REVIEW

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CURRENT OPINION

A roadmap for artificial intelligence in pain medicine: current status, opportunities, and requirements

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Purpose of review
Artificial intelligence (AI) represents a transformative opportunity for pain medicine, offering potential solutions to longstanding challenges in pain assessment and management. This review synthesizes the current state of AI applications with a strategic framework for implementation, highlighting established adaptation pathways from adjacent medical fields.

Recent findings
In acute pain, AI systems have achieved regulatory approval for ultrasound guidance in regional anesthesia and shown promise in automated pain scoring through facial expression analysis. For chronic pain management, machine learning algorithms have improved diagnostic accuracy for musculoskeletal conditions and enhanced treatment selection through predictive modeling. Successful integration requires interdisciplinary collaboration and physician coleadership throughout the development process, with specific adaptations needed for pain-specific challenges.

Summary
This roadmap outlines a comprehensive methodological framework for AI in pain medicine, emphasizing four key phases: problem definition, algorithm development, validation, and implementation. Critical areas for future development include perioperative pain trajectory prediction, real-time procedural guidance, and personalized treatment optimization. Success ultimately depends on maintaining strong partnerships between clinicians, developers, and researchers while addressing ethical, regulatory, and educational considerations.

Keywords
artificial intelligence, clinical decision support, interdisciplinary collaboration, machine learning, pain medicine

INTRODUCTION

Artificial intelligence (AI) is a potentially transformative technology for healthcare, with notable potential to address longstanding challenges in pain medicine. The complex, multifaceted nature of pain assessment and management makes it an especially promising but challenging area for AI applications. Recent advances in AI and machine learning have demonstrated various levels of success in pattern recognition for pain assessment using facial expression analysis [1], predictive modeling for treatment response in interventions like spinal cord stimulation [2▪], and approaches for chronic pain management [3▪▪].

However, while technological innovation drives AI development in many fields, healthcare implementation requires careful physician coleadership, specifically where clinicians work as equal partners with technical experts in order to ensure

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KEY POINTS

- Artificial intelligence (AI) applications in pain medicine show promising results in acute pain assessment through facial expression analysis, ultrasound guidance for procedures, and predictive modeling for persistent opioid use.
- Successful AI integration in pain medicine requires a structured approach across four key phases: problem definition, algorithm development, validation, and implementation.
- Strategic adaptation of AI tools from adjacent medical specialties offers an efficient pathway to implementation while addressing pain-specific requirements.
- Interdisciplinary collaboration with physician coleadership is essential to ensure AI solutions address genuine clinical needs while maintaining high standards of care.
- Critical areas for future AI development in pain medicine include perioperative pain trajectory prediction, real-time procedural guidance, personalized treatment optimization, and opioid risk management.

clinical relevance and practical utility [4▪]. This is particularly crucial in pain medicine, where subjective patient experiences intersect with complex physiological mechanisms and diverse treatment modalities [5▪].

This roadmap builds upon our previous work [4▪,6] by synthesizing the current state of AI applications in pain medicine and providing a comprehensive methodological framework for implementation. It identifies adoption pathways which pain medicine can leverage AI advances from adjacent fields, mapping these adaptation opportunities against pain medicine's unique challenges.

DISCUSSION

Current artificial intelligence-based technologies

Acute pain

Computer vision algorithms have demonstrated high accuracy in automated pain scoring through facial expression analysis [1], providing objective measures that may complement patient self-reporting. In regional anesthesia, AI-assisted ultrasound guidance systems have achieved regulatory approval in both US and European markets, offering real-time anatomical identification and procedure guidance [7,8▪▪]. Similarly, commercially available AI-based devices for preprocedural ultrasound scanning in central neuraxial blockade have demonstrated improvements in procedural metrics, being shown to increase first-pass success for needle insertion, reduce procedural time, and accurately identify the dura/extra-dural space [8▪▪,9]. In the perioperative setting, machine learning algorithms have been applied to predict persistent opioid use after major surgeries [10–12].

Chronic pain

Machine learning algorithms have improved diagnostic accuracy for musculoskeletal conditions through automated image analysis [13], potentially facilitating earlier and more precise interventions. Preliminary research suggests predictive models could help forecast individual patient responses to interventions like spinal cord stimulation [2▪], though most remain in investigational stages. Novel approaches to medication selection are emerging through AI-powered systems that integrate multiple data sources (e.g. molecular imaging and protein structural data) [14▪].

The NIH HEAL (Helping to End Addiction Long-term) Initiative has made significant progress in standardizing data collection across pain and opioid-related clinical trials through the implementation of common data elements [15–18]. This harmonization effort includes recent standardization of opioid morphine milligram equivalent data for research [19▪▪], and systematic approaches to coding and documenting opioid misuse provide frameworks for more reliable identification of problematic opioid use patterns [20]. Such standardization is foundational for AI development in pain medicine, enabling the aggregation and meaningful comparison of datasets from multiple trials and creating the infrastructure necessary for developing robust predictive models [21,22].

Clinical decision support systems

Recent developments in explainable AI have provided more interpretable reasoning for clinical decision support systems (CDSS) recommendations, enhancing the potential clinical utility of these tools [23]. Integration with electronic health records presents opportunities for real-time decision support, with emerging techniques like federated learning (a decentralized approach that trains algorithms across multiple institutions without exchanging sensitive data) showing promise for maintaining compliance with privacy regulations [24]. Simulation studies suggest that properly designed CDSS can augment clinical judgment without disrupting existing workflows [25,26], though real-world implementation studies with clinical outcomes remain limited.

The novelty of adapting artificial intelligence tools and technology from other clinical fields

These current applications demonstrate how AI technologies initially developed for other clinical domains have been successfully adapted for pain medicine contexts. This pattern of crossspecialty adaptation provides a strategic roadmap for future development. Rather than creating entirely novel systems, pain medicine can systematically identify, evaluate, and adapt promising AI applications from adjacent fields, accelerating the pathway to clinical implementation while addressing pain-specific requirements.

Areas of unmet clinical need for which artificial intelligence-based solutions may be developed

Several critical gaps in acute pain management could benefit from AI solutions. Perioperative pain trajectory prediction remains challenging, particularly in identifying patients at risk for transition to chronic postsurgical pain. AI models integrating preoperative risk factors, intraoperative variables, and early postoperative indicators could potentially enable more targeted preventive interventions [6], similar to approaches being explored in predicting the transition of mild traumatic brain injury to chronic headache pathology [27]. Early-stage research is examining whether machine learning applied to dynamic imaging could improve the prediction of systemic responses in other clinical areas (e.g. sepsis after kidney stone procedures) [28], but the translation of these types of approaches to post-procedural pain remains limited.

In addition to clinical practice, AI technologies may also offer training opportunities by providing automated feedback on procedural technique, sometimes called ‘digital guidance’, to instruct both medical trainees [29] and patients [30]. The development of AI-powered robotic assistance for ultrasound-guided procedures represents another frontier, potentially improving precision and reducing operator dependence [31].

Pain assessment in noncommunicative patients (e.g. critically ill, cognitively impaired, or pediatric populations) remains challenging. While preliminary work on automated pain detection through facial expression and physiological parameters shows promise [32▪], more sophisticated multimodal AI systems could improve objective pain assessment in these vulnerable populations.

In chronic pain management, several significant challenges await AI solutions. Treatment selection and optimization remains largely empirical, with limited ability to predict individual response to interventions. AI models incorporating comprehensive patient data, including genetic factors, psychosocial variables, and detailed pain phenotyping, could potentially enable more precise treatment matching [33]. Digital twin technology, computational models that simulate individual patient characteristics to predict responses to interventions, while still in early developmental stages for pain applications, holds theoretical promise for modeling responses to complex interventions like neuromodulation [33].

The development of adaptive, personalized pain management programs represents another key opportunity. AI systems could dynamically adjust behavioral interventions based on real-time patient feedback and adherence patterns [34]. Integration with wearable devices and mobile health platforms could enable continuous monitoring and intervention adjustment, particularly for patients with limited access to specialty care [35].

Opioid risk management remains a critical challenge where AI could provide value. While current risk assessment tools exist, AI models could improve the prediction of individual risk trajectories, identify early warning signs of problematic use patterns, and leverage CDSS to improve patient care [26,36,37]. Furthermore, building on existing prediction models [12], AI could help optimize the transition from opioid to nonopioid pain management strategies by predicting withdrawal risk and suggesting personalized tapering schedules. A key challenge, however, would be identifying the risk factors that an AI model would monitor, such as the PATIO study focused on AI monitoring of rheumatological flares during tapering of biological disease-modifying antirheumatic drugs [38].

Patient engagement and self-management support represent another area where AI could bridge current gaps. Intelligent systems could provide personalized education, monitor treatment adherence, and facilitate communication between clinic visits [39].

Adaptation pathways from adjacent fields

The successful integration of AI in pain medicine can be accelerated by strategically adapting validated approaches from adjacent medical specialties. For acute pain management, technologies initially developed for perioperative monitoring could be adapted to detect pain in noncommunicative patients [40–42]. These same algorithms could be refined to recognize pain-specific signatures by training on pain-related datasets.

In chronic pain, adaptation opportunities exist in several domains. Imaging analysis systems from radiology and orthopedics could be reconfigured to identify anatomical correlates of pain conditions [43,44]. Medication optimization algorithms from oncology pain management offer frameworks for personalizing analgesic regimens in noncancer pain [14▪,45]. Similarly, patient monitoring systems developed for chronic disease management could be adapted to track pain trajectories and treatment responses over time [46–48].

These adaptation pathways provide a more efficient route to implementation than developing entirely new systems. However, successful adaptation requires careful attention to the unique aspects of pain, including its subjective nature, complex biopsychosocial influences, and the heterogeneity of pain conditions.

Strategic pillars for artificial intelligence development in pain medicine

Interdisciplinary collaboration and coleadership

The subjective and multifaceted nature of pain necessitates a collaborative approach to AI development [4▪]. Successful implementation requires early engagement of diverse stakeholders including pain physicians, pain psychologists, developers, data scientists, patients, and regulatory bodies [5▪]. While commercial entities bring essential technical expertise and resources to healthcare AI development, clinical coleadership is crucial to ensure solutions address genuine needs and integrate effectively into practice [2▪,4▪].

Industry partnerships will inevitably drive many AI developments, but pain medicine encompasses unique domain-specific challenges best understood by practicing clinicians [4▪]. The field therefore requires active physician leadership in identifying priorities, guiding development, and evaluating outcomes. This clinical perspective helps ensure AI tools enhance rather than disrupt established care pathways [6].

Development framework

Problem identification must begin with clinician input to ensure resources target genuine needs rather than perceived challenges (Tables 1 and 2). Physicians and researchers understand the practical limitations in current pain assessment, diagnosis, and treatment, while healthcare administrators and policymakers grasp system-level obstacles. Technology experts can then evaluate the solution feasibility to address these concerns within the constraints of the healthcare system [25].

Data quality and representation are fundamental considerations. AI development requires diverse, multimodal datasets incorporating imaging, electrophysiological signals, patient-reported outcomes, and sociodemographic factors to capture pain's complexity [49▪]. Training data must reflect individual variations in pain experience and response to address existing differences in pain assessment and treatment [1].

Evaluation standards

The lack of standardized evaluation frameworks for AI in pain medicine currently hinders progress. Inconsistent assessment methods make it difficult to compare solutions or translate findings between specialties [9]. The field needs structured validation approaches that can be applied consistently across different AI applications [23]. Clinical testing must extend beyond technical performance to evaluate real-world impact on workflows, decision-making, and patient outcomes [34].

Implementation strategy

The operationalization of AI in pain medicine should follow a strategic adoption pathway that recognizes the varying maturity levels of available technologies (Table 1). Mature AI systems with strong validation in adjacent fields should be prioritized for near-term adaptation and implementation [13].

Medium-term adoption targets include technologies with promising results in analogous clinical contexts but requiring significant validation in pain-specific applications. Decision support systems for medication management that have shown success in other complex medication regimens could be adapted for pain management but would require validation studies demonstrating safety and efficacy in pain populations [50]. Long-term development should focus on novel applications addressing unmet needs unique to pain medicine, such as multimodal pain assessment systems or personalized prediction of chronic pain development [3▪▪,6]. This staged implementation approach allows pain medicine to benefit from AI advances while mitigating risks associated with emerging technologies.

Table 1. Methodological framework for developer-clinician partnerships in pain medicine

Phase	Key actions	Pain-specific adaptations	Implementation examples
Problem definition	• Codefine clinically relevant endpoints between clinicians and developers [25] • Establish clear metrics for success • Identify workflow integration points	• Prioritize validated pain assessment tools (e.g. PROMIS, BPI) [16] • Include patient-reported outcomes • Consider both functional improvement and pain intensity measures	• Pain assessment algorithms for noncommunicative patients • Automated opioid risk stratification tools [37] • Treatment response prediction models
Algorithm development	• Train models on multimodal pain-specific data [49■] • Incorporate domain expert feedback • Ensure complex dataset representation	• Integrate multiple data types (imaging, biomarkers, patient reports) [5■] • Account for individual variation in pain expression and experience [60] • Distinguish between pain types (nociceptive vs. neuropathic)	• Facial expression analysis systems • Digital twin models for treatment simulation [33] • Personalized CBT delivery algorithms [34]
Validation	• Conduct rigorous clinical testing • Assess performance across unique populations • Evaluate workflow impact	• Test in real clinical settings • Validate against established pain metrics • Measure impact on clinical decision-making [23]	• REACT trial methodology for CBT-AI Electrodermal activity validation [35] • Multicenter validation studies •Consistently report according to established guidelines
Implementation	• Integrate with existing EHR systems [36] • Provide clinician training • Monitor real-world performance • Ongoing system improvements	• Align with pain documentation workflows • Ensure compatibility with opioid monitoring requirements [51] • Maintain HIPAA/GDPR compliance [24]	• Clinical decision support tools [26] • Automated pain assessment systems • Treatment optimization algorithms

BPI, Brief Pain Inventory; EHR, electronic health record; GDPR, General Data Protection Regulation; HIPAA, Health Insurance Portability and Accountability Act; PROMIS, Patient-Reported Outcomes Measurement Information System.

Ethical and regulatory considerations

The novelty of healthcare AI poses challenges for both clinicians and regulatory bodies [4■,9,24,51]. Developing appropriate evaluation standards requires improved communication between clinical, technical, and regulatory stakeholders [52–54]. Model explainability is particularly important in pain medicine, where complex decision-making processes must be transparent to maintain clinician confidence and ensure appropriate use [35].

Privacy protection demands particular attention when handling sensitive pain-related data, including opioid use histories and behavioral health information. Solutions must adhere to established healthcare privacy standards (Health Insurance Portability and Accountability Act, General Data Protection Regulation) while enabling necessary data sharing for model development and validation [24,54].

Additionally, algorithmic bias represents a significant concern in pain medicine, where historical disparities in pain assessment and treatment across demographic groups are well-documented [55]. AI systems trained on biased datasets risk perpetuating or amplifying these disparities. Regular fairness audits across diverse patient populations and stakeholder involvement throughout development are essential safeguards [56]. Patients must be active participants in decisions about data usage, with transparent consent processes that clearly communicate both potential benefits and risks.

Educational integration

Successful adoption requires the development of AI literacy among pain medicine clinicians. Training programs should incorporate competency-based additions to curricula that ensure graduates can critically evaluate and appropriately utilize AI tools while understanding their limitations [39].

Table 2. Roadmap to artificial intelligence for pain medicine: questions to consider

Administrative and operational questions
How can AI be integrated into clinical documentation while ensuring seamless EHR compatibility and preserving physician autonomy?
What specific metrics should define successful AI implementation in preauthorization processes, considering both efficiency gains and cost-effectiveness?
How can AI tools be designed to reduce administrative burden while maintaining high accuracy and compliance standards?
What are the optimal approaches for integrating AI into scheduling and resource allocation to maximize practice efficiency?
Clinical implementation questions
How can AI diagnostic and treatment planning tools be validated through rigorous clinical trials while maintaining workflow efficiency?
What safeguards and monitoring systems should be implemented when using AI for pain prediction and treatment outcomes?
How can AI tools be optimized to support clinical decision-making while preserving physician judgment and autonomy?
What standards should govern the use of AI in identifying and monitoring patients at risk for opioid misuse?
Ethics, privacy, and legal framework
What specific privacy protection frameworks should be required for AI implementation in pain medicine?
How can transparency in AI decision-making be standardized while maintaining clinical efficiency?
What liability frameworks should be established to address potential errors in AI-assisted pain care?
How should bias in AI systems be monitored, measured, and mitigated in pain medicine applications?
Integration and implementation
What are the essential requirements for seamless integration of AI tools with existing clinical workflows?
How can AI implementation be structured to ensure appropriate physician oversight and control?
What training and support systems are needed to ensure the effective adoption of AI tools in pain practice?
How should ROI be measured and validated for AI implementations in pain medicine?
Quality and safety assurance
What ongoing monitoring systems should be required to ensure AI tool safety and effectiveness?
How can quality metrics be developed and standardized for AI applications in pain medicine?
What processes should govern the regular updating and maintenance of AI systems?
How should patient outcomes be tracked and measured in AI-assisted pain care?
How can AI tools enhance patient education and engagement while maintaining the physician-patient relationship?
Patient experience and engagement
What role should AI play in monitoring and supporting patient adherence to treatment plans?
How can AI facilitate shared decision-making in pain management?
What standards should govern AI-enabled patient communication and monitoring?
Research and development
What research priorities should be established for advancing AI applications in pain medicine?
How can collaboration between clinicians and AI developers be structured to optimize tool development?
What data standards should be established for AI research in pain medicine?
How can real-world evidence be effectively collected and analyzed to improve AI systems?
Education and training

Table 2 (*Continued*)

What competencies should be required for physicians using AI tools in pain practice?
How should CME evolve to address AI implementation in pain medicine?
What role should AI literacy play in pain medicine fellowship training?
How can peer-to-peer learning be facilitated in AI adoption?

AI, artificial intelligence; EHR, electronic health record.

Similarly, technology developers need education in pain medicine's unique challenges and clinical workflows to create more relevant solutions [57,58]. AI technologies can be leveraged to develop educational resources and simulation experiences for both clinicians learning about AI applications and data scientists learning about pain medicine [59], though such approaches should complement rather than replace traditional educational methods.

Emerging best practices

The successful integration of AI in pain medicine requires systematic approaches across several key domains:

Precision pain management

The development of personalized treatment approaches represents a crucial advance in pain medicine. Current implementations leverage reinforcement learning to dynamically adjust behavioral interventions based on patient responses, as demonstrated in AI-augmented CBT delivery [34]. Looking forward, digital twin technology shows particular promise for simulating individual responses to complex interventions like neuromodulation [33]. These applications align with the algorithm development phase outlined in Table 1, emphasizing the need for multimodal data integration and individual response prediction.

Quality assurance

Regular performance audits across diverse patient populations are essential for maintaining AI system reliability. Tools such as IBM's Fairness 360 toolkit (IBM; Armonk, New York, USA) enable systematic assessment of algorithm performance across different groups [23]. This aligns with the validation phase described in Table 1, emphasizing the importance of testing across unique populations.

Continuous system improvement

Healthcare AI systems must evolve with clinical practice. Federated learning approaches enable models to be trained by multiple institutions while avoiding data sharing, preserving privacy [24]. This supports the implementation phase outlined in Table 1, particularly in maintaining compliance with privacy regulations while enabling system improvement.

Challenges and future directions

Regulatory landscape

The pathway to regulatory approval for AI-driven pain management devices remains complex and evolving. Current challenges include undefined Food and Drug Administration clearance processes for novel applications, such as closed-loop neuromodulation systems [51]. Collaborative efforts between industry, academia, and regulatory bodies are needed to establish clear pathways for validating and approving AI technologies in pain medicine.

Educational gaps

Limited AI literacy among clinicians represents a significant barrier to adoption. Comprehensive training programs that balance technical understanding with practical clinical application are needed to bridge this knowledge gap [39].

Scalability and validation

Novel approaches to pain management through AI require rigorous external validation before widespread implementation. Frameworks like the LISA-CPI approach for predicting drug-receptor interactions show initial promise but require extensive validation across diverse populations and settings [14▪].

Technical integration

The integration of AI tools with existing clinical systems presents ongoing challenges. Solutions must seamlessly incorporate into established workflows while maintaining security and performance standards, through such methods as federated learning [24]. This requires close collaboration between technical teams and frontline clinicians throughout the development process.

CONCLUSION

This roadmap provides practical guidance for leveraging AI in pain medicine through strategic adaptation pathways from adjacent fields. By identifying technologies with successful implementation in related specialties and mapping adaptation requirements for pain-specific applications, pain medicine can accelerate the integration of AI tools while addressing the unique challenges of pain assessment and management. The successful development and implementation of AI in pain medicine requires a structured approach balancing innovation, clinical idealism, feasibility, and patient safety. This process demands careful attention to problem definition, algorithm development, validation, and implementation.

Success ultimately hinges on maintaining strong partnerships between clinicians, developers, and researchers throughout the development process [4■,25]. This collaborative approach, guided by robust evidence and ethical principles, will enable AI solutions that meaningfully improve pain assessment and management while maintaining high standards of clinical care.

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Conflicts of interest

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REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:
■ of special interest
■■ of outstanding interest

1. Fontaine D, Vielzeuf V, Genestier P, *et al*; DEFI study group. Artificial intelligence to evaluate postoperative pain based on facial expression recognition. Eur J Pain 2022; 26:1282–1291.
2. ■ Hagedorn JM, George TK, Aiyer R, *et al*. Artificial intelligence and pain medicine: an introduction. J Pain Res 2024; 17:509–518.

This paper provides an introductory framework for understanding AI applications in pain medicine, particularly highlighting predictive modeling for treatment response in neuromodulation therapies, establishing essential terminology and concepts for researchers entering this field.

3. ■■ Antel R, Whitelaw S, Gore G, Ingelmo P. Moving towards the use of artificial intelligence in pain management. Eur J Pain 2025; 29:e4748.

This review offers an analysis of current AI approaches specific to chronic pain management, detailing implementation challenges and providing practical guidance for clinical integration.

4. ■ Bowness JS, Kos S, Wiles MD. Artificial intelligence in healthcare: medical technology or technology medical? Anaesthesia 2025 [Epub ahead of print]

This paper is of special interest for its thoughtful examination of the physician coleadership model in healthcare AI development, emphasizing the critical partnership between clinical and technical expertise.

5. ■ Chang MC. Use of artificial intelligence in the field of pain medicine. World J Clin Cases 2024; 12:236–239.

This work is of special interest for its concise yet thorough analysis of how the multifaceted nature of pain poses unique challenges for AI applications, highlighting the importance of considering subjective patient experiences.

6. Adams MCB, Nelson AM, Narouze S. Daring discourse: artificial intelligence in pain medicine, opportunities and challenges. Reg Anesth Pain Med 2023; 48:439–442.
7. Bowness J, El-Boghdadly K, Burckett-St Laurent D. Artificial intelligence for image interpretation in ultrasound-guided regional anaesthesia. Anaesthesia 2021; 76:602–607.
8. ■■ Bowness JS, Metcalfe D, El-Boghdadly K, *et al*. Artificial intelligence for ultrasound scanning in regional anaesthesia: a scoping review of the evidence from multiple disciplines. Br J Anaesth 2024; 132:1049–1062.

This scoping review provides critical evidence synthesis across disciplines, offering concrete guidance for adapting AI technologies for ultrasound-guided procedures in pain management.

9. Bowness JS, Liu X, Keane PA. Leading in the development, standardised evaluation, and adoption of artificial intelligence in clinical practice: regional anaesthesia as an example. In: Elsevier; 2024.
10. Gabriel RA, Harjai B, Prasad RS, *et al*. Machine learning approach to predicting persistent opioid use following lower extremity joint arthroplasty. Reg Anesth Pain Med 2022; 47:313–319.
11. Simpson S, Zhong W, Mehdipour S, *et al*. Classifying high-risk patients for persistent opioid use after major spine surgery: a machine-learning approach. Anesth Analg 2024; 139:690–699.
12. Salehinejad H, Muaddi H, Ubl DS, *et al*. Deep learning predicts postoperative opioids refills in a multi-institutional cohort of surgical patients. Surgery 2024; 176:246–251.
13. Gitto S, Serpi F, Albano D, *et al*. Ai applications in musculoskeletal imaging: a narrative review. Eur Radiol Exp 2024; 8:22.
14. ■ Yang Y, Qiu Y, Hu J, *et al*. A deep learning framework combining molecular image and protein structural representations identifies candidate drugs for pain. Cell Reports Methods 2024; 4:100865.

This work is of special interest for its novel approach to medication selection through AI integration of molecular imaging and protein structural data, demonstrating potential pathways to personalized analgesic therapy.

15. Adams MCB, Brummett CM, Wandner LD, *et al*. Michigan body map: connecting the NIH HEAL IMPOWR network to the HEAL ecosystem. Pain Med 2023; 24:907–909.

16. Adams MCB, Hassett AL, Clauw DJ, Hurley RW. The NIH HEAL pain common data elements (CDE): A great start but a long way to the finish line. Pain Med 2025; 26:146–155.
17. Adams MCB, Hurley RW, Siddons A, *et al*. NIH HEAL clinical data elements (CDE) implementation: NIH HEAL initiative IMPOWR network IDEA-CC. Pain Med 2023; 24:743–749.
18. Adams MCB, Hurley RW, Topaloglu U. Connecting chronic pain and opioid use disorder clinical trials through data harmonization: Wake forest IMPOWR dissemination, education, and coordination center (IDEA-CC). Subst Use Addctn J 2025; 46:141–145.
19. ■■ Adams MCB, Sward KA, Perkins ML, Hurley RW. Standardizing research methods for opioid dose comparison: the NIH HEAL morphine milligram equivalent calculator. Pain 2025 [Epub ahead of print]

This methodological paper addresses a critical gap in standardization for opioid research, providing a validated tool essential for developing reliable AI applications in opioid management.

20. Hurley RW, Bland KT, Chaskes MD, *et al*. Diagnosis and coding of opioid misuse: a systematic scoping review and implementation framework. Pain Med 2025 [Epub ahead of print]
21. Adams MCB, Bann CM, Bayman EO, *et al*. Building community through data: the value of a researcher driven open science ecosystem. Pain Med 2025 [Epub ahead of print]
22. Adams MCB, Perkins ML, Hudson C, *et al*. Breaking digital health barriers: development and validation of an LLM-based tool for automated OMOP mapping. J Med Internet Res 2025 [Epub ahead of print]
23. Polevikov S. Advancing AI in healthcare: a comprehensive review of best practices. Clin Chim Acta 2023; 548:117519.
24. Aouedi O, Sacco A, Piamrat K, Marchetto G. Handling privacy-sensitive medical data with federated learning: challenges and future directions. IEEE J Biomed Health Inform 2023; 27:790–803.
25. Li RC, Asch SM, Shah NH. Developing a delivery science for artificial intelligence in healthcare. NPJ Digital Med 2020; 3:107.
26. Hussain MI, Nelson AM, Yeung BG, *et al*. How the presentation of patient information and decision-support advisories influences opioid prescribing behavior: a simulation study. J Am Med Inform Assoc 2020; 27:613–620.
27. Ramon-Gonen R, Granovsky Y, Shelly S. Predicting chronic post-traumatic head and neck pain: the role of bedside parameters. Pain 2025; 166:1050–1059.
28. Li J, Du Y, Huang G, *et al*. Constructing a machine learning model for systemic infection after kidney stone surgery based on CT values. Sci Rep 2025; 15:4327.
29. Narayanan S, Ramakrishnan R, Durairaj E, Das A. Artificial intelligence revolutionizing the field of medical education. Cureus 2023; 15:e49604.
30. Karlov M, Abedi A, Khan SS. Rehabilitation exercise quality assessment through supervised contrastive learning with hard and soft negatives. Med Biol Eng Comput 2025; 63:15–28.
31. Scholten HJ, Pourtaherian A, Mihajlovic N, *et al*. Improving needle tip identification during ultrasound-guided procedures in anaesthetic practice. Anaesthesia 2017; 72:889–904.
32. ■ Huo J, Yu Y, Lin W, *et al*. Application of AI in multilevel pain assessment using facial images: systematic review and meta-analysis. J Med Internet Res 2024; 26:e51250.

This paper is of special interest for its comprehensive meta-analysis of AI applications in facial expression-based pain assessment, providing quantitative evidence of effectiveness across various clinical contexts.

33. Bordukova M, Makarov N, Rodriguez-Esteban R, *et al*. Generative artificial intelligence empowers digital twins in drug discovery and clinical trials. Expert Opin Drug Discov 2024; 19:33–42.
34. Piette JD, Newman S, Krein SL, *et al*. Artificial intelligence (AI) to improve chronic pain care: evidence of AI learning. Intelligence-Based Medicine 2022; 6:100064.
35. Gouverneur P, Li F, Shirahama K, *et al*. Explainable artificial intelligence (XAI) in pain research: understanding the role of electrodermal activity for automated pain recognition. Sensors (Basel) 2023; 23:1959.
36. Radanliev P, De Roure D, Maple C, Ani U. Methodology for integrating artificial intelligence in healthcare systems: learning from COVID-19 to prepare for disease X. AI Ethics 2022; 2:623–630.
37. Hussain MI, Nelson AM, Polston G, Zheng K. Improving the design of California's prescription drug monitoring program. JAMIA Open 2019; 2:160–172.
38. Messelink MA, van der Leeuw MS, den Broeder AA, *et al*. Prediction aided tapering in rheumatoid arthritis patients treated with biologicals (PATIO): protocol for a randomized controlled trial. Trials 2022; 23:494.
39. Esmaeilzadeh P. Challenges and strategies for wide-scale artificial intelligence (AI) deployment in healthcare practices: a perspective for healthcare organizations. Artif Intell Med 2024; 151:102861.
40. Aasvang EK, Meyhoff CS. The future of postoperative vital sign monitoring in general wards: Improving patient safety through continuous artificial intelligence-enabled alert formation and reduction. Curr Opin Anaesthesiol 2023; 36:683–690.
41. Chatterjee A, Riegler MA, Ganesh K, Halvorsen P. Stress management with HRV following AI, semantic ontology, genetic algorithm and tree explainer. Sci Rep 2025; 15:5755.
42. Abd-alrazaq A, Alajlani M, Ahmad R, *et al*. The performance of wearable AI in detecting stress among students: systematic review and meta-analysis. J Med Internet Res 2024; 26:e52622.
43. Shrivastava M, Ye L. Neuroimaging and artificial intelligence for assessment of chronic painful temporomandibular disorders-a comprehensive review. Int J Oral Sci 2023; 15:58.
44. Cascella M, Leoni MLG, Shariff MN, Varrassi G. Artificial intelligence-driven diagnostic processes and comprehensive multimodal models in pain medicine. J Pers Med 2024; 14:983.
45. Salama V, Godinich B, Geng Y, *et al*. Artificial intelligence and machine learning in cancer pain: a systematic review. J Pain Symptom Manage 2024; 68:e462–e490.
46. Patel PM, Green M, Tram J, *et al*. Beyond the pain management clinic: The role of AI-integrated remote patient monitoring in chronic disease management - a narrative review. J Pain Res 2024; 17:4223–4237.
47. El-Rashidy N, El-Sappagh S, Islam SMR, *et al*. Mobile health in remote patient monitoring for chronic diseases: principles, trends, and challenges. Diagnostics (Basel) 2021; 11:607.
48. Pan M, Li R, Wei J, *et al*. Application of artificial intelligence in the health management of chronic disease: bibliometric analysis. Front Med (Lausanne) 2024; 11:1506641.
49. ■ Xing Y, Yang K, Lu A, *et al*. Sensors and devices guided by artificial intelligence for personalized pain medicine. Cyborg Bionic Syst 2024; 5:0160.

This work is of special interest for its innovative exploration of sensor integration with AI algorithms for multimodal pain data collection, highlighting emerging technologies that could transform personalized pain assessment.

50. Graafsma J, Murphy RM, van de Garde EMW, *et al*. The use of artificial intelligence to optimize medication alerts generated by clinical decision support systems: a scoping review. J Am Med Inform Assoc 2024; 31:1411–1422.
51. Transforming healthcare: A step-by-step guide to building and deploying AI medical devices. Linkedin. https://www.linkedin.com/pulse/transforming-healthcare-step-by-step-guide-building-ai-conjeti/. [Accessed 02 April 2025] 2025.
52. Labkoff S, Oladimeji B, Kannry J, *et al*. Toward a responsible future: recommendations for AI-enabled clinical decision support. J Am Med Inform Assoc 2024; 31:2730–2739.
53. Ling Kuo RY, Freethy A, Smith J, *et al*. Stakeholder perspectives towards diagnostic artificial intelligence: a co-produced qualitative evidence synthesis. EClinicalMedicine 2024; 71:102555.
54. Vo V, Chen G, Aquino YSJ, *et al*. Multi-stakeholder preferences for the use of artificial intelligence in healthcare: a systematic review and thematic analysis. Soc Sci Med 2023; 338:116357.
55. Rambachan A, Neilands TB, Karliner L, *et al*. Pain management inequities by demographic and geriatric-related variables in older adult inpatients. J Am Geriatr Soc 2024; 72:3000–3010.
56. Mohsin Khan M, Shah N, Shaikh N, *et al*. Towards secure and trusted AI in healthcare: a systematic review of emerging innovations and ethical challenges. Int J Med Inform 2025; 195:105780.
57. Harle CA, Listhaus A, Covarrubias CM, *et al*. Overcoming barriers to implementing patient-reported outcomes in an electronic health record: a case report. J Am Med Inform Assoc 2015; 23:74–79.
58. Adams MC, Denizard-Thompson NM, DiGiacobbe G, *et al*. Designing actionable solutions and curriculum for pain disparities education. Pain Med 2022; 23:288–294.
59. Nanda M, Grant SA. Leveraging artificial intelligence for regional anesthesiology curriculum development. Reg Anesth Pain Med 2024:rapm–2024. doi: 10.1136/rapm-2024-105906.
60. Wang P, Liu H, Xu M. An adaptive testing item selection strategy via a deep reinforcement learning approach. Behav Res Methods 2024; 56:8695–8714.