

Posturographic study of the human body vibrations for clinical diagnostics of the spine and joint pathology

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1. Introduction

Body sway at different stances can be detected in every individual and it is peculiar to normal healthy state. The most accessible and common method of detection of the sway parameters is the measurement of the position of the centre of pressure (COP) using the force platform. Computerized posturography is widely used as a convenient test for the diagnostics of different musculoskeletal, vestibular, nervous, auditory and visual pathology, age-related changes and even the emotional state of an individual [1-5]. The posturographic data can be used for the elaboration of control systems of mobile robots [6].

The variety of posturographic tests has been proposed for early diagnostics of pathology, the state of a patient before and after surgery operations and estimation of the treatment success [7], and as an alternative approach to the vestibular functions assessment. The patient can keep a quiet stance on the stable platform or try to keep the balance on the moving or unstable support. The dynamical curves $X(t)$, $Y(t)$, $Z(t)$ which are the coordinates of the COP of the human body can be obtained during any quiet stance on the force platform. Basing on the measurement data the trajectories $Y(X)$ of the projection of the centre of mass onto the horizontal plane and some other curves can be calculated and analyzed as well as the 3D trajectories $Z(X, Y)$. Usually a quiet two-legged stance is tested. As it was shown in our previous papers the comparative study of the two-legged and one-legged and some other stances can be used for the diagnostics of different pathology [3, 4, 8].

The problem of separation and biomechanical interpretation of different sway patterns and finding out the appropriate diagnostic parameters is important because various sway patterns have been found at different sensory organization and the motor control tests and associated with a variety of organic balance disorders [9]. As it was shown by vast measurements, an increase in the sway amplitude is the main prognostic parameter of different pathology and disorders [9]. In some tests the amplitude increased in sagittal (anterior-posterior direction) or in coronal (medial-lateral direction) planes or/and at special test conditions. For instance, the toxic effect of occupational and environmental neurotoxicants on vestibular, cerebral and spinocerebral functions of the workers and citizens can be revealed by posturographic analysis of the body sway [10]. Computerized dynamic posturography can accurately identify and document nonorganic sway patterns during

routine assessment of posture control [11]. The set of adequate tests for revealing real balance disturbance and the suspected "malingering" individuals has been found [11].

Posturography is also used in the studies of balance control by the nervous and vestibular systems. Sound-evoked activation of the vestibular system and the resulting postural responses lead to increasing of the body sway in the coronal plane at low and middle frequencies and in the closed-eyes condition [12]. It means these frequency ranges are mainly under vestibular control. Visual control of the body position is an important component of the nervous control and the test with open and closed eyes is simple to be carried out.

The symmetry of the body position is an important aspect of the problem. In healthy subjects the COP during the quiet two-legged stance lies along the sagittal axis of the body and can be slightly shifted from one foot towards another during the quiet stance. In patients with spastic hemiparesis the COP is usually shifted toward the unaffected limb and this asymmetry is present also during gait [13]. Thus the quiet stance asymmetry is different in right- and left-sided hemispheric lesions, and the changes are correlated with the degree of the stance asymmetry. Nevertheless patients with marked compensated scoliosis can exhibit high-level symmetry of the COP position, so the problem of separation of the healthy individuals and subjects with spine disorders remains topical.

In the present paper the postural balance of the healthy volunteers and the patients with some spine and joint pathology has been studied by posturographic examination of their 2-legged and 1-legged quiet standing with opened and closed eyes.

2. Materials and methods

Measurements were carried out in the Laboratory of Biomechanics M.I. Sytenko Institute of Spine and Joints Pathology (Kharkov, Ukraine). 30 young healthy volunteers without nervous or musculoskeletal disorders were examined as a control group (13 men, 17 women; mean \pm SD: age = 26 ± 3 , height = 172 ± 8 cm, and body weight = 75.3 ± 14.4 kg). A group of patients with osteochondrosis (15 men and 15 women; age = 54 ± 24 , height = 170 ± 8 cm, and body weight = 78.2 ± 12.3 kg) and with coxarthrosis (12 men and 18 women; age = 57 ± 23 , height = 169 ± 9 cm, and body weight = 77.34 ± 14.3 kg). That groups were chosen because of the topical clinical problem

of separation of the spine and joint pathologies which are often combined. The four reaction forces $F_{1l}, F_{2l}, F_{1r}, F_{2r}$ (Fig. 1) were measured by force platform (Statograph-M05/28), where $F_{1l} + F_{2l} + F_{1r} + F_{2r}$ is body weight. Each individual performed a series of tests including 30-s quiet comfortable two-legged standing with open eyes and arms pressed to the sides of the body, then 30-s two-legged standing with body weight shifted onto the right and then onto the left leg. Then the person was asked to make a step forward off the platform with his/her right leg, then come back onto the platform and repeat the step with his/her left leg. The corresponding trajectory $Y(X)$ of the COP of the body motion was registered by the force platform [4, 8]. The sets of tests are used in the laboratory of biomechanics in everyday clinical practice in diagnostics of the patients with different musculoskeletal disorders in M. I. Sytenko

Institute of Spine and Joints Pathology. After the 10 minutes rest a patient was asked to repeat the same tests with closed eyes. Similar tests have been examined for the healthy volunteers in the morning and after their working day [4]. The obtained curves are subject to some variability, but possess the same general patterns which have been revealed by statistical analysis of the data measured for the same groups during a week.

The lengths of the body segments have been measured for each individual to be able to use a mathematical model of the human body as an inverted multilink pendulum developed in [3]. The mass, moments of inertia and position of the centre of mass of each segment have been then determined using the statistical anthropometric data [14, 15]. The body weight and the lengths of the legs were found to be important determinants of the human body motion [16].

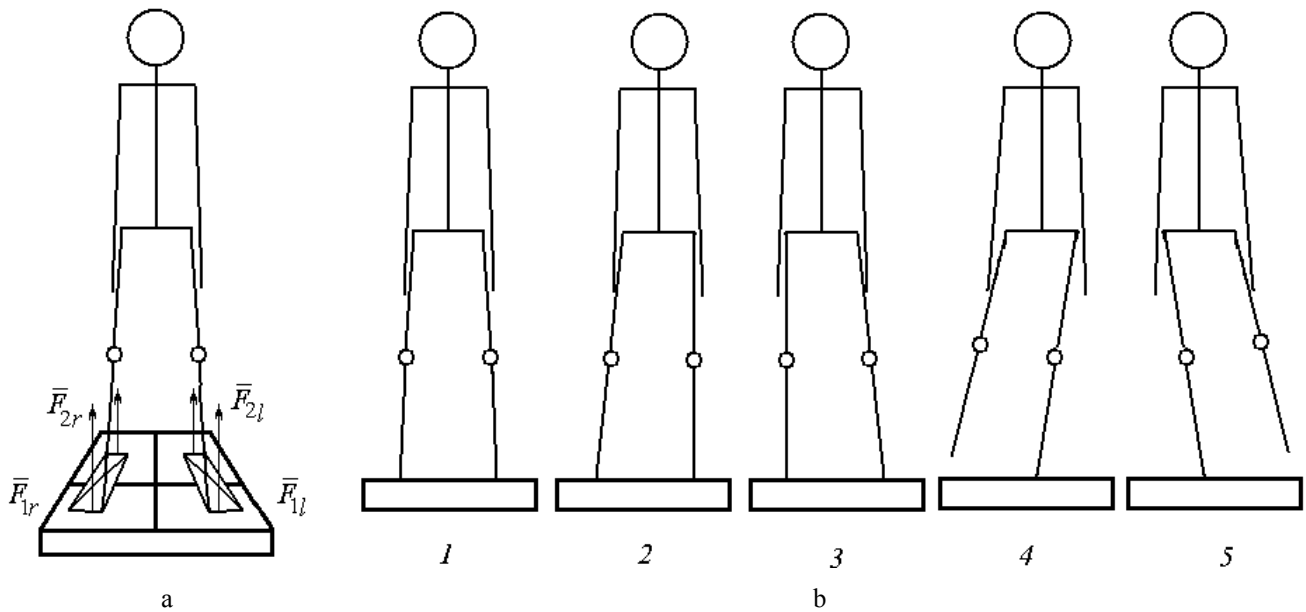


Fig. 1 Force platform with 4 separate measurement units (a) and the examined stances (b): 2 - legged stance (1), 2 - legged stance with the body mass shifted onto the left (2) and right (3) leg, 1 - legged stance on the left (4) and right (5) legs

3. Results and discussions

The calculated time series $(X(t), Y(t))$ have been amplified and the low ($f < 0.01$ Hz) and high ($f > 10$ Hz) frequency components have been subtracted using the 6th order Butterworth filter. The first two-second portions of the data series have been deleted for diminishing the numerical errors [11]. The examples of the trajectories $Y(X)$ are presented in Fig. 2.

Normal position of the COP during the 2 - legged stance is placed close to the Y -axis. When the body weight is shifted, the COP moves toward the bearing leg (Fig. 2, a), while some unusual locations of the COP have also been detected for the young healthy patients [3, 4, 11]. When a healthy person makes a step off from the platform, three different parts can be distinguished on the trajectory. First of all, the body is gradually shifted in the posterior direction for producing some initial acceleration, which can be revealed on the small loop in the initial part of the trajectory (Fig. 2, b). When a visual control is accessible

and the person can estimate the distance to be stepped over, the initial loop is quite small. Then the COP moves towards the bearing leg and the trajectory is close to the straight line. The third part of the trajectory is in anterior direction and shows the body motion straight ahead.

Some results of the tests for the patients with osteochondrosis and coxarthrosis are presented in Fig. 3 and Fig. 4. The patients with osteochondrosis exhibit bigger sway amplitudes. The maximal and minimal values of $Y(X)$ are estimated for each test and the sway amplitudes in the coronal ($Ampl_X$) and sagittal ($Ampl_Y$) planes have been calculated as

$$Ampl_X = \max\{X(t)\}_t - \min\{X(t)\}_t$$

$$Ampl_Y = \max\{Y(t)\}_t - \min\{Y(t)\}_t$$

The rectangles in Figs. 3, a and 4, a correspond to the maximal and minimal valued of the coordinates during the test. The sway amplitude can be calculated as

$Ampl = \sqrt{Ampl_X^2 + Ampl_Y^2}$ and determined by the diagonal of the corresponding rectangle. As it was revealed by analysis of the measurement data, the angles formed by the segment connecting the centers of the rectangles and the Y -axis can be used for the diagnostics of spine and joint pathology. The diagonal displacement of the centers of the three rectangles ($\varphi_l < \pi/2, \varphi_r > \pi/2$) is proper to the patients with coxarthrosis (Fig. 4, a). The patients with osteochondrosis exhibit displacement of the COP in the posterior direction while they shift their body weight onto one of the legs ($\varphi_{l,r} < \pi/2$) (Fig. 3, a).

Step off the platform is started with a significant displacement of the COP in the posterior direction when the body possesses some initial acceleration (segments OA_l, OA_r in Fig. 3, b). The second stage of the step is characterized by prominent motion in the anterior-lateral direction (segments $A_l B_l, A_r B_r$) followed by a rapid displacement into the posterior-lateral direction (segments $B_l B_l, B_r C_r$). As a result the segments A_l, B_l, C_l, r are convex in patients with osteochondrosis while it is straight in the healthy subjects (Fig. 2, b). Apparently the body acceleration achieved during the first stage (seg-

ments $OA_{l,r}$) is too big and the body moves past the target direction AC , so the control mechanisms correct the mistake changing the motion from the anterior-lateral to the posterior-lateral direction. Patients with joint pathology can exhibit normal trajectory when they step off standing on the healthy lower extremity (curve 2 in Fig. 4, b). When a patient transfers the body weight onto his injured extremity the trajectory is complex and possesses some loops, concave and convex segments (curve 1 in Fig. 4, b).

The averaged values of the sway amplitudes in the anterior-posterior and medial-lateral directions are presented in Table. Standard sway amplitude is $Ampl = 0 - 20$ mm and it can be significantly bigger for the patients with spine and joint problems. The healthy patients exhibit the following pressure distribution: $R_{1l,1r} = 15 - 25\%$, $R_{2l,2r} = 25 - 35\%$ of the body weight. As one can see the sway in the sagittal plane is bigger than in the coronal plane for both healthy individuals and patients. When the support of one of the two legs decreases, the sway increases in both planes. The sway asymmetry ($K_{X/Y} < 1$ or $K_{X/Y} > 1$) is proper to all the individuals and is affected by the joint pathology and may be changed significantly for the patients with coxarthrosis.

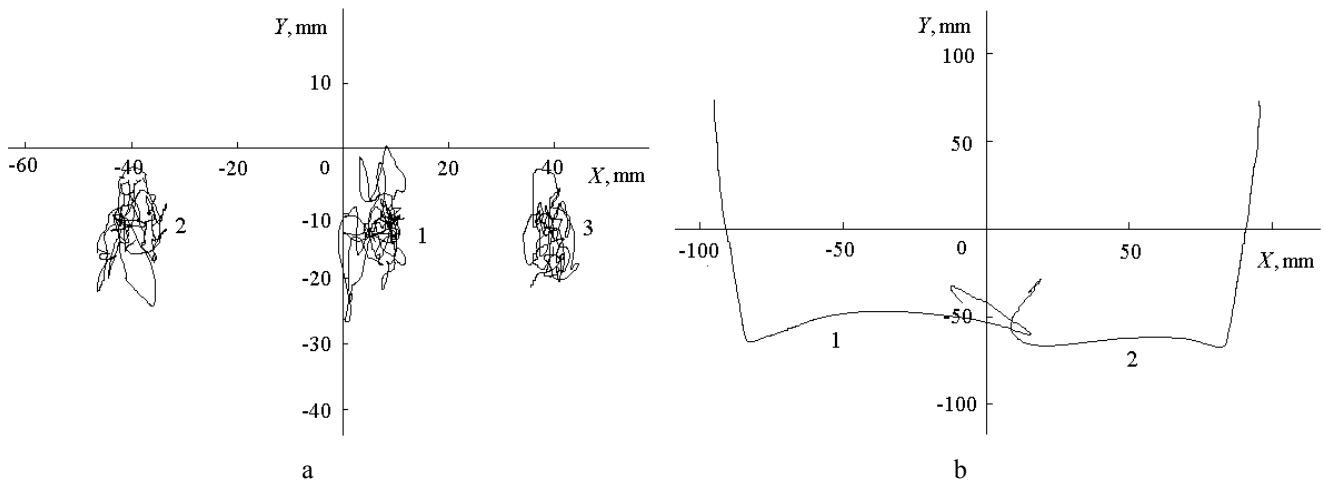


Fig. 2 a – trajectories $Y(X)$ of the COP of healthy young volunteers during the usual 2 - legged stance (1), standing on the two legs with the body weight transferred onto the left (2) and right (3) leg; b – step off the platform starting with left (1) and right (2) leg

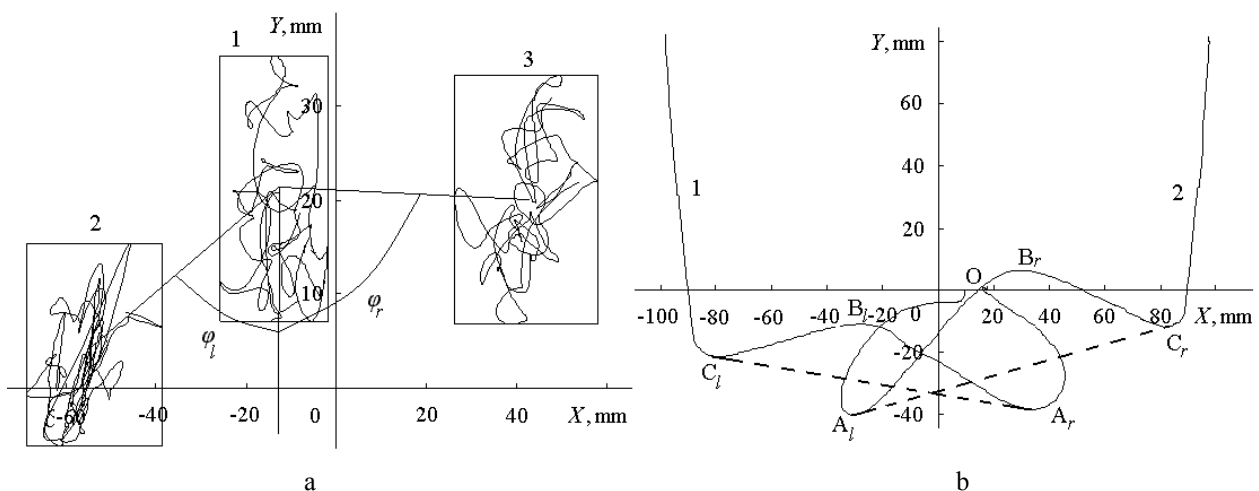


Fig. 3 Trajectories $Y(X)$ of the COP (a) and a step off of the platform (b) of a patient with osteochondrosis. The notations are the same as in Fig. 2

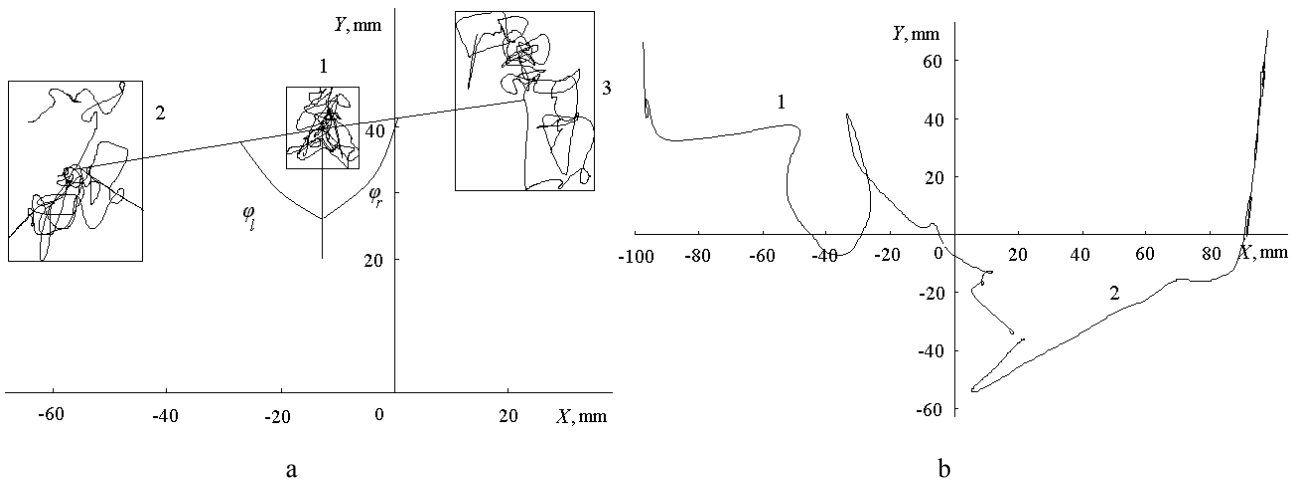


Fig. 4 Trajectories $Y(X)$ of the COP (a) and a step of the platform (b) of a patient with coxarthrosis. The notations are the same as in Fig. 2

Table

Data-averaged values of $Ampl_X$ and $Ampl_Y$ for different tests and three groups of volunteers

		Open eyes					Cosed eyes				
		Test1	Test2	Test3	Test4	Test5	Test1	Test2	Test3	Test4	Test5
Healthy individuals	$Ampl_X$	9±5.5	12.3±9.3	11.3±6.8	41.3±21.7	56.5±21	10.3±6.8	14.8±9.8	15±8.5	55.8±27.3	64.4±22.3
	$Ampl_Y$	10.8±5.3	10.8±3.8	15.5±9.5	22.3±8.8	31±20	11.8±6.3	15.8±7.3	16.3±6.8	35.2±18.9	43.6±20.8
	$K_{X/Y}$	0.77±0.44	1.2±0.88	1.21±0.95	2.3±1.1	2.5±1.35	0.91±0.63	1.35±0.9	1.29±0.75	2.7±1.3	2.9±1.6
Patients with osteochondrosis	$Ampl_X$	10.2±5.8	14.2±10.2	13.8±8.9	52.8±23.3	59.8±25.4	13.1±7.9	15.2±8.6	16.1±8.8	67.7±21.5	69.5±20.8
	$Ampl_Y$	11.9±5.9	11.8±4.2	16.4±10.2	33.4±9.5	39.8±16	14.7±8.9	14.9±9.3	15.3±9.6	41.2±17.5	43.3±19.2
	$K_{X/Y}$	0.89±0.54	1.3±0.92	1.32±0.98	2.6±1.7	2.7±1.2	1.1±0.52	1.3±0.67	1.36±0.84	3.1±1.5	3.3±1.9
Patients with coxarthrosis	$Ampl_X$	15.4±5.8	17.2±8.9	19.2±10.2	56.4±22.8	67.7±21.2	16.2±6.6	19.8±9.1	19.4±8.9	59.4±29.2	69.6±22.4
	$Ampl_Y$	18.3±6.6	19.2±9.7	21.3±9.9	35.1±9.2	39±21.1	21.1±10.2	20.8±9.4	21.2±10.2	60.2±28.4	68.4±21.9
	$K_{X/Y}$	0.98±0.54	1.4±0.76	1.4±0.93	3.2±1.8	3.4±1.9	1.2±0.98	1.7±0.89	1.8±0.92	2.2±1.2	2.3±0.9

The pathological joint exhibits some special sway patterns and bigger sway amplitudes when the body weight is born by the injured leg. One can conclude the obtained regularities are connected with pathologies of the musculo-skeletal system only, because all the volunteers had neither visual nor nervous disorders.

4. Conclusions

Basing on the analysis of the measurement data the following conclusions can be made:

1. The sway amplitudes of patients with spine and joint pathology are bigger in both anterior-posterior and mediolateral directions. Sway amplitude is an excellent parameter for early diagnostics of the balance problems.

2. Sway amplitudes are higher when the body weight is transferred to one of the legs and increase significantly during the 1 – legged stance. Visual control is an important determinant of the postural balance for all the studied groups of volunteers. Sway amplitudes increase in

2-3 times when the same test is performed with closed eyes.

3. Body oscillation parameters, position of the centre of mass of the body and trajectories of the step off the platform is a potential assessment tool for differential diagnostics of the spine and joint pathology.

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ŽMOGAUS KŪNO VIRPESIŲ POSTUROGRAFINIS TYRIMAS STUBURO IR ŠANARIŲ PATOLOGIJOMS DIAGNOZUOTI

R e z i u m ė

Posturografija yra vienas iš paprastesnių, bet efektyvių žmogaus kūno svyravimo parametrų registravimo būdų. Šiame straipsnyje pateikiami žmogaus kūno masės centro trajektorijų posturografinių matavimų, atliekant seriją bandymų, rezultatai. Apskaičiuotos svyravimo amplitudės, analizuojamos trajektorijos. Nustatyta, kad sveikų savanorių ir pacientų, sergančių osteochondroze bei koksartroze, kūno svyravimai sagitalioje ir frontaloje plokštumose smarkiai skiriasi.

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POSTUROGRAPHIC STUDY OF THE HUMAN BODY VIBRATIONS FOR CLINICAL DIAGNOSTICS OF THE SPINE AND JOINT PATHOLOGY

S u m m a r y

Posturography is one of the simple effective methods of registration of the sway parameters of the human body. In this paper the results of posturographic measurements of the trajectories of the centre of mass of a human body during a series of tests are reported. The sway amplitudes are calculated and the trajectories are analysed. A significant difference in the body oscillations in the sagittal and coronal planes for the healthy volunteers and patients with osteochondrosis and coxarthrosis are found.

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ПОСТУРОГРАФИЧЕСКОЕ ИССЛЕДОВАНИЕ ВИБРАЦИЙ ТЕЛА ЧЕЛОВЕКА ДЛЯ КЛИНИЧЕСКОЙ ДИАГНОСТИКИ ПАТОЛОГИЙ ПОЗВОНОЧНИКА И СУСТАВОВ

Р е з ю м е

Постурография является одним из простых и эффективных методов регистрации параметров колебаний тела человека. В настоящей работе приведены результаты постурографических измерений траектории движения центра масс тела человека в ходе выполнения ряда тестов. Проанализированы амплитуды качаний и траектории движения. Обнаружены существенные различия осцилляций тела во фронтальной и сагиттальной плоскостях у здоровых испытуемых и пациентов с остеохондрозом и коксартрозом.

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