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Evaluation of Joint Function and Hand Mobility in the Rehabilitation Process Using Kinematic Modeling and Statistical Analysis

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Abstract: Rheumatoid arthritis (RA) progressively alters hand biomechanics, disrupting interjoint coordination and promoting compensatory movement patterns that are insufficiently captured by conventional range-of-motion assessment. This longitudinal case report (n = 1) investigated the functional reorganization of the digital joint chain during rehabilitation using an integrated framework combining kinematic modeling and descriptive statistical analysis. A patient with RA was evaluated at three time points (Day 1, Day 10, Day 20) during a structured physiotherapeutic program. Flexion–extension movements of the dominant index finger were recorded using an inertial measurement unit (IMU)-based system, and kinematic parameters were processed through a MATLAB-based graphical interface to quantify joint behavior. Results demonstrated a progressive redistribution of motion within the digital chain. Distal compensatory flexion decreased, the proximal interphalangeal joint shifted from hyperextension toward functional flexion, and the metacarpophalangeal joint showed increased participation in movement generation. These changes reflect improved interjoint coordination and a more balanced functional organization of the finger. Technology-assisted kinematic assessment provides an objective approach for monitoring rehabilitation-induced adaptations and supports quantitative evaluation of functional recovery in rheumatoid arthritis.

Keywords: Rheumatoid arthritis, Finger kinematics, Kinematic modeling, Statistical analysis, Functional assessment

1. Introduction

The hand, as a distinct functional segment of the locomotor system, represents one of the most complex biomechanical assemblies, with its functionality resulting from the interaction between the osteoarticular structure, the integrity of periarticular tissues, and neuromuscular control [1]. These aspects cause impairment of the articular complex to generate major imbalances in the patient's quality of life, autonomy, and activities of daily living. In this context, the hand represents a key segment both for biomechanical research and for clinical practice in medical rehabilitation [2], [3], [4].

Regarding degenerative conditions, rheumatoid arthritis (RA) is a systemic autoimmune pathology characterized by persistent synovial inflammation, with a progressive course and destructive potential, predominantly affecting the small joints of the hand [4], [5]. The pathological process involves hypertrophy of the synovial membrane and progressive degradation of the articular cartilage and underlying bone, accompanied by inflammation [6]. The biomechanical consequences of these alterations include joint instability, structural deformities, and disruption of the physiological axes of rotation, with a direct impact on finger mobility and movement coordination [7], [8].

From a functional perspective, impairment of the metacarpophalangeal (MCP) and proximal (PIP) and distal (DIP) interphalangeal joints leads to reduced flexion–extension ranges of motion, morning stiffness, and pain during mobilization, factors that limit grasping ability and fine motor manipulation [5], [9]. Over time, as the pathology progresses, patients develop compensatory movement patterns by redistributing mechanical demands toward less affected joints or by altering the global movement trajectory of the hand [9], [10]. Although functionally beneficial in the short term, these adaptations may accelerate biomechanical degradation and contribute to the progressive loss of hand function [9], [11].

Functional assessment of the hand in rheumatoid arthritis is essential both for staging the extent of impairment and for monitoring the response to treatment and rehabilitation [5], [12]. In clinical practice, this assessment is based on physical examination, standardized functional tests, and goniometric measurements of joint ranges of motion [7]. However, the fluctuating inflammatory nature of the disease, symptom variability, and the emergence of compensatory adaptations often render conventional assessment insufficient to capture functional changes within the digital biomechanical chain [11], [12].

In the context of rheumatoid arthritis, limiting the assessment to isolated angular values does not reflect the global kinematic behavior of the fingers nor the actual impact on functional performance [13]. Progressive deformities and subtle alterations in interjoint coordination may be underestimated, and therapeutic progress can be difficult to quantify objectively. Therefore, the use of evaluation methods capable of describing the hand as an integrated kinematic system is required, in which function arises from the interaction between joints rather than from the isolated performance of each joint [14].

Kinematic modeling of the fingers as serial kinematic chains provides an appropriate mathematical framework for analyzing these functional modifications [15]. In rheumatoid arthritis, restriction of joint degrees of freedom and alteration of movement distribution result in a reduction of the fingertip workspace and in modifications of functional trajectories [16], [17]. These alterations can be objectively quantified using derived kinematic parameters, which more accurately reflect the impact of pathology on hand function than conventional clinical assessment [15].

Moreover, the clinical value of this information is enhanced by integrating objective statistical analysis into the evaluation process throughout the rehabilitation program. In a condition such as rheumatoid arthritis, the progression of the kinesiotherapeutic program is variable, and the response to intervention differs significantly depending on degenerative factors [5]. Statistical analysis of functional parameters enables the identification of evolutionary trends, the assessment of movement variability, and the differentiation of significant changes from physiological or transient inflammatory fluctuations. Consequently, progress is no longer evaluated subjectively but is supported by quantifiable indicators that are comparable over time.

In this context, the development of a dedicated software tool that integrates kinematic modeling and statistical analysis of joint chain mobility provides essential support for functional assessment in the rehabilitation of patients with rheumatoid arthritis. Such a system enables objective monitoring of hand function, correlation of biomechanical changes with clinical evolution, and supports clinicians by allowing adaptation and personalization of the rehabilitation plan. By transforming motion data into clinically relevant information, assessment becomes an active component of the therapeutic process, contributing to the optimization of intervention strategies and to long-term functional improvement.

The aim of this study was to evaluate the functional evolution of the digital joint chain during a structured rehabilitation program in a patient with rheumatoid arthritis, using an integrated approach based on kinematic modeling and descriptive statistical analysis. We hypothesized that rehabilitation would lead to a redistribution of motion within the digital chain, characterized by reduced distal compensatory behavior and improved interjoint coordination.

2. Material and methods

The study was designed to perform a functional assessment assisted by computational tools, aiming to objectively monitor finger joint mobility in the context of medical rehabilitation. The proposed approach integrates concepts of finger kinematic modeling and statistical analysis of functional parameters, using graphical user interfaces developed in the MATLAB environment. This integration enables the transformation of raw motion data into quantifiable, clinically relevant indicators that are easy to interpret and compare.

2.1. Study Design and Patient Characteristics

This study was designed as a single-patient longitudinal observational study (n = 1) conducted to objectively evaluate digital joint mobility during a structured rehabilitation program in rheumatoid arthritis. The participant was a 56-year-old female diagnosed with rheumatoid arthritis 8 years prior to enrollment, presenting predominant functional impairment at the level of the hands. The dominant right hand was more affected, with reduced fine motor control and reported difficulty in performing precision tasks.

Baseline clinical evaluation indicated moderate functional limitation of the dominant right index finger, characterized by joint stiffness and altered flexion–extension patterns. The dominant right index finger was selected for analysis, and the metacarpophalangeal (MCP), proximal interphalangeal (PIP), and distal interphalangeal (DIP) joints were evaluated during guided flexion–extension movements.

2.1. Joint kinematics

For a coherent analysis of finger motion, principles of articulated system kinematics were employed, in which each finger is modeled as an open serial kinematic chain composed of rigid segments (phalanges) interconnected by rotational joints. In this framework, the finger is considered a three-degree-of-freedom chain, corresponding to the metacarpophalangeal (MCP), proximal interphalangeal (PIP), and distal interphalangeal (DIP) joints, with the analyzed motions being flexion–extension movements [18].

From a mathematical standpoint, the geometric relationships between the segments of the kinematic chain are described using the standardized Denavit–Hartenberg (DH) parameterization, adapted to the biomechanical particularities of the fingers [4]. Thus, each joint is characterized by a rotation angle θ_i, considered the primary rotational variable, while the segments are defined by constant lengths corresponding to the phalanges [18].

The kinematic transformation between two consecutive segments is described by a homogeneous transformation matrix, and the global transformation from the base of the finger to the tip of the distal phalanx is obtained by composing these elementary transformations. The forward kinematics of the finger osteoarticular chain allows the determination of the fingertip position as a function of the joint angles, according to the general relationship:

$$p=f(\theta_{MCP}, \theta_{PIP}, \theta_{DIP}) \quad (1)$$

Where p represents the position of the fingertip in the plane of motion. This formulation highlights how individual joint rotations combine to generate the overall kinematic behavior of the finger [16].

From a functional perspective, an important outcome of forward kinematics is the definition of the direction of fingertip displacement, understood as the orientation of the resulting motion under existing joint constraints. The size and shape of this workspace are directly influenced by joint ranges of motion and phalangeal lengths. In a pathological context, restriction of motion ranges leads to a reduction of the functional displacement domain, with a direct impact on grasping ability and manipulation capacity [17].

1.3. Data Acquisition and Evaluation Protocol

Data acquisition was performed during standardized functional assessment sessions, with the objective of collecting kinematic parameters relevant to finger joint mobility. The patient was evaluated at three distinct time points: on the first day, prior to the initiation of the rehabilitation program; at the midpoint of the therapeutic process; and on the final day, following completion of all physiotherapy sessions. The intermediate reassessment was conducted to monitor functional progression and patient compliance with the treatment program.

Assessments were carried out under controlled conditions, with the patient instructed to perform guided flexion–extension movements of the analyzed fingers, considered functionally dominant motions. For each evaluation session, measurements consisted of two consecutive flexion–extension cycles. The protocol was designed to ensure measurement reproducibility and to minimize the influence of external factors or execution-related variability.

Data were acquired using an inertial measurement unit (IMU)-based system capable of recording orientation variations associated with joint movements. The sensors operated at a sampling frequency of 100 Hz, providing angular resolution appropriate for clinical flexion–extension assessment. Prior to each recording session, the system was calibrated using a neutral anatomical reference position in order to minimize drift and reduce measurement bias. Given that the primary focus of the present study was on kinematic modeling and statistical processing, the hardware configuration was maintained constant across all evaluations to ensure methodological consistency.

For each session, data series were recorded to reflect the kinematic behavior of the digital chain, with acquisition performed over sufficiently long time intervals to capture both movement amplitude and variability—key aspects in the functional assessment of patients with chronic joint disorders.

The data collection process was standardized across all evaluations, maintaining identical conditions of positioning, movement execution, and duration. This standardization enabled objective comparison of results across successive assessments and provided the basis for the subsequent descriptive and comparative statistical analyses conducted within the MATLAB graphical user interface.

2.3. Statistical Methods

Given the inherent variability of joint movements and the distinct characteristics of chronic inflammatory conditions, the statistical analysis was focused on descriptive and comparative methods, directly integrated into the MATLAB graphical user interface [4]. The primary purpose of implementing statistical methods was the objective characterization of individual functional performance and the monitoring of patient evolution over time throughout the rehabilitation program.

For each analyzed kinematic parameter, the interface computes descriptive statistical values that provide a global characterization at a given time point. Thus, the mean is used to describe the average level of mobility and is defined as:

$$\mu=\frac{1}{N}\sum_{i=1}^{N}x_i \qquad (2)$$

Where, x_i represents the successive values of the measured parameter, and N denotes the number of observations. From a clinical perspective, the mean reflects the patient's overall functional capacity within a given evaluation session [4], [18], [19].

The standard deviation – SD (σ) is calculated to quantify movement variability around the mean value (3), representing an important parameter in medical rehabilitation. A high standard deviation may indicate motor instability, impaired control, or the presence of compensatory strategies, even in cases where the mean range of motion shows improvement.

$$\sigma=\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i-\mu)^2} \quad (3)$$

In addition, the graphical user interface provides information on the minimum and maximum values of the analyzed parameters, which define the actual functional domain accessible to the patient (4). The difference between these values allows the clinician to observe the functional amplitude of movement and the limits imposed by the pathology. In the case of rheumatoid arthritis, narrowing of this interval reflects joint stiffness and a reduction in the available degrees of freedom.

$$x_{min}=\min(x_i)\,, \qquad x_{max}=\max(x_i)\,, \quad (4)$$

The integration of descriptive and comparative statistical methods within the graphical user interface enables the conversion of patient-derived kinematic data into functionally meaningful indicators with clinical relevance. This approach addresses the specific requirements of medical rehabilitation, where emphasis is placed on tracking the patient's individual functional evolution. In this context, statistical analysis emerges as a fundamental decision-support tool, facilitating the adaptation and personalization of rehabilitation programs based on objectively assessed functional responses [1], [11].

3. Results

The results presented in this section reflect the functional evolution of the fingers throughout the rehabilitation program, as evidenced by changes in the kinematic and statistical parameters obtained from successive assessments. The analysis primarily focuses on the distal interphalangeal (DIP) joint, considered the main functional indicator of progress, while the changes observed at the metacarpophalangeal (MCP) and proximal interphalangeal (PIP) joints are analyzed as biomechanical support elements and as contributors to the redistribution of motion within the digital kinematic chain.

For a clear interpretation of functional progress, the results are presented comparatively for the initial, intermediate, and final evaluations.

3.1. DIP Joint Evolution – Primary Functional Indicator

At the initial evaluation (Figure 1a), the DIP joint exhibits a kinematic behavior characterized by a predominantly flexed positioning, with a mean value of 55.10° (SD = 1.22°), minimum 52.25°, and maximum 57.97°. The temporal profile of the DIP joint angle indicates consistent utilization of this joint during movement execution, suggesting a compensatory pattern frequently observed in the context of proximal joint impairment. Movement variability is moderate but concentrated within the flexion range, reflecting limited control of active extension.

At the intermediate evaluation (Figure 1b), a clear modification in DIP joint behavior is observed, characterized by a decrease in the mean joint angle to 43.94° (SD = 2.55°), with values ranging between 38.68° and 48.63°. This evolution suggests a reduced tendency to maintain the finger in excessive flexion and an increased ability to explore the functional workspace. The movement profile becomes more balanced, with a more uniform distribution of values around the mean.

At the final evaluation (Figure 1c), the DIP joint demonstrates stabilization of statistical parameters, with a mean value of 30.04° (SD = 4.01°), minimum 22.58°, and maximum 37.49°. Movement variability increases compared to the intermediate stage, in accordance with the expanded functional domain, indicating improved motor control and more coherent execution of flexion–extension movements. This evolution reflects a genuine functional improvement of the DIP joint, both in terms of mobility and movement control.

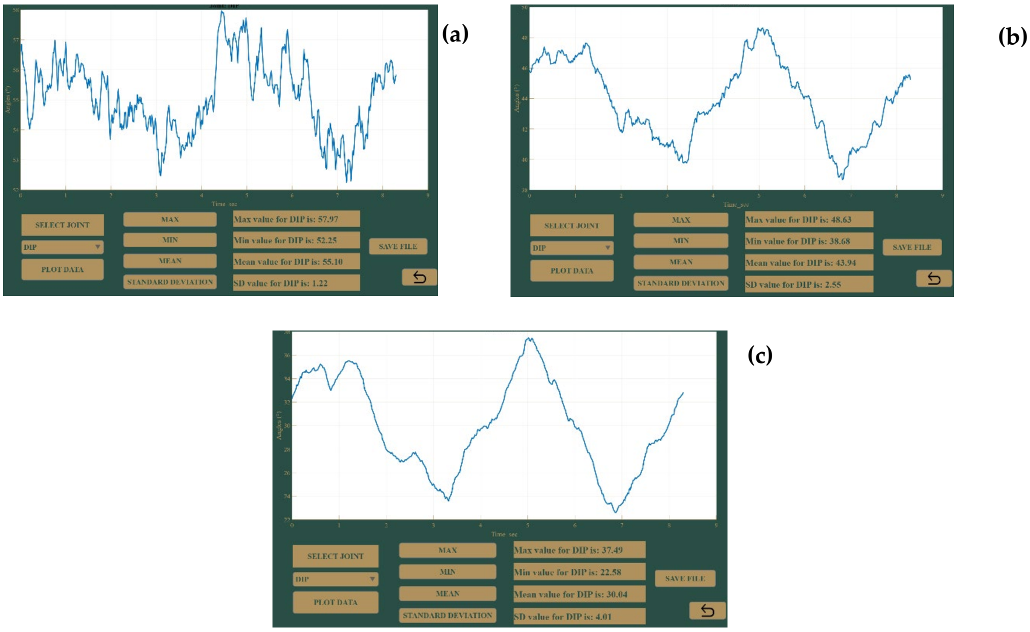


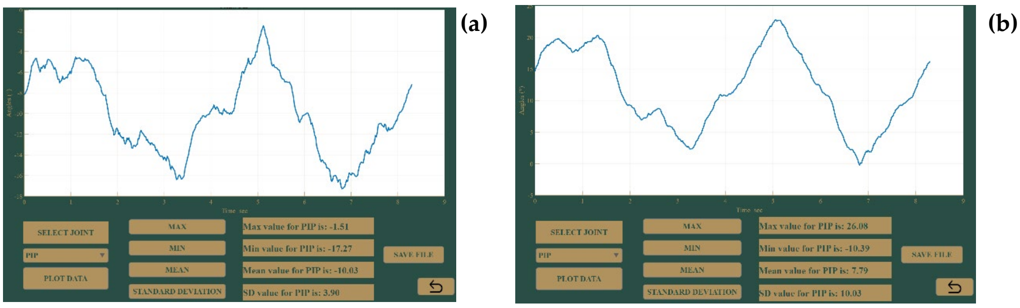
Figure 1. Evolution of the joint angle at the distal interphalangeal (DIP) joint during flexion–extension movements. (a) First day, prior to the initiation of the rehabilitation program. (b) Day 10 of the applied kinesiotherapeutic program. (c) Final day, following completion of the physiotherapy sessions.

3.2. Changes at the PIP Joint – Functional Stabilization and Redistribution

At the initial evaluation (Figure 2(a)), the proximal interphalangeal (PIP) joint exhibits a behavior characterized by marked hyperextension and increased movement variability, reflected by low minimum values and an imbalanced functional range, with a mean value of −10.03° (SD = 3.90°; Min = −17.27°; Max = −1.51°). This pattern indicates functional instability and an inefficient contribution of the PIP joint to the execution of global finger motion.

Throughout the rehabilitation program (Figure 2(b)), a progressive increase in the minimum PIP joint angle values is observed, suggesting a reduction in pathological hyperextension. Concurrently, maximum values increase, indicating an improvement in active flexion, with a mean value of 7.79° (SD = 10.03°; Min = −10.39°; Max = 26.08°). At the intermediate stage, movement variability becomes more pronounced, reflecting a phase of mobility recovery and neuromotor adaptation.

At the final evaluation (Figure 2(c)), PIP joint parameters tend to stabilize, with a mean value of 30.13° (SD = 17.67°; Min = −1.52°; Max = 62.88°) and a more uniform distribution of motion. This evolution suggests an improvement in the transfer role of the PIP joint within the kinematic chain, contributing to a more efficient redistribution of movement and to a reduction in excessive loading of the DIP joint.



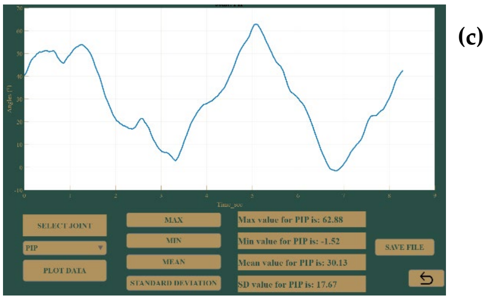


Figure 2. Evolution of the joint angle at the proximal interphalangeal (PIP) joint during flexion–extension movements. (a) First day, prior to the initiation of the rehabilitation program. (b) Day 10 of the applied kinesiotherapeutic program. (c) Final day, following completion of the physiotherapy sessions.

3.3. MCP Joint Evolution – Increased Proximal Contribution

At the initial evaluation (Figure 3(a)), the metacarpophalangeal (MCP) joint exhibits moderate mobility, with reduced active flexion amplitudes and a limited contribution to the generation of global finger motion, with a mean value of 10.01° (SD = 4.11°; Min = 2.63°; Max = 17.77°). The movement profile is relatively regular, indicating preserved motor control, but insufficient to adequately support overall finger function.

In subsequent evaluations (Figure 3(b)), a progressive increase in MCP joint movement amplitude is observed, reflected by an expansion of maximum values and a shift of minimum values toward the neutral position, with a mean value of 11.80° (SD = 6.19°; Min = −0.21°; Max = 22.76°). This evolution indicates increased involvement of the MCP joint in flexion–extension movements, contributing to a reduction in distal compensatory mechanisms.

At the final evaluation (Figure 3(c)), the MCP joint demonstrates a broader functional range and a more efficient movement profile, with a mean value of 14.06° (SD = 8.84°; Min = −1.92°; Max = 30.41°), suggesting a favorable redistribution of biomechanical effort within the digital joint chain.

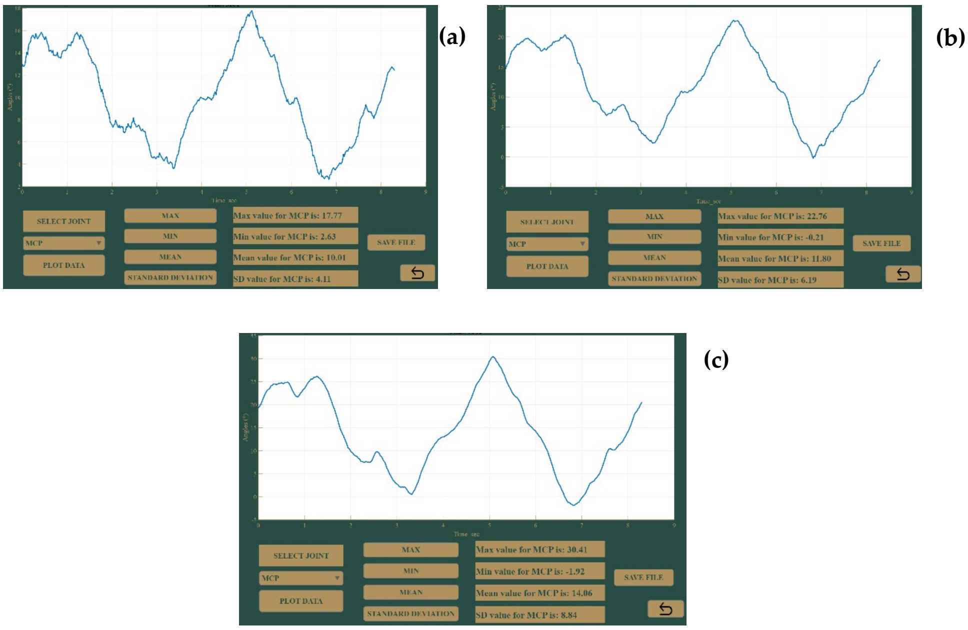


Figure 3. Evolution of the joint angle at the metacarpophalangeal (MCP) joint during flexion–extension movements. (a) First day, prior to the initiation of the rehabilitation program. (b) Day 10 of the applied kinesiotherapeutic program. (c) Final day, following completion of the physiotherapy sessions.

The integrated analysis of the metacarpophalangeal (MCP), proximal interphalangeal (PIP), and distal interphalangeal (DIP) joints highlights a progressive and functionally meaningful redistribution of movement throughout the rehabilitation program. The reduction of hyperextension at the PIP joint, combined with increased proximal joint (MCP) contribution, creates the conditions for a more balanced kinematic behavior of the DIP joint. Under these circumstances, the distal joint operates within a range closer to physiological behavior, characterized by more stable mean values and improved motor control during flexion–extension movements.

This redistribution of movement reflects a functional reorganization of the digital joint chain, in which biomechanical load is no longer predominantly borne by the distal joint but is more efficiently distributed between proximal and distal segments. From a clinical perspective, this aspect is essential, as excessive reliance on the DIP joint as a compensatory mechanism is frequently associated with overuse, stiffness, and impairment of fine hand function. The observed evolution therefore suggests not only a gain in mobility, but also an improvement in movement quality and interjoint coordination.

The results indicate that functional progress is not expressed exclusively through increases in isolated joint ranges of motion, but rather through optimization of the global kinematic behavior of the digital chain. This optimization is reflected by a structured increase in movement variability proportional to the expanded functional domain, increased efficiency of functional trajectories, and convergence of statistical parameters toward values considered physiological—features that cannot be adequately captured by traditional clinical assessments based solely on goniometry or subjective observation.

4. Discussion

The analysis of the evolution of kinematic parameters of the distal interphalangeal (DIP) joint reveals quantifiable changes in joint behavior throughout the rehabilitation program. At the initial evaluation (Day 1), the DIP joint exhibits a high mean flexion angle (Mean = 55.10°), associated with closely clustered minimum and maximum values (Min = 52.25°, Max = 57.97°), indicating a limited range of variation (ROM ≈ 5.72°). This distribution suggests reduced movement concentrated within a narrow domain, characteristic of a joint maintained in an almost constant flexed position, with limited capacity for active extension.

At the intermediate evaluation (Day 10), a decrease in the mean DIP joint angle to 43.94° is observed, accompanied by an increase in the range of variation (Min = 38.68°, Max = 48.63°, ROM ≈ 9.95°). Compared to the initial evaluation, this change reflects a shift of the joint's operating domain toward values closer to extension, as well as increased movement variability. From a kinematic perspective, this evolution indicates reduced stiffness and an enhanced ability of the joint to explore a broader functional domain during flexion–extension cycles.

The final evaluation (Day 20) demonstrates continuation of this trend, with a mean DIP joint angle of 30.04° and a further increase in the range of motion (Min = 22.58°, Max = 37.49°, ROM ≈ 14.91°). Compared to Day 1, the variation domain of the DIP joint nearly triples, and the mean value shifts by more than 25° toward extension. This redistribution of movement indicates a substantial reorganization of joint control and an increased functional capacity of the joint in relation to motor task demands.

The analysis of kinematic parameters of the proximal interphalangeal (PIP) joint highlights a considerable functional evolution throughout the rehabilitation program. At the initial evaluation (Day 1), the PIP joint presents a negative mean joint angle (Mean = −10.03°), associated with a negative minimum value (Min = −17.27°) and a maximum value close to full extension (Max = −1.51°). The resulting range of variation (ROM ≈ 15.76°) indicates joint behavior dominated by hyperextension and an uneven movement distribution, characteristic of biomechanical imbalances frequently observed in rheumatoid arthritis, where the PIP joint assumes compensatory loading.

At the intermediate evaluation (Day 10), a substantial modification of the mean functional position of the PIP joint is observed, with a Mean value of 7.79°, indicating a transition from hyperextension toward a functional flexion range. Extreme values change concurrently (Min = −10.39°, Max = 26.08°), leading to a significant increase in the range of motion (ROM ≈ 36.47°). This expansion of the variation domain suggests increased active mobility and reduced joint constraints, reflecting a favorable response to kinesiotherapeutic intervention and improved motor control.

The final evaluation (Day 20) further confirms this trend toward kinematic normalization. The mean joint angle increases to 30.13°, while the range of variation expands further (Min = −1.52°, Max = 62.88°, ROM ≈ 64.40°). Compared to the initial evaluation, the mean value shifts by more than 40° toward flexion, and the range of motion increases by over 50%. From a biomechanical standpoint, these results indicate a progressive restoration of PIP joint flexion function and a marked reduction in pathological hyperextension.

The analysis of kinematic parameters of the metacarpophalangeal (MCP) joint demonstrates a progressive increase in movement amplitude and a redistribution of the dominant functional position throughout the rehabilitation program. At the initial evaluation (Day 1), the MCP joint exhibits a relatively low mean value (Mean = 10.01°), with a positive minimum (Min = 2.63°) and a maximum of 17.77°, resulting in a range of variation of approximately 15.14°. This distribution indicates limited extension, with the joint maintained in a predominantly flexed domain, consistent with initial joint stiffness.

At the intermediate evaluation (Day 10), an increase in the maximum value to 22.76° is observed, accompanied by the emergence of a slightly negative minimum value (Min = −0.21°) and an increased mean value (Mean = 11.80°). The joint's range of variation thus expands to approximately 22.97°, reflecting improved active extension capacity and more effective mobilization of the MCP joint during flexion–extension cycles.

The final evaluation (Day 20) highlights stabilization of the achieved progress, with a further increase in the maximum value to 30.41°, a decrease in the minimum value to −1.92°, and an increase in the mean value to 14.06°. The total range of variation thus reaches approximately 32.33°, doubling compared to the initial evaluation. This significant expansion of the movement domain indicates a clear reduction in joint stiffness and a more active involvement of the MCP joint in generating global finger motion.

The obtained results demonstrate that recovery of hand function in rheumatoid arthritis requires an integrated functional assessment of the digital joint chain, capable of capturing movement redistribution and interjoint coordination. The evolution of kinematic parameters at the MCP, PIP, and DIP joints indicates a progressive reorganization of motor control that cannot be adequately assessed through isolated analysis of joint ranges of motion, but rather through a global approach focused on the kinematic behavior of the entire system.

The present findings are consistent with previous biomechanical investigations reporting altered interphalangeal coordination and compensatory movement strategies in patients with rheumatoid arthritis. Several kinematic studies have demonstrated that inflammatory joint involvement leads to redistribution of mechanical demand within the digital chain, often characterized by distal overloading and reduced proximal contribution. In particular, impaired PIP joint mechanics and compensatory DIP engagement have been described as characteristic adaptations in rheumatoid hand dysfunction. The progressive increase in proximal joint participation observed in the present case aligns with these observations and supports the hypothesis that structured rehabilitation may facilitate restoration of more balanced interjoint coordination. Although direct quantitative comparison is limited by the single-patient design, the overall trend of motion redistribution appears concordant with previously reported kinematic patterns in inflammatory joint disease.

The present study has inherent limitations related to its single-patient design (n = 1), which limits the generalizability of the findings. The absence of a control group and the short monitoring period restrict the ability to differentiate rehabilitation-induced changes from individual variability or disease fluctuations. Additionally, the analysis was confined to flexion–extension movements of a single finger, without inclusion of more complex functional tasks. Nevertheless, the study provides a proof-of-concept framework for integrating kinematic modeling and statistical analysis into rehabilitation assessment, supporting future investigations on larger patient samples.

5. Conclusions

The integrated approach to functional hand assessment, based on kinematic modeling and statistical analysis of digital movements, highlights the importance of analyzing interjoint coordination in the rehabilitation of patients with rheumatoid arthritis. The obtained results demonstrate that evaluation of functional progress should not be limited to the isolated assessment of joint ranges of motion, but should also include analysis of the global kinematic behavior of the digital chain.

The distal interphalangeal (DIP) joint emerges as a relevant functional indicator of rehabilitation progress, reflecting both changes in mobility and improvements in motor control. The progressive normalization of its behavior was closely correlated with modifications at the proximal joint levels, particularly the reduction of PIP hyperextension and the increased contribution of the MCP joint, underscoring the need for therapeutic interventions targeting the entire joint chain.

The integration of descriptive statistical analysis and kinematic modeling within a dedicated graphical user interface enabled objective quantification of functional progress and monitoring of individual evolution throughout the rehabilitation program. The use of this tool facilitates the identification of evolutionary trends and subtle changes in movement control that are difficult to capture through conventional clinical assessments, providing objective support for adapting therapeutic strategies.

The results suggest that technology-assisted assessment can represent a valuable component in the personalization of rehabilitation programs, particularly in chronic joint disorders characterized by clinical variability and fluctuating progression, such as rheumatoid arthritis. By objectively monitoring individual functional responses, therapeutic interventions can be adjusted in a more precise and effective manner.

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