

Exergames with Embedded Vision Technology: A New Era in Postoperative Orthopaedic Rehabilitation

Ranjith Kumar Yalamanchili, Deepak Kumar Maley and Deepankar Satapathy*

Department of Orthopaedics, All India Institute of Medical Sciences, Bibinagar, Hyderabad, Telangana, India

***Corresponding Author:** Deepankar Satapathy, Department of Orthopaedics, All India Institute of Medical Sciences, Bibinagar, Hyderabad, Telangana, India.

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Abstract

Exergames are interactive exercise programs that merge therapy with gaming and are emerging as a transformative approach in postoperative orthopaedic rehabilitation. By enhancing engagement and enabling remote delivery, exergames address common limitations of adherence seen in conventional home-based programs. Recent advances in embedded computer vision have further elevated their clinical utility by enabling marker-less motion tracking, real-time feedback, and automated assessment of joint kinematics, while maintaining outcomes comparable to standard physiotherapy in select case scenarios. Depth sensors and monocular pose estimation allow objective measurement of range of motion, repetition counting, and movement quality, while clinician dashboards facilitate remote monitoring, adherence auditing, and data-driven progression decisions. Tailoring exergame design to specific populations, particularly older adults, further enhances usability, engagement, and safety. Embedded vision platforms offer unique capabilities, including automated kinematic analytics, corrective biofeedback, and potential integration with pain or gait monitoring, positioning them as more than passive digital tools. While promising, challenges such as data privacy, security, rigorous clinical validation, and integration into standard care pathways remain. Future development should focus on home-based, non-critical rehabilitation programs, incorporating EMG feedback, patient and clinician dashboards, and scalable AI-driven analytics. Cross-disciplinary trials, open benchmarking datasets, and implementation studies are essential to optimize efficacy, safety, and accessibility. Exergames with embedded vision have the potential to redefine postoperative orthopaedic rehabilitation, providing scalable, measurable, and engaging therapeutic solutions that enhance patient outcomes while reducing dependence on in-person supervision.

Keywords: Exergames; Embedded Vision; Assistive Technology in Orthopaedics; Postoperative Rehabilitation; Marker-Less Motion Tracking

Exergames are interactive exercise programs that combine therapy with gaming, improving compliance by boosting engagement and allowing remote delivery of rehabilitation. Exergames that leverage embedded computer vision are poised to redefine postoperative orthopaedic rehabilitation with marker-less motion tracking, while maintaining outcomes comparable to conventional physiotherapy in few case scenarios [1-3]. Systematic reviews and trials have shown exergames and telerehabilitation to be feasible and, in many contexts, non-inferior to standard care, although earlier studies have often been heterogeneous and limited by small samples or off-the-shelf games not designed for therapy [4].

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The introduction of depth sensors and monocular pose estimation has transformed exergames from entertainment into clinically plausible rehabilitation tools, enabling real-time biofeedback, objective range-of-motion analytics, and remote adherence monitoring [4,5]. These systems close the gap between clinic-based supervision and home exercise by translating therapeutic tasks into game mechanics that incorporate set targets while improving attention and motivation. Such embedded vision allows scalable Artificial Intelligence based monitoring, shifting routine in-person visits to more patient centric bio feedback to doctors via a central dashboard [6,7].

In arthroscopic shoulder rehabilitation, a multicenter randomized trial demonstrated that exergame-based protocols achieved outcomes comparable to standard physiotherapy over 12 weeks, supporting their safe use in straightforward recoveries [1]. Similarly, in lower-limb surgery, home-based exergaming after total knee replacement has been linked to better early mobility (Timed Up and Go test) and higher patient satisfaction than standard unsupervised home exercise, suggesting advantages for adherence-sensitive outcomes in the early postoperative period [2,7]. While the biomechanical strength of the fixation device largely determines the rehabilitation strategy after surgery for articular fractures, patient motivation in rehabilitation plays an important role in promoting early recovery [8]. Ringgenberg, *et al.* showed that tailoring exergame design to the specific needs of older adults through usability adaptations and feedback can improve acceptance, safety, and long-term engagement in rehabilitation [9].

Why embedded vision matters?

Exergames with embedded vision offer key capabilities that conventional home programs lack. Marker-less motion capture enables precise joint angle estimation and repetition counting, while real-time feedback corrects compensations that undermine efficacy [7]. Clinician dashboards translate these raw kinematics into interpretable metrics like range of motion end points, speed of movement and can support remote progression decisions and adherence audits. In the future, integrating facial expression analysis could also provide useful insights into patient pain during sessions. These features position exergames as more than passive digital tools, offering dynamic, data driven rehabilitation that not only reinforces motor learning but also enhances safety, personalization, and patient engagement in postoperative care [10].

Dimension	Conventional Physiotherapy	Sensor-based Exergames	Embedded Vision Exergames
Hardware requirement	Clinic-based equipment	Sensors/depth cameras	Standard camera device
Objective measurement	Therapist assessment	Limited (sensor-driven)	Automated pose estimation
Patient engagement	Moderate	High	High
Scalability	Low-moderate	Moderate	High
Cost-effectiveness	Variable	Moderate	High (device-agnostic)

Table: Comparison of technology based rehabilitation approaches from conventional approach.

Future implementations: Upcoming technology on Visual Embedded exergames platforms should be designed to support non-critical, home-based rehabilitation programs requiring daily therapy, such as peri-arthritis shoulder or post-surgical rehabilitation after the initial phase of personalized sessions. These systems must integrate with clinician-accessible dashboards that can generate automatic alerts for both patients and clinicians regarding compliance or difficulty in performing prescribed activities, while maintaining regular audit trails. In parallel, patient dashboards should allow individuals to track their progress and monitor achievement of therapy goals. Incorporating EMG-based biofeedback to distinguish whether pain or a mechanical block is limiting range endpoints would also be highly valuable in providing user a real time feedback mechanism. For certain geriatric patients, monitoring recovery with gait analysis and fall detection using embedded vision technology could be a game changer [11].

Challenges: Camera-based systems handle sensitive data such as video recordings, posing security risks that require stronger encryption and on-device processing. New technologies in this field must be rigorously validated across diverse clinical scenarios and strictly adhere to patient safety standards.

The confluence of exergames and embedded vision is not a speculative future; it is an actionable opportunity to redesign postoperative orthopaedic rehabilitation around engagement, objective measurement, and scalable clinician oversight [12]. To realize this promise we need (a) cross-disciplinary clinical trials that combine therapeutic game design with validated vision algorithms and economic endpoints, (b) open benchmarking datasets from postoperative orthopaedic cohorts to accelerate algorithm validation, and (c) implementation studies focused on equity, workflow integration, and regulatory compliance [13]. When pursued carefully, exergames with embedded vision can move us toward rehabilitation that is cheaper, more engaging, more measurable, and ultimately more effective for our patients.

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