THE FUNCTIONAL INSTRUMENTAL TEST OF FLEXION-EXTENSION MOTION IN THE RADIOCARPAL JOINT: REFERENCE PARAMETERS

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ABSTRACT

BACKGROUND: *The stroke represents a significant medical-social problem due to its high morbidity and mortality with a tendency towards increasing the overall occurrence rates. A total 80% of the patients show persisting impaired functions of the upper limb. The current approaches, such as Clinical scales and Questionnaires, are being criticized for subjectivity and insufficient precision. It is necessary to develop an instrumental method for evaluating the functions of the upper limb, the method that is applicable in the clinical settings.* ***AIM:*** *To develop a functional test for the objective diagnostics of the wrist joint functions, applicable in the clinical settings.* ***METHODS:*** *A functional test was proposed for evaluating the biomechanics of the radiocarpal joint by means of using the inertial sensors. The research sample was a group of 15 healthy volunteers (5 males and 10 females aged from 23 to 33 years), not having any joint diseases or neurological disorders. The research was carried out within a period of one year (2022–2023). The primary endpoint was the determination of the amplitude, the time and the motion trajectory in the wrist joint when performing two tests — the "Wrist-0" and "Wrist-flex". An assessment was done of the duration of the motion cycle, of the motion maximal amplitude and phase.* ***RESULTS:*** *The evaluation of the upper limb functions using the clinical scales (ARAT, FMA-UE, MRC) has demonstrated, that the parameters correspond to the ones in healthy individuals. When using the "Wrist-0" test, the motion amplitude was significantly lower than in the «Wrist-flex» test (p <0.05). No statistically significant differences were found in the motion amplitude between the right and left limbs determined using both tests (p >0.05). The maximal flexion phase for the "Wrist-0" tests occurs significantly earlier than for the "Wrist-flex" test for the right hand (p <0.05). The duration of the motion cycle did not significantly differ between the tests for the right hand (p >0.05) and was significantly higher for the "Wrist-flex" test in the left hand (p <0.05).* ***CONCLUSION:*** *A set of reference values was established for the functional tests. Insignificant differences were reported for the functions of the right and left radiocarpal joints. The test proposed requires insignificant time for its implementation and it can be used for objective diagnostics of the radiocarpal joint functions in patients.*

Keywords: *cerebral stroke; upper limb; wrist joint; function; kinematics.*

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BACKGROUND

The stroke represents an important medical-social problem due to its high morbidity and mortality rates. In Russia, the annual registered number of cases reaches 170–380 cases per 100 000 of population with a total number of stroke cases being ~380 000 a year. The World Health Organization predicts an increase in the numbers of acute cerebrovascular event cases by 30% within a period until year 2025 [1].

The stroke causes the development of disorders in the motor, sensory, visual, affective, cognitive and speech aspects. About 80% of ischemic stroke survivors have persisting impaired functions of the upper limb, despite the conducted rehabilitation activities [2].

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ФУНКЦИОНАЛЬНАЯ ИНСТРУМЕНТАЛЬНАЯ ПРОБА ДВИЖЕНИЙ СГИБАНИЯ-РАЗГИБАНИЯ ЛУЧЕЗАПЯСТНОГО СУСТАВА: НОРМАТИВНЫЕ ПАРАМЕТРЫ

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АННОТАЦИЯ

Обоснование. *Инсульт представляет собой значимую медико-социальную проблему из-за высокой заболеваемости и смертности с тенденцией к увеличению общего числа заболевших. У 80% пациентов сохраняются нарушения функции верхней конечности. Существующие подходы, такие как клинические шкалы и опросники, критикуются за субъективность и недостаточную точность. Необходима разработка инструментального метода оценки функции верхней конечности, применимого в клинических условиях.* ***Цель исследования*** *— разработать функциональную пробу для объективной диагностики функции лучезапястного сустава, применимую в клинических условиях.* ***Методы.*** *Предложена функциональная проба для оценки биомеханики лучезапястного сустава с использованием инерционных сенсоров. Объектом исследования стали 15 здоровых добровольцев (5 мужчин и 10 женщин в возрасте от 23 до 33 лет), не имеющих заболеваний суставов и неврологических нарушений. Исследование проводилось в течение одного года (2022–2023). Первичной конечной точкой было определение амплитуды, времени и траектории движений лучезапястного сустава при выполнении двух тестов — «Кисть-0» и «Кисть-Сгиб». Проводилась оценка длительности цикла движения, максимальной амплитуды и фазы движения.* ***Результаты.*** *Оценка функции верхней конечности с помощью клинических шкал (ARAT, FMA-UE, MRC) показала, что параметры соответствуют показателям здоровых людей. В тесте «Кисть-0» амплитуда движений была достоверно ниже, чем в тесте «Кисть-сгиб» (p <0,05). Не найдено статистически значимых различий в амплитуде движений между правой и левой конечностями в обоих тестах (p >0,05). Фаза максимального сгибания в тесте «Кисть-0» наступает достоверно раньше, чем в тесте «Кисть-сгиб» для правой руки (p <0,05). Длительность цикла движения не отличалась достоверно между тестами для правой руки (p >0,05) и была достоверно выше в тесте «Кисть-сгиб» для левой руки (p <0,05).* ***Заключение.*** *Установлены нормативные параметры для функциональной пробы сгибания-разгибания лучезапястного сустава. Предложенная проба требует незначительного времени для проведения и может быть использована для объективной диагностики функции лучезапястного сустава у больных.*

Ключевые слова: *церебральный инсульт; верхняя конечность; лучезапястный сустав; функция; кинематика.*

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When assessing the functions of the upper limb, special attention is paid to the active extension in the radiocarpal joint, for this motion is required for grasping [3, 4] and for fulfilling the basic household activities [5, 6]; the active extension of the wrist is also the predictor of restoring the upper limb functions [7].

The main methods for the diagnostics of the upper limb functions are still the clinical scales and questionnaires. Such an approach is often criticized due to its low accuracy and high degree of subjectivity. The objective diagnostics methods are being actively researched by the scientific community, but the information on the real functioning of the upper limb is still lacking [8].

The important aspect of rehabilitation after a cerebrovascular stroke is the instrumental evaluation of the motor activity and dynamic registration of the rehabilitation using objective methods. An example of the objectivization of the upper limb movements is the video-analysis method [9–11]. Despite the high accuracy of motion capture systems, this method is relatively more costly, requiring significant amount of time for obtaining and processing the results, with the data evaluation performed only in the settings of a specialized laboratory.

As an objectivization instrument, myography can also be used. In the research by I.S. Hwang et al. [12], when using this method, it was found that the synkinesia level in the arm after a cerebrovascular stroke is related to its functionality. Despite the fact that electromyography is an important diagnostic tool for evaluating the muscle functions, the method only provides information on the electric activity of the muscles and does not allow for receiving information on the limb motion, not to mention such parameters as the motion amplitude and coordination.

The effective tool for motion registration is the goniometry method, often used during an evaluation of the motion amplitude in various joints of the upper and lower limbs [13], however, it is important to note that, as of today, the method of manual measuring the motion amplitude using the goniometer should be considered obsolete. Besides, the goniometry method allows for obtaining information about the maximal motion amplitude, but not about the motion process itself.

The inertial sensors used in the strap down navigation technology are a new generation of devices, showing high automatization degree and measurement accuracy [14, 15]. The inertial sensors were shown to be beneficial comparing to the motion video analysis method, for their use, not supposing the presence of special laboratory settings for collecting the information, requires significantly less time when preparing for testing. Recent trials have demonstrated that inertial sensors provide sufficient measurement accuracy comparing to the motion video analysis systems [16].

There are also other methods of objectivization of the upper limb functions, such as electrogoniometry and videoradiography, however, they are complex in terms of reproducibility and they are accompanied with large numbers of internal errors when performing the tests [17, 18].

Despite the significant number of high-accuracy instruments available for the evaluation of the wrist functions, there is no unified methods established at the present moment. For example, in the research by Y. Li et al. [19], a diagnostic protocol was compiled, consisting of 11 test movements for the upper limb, with the movements taken from the Fugl-Meyer Assessment scale (FMA), however, in clinical practice, its use is quite labour-intensive due to the large amount of information obtained from various sources.

During the course of their research work, C.I. Renner et al. [7], when evaluating the dynamic parameters and strength parameters of the upper limb in patients after a cerebrovascular stroke using the dynamometry and inertial sensors with its further comparison to the clinical scales, have accented the importance of dynamic parameters in the evaluation of restoring the upper limb functions, but the authors were not using the analysis of motion trajectory.

In the research by S.I. Lee et al. [20], small autonomous inertial sensors were used for evaluating the regularity of using the right and left palms in everyday household activity among healthy subjects. The proposed method, though it can be used for the evaluation of the motor functions of the upper limbs with determining multiple parameters, is more intended for quantitative evaluation of the motor functions. In turn, such parameters as amplitude, time and trajectory can be the key ones when compiling and adjusting the programs of rehabilitation activities in patients with impaired upper limb functions, nevertheless, the possibility of registering the household motions within a long-term period is very attractive.

Thus, the existing methods used for evaluating the upper limb functions, including the clinical scales and questionnaires, are criticized for their subjectivity, fragmentarity and often doubtful results, while the objective diagnostics methods include, for example, kinematic parameters, functional electromyography and motion dynamics parameters. The application of the whole set of biomechanical analysis tests appear to be a complex technical and methodical problem. Besides, the majority of devices capable of performing such a biomechanical analysis, are limited in terms of its use in the clinical settings. On the other hand, such technologies as inertial sensors allow for registering the previously inaccessible parameters, including the settings that were not previously even considered (for example, daily household activities).

The biggest problem, however, is that there is yet no unified and all-purpose method developed for

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evaluating the functions of the radiocarpal joint, while the existing methods are difficult to reproduce [21]. Upon designing such a test, it is important to keep in mind the specific features of muscle functioning and, in particular, the fact that the muscle can demonstrate significant force characteristics in the position of maximal tension [22]. Creating the all-purpose method for objective diagnostics, accessible for use in the settings of an average physician's office, could significantly promote to spreading the use of instrumental evaluation methods in private offices, in-patient departments and medical rehabilitation units.

Research aim — to develop a functional test for registering the flexion-extension motions in the radiocarpal joint with the possibility of using it in the clinical settings.

METHODS

Research design

Experimental, longitudinal, pilot research.

Conformity Criteria

Inclusion criteria: healthy volunteers without the locomotor system diseases or neurological disorders; aged from 23 to 33 years; absence of joint injuries or diseases in the past medical history; presence of written informed consent for participation in the research.

Non-inclusion criteria: presence of chronic joint diseases or neurological disorders; presence of injuries or recent traumas which may affect the functions of the upper limbs; intake of medicinal products, which may affect the motor function or kinematics; presence of cognitive disorders, which may hamper the implementation of the research protocols.

Exclusion criteria: incompliance of the research protocols or follow-up requirements; developing complications or adverse effects during the research.

Research Duration

The research was carried out during the time period from 2022 until 2023 at the laboratory of the Scientific-Research Center for Medical Rehabilitation under the Federal State Budgetary Institution "Federal Center of Brain Research and Neurotechnologies", subdivision of the Federal Medical-biological Agency of Russia.

Medical Procedure Description

Biomechanical evaluation method. For evaluating the functions of the radiocarpal joint, a functional test was developed, consisting of two tests, which include isolated wrist joint movements. For the purpose of performing the test, two inertial sensors were used, which are a part of "Stadis-Kinematika" set (Neurosoft, Russia) with attaching them to the human body using elastic bands with Velcro fasteners (Hook-and-loop), along with a personal computer with standard software installed and a writing desk with a chair.

When performing the test, the subject was positioned sitting on a chair touching the back of the chair with his trunk, with the legs bent at 90 degrees angle, with the feet firmly touching the floor surface. The writing desk was positioned on the test limb side. The forearm of the test limb was positioned on the desk at the pronated position (palm down). The sensors must be attached to the upper limb with their base facing the patient in the following way: sensor № 1 should be attached to the lateral surface and in the proximal part of the forearm (Fig. 1), sensor № 2 — to the edge of the palm. The test proposed consists of two kinematic tests — the "Wrist-0" and the "Wrist-flex".

The "Wrist-0" test should be performed at a limited amplitude and includes the extension of the wrist joint from the 0 degrees position. At the beginning of test, the wrist and the forearm of the patient are positioned on the surface of the writing desk (pronated), while the shoulder is abducted by ~20–30 degrees. Upon receiving the "Start" order, the patient needs to perform, at least, 3 (maximum -10) extension movements in the radiocarpal joint, reaching the maximum angle and following the rate chosen by the patient. The testing procedure shall be ceased upon receiving the "Stop" order.

The "Wrist-flex" test should be performed at the wrist flexion position (with the wrist freely hanging from the desk) and using the full amplitude. At the beginning of the test, the patient's forearm is positioned on the surface of writing desk at the pronated position, with the shoulder being abducted by ~20–30 degrees, the wrist is positioned at the flexing position (freely hanging from the desk). Upon receiving the "Start" order, the patient needs to perform the same number of movements as during the "Wrist-0" test, at a rate convenient for the patient. The testing procedure shall be ceased upon receiving the "Stop" order (see Fig. 1).

The software provides the following information: duration of the complete movement cycle (from the beginning of extension until returning to starting position) in seconds; the mean movement goniogram (the amplitude-time function) of the performed movement cycles; the maximal mean motion amplitude in degrees; the mean maximal amplitude phase (the time of maximal amplitude onset during the

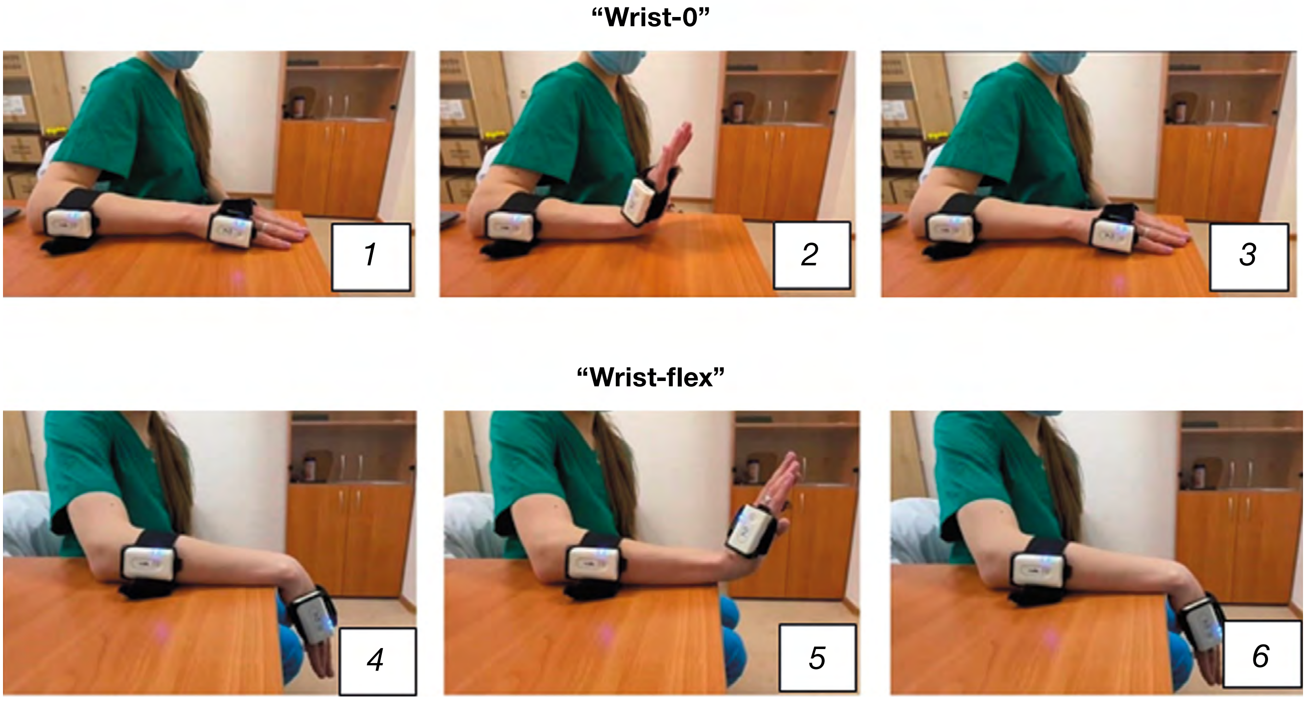

Fig. 1. The attachment of the sensors to the upper limb: "Wrist-0" test (*1* — positioning of the upper limb before the movement initiation; *2* — positioning with wrist extension; *3* — upper limb position at the end of the motion cycle) and the "Wrist-flex" test (*4* — positioning of the upper limb before the movement initiation; *5* — maximal wrist extension position; *6* — positioning of the upper limb at the end of motion cycle).

motion cycle) as a percentage (%) of the whole motion cycle time (Fig. 2).

Having two variants of the test allows for receiving more information on the functioning of the upper limb in a patient, as well as for evaluating the minimal, but conscious movements made by the patient at the position of maximal tension of wrist extensor muscles due to the effects of the palm's own weight ("Wrist-flex").

Research outcomes

The main research outcome. The obtained data include the biomechanical functional parameters of the radiocarpal joint, evaluated using two functional tests ("Wrist-0" and "Wrist-flex"). The key parameters are the motion amplitude, the maximal flexion phase and the duration of motion cycle. These parameters are necessary for achieving the research aim, for they allow for performing an objective evaluation of the efficiency of the functional tests proposed.

Additional research outcomes. Insignificant differences were found in the functions on the left and right sides.

Ethical review

The conduction of the research was approved by the local ethics committee of the Federal State Budgetary Institution "Federal Scientific and Clinical Centre for Specialized Types of Medical Care and Medical Technologies" under the Federal Medical-Biological Agency of Russia (protocol No. 11/25-04-22 dated 25.04.2022).

Statistical analysis

The processing of the obtained results was carried out using standard methods of descriptive variation statistics with calculating the median, the 25% and 75% quartiles. The "Statistica 12" software pack was

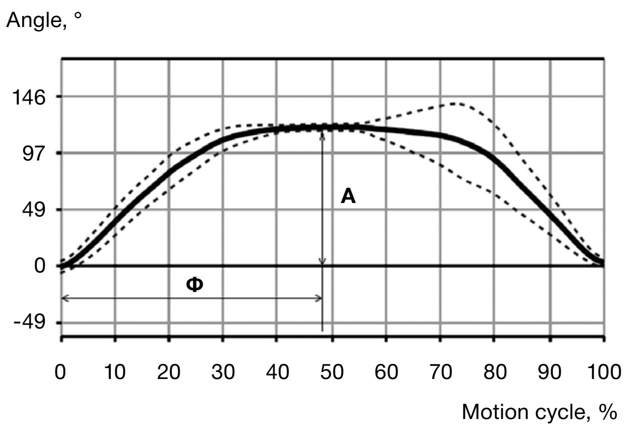

Fig. 2. Goniogram: A — motion amplitude; Φ — maximal angle phase of the flexion (within the complete motion cycle).

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used. The evaluation of the significance of differences was done using the Wilcoxon test with the $p < 0.05$. Comparative evaluation was performed for similar parameters of the left and the right wrists, as well as for the “Wrist-0” and “Wrist-flex” tests.

RESULTS

Research sample (participants)

The research included a total of 15 practically healthy volunteers, not having a past medical history of injuries or diseases of the locomotor system, of which 10 were females and 5 were males; the mean age was 26.5±3.5 (23–33) years. The informed consent was obtained from all the subjects before the research initiation. The healthy subjects did not have any diseases of the joints and did not have neurological disorders or injuries. Before the conduction of the research, all the participants had an assessment of the functions of the upper limbs using the following clinical scales: muscle strength assessment (Medical Research Council, MRC), Fugl-Meyer Assessment of Upper Extremity (FMA-UE), an assessment of motor possibilities in the upper limb (Action Research Arm Test, ARAT).

Primary findings

The results obtained when using the evaluation by means of the clinical scales are provided in table 1. As expected, they correspond to the parameters of a healthy individual.

The results for the tested parameters are provided in table 2. The motion amplitude registered when performing the “Wrist-0” test was significantly lower comparing to the motion amplitude obtained when performing the “Wrist-flex” test ($p < 0.05$). When comparing the motion amplitude in the right and left limbs, no statistically significant deviations were found for both tests ($p > 0.05$).

The maximal flexion phase during the “Wrist-0” test was registered significantly earlier comparing to the “Wrist-flex” test for the right side ($p < 0.05$). On the left side, the maximal flexion phase shows no significant differences ($p > 0.05$).

The duration of motion cycle did no significantly differ between the “Wrist-0” and “Wrist-flex” tests for the right side ($p > 0.05$), being significantly higher for the “Wrist-flex” test on the left side ($p < 0.05$).

DISCUSSION

Based on the results of the research, all the test subjects (healthy volunteers) have demonstrated the maximal points when using the clinical scales, which was the expected result.

The amplitude parameters have demonstrated complete matching between the left and the right arms in both tests, however, some differences were found in the maximal amplitude phase and in the motion duration. In particular, the maximum extension angle phase in the “Wrist-0” test occurs significantly earlier for the right side, while on the left such differences were not detected, which can indicate the presence of asymmetry in the motion control among the right-handed subjects, which corresponds to the data on the interhemispheric differences in terms of controlling the motor skills. The duration of the motion cycle for the right hand was similar for both tests, despite the presence of almost two-fold difference in motion amplitude. For the left arm, the motion cycle duration with the “Wrist-flex” test was significantly higher, which may indicate the specific features of motor activity in the left arm of the right-handed

Table 1

Evaluation of the upper limb functions using the clinical scales

Parameter	Right	Left
ARAT, points	57	57
FMA-UE, points	126	126
MRC, points	5	5

Table 2

Tested parameters of the amplitude, phase and cycle duration for the right and the left radiocarpal joints

Parameter	Right			Left		
	Amplitude, Degrees.	Phase, %	Cycle, Sec	Amplitude, Degrees.	Phase, %	Cycle, Sec
Wrist-0	79 [67; 86]*	41 [38; 45]*	1.78 [1.53; 2.46]	80 [74; 86]*	46 [39; 48]	1.85 [1.4; 2.06]*
Wrist-flex	137 [123; 156]	47 [42; 58]	2.27 [1.7; 2.57]	138 [124; 158]	43 [39; 53]	2.07 [1.74; 2.67]

Note. * Statistically significant difference comparing to the same parameter during of the “Wrist-flex” test ($p < 0.05$).

individuals. With this, the direct comparison of the same parameters in the right and left arms did not show significant differences: this allows for making a conclusion that the interhemispheric differences have a rather indirect type. The obtained data show that the interhemispheric differences were insignificant, which allows for supposing the possibility of compiling the general references for both limbs.

The research work by P.S. Santos et al. [23], just like our research, has employed similar positions of the hand and of the palm for evaluating the wrist functions, however, the main attention was paid to studying the tremors, not the characteristics of motion amplitude.

The research works headed by V. Costa [15] and M.A. Wirth [16], were also focused on the amplitude characteristics of wrist flexion-extension, and their results are comparable to ours: in particular, the parameters of wrist extension (~68° in the research by V. Costa [15] and 79° in our research for the “Wrist-0” test, as well as the value of ~126° in the research by M.A. Wirth [16] and 137° for the “Wrist-flex” test in our research) correspond to data obtained during these research. The pronated position of the wrist in our research could affect the muscle activity and the motion amplitude, especially in patients with neurological disorders. For example, the position in which the forearm is located at the table with the wrist protruding outside the borders of the working surface and experiencing tension, being parallel to the floor, like it was done by V. Costa [15], can be acceptable for healthy subjects, but it is associated with difficulties in patients with muscle weakness. Taking this into consideration, our research can be more applicable for patients with neurological disorders, for the position, in which the forearm muscles are initially in the relaxed state, better reflects the real motor capabilities. In the research work by M.A. Wirth [16], unlike our research, the wrist (during the evaluation process) was positioned with the thumb pointed upwards between the pronation and supination modes, while our research has employed the pronated positions. The position used by the authors, allows for practically ruling out the effects of the wrist’s own weight. This difference may also significantly affect the results, especially in patients with neurological disorders, for the wrist position affects the distribution of the muscle activity and movement coordination.

The amplitude parameters obtained during the research works headed by P.S. Santos [23] and M.R. Pourahmadi [24], were also similar to our “Wrist-0” test results, however, the evaluation in theses research works was carried out using accelerometers built into a smartphone. In this case, one should take into consideration the mass-inertial characteristics of the smartphone, which may hamper the conduction of the test movement in paresis patients.

As for the comparability of the results obtained during the evaluation of the biomechanical and clinical methods, the article by S. Patel et al. [25] reports high correlation between the results of evaluating the upper limb movement quality in each functional task (Functional Ability Scale, FAS) and the data from inertial sensors. A similar result was reported in terms of the ARAT and FMA tests for the upper limb in the article by M.N. McDonnell et al. [26], which shows the comparability of the data obtained using inertial sensors and the traditional clinical assessment methods.

The comparability of the data obtained using the inertial sensors and the golden standard — the motion video analysis, was evaluated for the given localization in the research by R. Pérez et al. [27]. The authors have reported high correlation between the motion analysis system based on inertial sensors and the video-analysis of the movements, which confirms the reliability of the inertial systems. However, the difference between the signals, resulting due to specific locations of placing the sensors on the clothes of the test subjects, can be the source of errors, which accentuates the necessity of strict calibration of sensors for the purpose of increasing the measurement accuracy. These data are useful for keeping in mind when developing the protocols of future research works. With this, the inertial technology allows for conducting the measurements in real life settings, which is inaccessible for video-systems.

Thus, in the healthy test subjects, the wrist position and the effects of gravity are not significant factors that limit the motion amplitude. This fact can also be used in clinical practice.

In the research works analyzed by us, the main attention was paid to the motion amplitude parameters, while the evaluation of movement cycle duration was less frequent. However, none of them contained the examples of analyzing the maximal angle phase, which constitutes an important underestimated aspect. This parameter plays the key role in the evaluation of the movement exercise quality, for it reflects the moment of achieving the maximal amplitude during the motion cycle. Besides, the analysis of the maximal angle phase allows for indirect evaluation of the degree of

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controlling of motion by a test subject at all the phases of the exercise. In particular, the synchronicity and the precision of the phase distribution within the motion may indicate the coordination of the muscle works and the presence of interhemispheric differences, which makes this parameter especially important for the objective diagnostics of motor functions.

Based on this research, reference values were obtained for the proposed functional tests. The functional tests for the evaluation of flexion-extension in the radiocarpal joint provide more detailed quantitative and qualitative information comparing to the conventional clinical scales. The test is easy to perform, it takes only several minutes and it can be implemented in everyday clinical practice for the diagnostics and monitoring of the rehabilitation of patients, for example, with paresis due to cerebral stroke.

Research Limitations

This research had a number of limitations. First of all, the small sample size (the number of test subjects). The small sample size can also decrease the statistical power of the analysis, especially when evaluating the small differences between the right and the left hand. The important direction for further research works could be increasing the sample size, which could increase the validity of the conclusions and include a wider spectrum of variations of the motor functions of the wrist in various categories of individuals.

Another limitation is that the research did not include the use of myography methods for the evaluation of muscle activity. This could provide more detailed information on muscle coordination and its contribution to the motion characteristics. In order to further improvement of the method and its implementation into clinical practice, additional research are required with using myography, which allows for more precise evaluation of the participation of the main muscles within the movement. It is also important to note that the positions of attaching the inertial sensors and the specific features of their calibration could affect the results. The individual differences in the limb biomechanics among the participants, such as anatomic features, could also affect the data, which requires additional analysis.

We suppose the future research should pay more attention to widening the sample size with including the patients having impaired functions of the wrist for more precise evaluation of the kinematic parameters and for their comparative analysis to a group of healthy test subjects. This should allow for defining the specific features of the impairment and for more precise determining the diagnostic value for the parameters, such as the maximal angle phase, the amplitude and duration of the motion cycle.

Besides, the perspective direction is the inclusion of the functional electromyography method together with the kinematic assessment. This could help determining how the muscles work during various phases of the motion, and performing a simultaneous monitoring of the muscle activity. Such an approach should provide a more complete insight on the mechanisms of motion and it should allow for comparing the kinematic data with the muscle control, which is of special importance when detecting small differences in the movement coordination and which has a great importance when working with the patients suffering from neurological abnormalities.

CONCLUSION

The reference data were obtained for the proposed functional tests of flexion-extension motions in the radiocarpal joint. The sensitivity of biomechanical diagnostics allows for obtaining the differences between the left and the right arms, with this, the characteristics of the differences allow for applying the general reference ranges.

The proposed functional test can be used for objective evaluation of the functional status and of dynamic changes in patients with neurological disorders of the upper limb and with impaired functions of the radiocarpal joint.

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