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# 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 mass (COM) using the force platform. Computerized posturography is widely used as a convenient test for diagnostics of different musculoskeletal, vestibular, nervous, auditory and visual pathology, age-related changes and even the emotional state of the individual [1-5]. The posturographic data can be used for elaboration novel types and 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 assess the vestibular functions. The patient can keep a quiet stance on the stable platform (static posturography) or try to keep the balance on the moving or unstable support (dynamic posturography). The dynamical curves X(t), Y(t), Z(t) which are the coordinates of the COM 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 easily 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 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. 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 separately 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 "malingerer" individuals has been found.

Posturography is also used in studies of the 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 COM 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 COM 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 COM 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 ± 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). The force platform (Statograph-M05/28) can measure the four reaction forces $F_{1l}, F_{2l}, F_{1r}, F_{2r}$ (Fig. 1), $F_{1l} + F_{2l} + F_{1r} + F_{2r} =$ 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 COM 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 series of tests with closed eyes. Similar tests have been examined for the healthy volunteers in the morning and after their working day [4].

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].

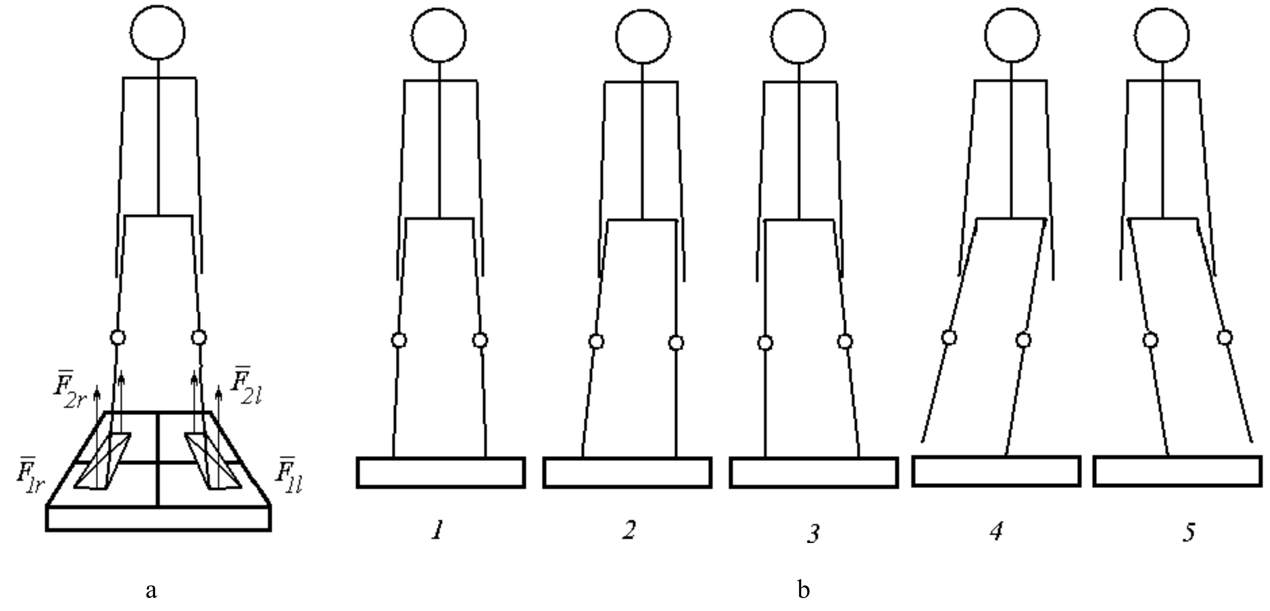

Fig. 1. Force platform with 4 separate measurement units (a) and the examined stances (b): 2-legged stance (1), 2-legged stance with the body mass shifted onto the left (2) and right (3) leg, 1-legged stance on the left (4) and right (5) legs.

## 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 6-th order Butterworth filter. A trend of the basic line has been eliminated by shifting the curves X(t) and X(t) relatively to their mean values $\langle X(t)\rangle_t$ and $\langle Y(t)\rangle_t$. 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) obtained for one of the volunteers are presented in Fig. 2.

Normal position of the COM during the 2-legged stance is placed close to the Y-axis. When the body weight is shifted, the COM moves toward the bearing leg (Fig. 2a), while some unusual locations of the COM have also been detected for the young healthy patients [3,4,11]. When a healthy person makes a step off the platform, three different parts can be distinguished on the trajectory. First of all, the body is gradually shifted in the posterior direction to accumulate some inertia and produce initial acceleration of the body, which can be revealed on the small loop in the initial part of the trajectory (Fig. 2b). 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 COM 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 corresponds to the body movement 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 Fig. 3a, 4a 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 diagnostics of the 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. 4a). The patients with osteochondrosis exhibit displacement of the COM in the posterior direction while they shift their body weight onto one of the legs ( $\varphi_{l,r} < \pi/2$ ) (Fig. 3a).

Step off the platform is started with a significant displacement of the COM in the posterior direction when the inertia is accumulated (segments $OA_l, OA_r$ in Fig. 3b). As it is known, the length of the lThe second stage of the step is characterized by prominent motion in the anterior-lateral direction (segments $A_lB_l, A_rB_r$ ) followed by a rapid displacement into the posterior-lateral direction (segments $B_lB_l, B_rC_r$ ). As a result the segments $A_{l,r}B_{l,r}C_{l,r}$ are convex in patients with osteochondrosis while it is straight in the healthy subjects (Fig. 2b). Apparently the inertia accumulated during the first stage (segments $OA_{l,r}$ ) is too big and the body starts to move 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. 4b). When a patient transfer the body weight onto his injured extremity the trajectory is complex and possesses some loops, concave and convex segments (curve *1* in Fig. 4b).

The averaged values of the sway amplitudes in the anterior-posterior and medial-lateral directions are presented in Table 1. Standard sway amplitude is $Ampl = 0 - 20\ mm$ and it can be significantly bigger in 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 significantly changed for the patients with coxarthrosis. 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 musculoskeletal system only, because all the volunteers had neither visual nor nervous disorders.

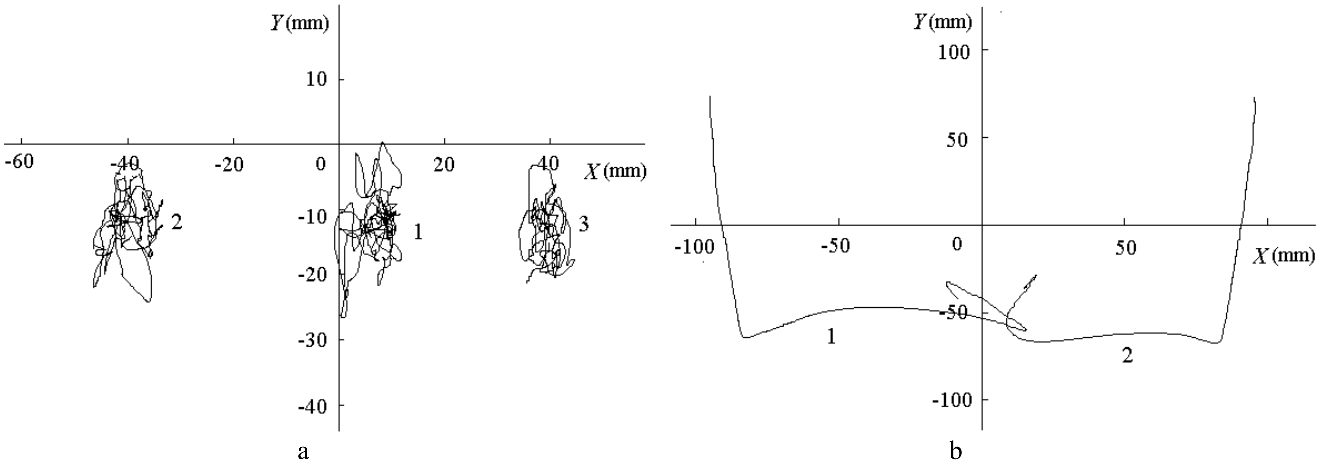

Fig.2. (a) -Trajectories Y(X) of the COM of healthy young volunteers during the usual 2-legged stance (*1*), standing on the two legs with the body weight transferred onto the left (*2*) and right (*3*) leg.
(b) - step off the platform starting with left (*1*) and right (*2*) leg.

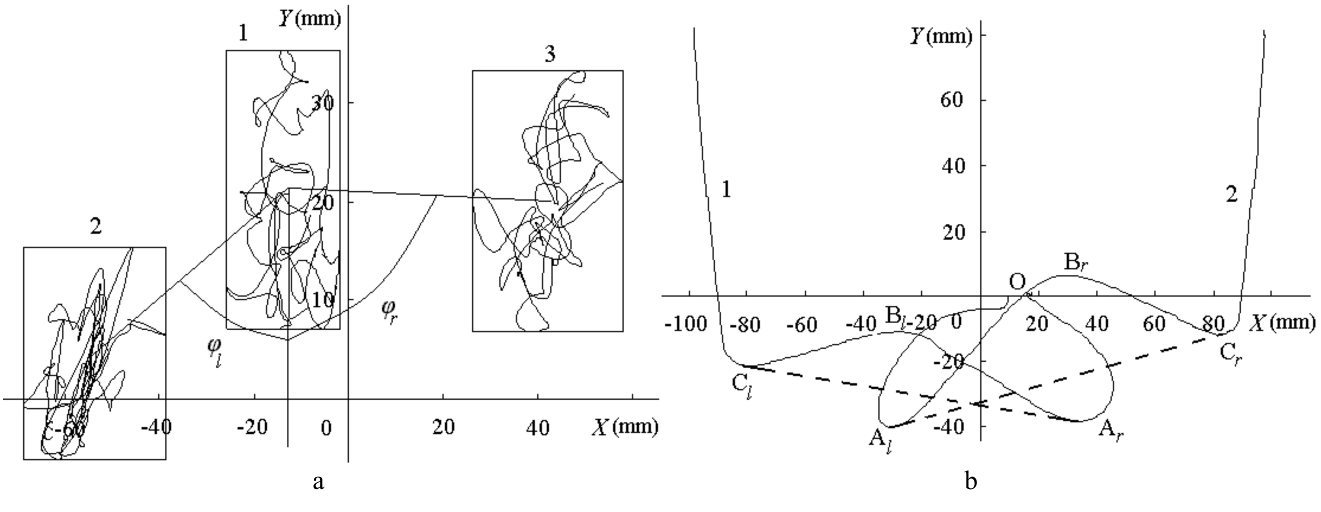

Fig.3. Trajectories Y(X) of the COM (a) and a step of the platform (b) of a patient with osteochondrosis. The notations are the same as in Fig.2.

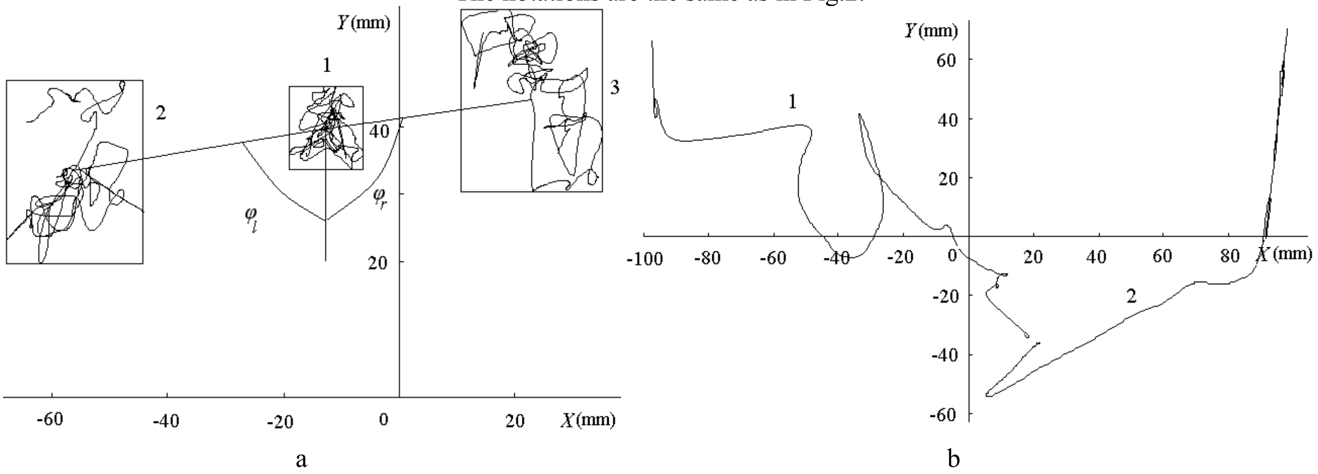

Fig.4. Trajectories Y(X) of the COM (a) and a step of the platform (b) of a patient with coxarthrosis. The notations are the same as in Fig.2.

Table 1

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

| | | open eyes | | | | | closed 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 |

## 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 join 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 are useful for differential diagnostics of the spine and joint pathology.

## 5. Acknowledgments

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

Summary

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 in the healthy volunteers and patients with osteochondrosis and coxarthrosis are found.

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## ВЯЗКОСТЬ РАЗРУШЕНИЯ МАТЕРИАЛОВ СВАРНЫХ СОЕДИНЕНИЙ ПАРОПРОВОДОВ

Резюме

Постурография является одним из простых и эффективных методов геристрации пораматров колебаний тела человека. В настоящей работе приведены результаты постурографических измерений траектория 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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