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Editorial

Artificial intelligence-driven gait analysis in knee osteoarthritis: redefining real-time biomechanical precision for personalized rehabilitation

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Globally, knee osteoarthritis (KOA) is an important contributor to pain, limited mobility, and long-term disability. Conventional assessment methods still primarily rely on radiographic results, subjective complaint reporting, and episodic clinical examination, despite advancements in musculoskeletal rehabilitation. However, the dynamic biomechanical dysfunction that underlies discomfort, instability, and increasing functional loss in people with KOA is often missed by these methods.[1,2]

Rarely do patients explain their disease using radiographic terminology. Rather, many report having trouble getting up from chairs, traveling long distances, ascending stairs, and continuing to participate in social and professional activities. These deficits include intricate changes in neuromuscular control, joint loading, and gait mechanics that may not be sufficiently detected by standard clinical evaluation alone. As a result, it is becoming increasingly clear that objective assessment of movement patterns in real-world settings is necessary for successful rehabilitation.[1]

Gait analysis powered by artificial intelligence (AI) is becoming a game-changing development in the field of rehabilitation. Clinicians can now more accurately measure gait abnormalities outside of traditional motion analysis labs by combining wearable biosensors, inertial measurement units (IMUs), pressure-sensitive insoles, markerless motion capture systems, smartphone-based video analysis, and machine-learning algorithms.[3,6] These technologies enable the examination of spatiotemporal gait characteristics, limb asymmetry, dynamic joint stress, cadence variability, and compensatory movement strategies in outpatient, community, and home-based settings, in a sustainable and ecologically acceptable manner.

Three-dimensional gait laboratories have historically been the gold standard for biomechanical evaluation, but their limited accessibility, high expense, and technical complexity have prevented their widespread use.[1] By enabling portable, real-time movement analysis while maintaining clinically significant biomechanical insights, AI-enabled digital biomechanics overcomes these constraints.

The clinical effectiveness of these systems is significantly improved with the addition of machine learning. Modern algorithms, such as temporal learning models and convolutional neural networks, can detect compensatory techniques and subtle gait abnormalities that may be missed by traditional visual observation. Moreover, the prediction of functional decline, fall risk, and treatment responsiveness may be supported by combining biomechanical data with patient-reported outcomes, imaging biomarkers, and physiological factors.[5] Furthermore, AI should be used as a clinical decision-support tool that enhances rather than replaces expert judgment.

The biomechanical variability of KOA increases the importance of AI-driven gait analysis. Different movement abnormalities, such as quadriceps avoidance gait, increased medial compartment stress, decreased stance stability, changed cadence, and compensatory trunk lean, are often seen in patients with identical radiographic severity.[2,3] Rather than using generic treatment methods, the identification of specific biomechanical phenotypes facilitates the creation of mechanism-based rehabilitation solutions.

Targeted gait retraining, neuromuscular strengthening, balance rehabilitation, orthotic therapies, and graded activity prescription customized to patient-specific functional deficiencies are a few examples of precision rehabilitation techniques. By providing real-time correction feedback that strengthens motor learning and increases adherence during at-home training regimens, wearable biofeedback systems further improve rehabilitation.[4,6] As a result, the goals of rehabilitation change from reducing symptoms to restoring meaningful functional engagement.

Additionally, there is significant potential for early intervention and long-term biomechanical monitoring through AI-enabled gait analytics. It is possible to detect aberrant loading patterns or progressive gait-symmetry deterioration prior to radiological evidence of irreversible structural degeneration.[7] Therefore, proactive rehabilitation treatments in line with precision medicine concepts may be made possible by predictive models that integrate biomechanics and patient-reported function.

Despite these developments, methodological rigor and ethical oversight remain necessary for wider clinical use. Implementation still requires strong multicenter validation studies, open reporting guidelines, and reproducibility across diverse demographics. Sensitivity, specificity, area under the curve (AUC), minimal detectable change (MDC), and test-retest reliability are key performance indicators that should be regularly reported and compared with clinically significant outcomes such as WOMAC scores, return to valued activities, and reduction in compartmental load.[8] In addition, concerns regarding algorithmic bias, interpretability, data governance, and privacy must be carefully addressed. Transparent reporting of dataset demographics and algorithmic decision pathways is essential to mitigate bias and build clinician trust.

Gait analysis and multimodal datasets, such as electromyography, imaging biomarkers, cardiometabolic profiles, and patient-centered functional outcomes, will likely be integrated into musculoskeletal rehabilitation in the future. Adaptive "digital twin" models that continually customize rehabilitation tactics in real time may be made possible by this confluence. Robotics, augmented reality, and closed-loop biofeedback systems are examples of emerging technologies that could broaden the application of precision rehabilitation.

Therefore, AI-driven gait analytics should be viewed as a therapeutically significant advancement in rehabilitation research rather than merely a technological one. Its ultimate value lies in converting movement intelligence into interventions that help people with KOA regain mobility, independence, and quality of life, rather than in producing vast amounts of biomechanical data. The degree to which AI-enabled gait intelligence reinstates freedom and involvement will be the final indicator of success, not the amount of evidence.

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