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Article

XClinic Sensors: Validating Accuracy in Measuring Range of Motion Across Trauma Conditions

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Abstract: Background: Accidents and injuries are major causes of chronic disability, leading to a loss of healthy years. Accurate assessment is essential for planning personalized rehabilitation programs. In recent years, wearable sensors have been introduced into research for motion analysis. This study aimed to validate the Xclinic wearable sensors for ROM assessment in patients with trauma. Methods: Participants were recruited from the Sapienza University of Rome (September 2023–November 2024) after road accident trauma. The active ROM of the hip, knee, and ankle was assessed bilaterally based on the injury. The SF-36 and other specific tools were also administered. Construct validity was tested using Pearson's correlation coefficient. Results: A total of 44 participants (mean age 42.7 ± 17.3 years, 69% male) were included. Item-by-item analysis revealed significant correlations, with notable findings related to other outcome measures. Conclusions: The correlation between joint restrictions, functional impairment, and psychosocial factors highlights the need to integrate physical and psychological care into rehabilitation. Further research is needed to refine assessment tools to improve patients' quality of life.

Keywords: trauma injuries; inertial sensors; range of motion; Xclinic; psychometric properties

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1. Background

Accidents and injuries are among the primary causes of long-term disability, particularly in younger individuals, significantly reducing their quality of life and productivity. Road traffic accidents, in particular, represent a critical global health challenge [1–4]; Peeters et al., 2015 [5]. According to the World Health Organization (WHO), these incidents are the leading cause of death among individuals aged 5–29 years, and millions of survivors face lifelong disabilities. Non-fatal injuries, including fractures, spinal cord damage, and traumatic brain injuries, often lead to complex physical, psychological, and social challenges [6–8]. These outcomes not only affect individuals' quality of life but also impose considerable economic and social burdens, emphasizing the importance of effective rehabilitation strategies [5,9–12].

Musculoskeletal impairments, such as reduced joint mobility, loss of strength, and impaired coordination, are common consequences of road traffic injury. Accurate assessment of these functional deficits is essential for guiding and optimizing rehabilitation interventions. While traditional evaluation methods remain widely used, they may lack the precision required to detect subtle changes or comprehensively assess the severity of impairments [13–15]. This highlights the increasing importance of advanced instrumental assessments in rehabilitation, which provide objective, reproducible, and detailed information. These tools enable clinicians to make evidence-based decisions and design personalized treatment plans, which are particularly valuable for addressing the complex recovery needs of road traffic injury survivors [16,17].

XClinic sensors, developed by Ferrox, represent an innovative tool for enhancing rehabilitation assessments. These sensors are specifically designed to capture accurate measurements of joint Range of Motion (ROM), a key indicator for evaluating functional recovery in individuals with musculoskeletal trauma ("Riabilitazione digitale per centri di fisioterapia–Ferrox", n.d.). Their application in both clinical practice and research has demonstrated promising results in improving the precision of rehabilitation planning. Notably, the reliability and validity of the XClinic sensors were established in a 2024 study by Galeoto et al. on healthy subjects. This prior validation supports their credibility as measurement instruments. Moreover, the article detailing this initial validation provides a comprehensive description of the sensor's usage and application methods, serving as a reference for its correct implementation in both research and clinical settings [18–21].

Nevertheless, further investigation is essential to confirm their performance in populations recovering from traumatic injuries, especially considering the high incidence of trauma resulting from road traffic accidents. Given the prevalence of such injuries, objective assessment is crucial to ensure that patients receive appropriate rehabilitation tailored to their specific needs. Validating the sensors in this context would support their use in accurately evaluating joint impairments, ultimately contributing to more effective and personalized rehabilitation interventions.

Objective

This study aimed to validate the reliability and accuracy of XClinic sensors (Software Version 10) in measuring the range of motion (ROM) of lower limb joints in individuals with trauma injuries, ensuring their applicability for objective assessment.

2. Methods

The study was conducted by a research group of Sapienza University of Rome named "Riabilitazione Evidenze e Sviluppo (RES)", which was involved in different studies on rehabilitation [22–25]. The methods are illustrated in Figure 1.

2.1. Participants

The study was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. Participants in this cross-sectional study were enrolled at the Sapienza University of Rome between September 2023 and February 2024.

All participants had to be injured in a road accident and aged between 18 and 80 years. Finally, only participants who provided informed consent were included. The exclusion criteria were as follows: surgery for other reasons in the last year, neurological or cardiopulmonary diseases, pregnancy, and psychiatric conditions. Finally, all participants provided informed consent to participate in the study [26,27]. The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Lazio Area 1, Policlinico Umberto I (protocol code 0969/2024 and date of approval 7 November 2024).

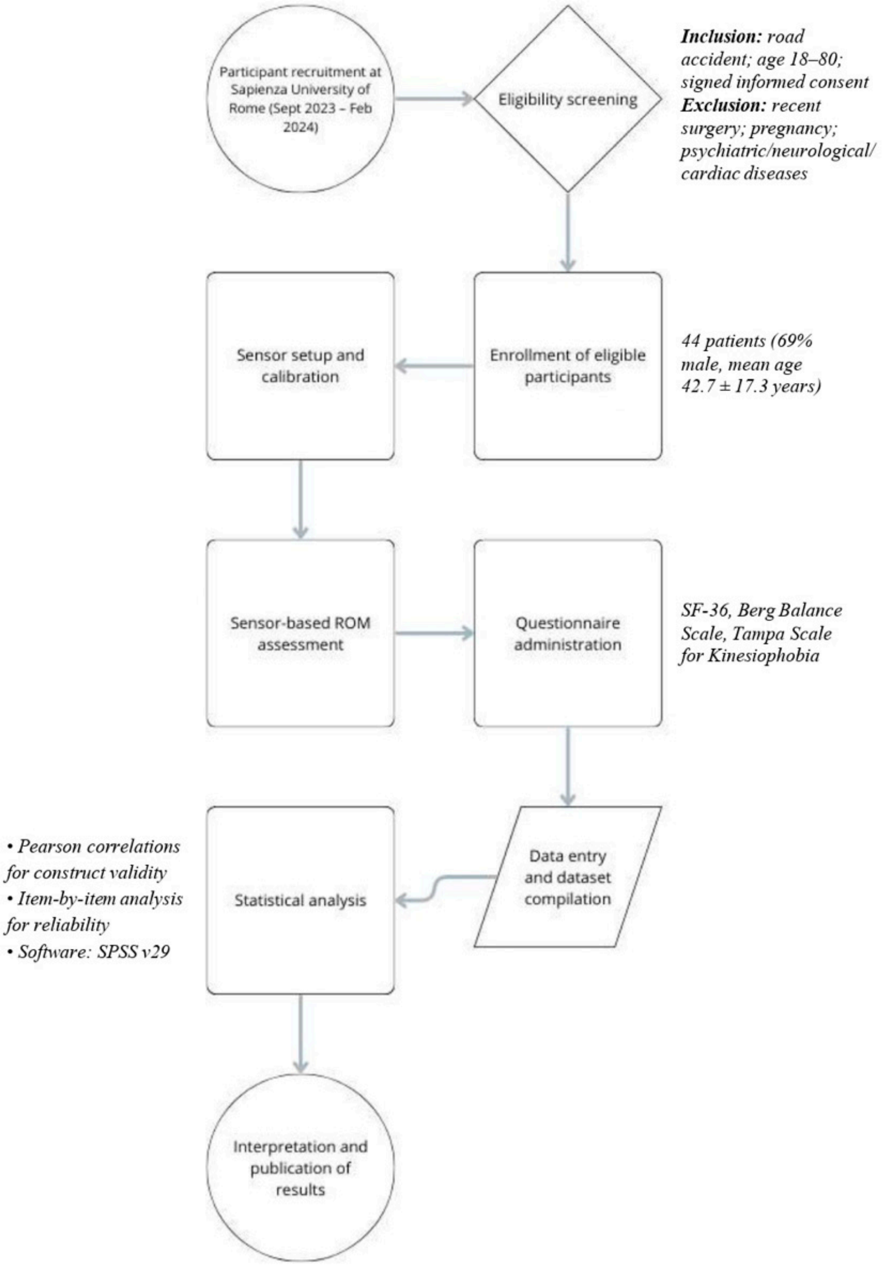

Figure 1. Experimental workflow of the study protocol.

2.2. Data Collection

All subjects were tested to assess the active Range of Motion (ROM) of the lower limb relative to the injured joint and the contralateral joint: hip, knee, and ankle bilaterally. For each joint, specific movements were tested using XClinic sensors (Software Version 10), a tool validated in 2024 by Galeoto et al. on healthy subjects, which has already demonstrated its reliability and validity [18]:

- Hip: flexion (with a flexed knee), extension, abduction, adduction, internal rotation, and external rotation.
- Knee: flexion and extension.

- Ankle: plantar flexion, dorsiflexion, inversion, and eversion.

In addition to ROM assessment, the Short Form Health Survey 36 (SF-36), Berg Balance Scale, and Tampa Scale for Kinesiophobia questionnaires were administered to the participants to investigate construct validity [28–30].

Three physiotherapists performed the ROM assessment and administered the questionnaires. Data were collected using an Excel Dataset.

2.3. Evaluation Using Sensors

The XClinic sensors used in this study are wearable inertial measurement units (IMUs) developed by Ferrox. Each device includes a triaxial accelerometer, a gyroscope, and a magnetometer, allowing it to capture three-dimensional movement with good precision. The sensors operate with a fixed sampling frequency of 100 Hz and use a sensor fusion algorithm to calculate the joint angles in real time, expressed as Euler angles. Data are transmitted wirelessly to a tablet through a dedicated app, which displays and stores the information. The system is designed to be user-friendly and suitable for clinical use, and its measurement range covers the typical joint movements observed in rehabilitation settings. These features make the sensors a reliable and practical option for assessing ROM outside laboratory environments [18].

The XClinic kit included two wearable sensors, a charging device, adjustable straps and bands to secure the sensors to the body, instructional materials, and a tablet with the XClinic app installed, which served as the user interface.

Before each assessment, the researchers carefully unpacked the sensors and related equipment and verified the presence of user manuals or quick-start guides. The sensors were then powered and charged to ensure that they were ready for use. Following the manufacturer's instructions, the devices were connected to a local Wi-Fi network to enable data transmission.

To accurately capture joint movements, the sensors were placed on the upper and lower segments of the joint under examination, ensuring that the positioning aligned with the guidelines provided by Ferrox. The software was then used to configure and calibrate the sensors to guarantee precise measurements. For each participant, a new user account was created within the app, allowing individualized data tracking. Once all steps were completed, the assessment of the range of motion (ROM) began, with the software recording the data in real time ("Riabilitazione digitale per centri di fisioterapia–Ferrox", n.d.). The joint angle estimation is based on XClinic's proprietary algorithm, which uses a sensor fusion process to integrate data from the accelerometer, gyroscope, and magnetometer. This built-in algorithm calculates the angular displacement in real time and provides direct measurements of the joint range of motion. The algorithm has been previously validated in a healthy population and showed good agreement with goniometric measurements [18].

Figures 2–5 show the positioning of the sensors for the assessment of the shoulder, hip, knee, and ankle range of motion. For each joint, the sensors were placed as follows: on the thorax and wrist for the shoulder, on the thorax and thigh for the hip, on the thigh and lower leg for the knee, and on the lower leg and foot for the ankle.

2.4. Statistical Analyses

SPSS Statistics version 29 was used for the statistical analyses. Demographic characteristics were calculated as mean ± SD or percentage, where appropriate.

Internal consistency (reliability) was calculated using item-by-item analyses for each assessed movement. Construct validity was estimated using Pearson's correlation between XClinic measurements and the Short Form Health Survey 36 (SF-36), Berg Balance Scale, and Tampa Scale for Kinesiophobia.

Methods followed the "COnsensus-based Standards for the selection of health Measurement Instruments" (COSMIN) [31].

Figure 2. Sensor placement—Shoulder.

Figure 3. Sensor placement—Hip.

Figure 4. Sensor placement—Knee.

Figure 5. Sensor placement—Ankle.

3. Results

3.1. Characteristics of the Sample

A total of 44 patients were recruited, all of whom had experienced an incident listed in a specific table table. The majority of these patients were men, representing 69% of the sample. Many of them had been involved in motorcycle accidents (47.73%). Regarding the location of the incident, 84% occurred on roads. Furthermore, more than half of the patients had experienced the incident within the past year, and the longest time since the incident was 9 years. These results are summarized in Table 1.

Table 1. Characteristics of the sample.

	Average ± SD	N° (%)
Age	42.7 ± 17.3	44
Gender		
Male N (%)		30 (69)
Kind of Damage N (%)		
Motorcycle accident		21 (47.73)
Car accident		9 (20.45)
Domestic accident		1 (2.27)
Hospital accident		1 (2.27)
Workplace accident		5 (11.36)
Fall		1 (2.27)
Pedestrian accident		6 (13.64)
Event location N (%)		
Road		37 (84.09)
Hospital		6 (13.64)
Work		1 (2.27)
Upper limb involved		13 (66)
Lower limb involved		37 (23)
Other involved districts		6 (11)
Years since the damage N (%)		
<1		27 (61.36)
>1		17 (38.64)

3.2. Item-by-Item Analysis

Regarding hip movements, there are statistically significant negative correlations between the average deficit on the left side and the individual movements of the left hip. Similarly, these correlations are observed between the average deficit on the right side and the individual movements of the right hip. Furthermore, internal and external rotation movements are strongly correlated with each other on both sides. Focusing on the specific ranges of motion (ROM) of the left side, abduction shows a statistically significant correlation with adduction and flexion on the same side and with abduction of the right hip. On the right side, hip flexion is significantly correlated with left-side adduction and abduction, as well as with right-side adduction and flexion. Additionally, left hip extension positively correlates with ipsilateral flexion and contralateral (right-side) extension.

In general, all movements of the right hip are intercorrelated except for extension, which correlates only with flexion. The data are presented in Table 2.

Regarding the knee joint, statistically significant negative correlations were observed in knee joint articulation. Specifically, the average deficits on the left side were significantly correlated with left-side movements. Similarly, a negative correlation was found between right-side movements and the average deficits calculated for right joint movements. The results are presented in Table 3.

Regarding the item-by-item analysis of the ankle, the calculated joint deficits were significantly inversely correlated with the individual movements of the respective sides. For both the left and right ankles, all movements were intercorrelated except for the left ankle dorsiflexion. Additionally, right ankle dorsiflexion was correlated with left plantar flexion and left eversion. Th correlations are presented in Table 4.

3.3. Construct Validity

Regarding the SF-36 questionnaire, only a few right-sided ROM deficits showed statistically significant correlations with the scale domains. Specifically, the average deficit in right knee ROM was negatively correlated with the “physical functioning” domain, as well as with the “social functioning” and “pain” domains (Table 5).

A statistically significant correlation was identified between the mean calculated deficit of the right and left hips and the total score on the Berg Balance Scale (Table 6).

Finally, regarding the TSK (Tampa Scale for Kinesiophobia), a statistically significant correlation was found between the average deficit of the left hip and the total score obtained on the scale (Table 7).

Table 2. Hip, item-by-item analysis.

		Left							**Right**						
		Extrarotation	**Intrarotation**	**Adduction**	**Abduction**	**Flexion**	**Exention**	**Mean Left Deficit**	**Extrarotation**	**Intrarotation**	**Adduction**	**Abduction**	**Flexion**	**Exention**	**Mean Right Deficit**
Left	Extrarotation	1	0.727 **	0.326	0.335	0.283	0.068	−0.663 **	0.279	0.261	−0.104	0.116	0.243	0.224	−0.168
	Intrarotation	0.727 **	1	0.380 *	0.308	0.231	0.045	−0.615 **	0.098	0.083	−0.138	0.020	0.120	0.075	−0.015
	Adduction	0.326	0.380 *	1	0.411 *	0.631 **	0.246	−0.784 *	0.233	0.093	0.361 *	0.207	0.181	0.094	−0.251
	Abduction	0.335	0.308	0.411 *	1	0.578 **	−0.009	−0.570 **	0.108	−0.073	0.066	0.363 *	0.135	−0.194	−0.095
	Flexion	0.283	0.231	0.631 **	0.578 **	1	0.424 *	−0.754 **	0.242	0.165	0.438 *	0.310	0.488 **	0.137	−0.389 *
	Extention	0.068	0.045	0.246	−0.009	0.424 *	1	−0.484 **	0.222	0.225	0.428 *	0.195	0.330	0.365 *	−0.387 *
	Mean Left Deficit	−0.663 **	−0.615 **	−0.784 **	−0.570 **	−0.754 **	−0.484 **	1	−0.168	−0.015	−0.251	−0.095	−0.095	−0.389 *	0.412 *
Right	Extrarotation	0.279	0.098	0.233	0.108	0.242	0.222	−0.352 *	1	0.743 **	0.627 **	0.639 **	0.499 **	0.321	−0.820 **
	Intrarotation	0.261	0.083	0.093	−0.073	0.165	0.225	−0.248	0.743 **	1	0.620 **	0.587 **	0.449 *	0.293	−0.790 **
	Adduction	−0.104	−0.138	0.361*	0.066	0.438 *	0.428 *	−0.352 *	0.627 **	0.620 **	1	0.676 **	0.682 **	0.345	−0.874 **
	Abduction	0.116	0.020	0.207	0.363 *	0.310	0.195	−0.353 *	0.639 **	0.587 **	0.676 **	1	0.593 **	0.201	−0.817 **
	Flexion	0.243	0.120	0.181	0.135	0.488 **	0.330	−0.417 *	0.499 **	0.449 *	0.682 **	0.593 **	1	0.600 **	−0.797 **
	Extention	0.224	0.075	0.094	−0.194	0.137	0.365 *	−0.263	0.321	0.293	0.345	0.201	0.600 **	1	−0.484 **
	Mean Right Deficit	−0.168	−0.015	−0.251	−0.095	−0.389 *	−0.387 *	0.412 *	−0.820 **	−0.790 **	−0.874 **	−0.817 **	−0.797 **	−0.536 **	1

* $p < 0.05$ ** $p < 0.01$.

Table 3. Knee, item-by-item analysis.

		Left			Right		
		Flexion	**Estention**	**Mean Left Deficit**	**Flexion**	**Estention**	**Mean Right Deficit**
Left	Flexion	1	0.222	−0.555 **	−0.003	−0.117	0.020
	Estention	0.222	1	−0.899 **	0.114	0.261	−0.130
	Mean Left Deficit	−0.555 **	−0.899 **	1	−0.063	−0.115	0.070
Right	Flexion	−0.003	0.114	−0.063	1	0.535 **	−0.863 **
	Estention	−0.117	0.261	−0.115	0.535 **	1	−0.844 **
	Mean Right Deficit	0.020	−0.130	0.070	−0.863 **	−0.844 **	1

** $p < 0.01$.

Table 4. Ankle, item-by-item analysis.

		Left					Right				
		Plantar Flexion	**Dorsal Flexion**	**Eversion**	**Inversion**	**Mean Left Deficit**	**Plantar Flexion**	**Dorsal Flexion**	**Eversion**	**Inversion**	**Mean Right Deficit**
Left	Plantar flexion	1	0.153	0.482 *	0.464 *	−0.569 **	−0.034	−0.411 *	−0.265	−0.260	0.301
	Dorsal flexion	0.153	1	0.535 **	0.405 *	−0.657 **	0.141	0.009	−0.103	0.083	−0.154 0.171
	Eversion	0.482 *	0.535 **	1	0.542 **	−0.758 **	0.006	−0.454 *	−0.083	−0.117	−0.003
	Inversion	0.464 *	0.405 *	0.542 **	1	−0.767 **	0.027	−0.257	0.019	−0.003	−0.765 **
	Mean Left Deficit	−0.569 **	−0.657 **	−0.657 **	−0.767 **	1	0.000	0.258	0.029	0.107	−0.063
Right	Plantar flexion	−0.034	0.141	0.006	0.027	0.000	1	0.398 *	0.416 *	0.693 **	−0.765 **
	Dorsal flexion	−0.411 *	0.009	−0.454 *	−0.257	0.258	0.398 *	1	0.471 *	0.642 **	−0.685 **
	Eversion	−0.265	−0.103	−0.083	0.019	0.029	0.416 *	0.471 *	1	0.604 **	−0.694 **
	Inversion	−0.260	0.083	−0.117	−0.003	0.107	0.693 **	0.642 **	0.604 **	1	−0.903 **
	Mean Right Deficit	0.301	−0.154	0.171	−0.003	−0.063	−0.765 **	−0.685 **	−0.694 **	−0.903 **	1

* $p < 0.05$ ** $p < 0.01$.

Table 5. SF-36.

	Anca		Ginocchio		Caviglia	
	Media Deficit Sx	**Media Deficit Dx**	**Media Deficit Sx**	**Media Deficit Dx**	**Media Deficit Sx**	**Media Deficit Dx**
Physical functioning	0.003	−0.362	−0.068	−0.503 *	−0.071	−0.196
Role limitations due to physical health	0.211	0.128	0.010	−0.228	−0.100	0.055
Role limitations due to emotional problems	0.254	0.110	0.054	−0.244	−0.074	0.034
Energy/fatigue	0.267	−0.048	−0.042	−0.376	−0.106	0.028
Emotional well-being	0.125	−0.221	−0.063	−0.380	−0.068	−0.063
Social functioning	0.064	−0.045	−0.301	−0.426 *	−0.024	−0.119
Pain	−0.101	−0.286	−0.376	−0.497 *	−0.010	−0.219
General health	0.085	−0.068	−0.208	−0.296	0.082	0.070
Health change	0.275	0.084	0.094	−0.128	0.398	0.080

* $p < 0.05$.

Table 6. Berg Balance Scale.

	Anca		Ginocchio		Caviglia	
	Media Deficit Sx	**Media Deficit Dx**	**Media Deficit Sx**	**Media Deficit Dx**	**Media Deficit Sx**	**Media Deficit Dx**
Total score	−0.667 **	−0.780 **	−0.259	−0.366	−0.360	−0.273

** p <0.01.

Table 7. Tampa Scale for Kinesiophobia.

	Anca		Ginocchio		Caviglia	
	Media Deficit Sx	**Media Deficit Dx**	**Media Deficit Sx**	**Media Deficit Dx**	**Media Deficit Sx**	**Media Deficit Dx**
Total score	0.465 *	0.205	0.213	−0.045	0.198	0.242

* $p < 0.05$.

4. Discussion

This study aimed to evaluate the psychometric properties of the XClinic sensors developed by Ferrox. The results showed moderate reliability across the measured parameters through item-by-item analysis, while construct validity presented low to moderate values. These findings highlight the need for further studies to explore the validity of these sensors, particularly in populations with injuries. Despite these limitations, the identified correlations offer valuable preliminary insights and serve as a solid basis for future investigations aimed at refining these devices and improving their accuracy.

The descriptive results of this research provide important context regarding the nature of road traffic accidents, especially those involving motorcycles (Montella et al., 2012 [11]). The predominance of male patients and the high occurrence of accidents on the road are consistent with international reports that highlight the increased vulnerability of motorcyclists in urban environments [32]. These findings highlight the need for targeted prevention measures and tailored rehabilitation approaches for patients with severe injuries.

Statistically significant negative correlations between mean deficits and specific hip movements underscore a consistent relationship between joint restrictions and functional impairment. Greater deficits in the range of motion (ROM) were associated with reduced capability in specific hip movements [33,34]. The strong association between internal and external rotations on both sides emphasizes the biomechanical interdependence of these movements, likely due to shared muscular and joint dynamics [35].

Interestingly, the significant correlation between left hip abduction and both ipsilateral (adduction and flexion) and contralateral (right hip abduction) movements suggests compensatory mechanisms in bilateral hip function. These dynamics align with the biomechanics of the lower limbs, where limitations on one side influence contralateral functionality. The positive association between left hip extension and ipsilateral flexion and contralateral extension further supports this relationship [36]. However, the lack of similar correlations for right hip extension may suggest that these movements are more isolated or influenced by different factors, warranting further investigation.

The negative correlations observed between knee ROM deficits and specific joint movements confirm the expected relationship, as restricted mobility in the knee directly impacts its functional capacity [37]. Similarly, the inverse relationship between ankle deficits and individual movements highlights the fundamental role of ankle ROM in maintaining overall mobility. The observed correlations between right ankle dorsiflexion and left plantar flexion or eversion suggest adaptive mechanisms that preserve stability and function, even when mobility is compromised on one side [38].

Further insights emerged from the associations between knee ROM deficits and domains of the SF-36 scale, including “physical functioning”, “social functioning”, and “pain”. These correlations suggest that joint restrictions in the knee affect not only physical abilities but also social participation and pain experiences, highlighting the broader impact of these deficits on quality of life (QoL), which is consistent with the current literature [39]. Addressing these limitations is critical for improving the overall well-being of affected individuals.

The relationship between hip deficits and Berg Balance Scale scores demonstrates the importance of hip mobility in maintaining balance and preventing falls. As the hips are crucial for weight shifting and postural control, restrictions in their movement compromise balance [40]. These findings highlight the importance of incorporating hip-targeted mobility interventions into rehabilitation programs that focus on balance restoration. Additionally, the correlation between left hip deficits and higher scores on the Tampa Scale of Kinesiophobia (TSK) suggests that limited hip mobility contributes to fear of movement, a psychological barrier that may delay recovery [41]. Addressing ROM deficits can alleviate these fears and enhance patient confidence in their physical abilities.

A comprehensive rehabilitation assessment is critical for developing personalized therapeutic plans. In this regard, advanced movement analysis tools and functional assessment scales are indispensable for this purpose. These tools offer precise and objective evaluations of a patient’s progress, enabling clinicians to identify compensatory patterns, inefficiencies, or abnormalities that may hinder recovery. Integrating movement analysis technologies into clinical practice allows for better customization of physiotherapy interventions, ensuring that treatment is optimally tailored to the individual needs.

Additionally, functional assessment scales provide a reliable means of monitoring the recovery over time. By measuring aspects such as balance, strength, and joint mobility, these tools enable clinicians to pinpoint specific areas that require more focused attention. This continuous evaluation ensures that rehabilitation remains dynamic and responsive to the patient’s evolving condition, ultimately resulting in a more effective recovery.

5. Medico-Legal Implications

In Italy, Legislative Decree 62/2024 redefines disability as a lasting physical, mental, intellectual, neurodevelopmental, or sensory impairment that, in interaction with various barriers, hinders full and equal participation in life contexts. This aligns with the UN Convention’s shift from the ICDH health model, which focuses on physical limitations, to a human rights model that emphasizes individuals’ rights to shape their life paths with appropriate support. Disability is thus viewed relationally, reflecting the interaction between a person and their environment, with an emphasis on self-determination, equality, and inclusion [42].

Central to this approach is a multidimensional assessment structured in four phases: identifying the individual’s goals and functioning profile, assessing barriers and adaptive capacities, determining support needs, and defining life objectives with tailored interventions and outcome evaluations. This process ensures comprehensive support, considering existential, relational, emotional, educational, and cultural needs, and promotes both independence and social participation [43]. Assessment units are designed to integrate diverse expertise while prioritizing individual choices and expectations, culminating in a life project. This project specifies tools, resources, interventions, and services—such as suitable housing and home care—aimed at removing barriers and facilitating inclusion in education, employment, and social life. Unlike standardized criteria, it offers personalized solutions, ensuring that individuals can choose where and how to live, in line with Article 19 of the UN Convention.

Given this framework, medico-legal evaluations require strict adherence to both clinical and dynamic-relational criteria, addressing individuals' ability to independently engage in daily, social, and professional activities. Instruments such as rating scales and motion sensors provide an accurate assessment of these limitations, supporting the eligibility for disability benefits. For example, osteoarticular problems that increase the risk of falls or hinder stair climbing highlight the importance of comprehensive assessments, including objective measures of functional limitations [44]. By correlating physical impairments with real-life challenges, these tools offer a holistic evaluation method that aligns with the decree's emphasis on personalized support and complete social inclusion.

6. Conclusions

This study highlights the importance of a comprehensive and tailored approach to rehabilitation in individuals recovering from trauma-related injuries. Physiotherapy interventions, enhanced by the use of advanced tools for movement analysis and functional evaluation, play a pivotal role in addressing joint mobility limitations and improving physical function. The relationships observed between joint restrictions, functional impairments, and psychosocial outcomes underscore the need to integrate both physical and psychological care into rehabilitation programs. Moving forward, further research should focus on optimizing these assessment tools and treatment strategies to ensure effective recovery and lasting improvement in patients' quality of life.

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Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors upon request.

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