore, large-scale clinical trials are required to examine the efficacy of these methods on a larger cohort and over a longer period [13].

Moreover, the collection and analysis of sensitive patient information by AI systems raise concerns regarding privacy and data security. The development and utilization of AI-based interventions for pain management necessitate transparency and accountability to safeguard the safety, effectiveness, and equitable application of these technologies for all patients [83]. It requires a lot of data from the individuals, including physiological and behavioral pain response profiles while data collection is difficult due to limited resources and patient privacy concerns [8].

Healthcare providers and policymakers must also consider the potential impact of AI on healthcare costs and access to care, particularly for vulnerable populations. Implementing personalized ML-based pain management interventions in clinical settings can be challenging due to several reasons [84, 85].

Furthermore, the lack of standardization in the utilization of ML algorithms for pain management poses challenges in comparing results across studies and implementing personalized interventions in clinical settings [13]. Furthermore, the majority of the studies that used ML have investigated small sample sizes as a pilot study; accordingly, this issue raises concerns about the generalizability of the findings to larger populations [13, 17].

Finally, integrating ML-based pain manage-

**Table 1:** The applications of Artificial Intelligence (AI) models in specific pain conditions.

| Application | AI models | Conditions |
|---|---|---|
| Diagnosis | NNs | Low back pain [27]<br>Post-operative pain [71] |
| | CNN | Scoliosis [21]<br>Vertebral fracture [20] |
| | SVM | Low back pain [27]<br>Degenerative disc disease [72]<br>Post-operative pain [71] |
| | Decision tree | Low back pain [27]<br>Chronic spinal pain [17] |
| | Random Forests | Low back pain [27]<br>Knee pain [73]<br>Fibromyalgia [74] |
| | Deep Learning methods | Knee osteoarthritis [24] |
| | ANNs | Lumbar spine osteoarthritis [26]<br>Facial pain syndromes [32] |
| | Gradient-Boosted trees | Knee pain [73] |
| | Extreme Gradient Boosting | Knee pain [73] |
| | Naïve Bayes Classifier | Dental pain [75] |
| | NLP | Headache [42] |
| Assessment | Probabilistic models | Sickle cell disease [59] |
| | SVM | Low back pain [76, 77]<br>Musculoskeletal pain [78] |
| | ANNs | Low back pain [79] |
| | Naïve Bayes | Low back pain [77] |
| | Random Forest | Low back pain [77]<br>Musculoskeletal pain [78] |
| | Gradient-Boosted trees | Musculoskeletal pain [78] |
| | Decision tree | Musculoskeletal pain [78] |
| | Regression models | Musculoskeletal neck pain [38] |
| Management | Random Forest | Cancer pain [65]<br>Post-surgical pain [80] |
| | ANN | Cancer pain [65]<br>Efficiency of spinal cord stimulation in post spinal surgery pain [69] |
| | SVM | Pharmacologic response [81] |
| | Reinforcement learning | CBT in chronic back pain [64] |
| | Gradient-Boosted Machine | Cancer pain [65]<br>Post-surgical pain [80]<br>Efficiency of spinal-cord stimulation in post spinal surgery pain [69] |
| | Naïve Bayes classifier | Efficiency of spinal-cord stimulation in post spinal surgery pain [69] |

AI: Artificial Intelligence, NNs: Neural Networks, CNN: Convolutional Neural Network, SVMs: Support Vector Machines, ANNs: Artificial Neural Networks, NLP: Natural Language Processing, CBT: Cognitive Behavioral Therapy ment interventions into clinical workflow can be challenging due to the need for specialized software and hardware and also training healthcare professionals to use these tools efficiently [7, 12].

Addressing these challenges requires collaboration between researchers, healthcare professionals, and patients to develop standardized approaches for collecting and analyzing data and guidelines for implementing personalized ML-based pain management interventions in clinical settings. As AI-based interventions for pain management continue to advance, it is crucial to prioritize patient-centered care and ensure that these interventions are safe, effective, and equitable for all individuals.

### Future Directions

The integration of AI into chronic pain management is still in its early stages, and further research and development are necessary. In the future, it is crucial to refine AI algorithms through larger and more diverse datasets and establish ethical guidelines for the use of this technology in pain management. Also, effective educational strategies should be implemented for training healthcare professionals in AI-enabled practices [11, 36, 86].

Moreover, integrating AI with other emerging technologies has the potential to revolutionize pain management by combining advanced technologies with remote patient care, enabling real-time assessment, personalized interventions, and improved patient engagement. By leveraging the power of AI algorithms with telerobotic systems, healthcare providers can deliver efficient, patient-centered care, regardless of geographical barriers [87-89].

Although challenges exist, ongoing research and development in this field hold the promise of transforming pain management and enhancing the quality of life for individuals living with pain.

## Conclusion

AI has the potential to revolutionize the diagnosis, assessment, and management of chronic pain.

However, challenges and limitations must be addressed to ensure efficacious implementation. Continued research and development are essential to maximize the benefits of AI in pain management.

Most reports are pilot studies and more pilot studies with physiological pain measures are required before these approaches are ready for large clinical trials. Additionally, AI-based interventions may not be suitable for all patients, and some patients may prefer human interaction over this technology.

Finally, more research and development are crucial to further refine and expand the role of this emerging technology in pain management. Addressing the limitations and challenges associated with AI implementation is necessary to ensure successful integration into clinical practice. This technology has the potential to transform pain management, but careful consideration must be given to ethics, safety, and efficacy.

## Authors' Contribution

H. Zakeri contributed to the conceptualization and study design; M. Radmehr, F. Khademi, L. Montazeri, M. Ghanaatpisheh, B. Rahnama, P. Mahdiyar, S. Moalemi, and F. Hemati contributed in finding and choosing relevant studies; A. Karimi contributed in preparing the primary draft; P. Pedramfard revised the manuscript. All authors read and approved the final manuscript.

## Conflict of Interest

None

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