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Biomechaniczne aspekty czynności stawu łokciowego w reumatoidalnym zapaleniu stawów

Biomechanical aspects of elbow joint action in rheumatoid arthritis

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Streszczenie:

Celem przedstawionej pracy jest weryfikacja prostej i obiektywnej metody oceny funkcji stawu łokciowego, metody, która u chorych z reumatoidalnym zapaleniem stawów pozwoliłaby na doraźną ocenę zaawansowania zmian chorobowych w stawie, jak też na monitorowanie postępu choroby.

Materiały i metody. Badaniami charakterystyk cyklicznych ruchów zginania i prostowania przedramienia w stawie łokciowym objęto grupę 82 osób. Stanowisko pomiarowe składało się z kontrolowanego komputerowo urządzenia do badania ruchów w stawie łokciowym (manipulandum). Urządzenie to pozwala na badanie stanu czynnościowego stawu łokciowego przy wykonywaniu cyklicznych izokinetycznych ruchów zgięcia i wyprostu. Ruch wykonywany był: 1. z minimalną szybkością, najwolniejszy jaki był możliwy do wykonania przez pacjenta, 2. z preferowaną szybkością – szybkość ruchu zależała od woli i nawyków badanego, 3. szybki – wykonywany z największą możliwą do wykonania szybkością. Badania przeprowadzono dwukrotnie – na początku i na zakończenie trzytygodniowego leczenia usprawniającego. **Resultaty.** Otrzymane wyniki pokazują, że charakterystyka ruchów w grupie pacjentów z RZS różniła się znacznie od normy. Różnice dotyczyły przede wszystkim obniżenia prędkości i amplitudy ruchy, a także częstotliwości i okresu. Stwierdzono również znaczną asymetrię faz zginania i prostowania ruchów cyklicznych w stawie łokciowym. **Wnioski.** Należy przypuszczać, że główną przyczyną obserwowanych zmian zarówno w stosunku do normy jak i do okresu początkowego terapii jest sztywność stawu łokciowego spowodowana reakcją bólową i zwiększonymi oporami ruchu wywołanymi zmianami patologicznymi w obrębie badanego stawu. W tym kontekście zastosowana metoda badania ruchów izokinetycznych pozwala na obiektywną ocenę patologicznych zmian kontroli motorycznej w RZS.

Słowa kluczowe:

rehabilitacja, łokieć, biomechanika, reumatoidalne zapalenie stawów

Abstract

Functional limitations associated with RA-induce changes within the elbow joint and result in biomechanical disturbances. Objective data on the mobility of the affected articulation would facilitate the assessment of disease severity, selection of optimal physiotherapy interventions. ***Materials and Methods.*** Our study participants performed cyclic forearm extension and flexion elbow movements with different angular velocities. Biomechanical assessment comprised of spatiotemporal properties of cyclic movements. Spatial analysis of movement included the determination of movement direction (flexion, extension) and amplitude whereas the temporal analysis included the duration of particular movement phases as well as time-frequency analysis of a movement cycle. ***Results.*** The obtained results indicate that movement parameters in patients with rheumatoid arthritis differ significantly compared to normal ranges. Movement speed and amplitude as well as frequency and duration of movement are decreased. RA patients also exhibited considerable asymmetry of cyclic flexions and extensions of the elbow joint. ***Conclusion.*** It can be concluded that a biomechanical analysis using a manipulandum apparatus is a valuable diagnostic tool allowing objective evaluation of elbow function in rheumatoid arthritis. The measurements are highly sensitive, and hence, if performed in a larger patient population, they might help develop a classification of movement dysfunction in rheumatoid arthritis of the elbow joint. The analysis might also facilitate the assessment of hand dysfunction at various stages of RA development.

Key words:

rehabilitation, elbow, biomechanical, rheumatoid arthritis

Introduction

Functional limitations associated with RA-induced changes within the elbow joint result in biomechanical disturbances [1, 2]. Range of motion, and especially the ability to gain full extension, decreases gradually. Forearm rotation also becomes limited. Acute osteoarthritis of the elbow is associated with painful flexion contracture which interferes with the performance of several everyday routines including washing, hair combing and brushing and eating [3, 4]. Later stages involve severe damage to articular surfaces resulting in range of motion limitation and chronic contracture [5]. Elbow joint exudates may cause compression of the ulnar nerve resulting in parasthesia and pain in the area supplied by the nerve. Elbow pathologies aggravate the dysfunction of the joints included in upper extremity kinetic chain, ie., the glenohumeral joint as well as the joints of the wrist and hand [6, 7]. Thus, limitation of elbow mobility frequently results in disability. Because the aim of the investigations was to verify the effectiveness of a simple and objective method of elbow function evaluation in patients with rheumatoid arthritis. The method was expected to help determine disease severity and to monitor disease progression.

Material and methods

The study was approved by the Bioethics Committee for Scientific Research at the Academy of Physical Education in Katowice. Eighty-two patients were recruited. The study group (Group S) comprised 42 patients. There were 26 women and 16 men aged 35 to 75 years. All participants were diagnosed with rheumatoid lesions within the elbow. Disease severity was graded with the Steinbrocker Staging System; four patients were classified under Class II, 24 under Class III and 14 under Class IV. Baseline evaluation also included the assessment of physical dysfunction the using the Mayo Elbow Performance Index. All patients scored below 60 points; 20 patients scored 55, 17 patients scored 35 and 5 patients scored 30 points.

In Group S, elbow function was examined twice, ie., at the baseline and at the end of hospital treatment (prior to and after the therapy). In order to eliminate the influence of the circadian rhythm [8], all examinations were performed at a fixed time, ie., after morning gymnastics.

During a 3-week stay in hospital all study participants also received pharmacotherapy. Thirty-three patients were treated with encorton and methotrexate. Seven patients were also given methotrexate, but, instead of encorton, used betamethasone sodium phosphate (Diprophos) or methylprednisolone sodium acetate (Solu-medrol). Along with pharmacotherapy, each patient underwent a series of physiotherapy interventions. Thirty-six patients received liquid nitrogen cryotherapy, fifteen patients underwent diadynamic therapy. Fourteen patients received ultrasound treatment, twelve patients underwent low frequency magnetic field therapy, and 10 underwent massage to facilitate tissue relaxation and improve blood supply. All participants took part in group and individual gymnastic (decompression exercises with resistance flexors and extensors of the elbow).

The control group (Group C) consisted of 40 participants including 25 women and 15 men aged 40 to 80 years. Osteoarticular diseases were ruled out by clinical history and physical examination.

The measuring station consisted of a computer-controlled apparatus for studying elbow movements (manipulandum) developed in the Motor Behavior Laboratory, University of Wisconsin-Madison, USA. The device allows the examination of elbow function during isokinetic flexion and extension. The manipulandum used in our investigations consists of a mechanical part, a movable arm fixed to a stationary base of support (Fig.1). Such a design allows easy (resistance-free) rotational movement of the manipulandum arm in relation to the base of support. A multi-rotation type linear potentiometer, with stabilized voltage supply, is attached to the axis of manipulandum rotation. Changes in mandibulandum arm position during the patient's forearm flexion and extension cause changes in the voltage signal. The signal of angular changes was sampled using a sampling frequency of 1000 Hz and stored on computer disk using the Axotape (Axon Instruments Inc., USA). After the experimental session, kinetic parameters of the movement were calculated with a specially designed

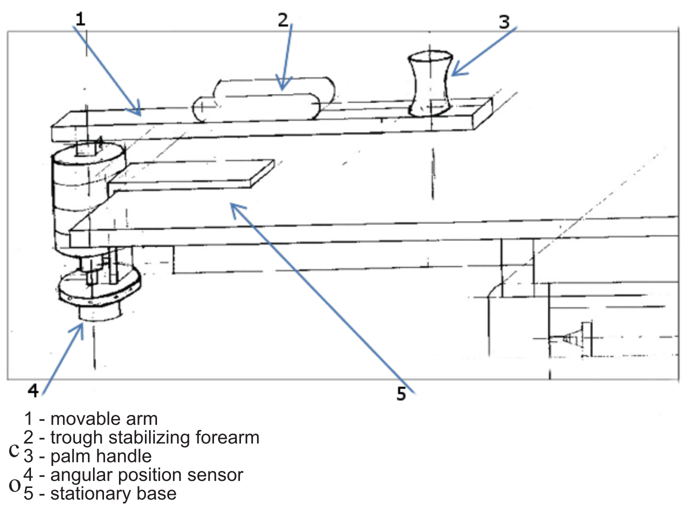

Fig. 1. Technical drawing of the manipulandum

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mputer software.

Each participant placed their right forearm on the manibulandum so that the elbow's axis ran parallel to the axis of manipulandum rotation. The forearm position was secured with a forearm and hand positioning device and hand grip. In order to eliminate the effect of gravitation on elbow movements, the upper limb was positioned horizontally. As a result, the plane of elbow movements ran vertically to gravitational forces. Gravitation effect was fully eliminated due to the properties of the measurement station.

Our study participants performed cyclic forearm extension and flexion movements with different angular velocities. The following movement speeds were studied:

• slow movement – the slowest movement possible for each particular patient,

• preferred speed movement – movement speed was consistent with patient preferences and habits,

• maximum speed movement – performed at the fastest possible speed.

Each measurement session comprised three tests (each at a different velocity) repeated three times. The interval between each test lasted 1 minute. The duration of a single session did not exceed 20 minutes.

The following movement parameters were calculated and analyzed:

• amplitude (range of elbow movements) [rad],
• movement frequency [Hz],
• duration of elbow extension [s],
• duration of elbow flexion [s],
• angular velocity of elbow extension [rad/s],
• angular velocity of elbow flexion [rad/s],
• symmetry index within a movement cycle defined as the duration of flexion to extension components within one movement cycle.

Biomechanical assessment comprised of spatiotemporal properties of cyclic movements. Spatial analysis of movement included the determination of movement direction (flexion, extension) and amplitude whereas the temporal analysis included the duration of particular movement phases as well as time-frequency analysis of a movement cycle.

Descriptive statistics was calculated for research data including the means, standard deviations, the ranges of particular parameters in the study and control groups as well as for each movement speed. In the study group, the above mentioned parameters were calculated both before and after rehabilitation interventions. The results were hypothesized to have normal distribution; the hypothesis was assessed using the Shapiro-Wilk test. If the significance value of the Shapiro-Wilk Test is greater than 0.05, the data is normal. If it is below 0.05, the data significantly deviate from a normal distribution.

Changes in movement parameters during movements performed with different angular velocities were analyzed using the Wilcoxon test for paired samples which is considered the non-parametric equivalent of the paired samples t-test.

The level of significance was set at $p<0.05$.

Results

Based on the obtained data, we evaluated the characteristics of cyclic flexion-extension movements in the elbow joint under three experimental conditions:

• slow movement,
• preferred speed movement,
• maximum speed movement.

The preliminary analysis of the research findings revealed that

RA patients experienced considerable difficulties when performing slow cyclic movements at a constant speed. Thus, slow movement did not satisfy any of the four requirements to perform a one-way ANOVA test.

1. normal distribution,
2. adequate sample size, ie., n>100,
3. variance stability,
4. linear effect of several factors (age, pharmacotherapy, rehabilitation).

Detailed analysis was performed regarding the parameters of movements performed at the preferred and maximum speed.

Our findings showed that movement frequency was significantly lower in the study group when compared to the control. The difference was most clearly seen with respect to the preferred speed movements, the mean frequencies of which were 0.35 Hz (SD 0.12) and 0.47 Hz (SD 0.16) in the study and control groups, respectively. The frequency of maximum speed movement in the study group was 0.58 Hz (SD 0.21), ie., significantly lower compared to that of control participants (0.7 Hz, SD 0.25). The Mann–Whitney U test revealed that the frequency of preferred speed movements performed by the patients was lower than that measured in the control group ($z = -2.73$, $p < 0.0007$). The mean frequency of maximum speed movements was also significantly lower in the patient

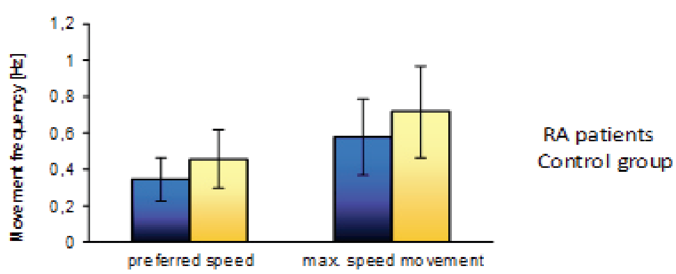

Fig. 2. Mean (± SD) values of preferred and maximum speed movement frequency in the elbow joint.

group ($z = -2.79$; $p < 0.006$)(Fig.2).

The range of motion of patient-preferred movement was 1.059 rad (SD 0.772), which value was by approximately 80% lower compared to the mean amplitude of preferred speed movement in the control group (1.824 rad, SD 0.178). The results of Mann-Whitney U test confirmed statistical significance of intergroup differences in mean amplitudes of preferred speed movement ($z = -3.81$, $p < 0.0002$). The mean amplitudes of maximum speed movement were 1.433 rad (SD 0.638) and 1.943 rad (SD 0.182) in the study and control participants, respectively. The difference between the groups was statistically significant ($z = -3.48$; $p < 0.00005$) (Fig.3).

The mean value of patient-preferred movement cycle duration was 3.40 s (SD 1.31). The corresponding value of the control group was significantly lower, ie., 2.66 s (SD 1.43). The results of Mann-Whitney U test confirmed statistical significan-

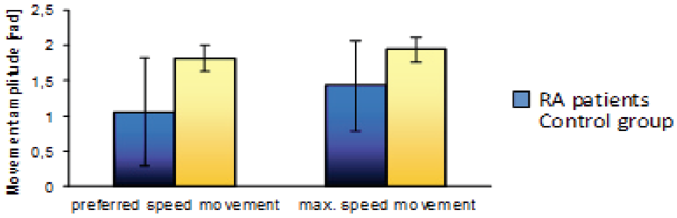

Fig. 3. Mean (± SD) values of preferred and maximum speed flexion and extension amplitudes in the elbow joint.

ce of intergroup differences (z = -2.78; p<0.006).
The mean duration of maximum speed movement cycle in RA and control participants was 1.97 s (SD 0.68) and 1.69 s (SD 0.97), respectively. The Mann-Whitney U test confirmed statistical significance of differences in mean values of this parameter between the study and control groups (z = -2.85;

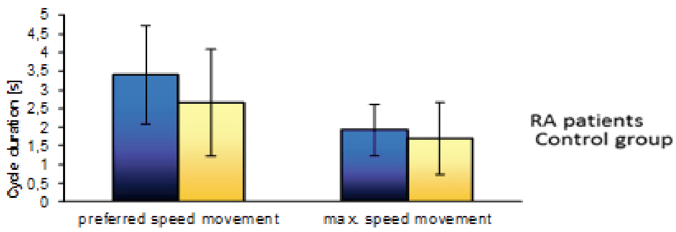

Fig. 4. Mean (± SD) values of preferred and maximum speed movement cycle duration in the elbow joint.

p<0.005) (Fig.4).
Elbow extension time during preferred speed movement was significantly shorter in control participants 1.24 s (SD 0.69) compared to RA patients 1.41 s (SD 0.78) (z = -3.31, p < 0.002). Mean elbow extension times during maximum speed movements were 0.93 s (SD 0.63) and 0.88 s (SD 0.40) in RA and control participants, respectively (z = -3.02,

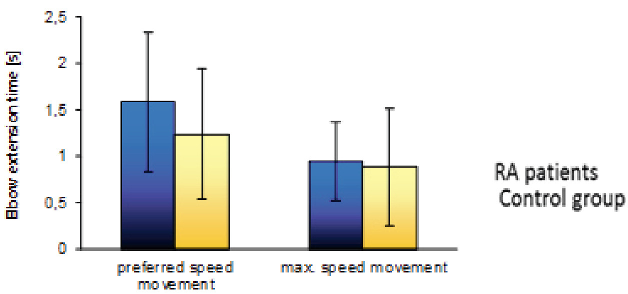

Fig. 5. Mean (± SD) times of elbow extension during preferred and maximum speed movements.

p < 0.004) (Fig.5).
Elbow extension angular velocities during preferred speed movement were significantly higher in the control (1.81 rad/s, SD 0.63) compared to the RA group (0.66 rad/s, SD 0.47). The Mann-Whitney U test confirmed statistical significance of differences in mean values of this parameter between the stu-

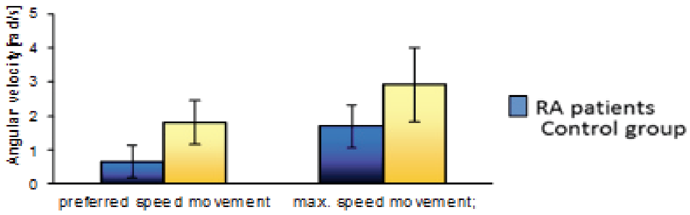

Fig. 6. Mean (±SD) values of elbow extension angular velocities during preferred and maximum speed movements.

dy and control groups (z = -4.88; p<0.000001) (Fig. 6).
Elbow extension angular velocities during maximum speed movement were also significantly higher in the control (2.9 rad/s, SD 1.08) compared to the RA group (1.7 rad/s, SD 0.63). The difference between the groups was statistically significant (z = -3.8; p < 0.0002).
Elbow flexion time during preferred speed movement was longer in RA patients (2.03 s, SD 0.62) compared to control participants (1.24 s, SD 0.49). However, the difference did not reach the level of statistical significance (z = -1.6; p < 0.11). Mean elbow flexion times during maximum speed movements were 0.98 s (SD 0.35) and 0.80 s (SD 0.37) in RA and control participants, respectively. The intergroup differences were

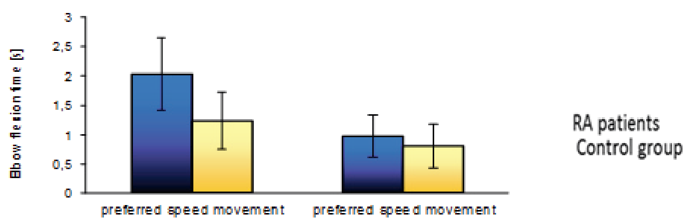

Fig. 7. Mean (±SD) times of elbow flexion during preferred and maximum speed movements.

statistically significant (z = -2.44; p < 0.02) (Fig.7).
Mean values of elbow flexion angular velocities during preferred speed movement were twice as high in the control (1.8 rad/s, SD 0.63) compared to RA patients (0.76 rad/s, SD 0.55); the difference was statistically significant (z = -5.03; p < 0.000001). Angular velocities of elbow flexion during maximum speed movements were also statistically different (z = -3.78; p < 0.0002) (Fig.8).

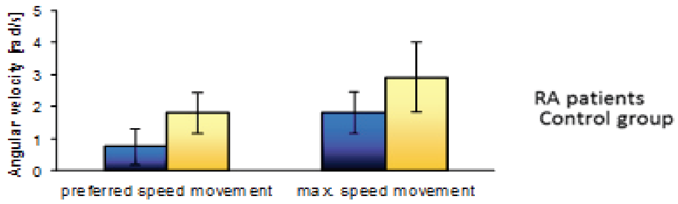

Fig. 8. Mean (±SD) values of elbow flexion angular velocities during preferred and maximum speed movements.

The mean values of symmetry index during preferred speed movement were 1.71 (SD 0.5) and 1.16 (SD 0.25) in RA and control participants, respectively. Thus, movement symmetry index was significantly higher in RA patients ($z = -2.2$; $p < 0.03$). During maximum speed movement, the values of the symmetry index were lower in both groups and amounted 1.1 (SD 0.34) and 0.99 (SD 0.14) in RA and control groups, respectively. The difference did not reach the level of statistical significance ($p < 0.34$) (Fig.9)

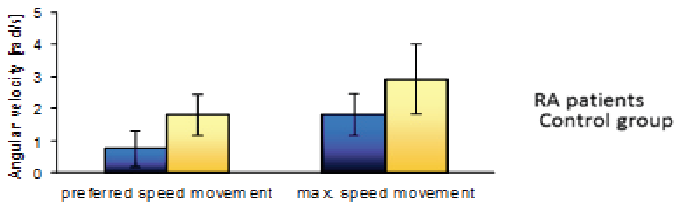

Fig. 9. The symmetry index of flexion to extension components (mean values +SD) during preferred and maximum speed movements.

Discussion

Our findings have confirmed that full range of motion and considerable dynamics of elbow movements performed with slow, preferred and maximum speeds as well as complete symmetry of flexion and extension phases are typical of healthy individuals. In contrast to the control participants, RA patients exhibited disturbances in the fluency of slow movements, flexion and extension symmetry, and a decrease in dynamic parameters of motor behavior. The speed of preferred movements was significantly lower and elbow flexion-extension range smaller compared to the control. RA was also characterized by a considerable asymmetry between flexions and extensions.

In order to account for our results, it is necessary to discuss the biomechanics and control of elbow joint cyclic movements under physiological and pathological conditions. Normal joint movements require undisturbed neural control and proper function of the locomotor system including its osteoarticular and muscular components. Movement fluency of a particular joint is affected by active and passive contributions to stiffness, damage to articular surfaces and associated increase in passive resistance mechanisms [10, 11].

The elbow complex is made up of three bones and three separate articulations enclosed inside a connective tissue capsule. The basic movements include flexions and extensions around the axis passing through the centre of the trochlea and the radial head of the humerus at the level of the medial and lateral epicondyles [12, 13, 14, 15]. The axis of rotation of the elbow is adapted for stability through a wide range of pronation-supination and flexion-extension [16]. Thus the manipulandum fulfilled the criteria of elbow joint movements testing device; the apparatus did not cause any perturbations and allowed the performance of unlimited cyclic movements.

The elbow is one of the most important joints of upper extremity kinematic chain [15]. Functional limitation not only severely affects the quality of life but also leads to disturbances in the remaining components of upper extremity kinematic chain. RA patients exhibit a decrease in muscle strength [17, 18] and efficiency [17, 18, 19] – two basic factors determining the quality of human locomotion, which is characterized by cyclic movements. Muscle strength and efficiency also regulate the speed and amplitude of cyclic movements including elbow movements. Meireles et al. studied changes in isokinetic strength in 50 patients with rheumatoid arthritis of the knee [20]. Their results indicated that knee strength parameters were decreased in RA participants compared to the control, which is fully consistent with our results.

It should be emphasized that Meireles et al. were the first to mention the asymmetry of extensor and flexor movements [20]. Our investigations revealed significantly higher values of the symmetry index in RA patients compared to the control. Although maximum speed cyclic movements performed by healthy individuals are characterized by full symmetry of the flexion / extension phases, slight asymmetry was observed during preferred speed movements carried out by our control participants. This might have been due to anatomical and functional asymmetry of elbow muscles during motor force generation [21]. In particular, the biceps brachii, whose major function is to flex the the elbow, has a considerably greater mass and physiological cross-sectional area than its antagonist, ie., the triceps muscle. Therefore, during movements against gravity (horizontal positioning of the upper extremity) flexion forces might will predominate over elbow extension forces. Rheumatoid arthritis might be expected to aggravate movement asymmetry as a result of pain and pain-related stiffness. Rehabilitation combined with anti-pain and anti-inflammatory pharmacotherapy in RA patients results in noticeable improvements in movement [22]; our findings revealed better flexion/extension symmetry and range of motion improvement.

In RA patients, muscle strength and the endurance of the elbow joint are negatively affected by several factors including intra- and extra-articular inflammatory processes, hypoactivity, reflex inhibition of the elbow muscles in response to pain and joint oedema, reduced proprioception, loss of joint stability and adverse effects of pharmacotherapy [23, 24]. The most important conclusion reached by several researchers is that physical activity alleviates motor dysfunctions in RA patients [24, 25, 26, 27]. Forced exercise interventions might slow down or even stop pathological processes [28]. Physical training has been shown to improve hand function as evidenced by improvements in grip strength [24, 29], and an increase in muscle strength [30].

Movement fluency indicates normal function and sufficient control of a motor organ. Our patients exhibited considerable difficulties in maintaining this fluency, especially during slow movements, but also during preferred speed movements. Movement fluency disturbances were hardly noticeable during maximum speed movements. Full range of motion and stability are the prerequisites for elbow movement fluency. The loss of joint stability causes pain, and, in consequence, abnormal joint function [15]. Articular pain is typical of rheumatoid arthritis; it causes excessive and uneven tension of periarticular muscles resulting in increased joint stiffness [31]. Under such conditions, cyclic movements become slower, reflex response to pain increases and, consequently, movement fluency is lost. During maximum speed movements, the control from the peripheral nervous system loses its predominance and hence movement fluency is restored. However, all cyclic movements were slower in RA patients, which might be associated with fear of movement-related pain. Therefore preferred speed movement – an indicator of the efficiency of the kinematic chain and neuromuscular control – was performed much slower and was much more restricted in our RA participants.

It can be concluded that a biomechanical analysis using a manipulandum apparatus is a valuable diagnostic tool allowing objective evaluation of elbow function in rheumatoid arthritis. The measurements are highly sensitive, and hence, if performed in a larger patient population, they might help devise a classification of movement dysfunction in rheumatoid arthritis of the elbow joint.

Conclusions

The analysis might also facilitate the assessment of hand dysfunction at various stages of RA development. Our findings strongly indicate a need for further investigations to compare the characteristics of cyclic movements with the results of other assessment techniques of elbow function in RA. Such investigations would allow more precise determination of the diagnostic value of the biomechanical analysis described in the present paper.

The results would be of considerable importance for selection of appropriate physiotherapy interventions. Interventions should still be based on passive movements, which, however, should be performed at the highest possible speed. Under such conditions, the patient is forced to concentrate on task performance and not pain-avoidance behaviour.

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