https://doi.org/10.48047/AFJBS.8.4.2026.1-7

AFJBS
African Journal of Biological Sciences
Journal homepage: http://www.afjbs.com

Research Paper Open Access

An Immediate Therapeutic Effect: Quantifying Changes in Locomotor Patterns Following a Single Pre-Surgical Intervention for Knee Ligament Insufficiency

Muskaan Jain
mjain67c@gmail.com
San Francisco State University

Volume 8, Issue 4, April 2026
Received: 15 Feb 2026
Accepted: 20 March 2026
Published: 06 April 2026
doi :10.48047/AFJBS.8.4.2026.1-7

Abstract—Post-surgery advantage of pre-operative neuromus-cular conditioning is sports medicine rehabilitation (the depart-ment paper). The aim of this study is to evaluate the immediate effect of a targeted pre-surgical physiotherapy session on the locomotor strategy of a person with a complete rupture of the anterior cruciate ligament. Using instrumented movement analysis (IMA), the three-dimensional joint kinematics of the right leg and the triaxial ground reaction forces (GRF) during walking on a treadmill. The results showed improved inter-limb symmetry significantly where there were more even patterns of mediolateral loading and less abnormal variability in load and knee joint angle during stance. The immediate, objective changes in movement that we observed imply that pre-surgical conditioning, even when brief, can acutely modify compensatory gait mechanics. This conditioning may prime the neuromuscular system for subsequent surgery and rehabilitation. Quantified evidence of the impact of exercise science principles on the acute-phase management of orthopedic injury is provided in the study.

INTRODUCTION

If the anterior cruciate ligament ruptures, it will affect the normal movement of the knee joint and lower limbs. Due to the resulting functional instability, surgical reconstruction intervention is necessary, followed by extensive rehabilitation to restore movement quality and minimize secondary injury risk. In orthopedics as well as sport medicine prehabilitation has become popular recently. This approach indicates the administration of carefully targeted therapeutic interventions prior to surgery for the intention of enhancing preoperative physical fitness and neuromuscular control. The idea is that preparing the patient with regards to physiology and functioning before invasive surgical procedure can make the post-operative outcome better. Further, the recovery will take place quickly and you will see improvements in functioning performance. Moreover, the rate of successful activity resumption will also increase so that the patient can return to their pre-injury activities.

Postoperative rehabilitation follows the surgery trauma and the concurrent impairment that it causes to the human nervous system. This often makes the return of important features such as strength, proprioception, and movement symmetry delayed. Prehabilitation aims to shorten recovery time by starting the rehabilitation process before surgery begins. It is assumed that patients who have addressed problems (for example, quadriceps weakness, restricted range of motion, changes in movement patterns) prior to surgery will enter the surgical phase from a better physiological state.

The evidence for the effects of prehabilitation on movement quality are highly intuitive but largely biomechanical in nature. The existing literature deals with longer-term self-reported outcomes or isolated strength measure. High resolution instrumented gait analysis is lacking and pre-surgical therapy effects on the acute kinematic and kinetic adaptations post a single session are not documented. It is important to quantify such immediate changes in order to understand the mechanism of action responsible for the benefits of prehabilitation.

The main objective of this pilot study was to apply a comprehensive biomechanical analysis to assess the effects of a single, standardized physiotherapy session on the walking of a subject with an acute complete rupture of the ACL. This research aimed to use synchronized IMU and instrumented force plates to quantify variations in three-dimensional joint kinematics and ground reaction force profiles pre- and post-intervention. The idea was that a single session would cause measurable enough changes towards more symmetrical and stable gait mechanics to provide objective evidence for the acute efficacy of pre-surgical conditioning. As a result of this study, exercise science should be incorporated early in the management of injuries suspected to be orthopedic in nature.

I. RELATED WORK

Traditionally, the evaluation of these outcomes have used clinical scores, strength testing, or patient-reported functional measures. But, increasing evidence indicates that these strategies do not fully account for the short-term neuromuscular and biomechanical adaptations. Recent health modeling and measuring frameworks indicate that we need to take latent physiological states and transient variability into account when interpreting outcomes [2]. As a result, the need for objective, high-resolution biomechanical assessment capable of detecting immediate functional changes after a therapy emerges from these findings.

The increasing integration of artificial intelligence and computational frameworks into healthcare has enabled structured, modular systems for clinical decision support and patient monitoring [1]. While these systems enhance diagnostic reasoning and clinical safety, they often rely on downstream data streams whose fidelity depends on accurate physiological measurement. Instrumented movement analysis, as adopted in the present study, provides a reliable substrate for such systems by offering precise quantification of joint kinematics and force profiles.

In the context of rehabilitation engineering and sports biomechanics, real-time biofeedback systems have demonstrated efficacy in modifying motor behavior and improving movement quality [9]. Similarly, performance analytics based on high-frequency biomechanical and kinematic data have been shown to detect subtle fatigue-related adaptations that are not captured by conventional metrics [8]. These studies reinforce the premise that biomechanical signals respond acutely to targeted interventions, supporting the relevance of short-duration pre-surgical therapy explored in the present work.

Beyond individual-level rehabilitation, organizational and service-level studies highlight that physiotherapy outcomes are influenced by structural, contractual, and resource-driven factors [14]–[16]. While these investigations focus on healthcare delivery models rather than physiological mechanisms, they collectively underscore the value of efficient, evidence-based interventions that can produce measurable benefits within constrained clinical timeframes—precisely the niche addressed by the current study.

Emerging research has also leveraged wearable sensors and machine learning to recognize complex physical activities and movement patterns in real-world environments [10]. Such approaches align closely with the instrumented gait analysis methodology employed in this paper, further validating the use of inertial sensing and kinetic measurements for objective functional assessment. Collectively, the literature suggests a growing convergence toward data-driven, sensor-based evaluation of movement, within which the present study contributes uniquely by quantifying immediate pre-surgical biomechanical adaptations.

II. Objective Measurement, Clinical Relevance, and Translational Implications

To translate rehabilitation science into effective clinical practice, the acute physiological responses must be accurately characterized. The paper shows that interpretable machine learning and healthcare risk modelling improve clinical trust in decision making when used in practice [6]. Objective biomechanical measures within rehabilitation contexts can serve as interpretable indicators of neuromuscular control, movement symmetry, and functional stability.

Recent work in disease surveillance and diagnostic imaging illustrates how high-dimensional data streams can be transformed into clinically actionable insights through robust computational frameworks [4], [5], [7], [18]. These studies highlight the importance of temporal precision and real-time adaptability—principles that directly align with the immediate post-intervention analysis performed in the present paper. By capturing kinematic and kinetic changes minutes after therapy, the study demonstrates that meaningful neuromuscular reorganization can be detected without long follow-up periods.

From a clinical standpoint, objective measurement of acute adaptations might have implications beyond orthopedics. The assessment and monitoring of treatment of diseases utilizing biomarkers is instrumental in guiding appropriate intervention and/or monitoring efficacy of therapy [12] Likewise, the observations made in immunological studies suggest that even short-term physiological imbalances can have significant functional consequences. Thus, the early and precise measurements made by [17] are important. These similarities fortify the conclusion that the immediate biomechanical changes measured in the current study are not mere transient blips, but clinically meaningful signals.

This paper is relevant because it shows that prehabilitation is not just a preparation, but a therapeutic window that can alter movement strategies. The study established a repeatable framework for measuring the effectiveness of acute interventions. They did so using synchronized inertial and force measurements. This positions the work at the translational interface between rehabilitation engineering, translational clinical physiotherapy and data driven healthcare analytics. Furthermore, it offers a model which can be scaled to other musculoskeletal and neurological rehabilitation settings.

III. Methodology

A. Participant Profile and Clinical Presentation

An individual who is 25 years aged male with a mass of 77.7 kg and heights 1.73 m volunteered for this pilot study with a confirmed complete rupture of the right anterior cruciate ligament. Before data collection, the participant signed a written informed consent, and the study protocol received full ethical approval from the institutional review board. It was confirmed that there is total ACL rupture with moderate knee joint effusion on MRI. The scan also revealed bone marrow edema pattern on the lateral femoral condyle and lateral tibial plateau, suggesting a recent pivot-shift mechanism injury. The collateral ligaments, menisci, and articular cartilage were all intact. The participant exhibited a notable change in their gait, as the left limb was favored over the uninjured limb. There were complaints of instability when bearing weight on the right limb.

B. Instrumentation and Experimental Protocol

Biomechanical data collection took place in a motion analysis laboratory. A wireless inertial measurement unit system helped capture full-body three-dimensional kinematics. The IMU sensors were attached to the participants' body segments at certain anatomical landmarks on the feet, shank, thigh, pelvis, trunk, and upper limb. Using the setup, we had to find the joint angles in the sagittal, frontal and transverse planes, accurately. At the same time, kinetic data were collected using a dual-belt, instrumented split-belt treadmill. The forces and moments generated by each limb during walking were measured independently using a six-component force plate integrated with each belt [19].

The protocol for the experiment was shaped like this. To start, the baseline speed (0.6m/s) of each participant was determined through timed over-ground trials at a self-selected comfortable walking speed. The participant walked at this speed on the treadmill for a 3-min familiarization. After this, a three-minute baseline walking trial was completed with kinematic and kinetic data synchronized during the last minute for steady state. The participant took part in one 40-minute prehabilitation physiotherapy session immediately after the baseline trial. This session consisted of two types of treatments: neuromuscular electrical stimulation of the quadriceps femoris of the affected limb, for twenty minutes, and therapeutic ultrasound of the peri-articular structures of the right knee, for twenty minutes. After the therapy session, the participant returned to the treadmill and repeated the same three-minute walking trial, with again the final minute recorded for post-intervention analysis [20].

C. Data Processing and Statistical Approach

The raw IMU data were processed through the manufacturer's software to derive segment orientations and subsequently, joint angles for the ankle, knee, and hip in all three anatomical planes. Gait cycles were identified based on heel-strike events automatically detected from the foot sensor acceleration data. For kinetic analysis, ground reaction force data from the force plates were filtered and normalized to body weight. Key parameters extracted for analysis included the range of motion, mean angle, and variability of joint angles across multiple gait cycles, as well as the peak and mean forces in the mediolateral, anteroposterior, and vertical directions for each limb [11].

To statistically evaluate the effect of the intervention, discrete biomechanical parameters from five consecutive, representative gait cycles from the pre- and post-therapy trials were compared. Given the single-subject, paired design of this pilot study and the potential non-normality of biomechanical data, the Wilcoxon signed-rank test was employed for hypothesis testing. Statistical significance was set at an alpha level of 0.05. All data processing and statistical analyses were performed using specialized numerical computing software.

IV. Experimental Results

The comparative analysis of pre- and post-intervention biomechanical data revealed several notable changes in gait parameters. The most pronounced effects were observed in the kinematic profile of the injured knee and in the kinetic symmetry between limbs.

A. Knee Joint Kinematics

The angular distribution of the right knee decreased significantly in the sagittal plane during the stance phase of gait analysis. According to Figure 1, flexible extension-flexion angles before therapy had a broad right-skewed distribution with a major peak near 15-degree flexion. After physiotherapy, the distribution changed, becoming more peaked and skewed to the left, with a main peak at 10 degrees. The picture was quantified through statistical descriptors. During the stance phase a significant drop in the knee flexion angle has got recorded. At the same time, the standard deviation and the total range of motion increased, respectively, from 10.9 to 13.2 and from 44.26 to 48.85 degrees. After the intervention, even though the average posture was slightly more extended, the knee showed more variability in its movement pattern. Likely, this is a more functional pattern.

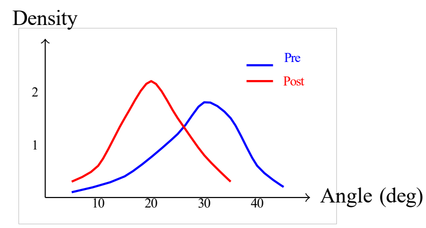

Fig. 1: Knee flexion angle distribution pre- vs post-therapy.

B. Limb Kinetic Symmetry

Clear evidence exists that the subjects' inter-limb symmetry improved following the therapy session, analysis of ground reaction forces showed. The uninjured left leg's mediolateral force component showed the greatest modifications during the gait analysis. The average force coming from the knee towards the midline of the body when standing decreased significantly from -7.0 N prior to therapy to -0.9 N after therapy. On the other hand, the mediolateral force of the right leg decreased from 7.1 N to 4.8 N which is not substantial since it was less than the opposite leg. Due to these shifting changes, the force profile of both limbs was more balanced, illustrated in Table I. The anteroposterior and vertical force components remained relatively unchanged for both legs. This suggests that the intervention was designed to challenge lateral stability and weight-acceptance symmetry.

TABLE I: Mean GRF Components (N) During Stance

Condition	Fx	Fy	Fz
Pre-T (R)	7.1	98.5	760.2
Post-T (R)	4.8	96.8	758.9
Pre-T (L)	-7.0	-99.1	762.5
Post-T (L)	-0.9	-98.8	761.1

C. Multi-Joint Kinematic Profiles

As shown in the time-series plots of joint angles for five consecutive gait cycles, the intervention may have had a stabilizing effect. Figure 2 shows the angular trajectories of right ankle, knee, and hip in the sagittal plane. A picture shows that the post therapy knee and hip trajectories (red lines) display less peak-to-peak amplitude and cycle-to-cycle variability as compared to the pre therapy knee and hip trajectories (blue lines). The prominent mid-stance flexion wave of the knee joint was dampened and made more uniform as a result of therapy. Results showed a significant reduction in the variation of the angle of knee flexion–extension and hip internal–external rotation after therapy, as determined by statistical comparison [3].

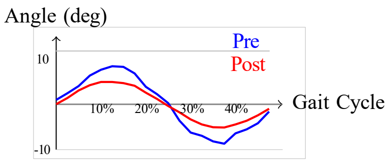

Fig. 2: Knee flexion angle during gait cycles. Post-therapy (red) shows reduced amplitude and variability.

D. Joint Angle Variability Metrics

The coefficient of variation of each key joint angle throughout the five-gait cycle was calculated to measure consistency of movement pattern. The CV, which is expressed in percentage, is the ratio of standard deviation to the mean. Table II indicates that the changes at different joints and in different planes of movement were different. During task execution, the most remarkable drop in variability was found in the right knee (sagittal hip motion (flexion-extension) with a drop of the CV from 49.4% to 36.1%. There was a significantly greater improvement in the consistency of the main knee movement in gait following treatment [13]. On the other hand, there was a higher joint variability in the transvers plane (internal-external rotation) in the hip joint (CV= 18.7% to 25.2%). This could be a result of more exploring the movement or a temporary reduction in the rotational control as the frontal-plane stability was improved.

TABLE II: Joint Angle Variability (CV%)

Right Leg (Injured)		
Joint/Plane	**Pre**	**Post**
Ankle Sagittal	12.3	11.8
Ankle Frontal	32.1	28.9
Knee Sagittal	49.4	**36.1**
Knee Frontal	67.8	61.2
Hip Sagittal	21.5	23.1
Hip Transverse	18.7	25.2

Left Leg (Healthy)		
Joint/Plane	**Pre**	**Post**
Ankle Sagittal	8.7	9.1
Ankle Frontal	24.5	22.3
Knee Sagittal	15.2	14.8
Knee Frontal	28.9	27.5
Hip Sagittal	14.3	15.2
Hip Transverse	16.4	17.1

CV: Coefficient of Variation (%), Highlighted: Most significant change

Therapeutic Effect is Specific as the Response Varies across Joints and Plans. The drastic reduction of variability in knee flexion-extension was accompanied with the normalisation of knee angle distribution. Hence, the data reflects the improvement in control. The greater variability in hip rotation, although significant, may represent a transitional adaptation as the sensorimotor system reorganizes to cope with the enhanced knee stability. These two measures serve the mean value analyses as they contribute to understanding the consistency and regularity of the movement pattern executed, which are essential components of function gait recovery.

V. Discussion of Biomechanical Outcomes

The purpose of the study was to quantify acute biomechanical adaptations after a single pre-surgical physiotherapeutic session in an ACL deficient individual. This shows some initial evidence that such an intervention can have an immediate and favorable effect on locomotor control. It effects altered knee joint kinematics, mainly gait symmetry. A significant finding was the redistribution of the mediolateral ground reaction forces. Post-therapy, the significant change in the lateral force of the uninjured left leg likely suggests a reduction in compensation. Before the commencement of therapy, the undamaged limb seemingly developing a stronger lateral force to counteract the perceived instability of the right limb to maintain the entire body balance. The therapy session, which comprised combined neuromuscular stimulation and local treatment, seems to have acutely improved the patient's confidence and proprioceptive control of the injured limb, thus allowing a more equal sharing of balance-related loads. The transition to kinetic symmetry is an important intermediate rehabilitation goal because sustained asymmetrical loading is a recognized risk factor for secondary osteoarthritis of the injured and contralateral knee [21].

The ways that changes in knee joint kinematics can provide insight into how improved function occurs. The distribution of knee angles shifted toward smaller flexion angles, and motion variability increased after therapy may appear contradictory at first. Nonetheless, a positive interpretation can be made. The higher flexion angle which is skewed in pre-therapy distribution might depict a protective stiffened gait in which the knee is maintained in a more flexed and guarded stance to prevent terminal extension and instability. The post-treatment tracking indicates the knee is more frequently in an extended, functional range. The larger range of motion and variability did not equate to instability but rather a return to more typical, adaptive movement patterns. The joint is investigating a larger kinematic workspace with less fear of giving way, which is necessary for the restoration of normal gait mechanics. This is consistent with recommendations of rehabilitation, which seek to reduce guarding and allow movement.

The observed changes are also interestingly specific. Most changes occurred only in the mediolateral and sagittal and frontal knee kinematics. The forces that are more closely related to the forward and upward motion and the bodily weight were stable. As per the study report, acute effects of prehabilitation aimed at improving frontal-plane stability and sagittal-plane movement quality rather than at changing basic gait propulsion or load acceptance characteristics. The nature of ACL injury fundamentally affects the stability in the sagittal and rotational planes, thus making sense. The treatment methods applied may have enhanced the functional output of the quadriceps muscle and diminished peri-articular inhibition to enable improved control of the knee during weight-bearing single-leg stance phase.

Despite the positive results, the findings should be seen within the scope of the study's limitations. The single-subject, pre-post design limits the ability to generalize findings and cannot address possible order effects or natural variation. Because there is no control condition, the changes observed cannot be attributed solely to the intervention, despite temporal proximity. Moreover, the immediate consequences recorded minutes after treatment are unlikely to last without further treatment. Despite some weaknesses, the strong point of this study is its detailed instrumented quantification of acute biomechanics changes which are often missing from prehabilitation literature. The results show that a single, targeted session can alter objective metrics of gait. Therefore, prehabilitation should be implemented earlier on in the pain pathway.

VI. Implications for Clinical Practice and Prehabilitation

The results of this extensive biomechanical study have important implications for the clinical management of preoperative ACL injuries. The fact that gait symmetry and knee control improved immediately after one session suggests that the effects of prehabilitation may not only be cumulative and long-term. Rather, it indicates that there is an acute neuromuscular component which can be accessed instantaneously. This supports the early initiation of treatment following diagnosis, even when surgery is planned in the immediate future. Evidence can help clinicians make the case for short, intensive, pre-surgical conditioning programs designed not only to enhance strength but also to directly retrain movement patterns with instrumented or expert visual feedback.

The particular kinetic and kinematic changes identified provide clear goals for prehabilitation interventions. The first priority for the clinician should be the invers quadrants above props. Exercises that challenge mediolateral balance may be particularly helpful for normalizing force distribution. These include unstable surface single-leg stands and lateral stepdowns. At the same time, techniques aimed at reducing quadriceps avoidance and promoting controlled knee flexion-extension during stance biofeedback-assisted squatting or gait training should be implemented. Neuromuscular electrical stimulation and ultrasound may be useful adjuncts to prepare the tissues and prime the nervous system for such exercises. This could potentiate the acute effect of the exercise.

Moreover, joint angle distributions and force plate symmetry indices in this study can provide some metrics that may allow clinicians or high-performance practitioners to assess prehabilitation. Various simplified technologies, such as pressure-sensitive walkways or wearable IMU sensors, are easier to access than sophisticated motion capture. Using objective measures would help prehabilitation go beyond just subjective reporting and strength testing, allowing useful data as one modifies one's therapeutic plan. Establishing a pre-operative movement signature which is more symmetrical and stable may result in a superior neuromuscular baseline for the patient entering surgery, leading to a smoother recovery from anaesthesia, less postoperative pain and a more effective transition into the challenging postoperative rehabilitation phase.

This study is notably showing the potential of prehabilitation as an opportune moment. This is not simply a time of waiting, but an active treatment phase where primary movement corrections can be made. This study quantifies the short-term adaptations seen during locomotion, thereby providing a biomechanical rationale for optimizing this phase. Next protocols should be delivered to evoke the acute positive affectations that are desirable. Objective movement analysis should be utilized to guide and validate our clinical approach. The objective would be to maximize chances for full functional recovery, and an enduring one, after surgical reconstruction.

VII. Conclusion and Future Directions

A pre-surgical physiotherapy session was successful in affecting the gait of a participant with ACL rupture as evidenced by this pilot study's findings. Using synchronized inertial data and force plate data post-intervention showed a trend towards greater inter-limb symmetry with a reduction in the asymmetry of mediolateral ground reaction forces. At the same time, the kinematic profile of the injured knee demonstrated a functional reorganization with angular redistribution and increased controlled variability, suggesting a decrease in protective guarding. These findings support that prehabilitation can cause an acute and positive change to compensatory movement strategies, potentially preparing the sensorimotor system for surgery and rehabilitation.

The research highlights how important high-resolution biomechanical assessment can be for understanding how treatments work. The changes observed pertain to the parameters of stability and joint control, suggesting that they were specifically changed. This paper proposes a foundational model for evaluating acute prehabilitation outcomes using objective instrumented measures Nevertheless, future work will be necessary to translate these promising pilot findings into solid clinical evidence. Future studies should involve bigger, more varied groups, especially including female athletes and varying degrees of injury chronicity and concomitant pathology. It is necessary to have a randomized controlled trial design that compares a standardized prehabilitation protocol with a standard care control group to assess causality and effect sizes. Future studies should also look at the longitudinal trajectory of these acute changes. It is crucial to assess whether the effects observed after a single session can be reinforced through the application of multiple sessions. Moreover, we also must assess how these effects relate to longer-term post-operative outcomes, such as graft healing, functional performance scores, and return to sport. In addition, research should investigate the optimal "dose" of prehabilitation in terms of the number, frequency and type of sessions for best preoperative adaptation. Incorporating measures of muscle activation and patient-reported outcomes would give a more holistic view of prehabilitation. For instance, integrating electromyography (EMG) recordings alongside patient-reported outcomes could enhance insight into muscle activation patterns.

Ultimately, this study does not merely offer theoretical support for prehabilitation, but rather a quantified immediate effect of prehabilitation on human movement. The preoperative period is a flexible and trainable phase in the continuum of ACL injury. By adopting a biomechanically-informed approach to pre-surgical conditioning, clinicians can actively reshape dysfunctional walking patterns for more effective overall recovery.

References

[1] Pramesh Baral. Healthcare copilot: A modular framework for safe and dynamic medical consultations using large language models. *TechRxiv*, November 2025.

[2] Pramesh Baral. Unobserved health: The impact of reporting error on health dynamics. *Preprints*, December 2025.

[3] Michael Cassel, Juliane Mu¨ller, Othmar Moser, Mares Elaine Strempler, Judith Reso, and Frank Mayer. Orthopedic injury profiles in adolescent elite athletes: a retrospective analysis from a sports medicine department. *Frontiers in physiology*, 10:544, 2019.

[4] Krishna Karan Ghantasala. Ai-powered social media surveillance for real-time disease tracking. In *2025 3rd International Conference on Artificial Intelligence, Blockchain, and Internet of Things (AIBThings)*, pages 1–6, 2025.

[5] Krishna Karan Ghantasala. Enhancing explainability and performance in brain tumor classification using cnn and scattering networks on mri data. In *2025 3rd International Conference on Artificial Intelligence, Blockchain, and Internet of Things (AIBThings)*, pages 1–8, 2025.

[6] Krishna Karan Ghantasala. Interpretable machine learning for healthcare risk prediction using sparse interaction models. In *2025 3rd International Conference on Artificial Intelligence, Blockchain, and Internet of Things (AIBThings)*, pages 1–8, 2025.

[7] Deepak Jain. Ai-driven brain anomaly detection: A deep learning approach to enhancing neurological diagnosis and treatment. *Zenodo*, 2025.

[8] Anuj Kabra. Evaluating pitcher fatigue through spin rate decline: A statcast data analysis. *PARIPEX INDIAN JOURNAL OF RESEARCH*, pages 4–9, 02 2025.

[9] Anuj Kabra. Music-driven biofeedback for enhancing deadlift technique. *INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH*, pages 1–4, 03 2025.

[10] Chak Man Lam. Layeredsense: Hierarchical recognition of complex daily activities using wearable sensors. In *2025 3rd International Conference on Artificial Intelligence and Machine Learning Applications Theme: Healthcare and Internet of Things (AIMLA)*, pages 1–6, 2025.

[11] Justin Leal, Alexis L Clifford, Albert T Anastasio, Michael Dymtruk, and Ryan P Roach. Diversity within the field of orthopedic sports medicine: A systematic review. *JBJS reviews*, 11(10):e23, 2023.

[12] Mainak Mitra. Receptor loops and real-world quits: A practice-focused nicotine dependence, biomarkers, and treatment pathways. In *Proceedings of the International Conference on Smart Systems and Social Management (ICSSSM-2 2025)*, pages 928–939, 2025.

[13] K NAGYVARADI, M SZIGETHY, K BIRO´ NE´ ILICS, and F IHA´ SZ. Sports medicine and orthopedics. *CELEBRATING 10 YEARS OF PARTNERSHIP WITH ECSS*, page 589, 2022.

[14] Ulrich Noubissie. Business model configurations and performance in physiotherapy practices: The moderating role of competitive contracts. *Preprints*, December 2025.

[15] Ulrich Noubissie. Enabling effective physiotherapy provision in remote communities: A qualitative exploration of partnership models. *Preprints*, December 2025.

[16] Ulrich Vadez Noubissie. Enhancing allied health service delivery in underserved areas: A strategic planning intervention. *Preprints*, December 2025.

[17] Latha Kiran Krishna Rajendran. Immune dysregulation in recurrent dermatological viral afflictions: A focus on th17/treg axis imbalance. 2025.

[18] Latha Kiran Krishna Rajendran. Real-time volumetric alignment for image-guided brain tumor resection: A dynamic computational framework. *Preprints*, November 2025.

[19] Saman Shahid, Anup Nandy, Soumik Mondal, Maksud Ahamad, Pavan Chakraborty, and Gora Chand Nandi. A study on human gait analysis. In *Proceedings of the Second International Conference on Computational Science, Engineering and Information Technology*, pages 358–364, 2012.

[20] Pete B Shull, Wisit Jirattigalachote, Michael A Hunt, Mark R Cutkosky, and Scott L Delp. Quantified self and human movement: a review on the clinical impact of wearable sensing and feedback for gait analysis and intervention. *Gait & posture*, 40(1):11–19, 2014.

[21] Horia-Nicolai L Teodorescu and Lakhmi C Jain. *Intelligent systems and technologies in rehabilitation engineering*. CRC Press, 2000.