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Relationship between Movement Stereotype and Focus Location in the Early Recovery Period after Mild Ischemic Stroke

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Objectives. To study the characteristics of the movement stereotype in the early recovery period of ischemic stroke in the basin of the internal carotid artery and the vertebrobasilar system. **Materials and methods.** Eleven patients (five men, six women, mean age 57.2 ± 5.2 years) were studied 4–6 weeks after ischemic stroke. Initial scores on the NIHSS averaged 6.2 ± 0.8, with 3.9 ± 0.7/3.7 ± 0.8 points for arm/hand paresis and 4.3 ± 0.6/4.0 ± 0.5 points for leg/foot paresis. Foci were located in the basin of the internal carotid artery in seven patients and in the vertebrobasilar system in four. Investigations were run on admission and after 2–2.5 weeks. Changes on the FIM and Ashworth spasticity scales, a hand dexterity test (nine hole peg test, NHPT), and the Timed Up and Go test (TUG) were evaluated, along with changes on the Berg balance test and the 20-point vertigo scale, the MMSE, and the Beck and Spielberger questionnaires. Video analysis of movements was carried out using a Physiomed Smart system (Physiomed, Germany) using the Davis protocol. **Results.** On the background of rehabilitation measures, all patients showed decreases in the severity of paresis, improvements on the FIM, Ashworth, and Berg scales and on the NHPT and TUG tests. Patients with foci in the vertebrobasilar system, in contrast to those with foci in the basin of the internal carotid artery, had impairments to balance detected on the 20-point vertigo scale. On video analysis, all patients showed changes in the movement stereotype in the form of shortening of the length and increases in the width of the gait, with decreases in speed and lengthening of the stepping cycle; these changes were more marked for foci in the vertebrobasilar system. A distinguishing feature for foci located in the vertebrobasilar system was forward tilting of the pelvis, while lateral tilting of the pelvis was seen with foci located in the basin of the internal carotid artery. **Conclusions.** Focus location in mild ischemic stroke can affect the features of recovery and movement stereotypy, and this should be considered in rehabilitating these patients.

Keywords: ischemic stroke, hemiparesis, video movement analysis, rehabilitation, gait, stepping cycle.

WHO data indicate that neurological diseases are among the most important causes of chronic disability throughout the world; stroke is the leading of these. In 2010, 16.9 million new cases of stroke were recorded around the world – which is 68% more than in 1990. However, the number of people surviving stroke has increased by 84% since 1990, such that 33 million people survived stroke in 2010 [1]. In recent decades, most developed countries of the world have experienced a stable decrease in age-standardized mortality from stroke [2, 3]. However, the decrease in mortality is not always accompanied by satisfactory functional recovery, such that post-stroke disability persists at quite high levels [1, 3].

One of the main causes of post-stroke disability consists of disorders affecting movement functions, seen to different extents in most patients [4] and affecting social independence and the ability to work. The spectrum of motor disorders is multifarious and includes pyramidal, extrapyramidal, and cerebellar syndromes: impairments to posture and gait are particularly important.

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Gait is a voluntary, targeted action, which is controlled by the cerebral cortex of the brain [5]. The main functional unit of gait is the stepping cycle. The mean duration of the stepping cycle in natural gait is about 1 sec. The stepping cycle for each limb consists of two periods: the support phase and the transfer phase. The duration of the support phase accounts for 58–61% of the stepping cycle, while the transfer phase accounts for 42–39%. Right and left stepping cycles are discriminated on the basis of having right and left legs [6]. Voluntary gait speed is a significant and sensitive indicator of the productivity of gait [7]. The kinematic profile, especially in the sagittal plane, makes a significant contribution to gait speed. Gait parameters (gait width, the ratio of the stepping phases, the duration of the stepping cycle, joint movement amplitudes) in healthy people aged up to 60–65 years do not change significantly [8, 9].

As compared with normal people, gait in people who have had strokes is characterized by a decrease in voluntary speed, changes in the kinematic and kinetic gait profiles (ranges of movement angles at the joints, peak moment, peak power, etc.), and the patterns of movement in the different planes [10–14]. At the same time, the link between focus location and movement stereotype after stroke, especially in the absence of severe paresis, has received virtually no study. Moon et al. [15] conducted a retrospective study of patients with severe movement impairments (mean FIM score 72.4 ± 30.5 points) and found no relationship between supra- and subtentorial focus locations and impairments to balance on the Berg scale.

Detailed study of the movement pattern in post-stroke patients is needed for targeted selection of specialized rehabilitation methods. The main method used in studies of the movement system overall and the individual components of a motor act in particular is video analysis. This method allows us to study: a) the temporospatial parameters of the stepping cycle (length, width, speed, stepping frequency, the turning angle of the foot, and the percentages of the support and transfer phases); b) the kinematics of movements (spatial organization of movements at joints); c) kinetic parameters; d) the level of activity of various muscle groups and intermuscle interactions by dynamic electromyography [16]. Overall, the video analysis method throws light on the nature of the impairment to motor function and provides the opportunity for targeted rehabilitation and monitoring of the process of recovery [17–19].

Physical rehabilitation is recognized as a first-line strategy for decreasing impairments to sensorimotor function and movement disorders after stroke, stimulating the reorganization of the motor zones of the cerebral cortex, and improving functional outcomes [20, 21]. Data presented in the review provided by Pollock et al. [22] and the 2016 guidelines of the AHA/ASA [23] indicate that physical rehabilitation methods have an evidence base of IA-IIB.

The aim of the present work was to assess differences in changes in the movement stereotype in the early recovery period of mild ischemic stroke (total NIHSS score 6.2 ± 0.8) in the basin of the internal carotid artery (ICA) and the vertebrobasilar system (VBS).

Materials and methods. Eleven patients were studied during the early recovery period of ischemic stroke; patients had been directed to the second stage of rehabilitation immediately after the end of the acute period (4–6 weeks). The ischemic focus in all patients was confirmed by neuroimaging investigations. The ischemic focus in seven patients was located in the basin of the ICA and the focus in four patients was in the VBS. The group consisted of six men and five women. Mean age was 57.2 ± 5.2 years. The study included patients with decreased muscle strength to no more than 3.5–4.0 points. All patients were investigated twice: on admission and prior to discharge. The interval between investigations was 2–2.5 weeks. The main task was to clarify changes in the movement pattern and the gait pattern for lesion foci in different locations.

On admission and prior to discharge, all patients underwent clinical observations and investigations using scales. The severity of neurological deficit was assessed using the National Institutes of Health Stroke Scale (NIHSS). Changes on the Functional Independence Measure (FIM), the six-point paresis severity scale, the modified Ashworth spasticity scale, the nine hole peg test for hand and finger dexterity function, the timed up and go test (TUG), the balance and stability scale (Berg test), and the 20-point vertigo scale were monitored. Mental status was also assessed on the Mini Mental State Examination (MMSE), depression on the Beck scale, and anxiety on the Spielberger scale.

Video movement analysis was run using the specialized Physiomed Smart laboratory (Germany) fitted with a SMART-D precision high-resolution digital optoelectronic system for analysis of all types of movements. Studies were carried out twice, on days 2 and 14 after admission to hospital. The video movement analysis method is based on contactless computerized analysis of movements. Using the Davis protocol, 22 light-reflecting probes of size up to 20 mm were attached, and signals from these were recorded using 10 main digital cameras, along with three video cameras for additional video frames. The cameras had high-sensitivity detectors and a scan rate of 100 scans/sec (100 Hz), which is many times greater than the frequency spectrum of angular displacements in normal movements. All cameras were synchronized and were controlled using a local computer network for sending data to the computer and subsequent processing. For the videos, patients were told to walk along a marked locomotor lane with their usual gait at a comfortable speed, completing 3–5 sequential cycles. Movements were recorded and reports were generated for analysis of the kinematic characteristics of the movements. These investigations produced “individual movement patterns.”

The study results were processed using SPSS 22.0. Descriptive statistics were presented as means (M) and standard deviations (SD), as well as medians (Me). Pairs of

TABLE 1. Changes in Movement Activity, Coordination, Balance, and Mental State in Study Patients (M ± SD)

Scale	Normal	Basin of ICA (n = 7)		VBS (n = 4)	
		admission	discharge	admission	discharge
FIM scale	126 points (max)	117.1 ± 4.3*	120.8 ± 4.6* **	119.3 ± 7.5*	123.2 ± 3.6* **
Severity of paresis					
Upper limb					
proximal	5 points	3.9 ± 0.7	4.3 ± 0.4	4.1 ± 0.9	4.4 ± 0.6
distal	5 points	3.4 ± 0.9	3.7 ± 1.1	3.9 ± 0.8	4.1 ± 0.9
Lower limb					
proximal	5 points	4.3 ± 0.3	4.4 ± 0.2	4.3 ± 0.6	4.5 ± 0.4
distal	5 points	4.1 ± 0.4	4.3 ± 0.4	3.9 ± 0.8	4.2 ± 0.6
NHPT scale – paretic limb	18–20 sec	48 ± 33*	29 ± 8*	25 ± 5	24 ± 5
TUG test	<10 sec	12.7 ± 1.4*	11.7 ± 1.3* **	15.2 ± 2.8*	13.1 ± 1.7* **
Berg scale	56 points (max)	50.3 ± 2.1*	53.0 ± 1.4* **	49.3 ± 3.2*	51.3 ± 2.6*
20-point vertigo scale	0–4 points	–	–	7.8 ± 0.5*	6.5 ± 1.3* **
MMSE	28–30 points	29.0 ± 0.6	29.3 ± 0.8	28.5 ± 1.0	28.8 ± 0.9
Beck scale	0–9 points	15.5 ± 8.1* #	10.1 ± 5.2* # **	11.5 ± 5.5	10.5 ± 4.3
Spielberger scale	<30 points low level of anxiety disorder				
endogenous anxiety		49.0 ± 9.6* #	41.3 ± 7.8* # **	38.2 ± 2.8* #	36.4 ± 2.6* #
situational anxiety		52.2 ± 6.1* #	47.5 ± 6.2* # **	44.7 ± 5.3* #	44.2 ± 7.4*

*Significant differences from normal, $t > 2.57$, $p < 0.039$; #significant differences between groups with lesions in the ICA and VBS, $t > 2.83$, $p < 0.027$; **significant differences in dynamics, $t > 2.49$, $p < 0.041$.

independent groups were compared using the t test for independent sets; linked groups were compared using the t test for paired (linked) sets. Differences were regarded as statistically significant at $p < 0.05$.

Results and discussion. The mean NIHSS score on admission was 6.2 ± 0.8 points (6.1 ± 0.7 points for lesion foci in the ICA and 6.3 ± 0.9 for those in the VBS). The total score on the FIM ranged from 110 to 121 for foci in the basin of the ICA and from 108 to 122 for foci in the VBS (Table 1); there were no significant differences between these groups. On discharge, there were significant improvements as compared with admission on analysis for the whole group ($t = 3.85$, $p = 0.004$) and for groups with stroke in the ICA system ($t = 3.56$, $p = 0.016$). There were no significant improvements on the FIM in patients with stroke in the VBS ($t = 1.79$, $p = 0.17$), which is probably associated with the small number of observations in this group. At the same time, it should be noted that each patient in this group, as in the group with stroke in the basin of the ICA, showed increases in scores on the FIM, reflecting the efficacy of the rehabilitation measures used ($r = 0.97$, $p = 0.032$ and $r = 0.83$, $p = 0.042$, respectively).

Studies of the dynamics of movement impairments in both groups revealed significant increases in strength in the arm and leg ($t > 2.41$, $p < 0.026$). The initial NHPT was performed worse in patients with foci in the ICA, due to more marked paresis in the hand ($t = 1.92$, $p = 0.085$). Positive but non-significant changes were seen by the end of rehabilitation (see Table 1).

Spasticity is another serious consequence of stroke. Spastic increases in muscle tone are seen in the first weeks after stroke in 21–25% of patients [24]. Initially, four patients with stroke in the ICA showed increased muscle tone to 1 point on the Ashworth scale, which decreased to 0 points on the background of rehabilitation exercises.

Regardless of the locations of ischemic strokes, assessments using the TUG test showed that all patients took more than the normal amount of time (≤10 sec) but stayed within the threshold of 20 sec, indicating retention of independent movement but with an increased risk of falls [25]. Patients with stroke in the ICA performed this test better than those with foci in the VBS – $t = 2.06$, $p = 0.069$ (see Table 1). Regardless of which basin contained the focus, there were improvements in performance of the TUG test, with significant differences for all groups ($t = 3.28$, $p = 0.000$) and for the group with stroke in the ICA ($t = 2.74$, $p = 0.041$). In the group of foci located in the VBS, there was a tendency to

TABLE 2. Temporospatial Parameters of the Stepping Cycle Stratified by Stroke Focus Location (M ± SD)

Parameter	ICA (n = 7)		Normal	VBS (n = 4)	
	healthy side	paretic side		healthy side	paretic side
Step length, m	0.55 ± 0.05*[#]	0.53 ± 0.06*[#]	0.73 ± 0.12	0.47 ± 0.09*[#]	0.42 ± 0.09*[#]
Step width, m	0.17 ± 0.03*		0.11 ± 0.03	0.19 ± 0.02*	
Step speed, m/sec	1.07 ± 0.18*[#]	1.08 ± 0.17*[#]	1.39 ± 0.37	0.82 ± 0.16*[#]	0.78 ± 0.19*[#]
Step frequency, steps/min	108 ± 8*[#]		113 ± 4	98 ± 7*[#]	
Transfer speed, m/sec	2.37 ± 0.38*	2.48 ± 0.30*[#]	3.31 ± 0.14	2.05 ± 0.17*	1.76 ± 0.47*[#]
Support phase, %	60.6 ± 1.4	61.3 ± 1.6	60%	64.2 ± 5.4	59.3 ± 0.7
Transfer phase, %	38.9 ± 1.4	39.1 ± 1.7	40%	36.3 ± 5.7	40.4 ± 0.3
Support phase, sec	0.61 ± 0.08[#]	0.68 ± 0.05	0.63 ± 0.11	0.81 ± 0.12*[#]	0.75 ± 0.06*[#]
Transfer phase, sec	0.40 ± 0.05[#]	0.42 ± 0.04[#]	0.43 ± 0.13	0.46 ± 0.02[#]	0.47 ± 0.03[#]
Stepping cycle, sec	1.16 ± 0.08*[#]	1.13 ± 0.06*[#]	1.05 ± 0.15	1.27 ± 0.10*[#]	1.22 ± 0.07*[#]

*Significant differences from normal, $t > 2.32$, $p < 0.046$; [#]significant differences between groups with lesions in the ICA and VBS, $t > 2.5$, $p < 0.033$.

significant differences ($t = 2.19$, $p = 0.12$), which can be explained by the small number of cases. At the same time, each patient in this group with a TUG test time of greater than 10 sec showed improvements, reflected in the high correlation between TUG test scores on admission and discharge ($r = 0.96$, $p = 0.036$).

Initial values on the Berg scale showed no differences between groups with foci in the ICA and VBS (see Table 1) and identified that patients were independent of assistance for movement. All patients with stroke in the ICA demonstrated significant improvements ($t = 6.32$, $p = 0.001$). Patients with stroke in the VBS showed positive but non-significant changes on this test ($t = 1.86$, $p = 0.066$), which may be due to the small number of cases.

Patients with stroke in the VBS, in contrast to those with foci in the ICA, showed dysfunction of the vestibular system in the form of impaired coordination, balance, and maintenance of posture, which was not detected on the Berg scale but was diagnosed on the 20-point vertigo scale – 7.8 ± 0.5 points (see Table 1). These impairments decreased with treatment – 6.5 ± 1.3 points ($t = 2.61$, $p = 0.082$) but did not reach the upper boundary of the normal range (see Table 1).

MMSE results indicated that cognitive impairments were not present. Investigations using the Beck questionnaire identified mild depressive disorders in all patients, which on admission were more marked in patients with foci in the ICA (see Table 1). Significant improvements on the Beck questionnaire were seen only in the group with foci in the ICA ($t = 2.78$, $p = 0.039$). Assessment of anxiety on the Spielberger scale showed that initially, patients with foci in the ICA had higher levels of anxiety ($t = 2.84$, $p = 0.02$), especially situational, than patients with foci in the VBS (see Table 1). Both groups showed decreases in endogenous and situational anxiety, more marked in patients with foci in the ICA, but not reaching statistical significance ($t < 2.21$, $p > 0.077$).

Temporospatial parameters of the stepping cycle and focus location. Video analysis showed that regardless of focus location, there were significant reductions in step length and speed from normal values, with the result that the stepping cycle increased (Table 2), which is consistent with results from previous studies [10, 13, 14]. Assessment of the effects of focus location on step length revealed significant between-group differences for patients with strokes in the ICA and VBS for both the paretic and healthy limbs. Steps were shorter on the paretic and healthy sides in patients with foci in the VBS than in in those with foci in the ICA – $t = 2.46$, $p = 0.036$ and $t = 1.93$, $p = 0.085$, respectively (see Table 2). Analogous differences were noted in step speed and frequency, which were significantly smaller for both the healthy and paretic limbs in patients with stroke in the VBS ($t > 3.41$, $p < 0.011$). In addition, patients with foci in the VBS had a tendency to lengthening of the stepping cycle for both the healthy and paretic limbs ($t > 1.87$, $p < 0.092$).

The next major parameter of the stepping cycle is gait width (base). Gate width determines stability on walking. A typical reaction to stroke is an increase in gait width, pointing to impaired balance and providing better stabilization [10, 14]. Step width in both variants of stroke location increased significantly as compared with normal: $t > 3.72$, $p < 0.003$ (see Table 2). Strokes located in the VBS produced a slightly greater increase in gait width than those in the ICA. Video analysis showed that the increase in gait width for foci in the ICA was linked mainly with a decrease in muscle strength, while for strokes in the VBS it was linked with decreases in postural control and postural motor function. Thus, patients with stroke in the VBS had greater impairments to the ability to stabilize the body's center of gravity

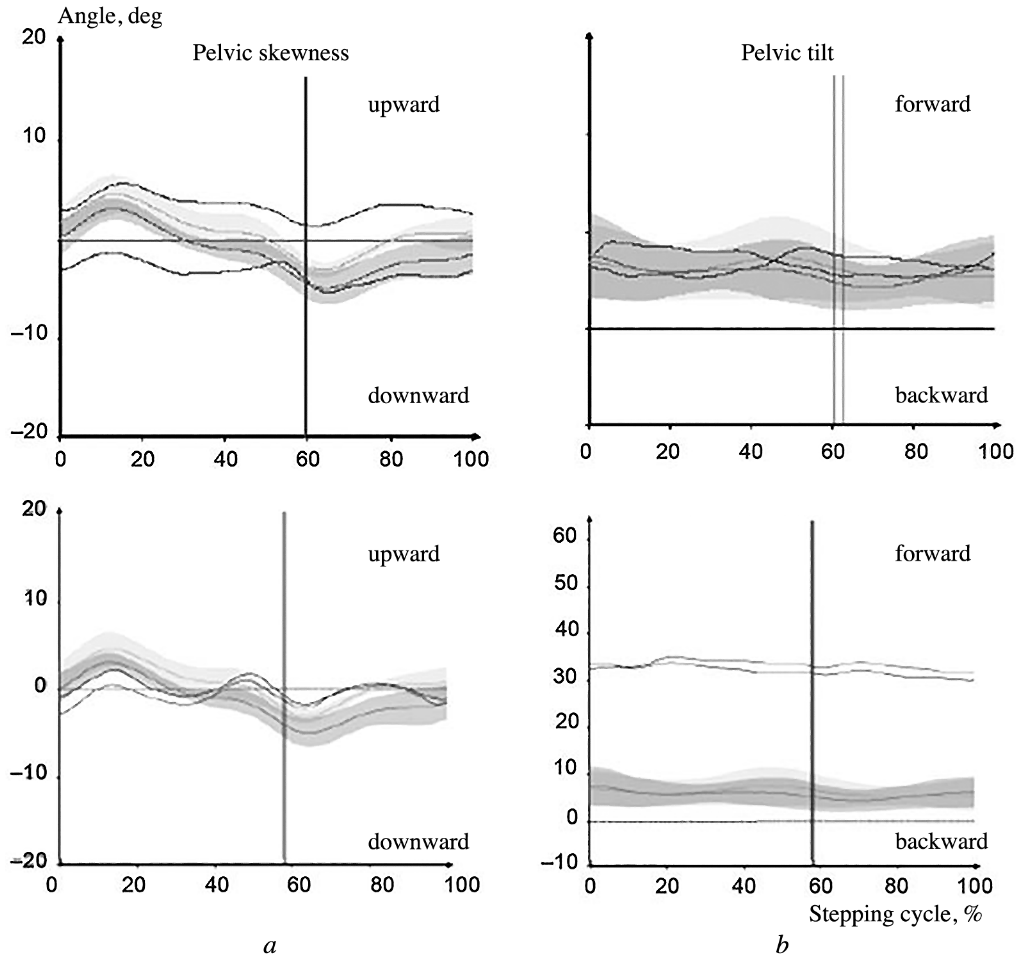

Fig. 1. Changes in pelvic movements in the sagittal and frontal planes. *a*) Stroke in ICA; *b*) stroke in VBS. Abscissa – duration of stepping cycle (%); ordinate – angle of pelvic deviation (deg). The normal range of movements for each plane is shown in gray; patients' results are shown as thin lines.

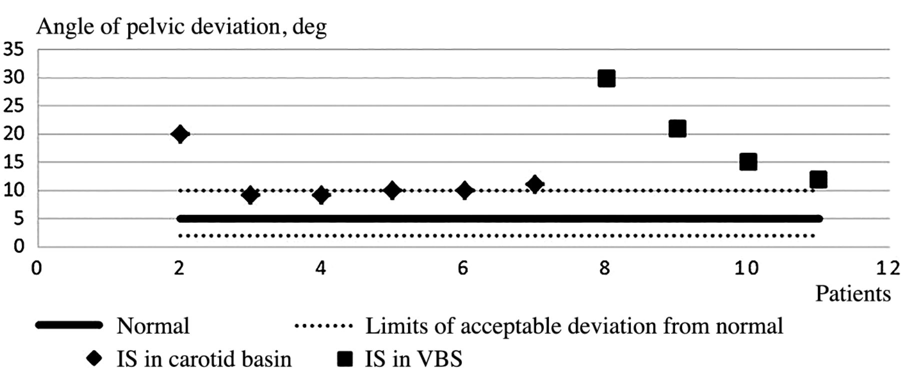

Fig. 2. Pelvic deviation in the sagittal plane (forward) for foci in the basin of the ICA and the VBS. aCVA – acute cerebrovascular accident.

on dynamic movements, predict the position of the center of gravity (centering), and retain the relationship between body segments for balance than patients with stroke in the ICA.

Analysis of measures of the durations of the components of the stepping cycle showed an increase in the duration of the support phase for the paretic limb, an increase in the duration of the stepping cycle, and a decrease in the stepping frequency per minute as compared with normal, which is due to decreases in the step speed and/or frequency (see Table 2). These changes were significantly more marked in patients with stroke in the VBS than in those with foci in the ICA ($t > 2.73, p < 0.038$).

Kinematic parameters of the stepping cycle and focus location. During the stepping cycle, the normal pelvis makes movements in the frontal plane with an amplitude of about 4°. Patients with stroke in the ICA showed tilting of the pelvis: on the paretic side, the pelvis was elevated above the healthy side by an average of 1.5° (Fig. 1, *a*). Forward displacement of the pelvis in the sagittal plane was by no more than the upper limit of normal (Fig. 1, *b*; Fig. 2). Conversely, patients with stroke in the VBS showed marked forward displacement of the pelvis (the angle of deviation from normal was greater than 15°), which suggests displacement of the center of gravity and instability. Forward positioning of the pelvis was probably due to dysfunction of the thigh flexor muscles (the muscles tensioning the fascia lata of the thigh) and the extensor muscles of the hip joint (gluteus maximus and gluteus minimus), whose functions are to stabilize the pelvis in the sagittal plane. Hypofunction of the hip joint extensors is also indicated by the extreme flexion of the hip joint with inadequate extension in the sagittal plane.

Conclusions. Rehabilitation of patients with neurovascular pathology is one of the most difficult of medical and social tasks. The aim of rehabilitation programs is to improve the patient's movement activity. The efficacy of physical exercise is comparable with that of medications as long as the exercise is individually prescribed, targeted, with safe and fractionated intensity, frequency, duration, and type of training. Heavily repeated physical exercise promotes formation of new neuronal connections and stimulates various plasticity mechanisms [26].

The gold standard for studies of movements is video analysis. The video analysis method provides clear definition of the nature of impairments to motor functions and supports monitoring of recovery [16, 17].

The results of previous studies show that most parameters of the stepping cycle, including step length and width, joint movement amplitudes, and others have no specific age-related differences to age 60–65 years in healthy subjects [8, 9]. As the mean age of the patients in the present study was 56.7 ± 6.8 years and that the history and clinical examination revealed no symptoms of chronic movement disorders, we can conclude that stepping parameters in both legs were normal before onset of illness.

Analysis of the present results shows that patients with stroke and even minor levels of paresis have significantly altered gait patterns, with changes to the synergism of the different groups of muscles. These changes were confirmed by dynamic electromyography, which demonstrated "tonic" muscle activity throughout the movement cycle, with asymmetry between the paretic and healthy sides even when there was no clinically detectable paresis [27]. Our studies also noted deviations in the temporospatial and kinematic parameters of the step. Patients showed abnormalities of joint movements, displacement of the center of gravity, and an increase in step width. Furthermore, impairments to muscle function and postural motor function altered the posture of the lower limb during movements.

The study results showed that changes in gait parameters after stroke can be divided into general and specific changes, the latter linked with a particular basin. Common stroke basin-independent changes affected gait speed due to step length and width and the corresponding increase in the duration of the stepping cycle. Specific changes linked with strokes located in the VBS included more significant increases in step width and marked forward displacement of the pelvis due to decreased postural control and degraded postural motor function and balance. These changes were combined with more marked deviations from normal in execution of the TUG test and assessment on the 20-point vertigo scale and reflected increases in instability and the risk of falling. Comparative analysis of the Berg scale and the 20-point vertigo scale showed that the latter was more sensitive, such that it can be recommended for determining the extent of vestibular dysfunction when there are no marked changes on the Berg scale. One feature of stroke in the ICA was asymmetry of the pelvis, with elevation on the paretic side by a mean of 1.5°. Forward displacement of the pelvis was within the upper limit of the normal range and was significantly different from displacement in patients with stroke in the VBS. Our data on the relationship between post-stroke movement impairments and the locations of ischemic foci correlate with results from studies reported by Lee et al. [28], whose fMRI scan results revealed differences in the recovery of functional relationships controlling movements and balance in patients with lesions with supra- and subtentorial locations. It is important to note that stroke severity on the NIHSS as reported by Lee et al. [28] and in our study were comparable: 5.9 ± 2.6 and 6.2 ± 0.8 points, respectively. At the same time, our results differed from results reported by Moon et al. [15], who found no differences in changes in gait speed or retention of balance between groups with supra- and subtentorial strokes. These differences can be explained on the one hand by the significantly more severe movement impairments in the study reported by Moon et al. [15]. Mean FIM scores on admission and discharge were 57 ± 24/72 ± 30 [15], compared with our values of 118 ± 6/122 ± 4, respectively, $t > 5.42$, $p = 0.000$. It should be noted that severe movement disorders can mask balance problems. On the other hand, our video analysis identified finer movement and balance impairments which were not detected on the Berg scale.

It should be noted that the healthy side is involved in compensating for movement asymmetry virtually from the first month of the post-stroke recovery period, so rehabilitation programs need to pay attention to the healthy side as well as the impaired side. The healthy side, compensating for and to some extent reproducing the pathological stereotype of the paretic side, carries a greater load in the transfer phase, which can lead to the development of pain in the knee and hip joints and alter spinal biomechanics.

Thus, determination of kinematic and kinetic movement parameters in patients in the early post-stroke rehabilitation period by video analysis provided objective evaluation of the movement pattern and determination of target indicators for rehabilitation strategies directed to increasing movement effectiveness. In addition, these results point to the value of differentiating rehabilitation programs in relation to the locations of the vascular process, even when paresis is identical in terms of severity; they also support including balance and postural control training exercise in patients with strokes in the VBS, including work on the sensory pathway to improve/restore the temporospatial parameters of the stepping cycle.

The authors have no conflicts of interests.

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