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Analysis of postural disorders using a stabilometric platform in patients with rheumatic diseases

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Abstract

Introduction: In the course of rheumatoid arthritis (RA), an important problem that affects the stability and symmetry of lower limb loading is the global motor impairment of the foot due to its planovalgus deformity, as well as the occurrence of numerous lesions in the foot joints. In ankylosing spondylitis (AS), there is eventually a permanent limitation of spinal mobility, which results in impaired lower limb loading and body balance. In systemic sclerosis (SSc), pain and joint contractures negatively affect the proper posture and stability of the body and the normal lower limb loading.

Material and methods: Tests of body balance, stability and symmetry of lower limb loading were performed on a computerised two-plate stabilometric platform. The testing consisted of two trials — the first performed with eyes open (open-eye test) and the second performed with eyes closed (closed-eye test).

Results: There were a total of 50 AS patients, 68 RA patients and 53 SSc patients examined. There were no statistically significant differences between the study groups including the open-eye test and the closed-eye test. Each study group revealed statistically significant higher values for the total distance travelled by the patient's centre of pressure of the feet over the course of testing as assessed using the closed-eye test compared to the open-eye test.

Discussion: The groups analysed in this paper represent three functionally distinct connective tissue diseases that are marked by involvement of different constituents of the motor system component. Systemic sclerosis (SSc) presents itself as a disease with a completely different movement pattern that is marked by a reduction in the amplitudes of the centre of pressure (CoP) in both the closed-eye test and the open-eye test.

Conclusions: Postural and balance disorders are common in rheumatic diseases, and the pattern of movement disorders is disease-specific.

Keywords: rheumatic diseases; rheumatoid arthritis; ankylosing spondylitis; systemic sclerosis; stabilometric platform; postural disorders

Introduction

In European countries, rheumatic diseases involving postural and balance disorders affect 120 million people. One in five Europeans with these diseases receives long-term care. In Poland, it is estimated that approximately 10 million people suffer from musculoskeletal disorders, and 61.2% of the adult population experiences cyclic or constant rheumatic pain. This pain is more prevalent in women (66.6%) compared with men (54.8%) [1].

In the course of rheumatoid arthritis (RA), an important problem that affects the stability and symmetry of lower limb loading is the global motor impairment of the foot due to its planovalgus deformity, as well as the occurrence of numerous lesions in the foot joints. These deformities also indirectly affect the hip, knee and spinal joints, resulting in an impaired gait. Furthermore, they are further aggravated by inflammatory changes in the joints and structures of the periarticular system such as tendons, peridesmium and bursae [2, 3].

The pain symptoms experienced by RA patients often result in flexor contractures and extensor weakness. As pain is exacerbated during motor activities, patients try to keep their limbs in a non-painful position, usually in flexion, which results in joint contractures. Excessive muscle tension in the peripheral muscles of the limbs negatively affects central stabilisation, resulting in body balance impairment [4].

Synovitis of the atlanto-occipital, atlanto-axial and atlanto-dental joints, as well as destruction of the odontoid process and transverse ligament, and the development of rheumatoid granulation tissue between the C1 arch and the C2 tooth are responsible for the presence of occipitovertebral or atlanto-axial instability, which has a significant impact on balance and trunk stabilisation [5].

Ankylosing spondylitis (AS), a typical representative of inflammatory spondyloarthropathies (SpAs), is described by inflammation of the spinal joints, sacroiliac joints, ligaments and paraspinal soft tissues. As the disease progresses, ligaments of the spine ossify and produce an image resembling a Flemish column or a bamboo stick. Pathological changes in the lumbar spine include a reduction in its physiological lordosis and increased tension in the paraspinal soft tissues, resulting in limited mobility to the point of full stiffness. In the thoracic spine, there is an increase in thoracic kyphosis and decreased mobility due to damage to the intervertebral, costotransverse and costovertebral joints. Changes in the thoracic region of the spine result in protraction of the shoulders, more distance between the shoulder blades and the line of the spine, contracture of the pectoral muscles and formation of a round back. Involvement of the cervical spine results in protraction of the head, contracture of the suboccipital muscles and, over time, complete stiffening of the cervical spine and development of spondylolytic posture. In the next stage, contractures develop in knee and hip joints, forcing the patient to adopt a so-called skier's posture. Ultimately, the course of the disease results in a permanent limitation of spinal mobility in each of the possible planes and anteflexion, which results in impaired lower limb loading and impaired body balance [5, 6].

In systemic sclerosis (SSc), the main symptom is hardening of the skin with its characteristic proximal and distal involvement (mainly on the upper and lower limbs and trunk). There is also an increase in skin tension and connection to the subcutaneous tissue. In addition to dermatological symptoms, there is also fibrosis of peridesmium and fasciae, resulting in limited joint mobility and flexion contractures. Painful and difficult-to-heal ulcers form on the fingertips, resulting in pitting scars. Pain and joint contractures negatively affect the proper posture and stability of the body and the normal lower limb loading [7–9].

This study aims to assess the stability and symmetry of lower limb loading and compare the differences in this area, which are found between patients with rheumatoid arthritis (RA), ankylosing spondylitis (AS) and systemic sclerosis (SSc).

Material and methods

Patients

Patients meeting the classification criteria of three systemic connective tissue diseases were included in the study: 1. Rheumatoid arthritis classified according to the 2010 *European League Against Rheumatism/American College of Rheumatology* (EULAR/ACR) classification criteria [10], 2. Ankylosing spondylitis diagnosed based on the modified New York Criteria [11] and 3. Systemic sclerosis (SSc) diagnosed based on the 2013 EULAR/ACR criteria [12]. A signed consent to voluntarily participate in the study was a condition of participation.

Exclusion criteria included:

1. Coexistence of another systemic connective tissue disease, osteoarthritis, congenital/acquired joint deformities, acute/chronic arthritis of a weight-bearing joint (hip joint, knee joint, ankle joint, foot joints) of another aetiology.
2. Acute/chronic inflammation of the anterior segment of the eyeball that, in the opinion of the researcher, could impair vision.
3. Sustaining injuries to limbs resulting in permanent disability or until full functionality is regained.
4. Neurological diseases that cause balance disorders and impair muscle strength.
5. Myopathies and polyneuropathies.

Study design

Tests of body balance, stability and symmetry of lower limb loading were performed on a computerised two-plate stabilometric platform (DP01). Strain gauge sensors were placed at the corners, registering the central pressure of the feet on the ground and its displacement in two axes (anterior-posterior and medial-lateral). Measurements were taken after the subject had rested for 5 minutes in a sitting position. The testing consisted of two trials — the first performed with eyes open (open-eye test) and the second performed with eyes closed (closed-eye test). During each trial, the test subject stood without footwear so that each foot was on a separate plate, adopting a relaxed position with the upper limbs placed along the body. During the trials, which lasted 30 seconds each, the subject remained motionless. During the part of the test in which the subject's eyes were open, their gaze was focused on a monitor screen with a still image ("blank" statokinesiogram as a reference) to adopt the correct posture. The test results are shown in the form of two graphs — a statokinesiogram, which shows the displacement of the centre of pressure (CoP) in the X-axis (right and left deviations) and Y-axis (forward and backward deviations), and a stabilogram, which shows the position of the CoP as a function of time (separately for right and left movement and separately for forward and backward movement). The parameters measured during the test on the stabilometric platform are shown in Table I.

Statistical analysis

Interval scale data with a normal distribution were shown as mean ± standard deviation, and those deviating from a normal distribution were shown as median, lower and upper quartiles. Qualitative data are shown as counts and percentages. The normality of the data distribution was assessed using the Shapiro-Wilk test and quantile-quantile (Q-Q) plot. A twoway ANOVA and post-hoc contrast analysis were used for the comparison of interval scale data between groups. Variables for which the significance level p was < 0.05 were considered statistically significant parameters. Calculations were performed using Statistica 12.0 version PL.

Results

Study population

A total of 171 patients were tested: 50 AS patients, including 18 (36.0%) women, aged 37 ± 11 (mean disease duration 8.9 ± 7.8 years), 68 RA patients, including 55 (80.9%) women, aged 55 ± 12 (mean disease duration 11.4 ± 10.7 years) and 53 SSc patients, including 37 (69.8%) women aged 55 ± 12 (mean disease duration 5.2 ± 6.4 years).

Stabilometric platform test analysis

For the open-eye test, there were no statistically significant differences registered from the reference value of 1. For the closed-eye test, however, body balance was statistically significantly higher than 1 ($p < 0.05$) in AS and SSc patient groups, which tends to indicate a greater pressure of the right foot on the ground. There were no statistically significant differences between the study groups including both the open-eye test and the closed-eye test (Fig. 1).

Moreover, in each study group, there were statistically significantly higher values for the total distance travelled by the patient's *CoP* over the course of testing, as assessed using the closed-eye test compared to the open-eye test, performed in both planes (2D) and in the anterior-posterior (AP) plane. For the medial-lateral (ML) plane, significantly higher values in the closed-eye test compared to the open-eye test were found only in the RA group (Fig. 1).

It was also found that the mean amplitude of CoP from point 0 was: 1 — statistically significantly lower in the SSc group compared to the RA and AS group, when patients were tested with eyes closed and in 2D planes, with no significant differences found in other comparisons, 2 — statistically significantly lower in the SSc group compared to the RA and AS group, when patients were tested with eyes open and closed in the AP plane, with no significant differences found in other comparisons. Moreover, there were no significant differences between the groups when patients were tested with eyes open and closed, in the ML plane (Fig. 2). The maximum amplitude of CoP from point 0, assessed in the AP plane in patients with both eyes open and closed, was statistically significantly higher in the RA group compared to the SSc group.

In addition, it was found that in the closed-eye test there were statistically significantly higher mean velocity values in 2D planes and in the AP plane across all study groups, compared to the open-eye test. In the closed-eye test, there was a statistically significantly higher velocity value in the RA group compared to the SSc group. For the test in the ML plane, there were only statistically significantly higher mean velocity values in the closed-eye test in the RA group, compared to the open-eye test (Fig. 3).

In terms of the sway area covered by the path diagram, there were statistically significantly higher values in the closed-eye test compared to the open-eye test in the group with AS and RA. There were significantly lower values in the closed-eye test in the group with SSc compared to AS and RA patients. The ratio of the length of statokinesiogram (sway path) to its sway area was statistically significantly higher in the closed-eye test in the SSc group compared AS and RA patients. There were no statistically significant differences between the other groups (Fig. 4).

Also, there were no differences in terms of the mean frequency; however, in the case of the percentage of time spent by the CoP within a circle of radius R = 5 mm, there were significantly higher values when assessed with both eyes open and closed in the SSc group compared to AS and RA patients — (Fig. 4). In all study groups, there was a greater number of amplitudes from the centre of gravity in the closed-eye test, in the AP plane, compared to the open-eye test. Moreover, AS patients had a statistically significantly lower number of amplitudes compared to SSc patients in the open-eye test, while they had statistically significantly lower number of amplitudes compared to RA patients in the closed-eye test. In the test that was performed in the ML plane, there was a significantly greater number of amplitudes in the closed-eye test compared to the open-eye test in the RA and SSc group, but not in the AS group. Furthermore, SSc patients, when assessed with their eyes open, had statistically significantly lower number of amplitudes compared to AS and RA patients (Fig. 5).

Discussion

The groups analysed in this paper represent three functionally distinct connective tissue diseases that are marked by involvement of different constituents of the motor system component. The lesions include, mainly but not exclusively, the peripheral joints in RA, the sacroiliac joints and spinal joints in AS, and the tendons, soft tissues and, to a slightly lesser extent, the peripheral joints in SSc.

Tests on the posturometric platform, which were performed in patients with RA and degenerative changes by Sokołowska et al., proved to be an effective and non-invasive method to assess balance and postural stability in people with rheumatic diseases. There were significantly greater problems with balance compared to healthy subjects, and RA patients showed greater imbalances compared to patients with degenerative changes, although the difference did not reach statistical significance [13]. To the authors' surprise, only minor differences were found between RA patients and AS patients despite the involvement of different elements that affect movement in both diseases. Against this background, SSc presents itself as a disease with a completely different movement pattern that is marked by a reduction in the amplitudes of CoP in both the closed-eye test and the open-eye test. Furthermore, compared to RA, SSc patients had lower CoP velocity values. These data indicate stiffening of the posture in these patients, likely due to soft tissue stiffness, increased tendon tension, and fibrosis within the periarticular system. As recently shown, SSc patients exhibit an impaired balance pattern that predisposes them to an increased risk of falls [14]. A recently published study also found that there is significant impairment of back muscle function in the course of SSc, resulting in a significant change in movement pattern [15]. These data may at least partly explain the occurrence of different movement patterns precisely among SSc patients.

The data obtained during this study are in agreement with the published posturometric study confirming the deficit in obtaining a normal statistical pattern. Following this, a reduction in foot movement in the tested planes may indicate an increased predisposition to the patient's loss of static balance in a straight line, leading to a fall with all its negative consequences [16].

Park et al. studied patients with degenerative changes in the knee joints. They performed two trials, one with eyes open and one with eyes closed. No correlation was found between pain intensity and degree of problems with balance. The authors found that patients performed worse due to age rather than disease severity and duration [17]. The opposite observation was reported by Hinman et al. who proved that patients with knee osteoarthritis have poorer posturographic performance as the severity of knee pain increases [18]. These data are in agreement with the results obtained during this study. The discrepancies found during testing in the ML plane, involving a significantly greater number of amplitudes in the closed-eye test compared to the open-eye test, between the group of RA and SSc patients in comparison to the group of AS patients, may result from different distribution of inflammatory changes in peripheral joints in these respective diseases. This is marked by a higher frequency of involvement of weight-bearing joints in RA and SSc, with minimal involvement of peripheral joints in axial SpA (axSpA) patients. This is supported by the study by Sokołowska et al., who found that the results are also affected by the severity and extent of the disease. Kim et al. studied 80 patients with knee osteoarthritis. They performed two trials with eyes open and closed. They found that subjects in the moderate and advanced stages of the disease performed worse than subjects with mild disease symptoms. The authors concluded that patients with reduced muscle strength and greater pain symptoms had poorer balance [19].

In another study involving 18 RA patients at an advanced stage of the disease, there was evidence of problems with balance and postural stability [20], confirming the findings of the study. Yasunari Ikuta et al. who studied postural stability in 101 adolescent athletes imply that hindfoot valgus deformity causes poorer posture and stability [21].

This study found higher values for the total distance travelled by the patient's CoP of the feet, as assessed using the closed-eye test compared to the open-eye test, across all study groups. There were no significant differences between the groups. These data indicate better control of body balance in space with eyes open compared to eyes closed regardless of the disease entity, which is most likely the norm for every individual. This is confirmed by studies conducted on a group of healthy people with no visual problems. The studies revealed a significant effect of visual control on balance [22].

The limitations of this study are due to the size of study groups, which precludes more detailed analyses that are related to disease severity. In addition, the tests performed on the posturographic platform were carried out by the researcher for the first time, who made every effort and carried them out to the best of their knowledge.

Conclusions

1. Motor and postural disorders are common in patients with rheumatic diseases.
2. The pattern of movement disorders is conditioned by the predominant form of damage to the musculoskeletal system in a given disease.
3. The rheumatic diseases studied affect the maintenance of normal balance to varying degrees, and RA is a condition in which deviations from the norm occur most frequently.

Data availability statement

Ethics statement:

Author contributions

Funding

None declared.

Conflict of interest

Authors declare no conflict of interest

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Table I. Parameters measured during the test performed on the stabilometric platform

Parameter	**Unit**
Sway path — the path legth, i.e. the total distance travelled by the patient's CoP of the feet over the course of testing in 2D axes and in the AP plane and ML plane	Millimetre
Mean amplitude of CoP from point 0, in 2D axes, AP plane and ML plane	Millimetre

Maximum amplitude of CoP from point 0, in the AP plane and ML plane	Millimetre
Mean velocity at which the CoP moved during testing, in 2D axes and in the AP plane and ML plane	Millimetre/second
Sway area covered by the path diagram	Millimetre²
Ratio of the sway path to its sway area	1/millimetre
Mean frequency	Hertz
Percentage of time spent by the CoP within a circle of radius R = 5 mm	–
Number of amplitudes of the CoP in the AP plane and ML plane	–
Romberg's test — the ratio of the parameters obtained in tests performed with eyes open to parameter values obtained in tests performed with eyes closed	
1. Sway path — the total distance travelled by the CoP	–
2. Sway area covered by the path diagram	–

CoP — centre of pressure of the patient's feet; AP — anteroposterior; ML — mediolateral

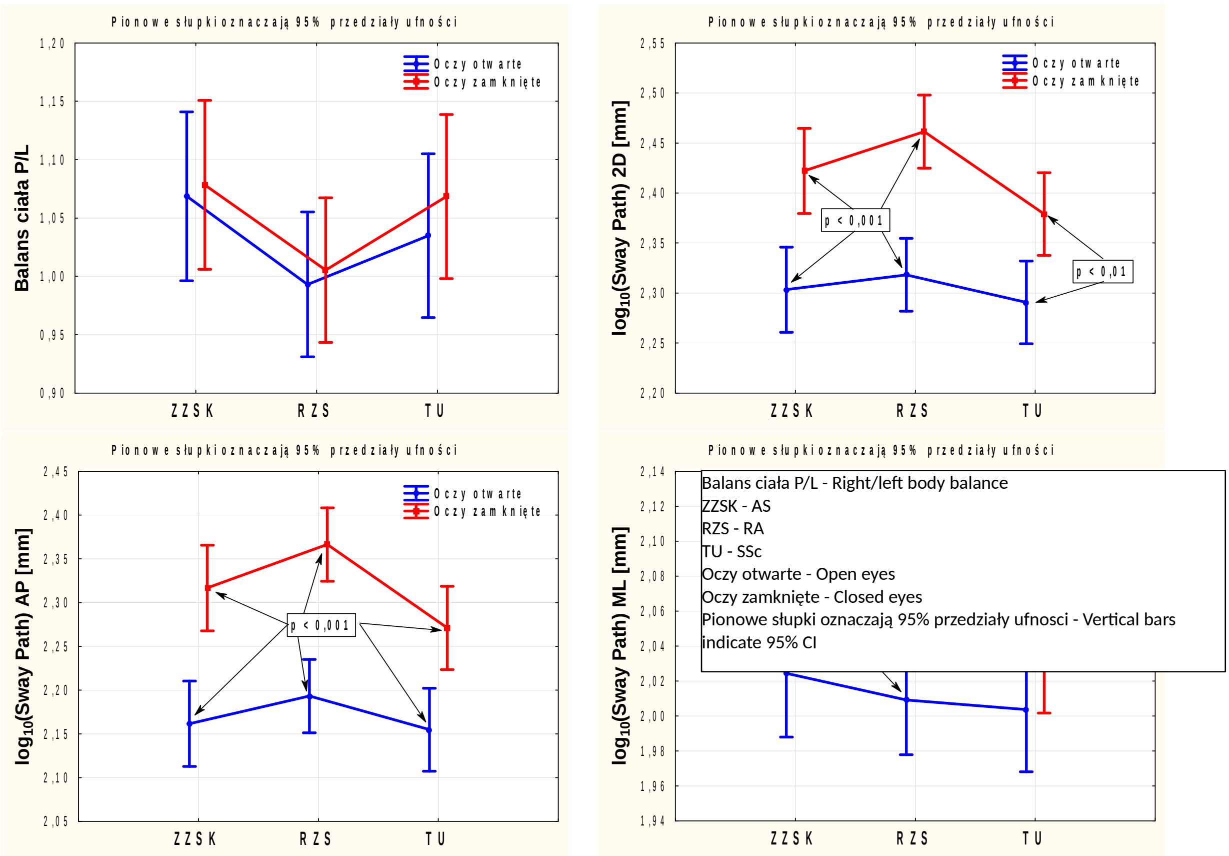


Figure 1. Comparison of body balance values and *sway path* in three measurement planes across all study groups. AS — ankylosing spondylitis; RA — rheumatoid arthritis; SSc — systemic sclerosis

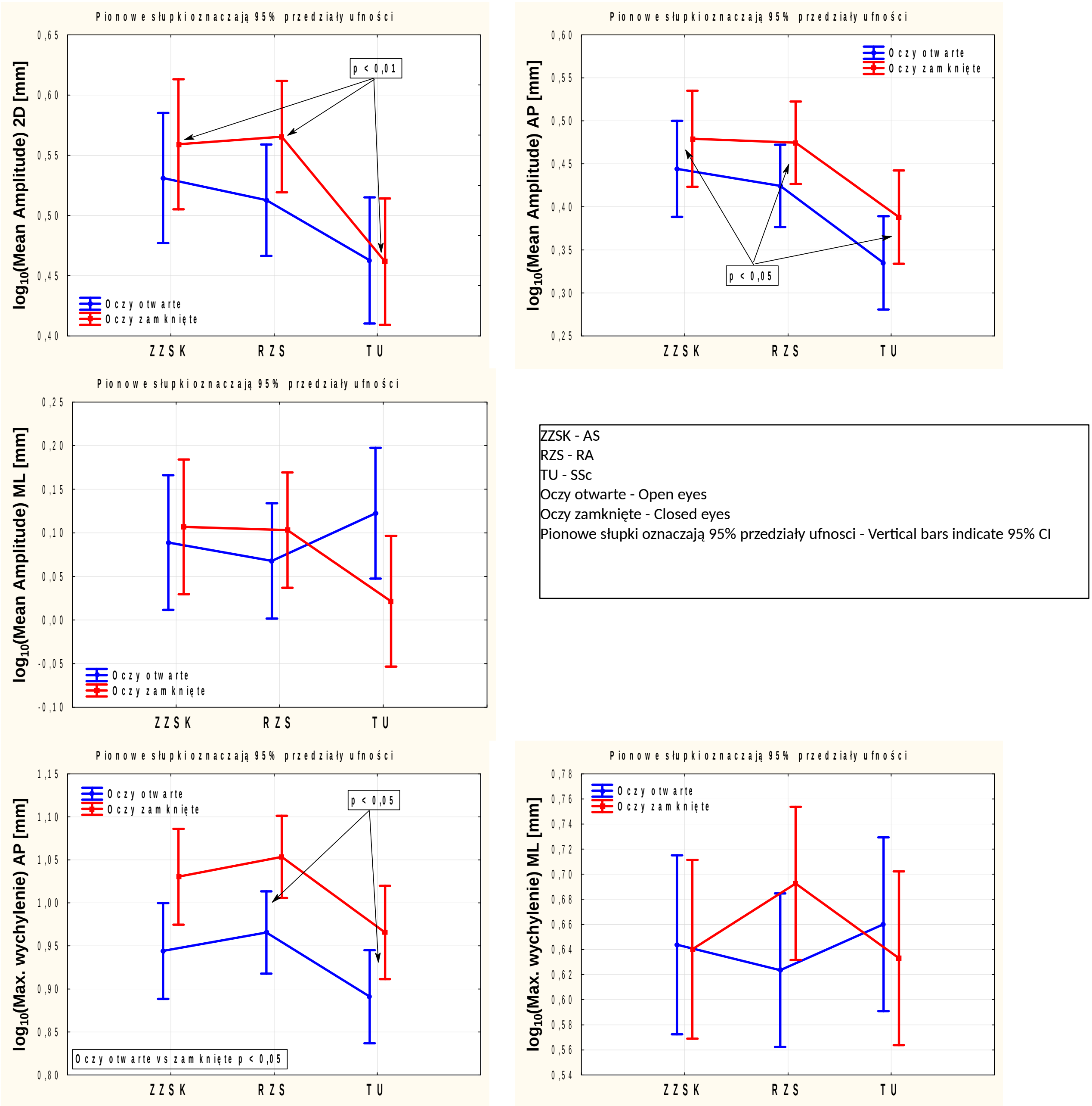


Figure 2. Comparison of the values of the mean amplitude of CoP from point 0 in three measurement planes and the maximum amplitude in the AP and ML planes across all study groups. AS — ankylosing spondylitis; RA — rheumatoid arthritis; SSc — systemic sclerosis

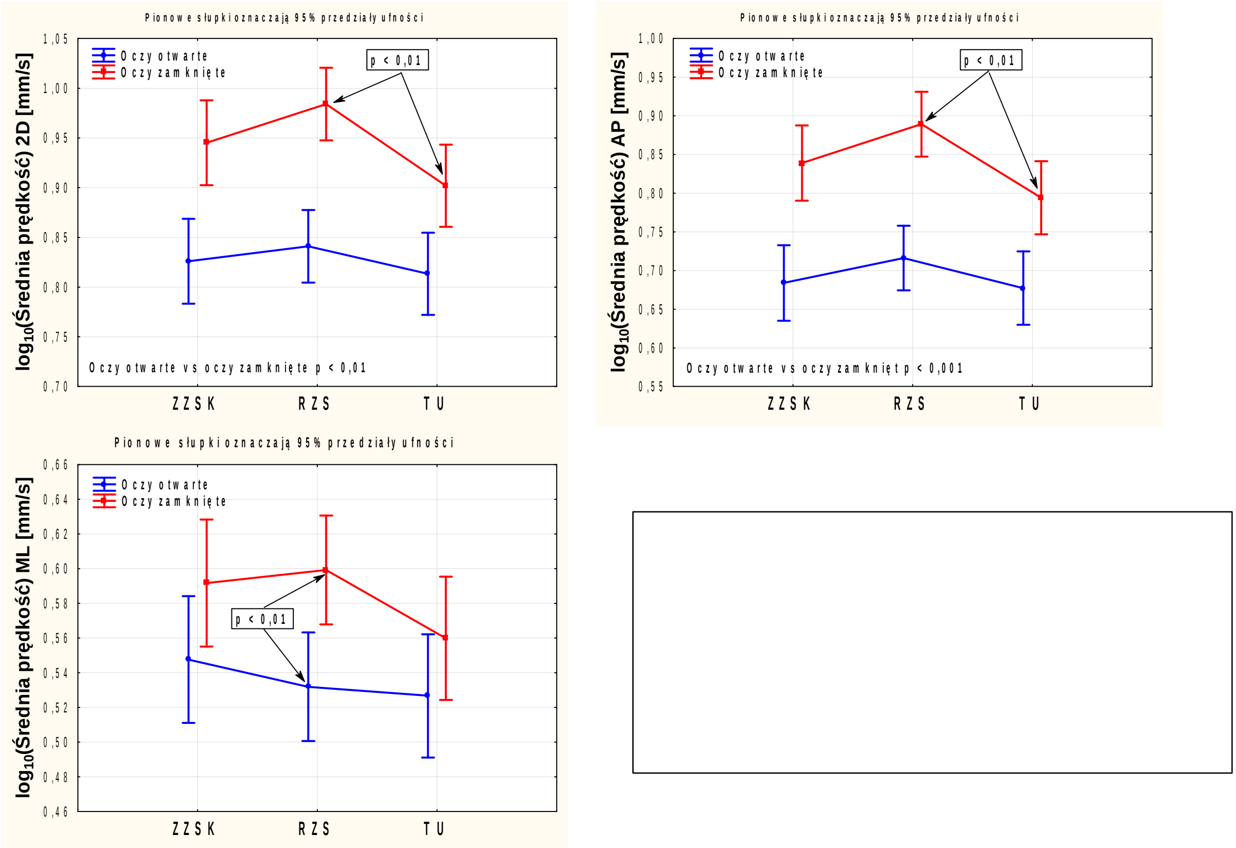
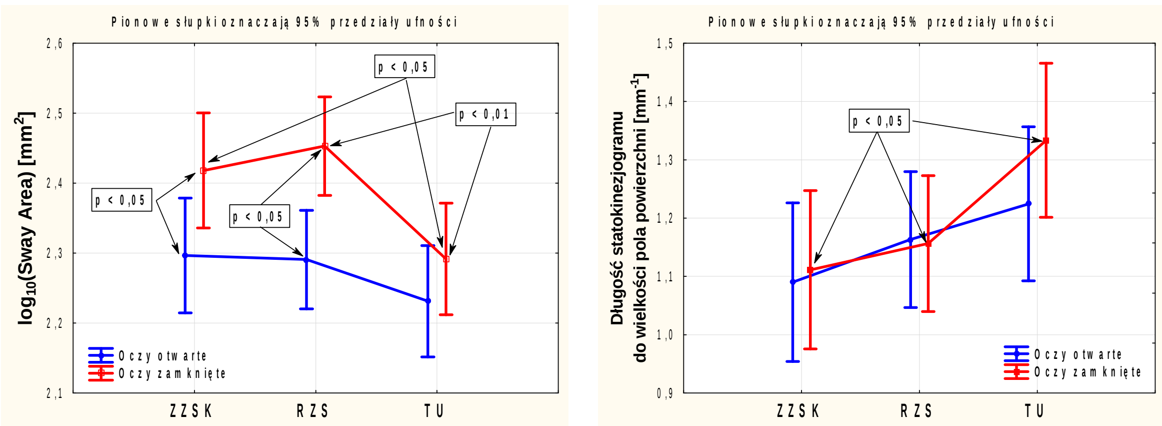


Figure 3. Comparison of the values of the mean velocity at which the CoP of the feet moved during testing in three measurement planes across all study groups. AS — ankylosing spondylitis; RA — rheumatoid arthritis; SSc — systemic sclerosis



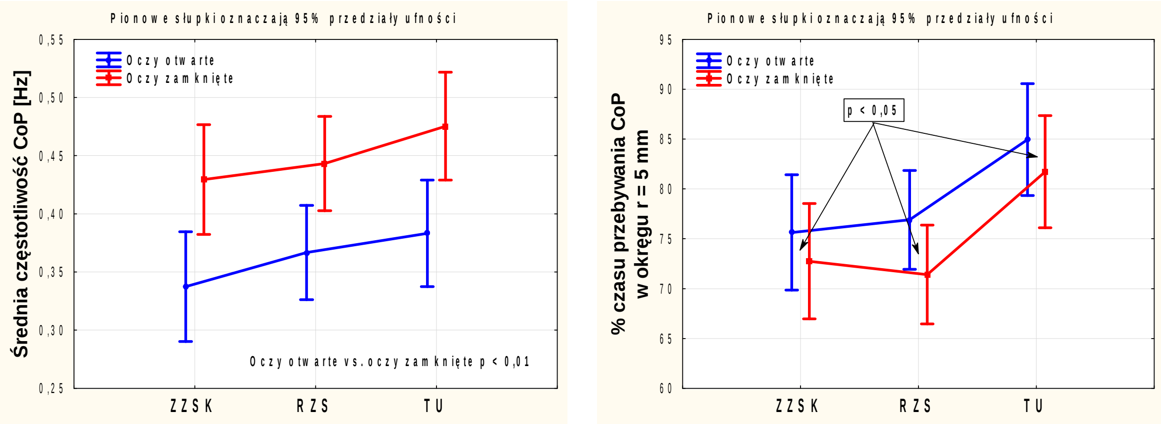


Figure 4. Comparison of the size of the sway area outlined by the point of application of foot pressure on the ground, the sway path in relation to *sway area*, mean frequency of CoP and the percentage of time spent by the CoP within a circle of radius R = 5 across all study groups. AS — ankylosing spondylitis; RA — rheumatoid arthritis; SSc — systemic sclerosis

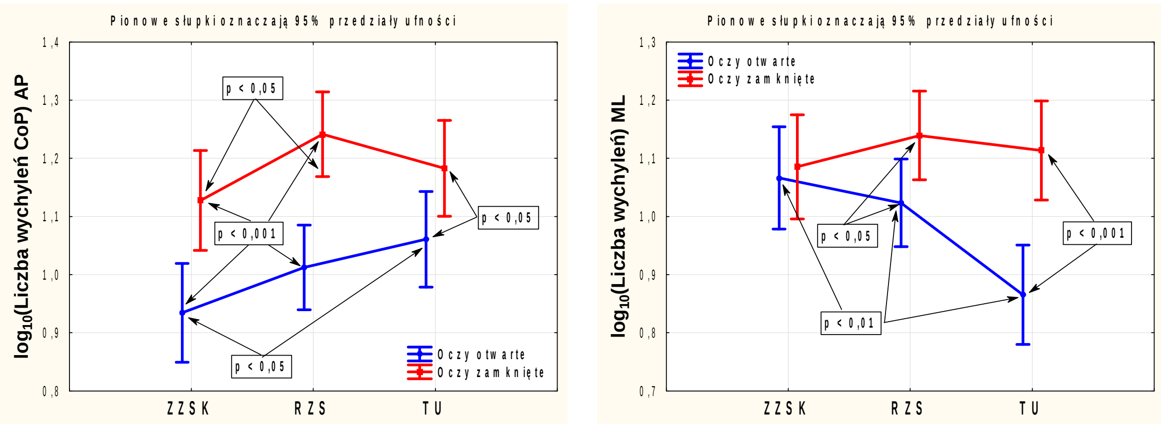


Figure 5. Comparison of the number of amplitudes of the CoP in the AP and ML planes across all study groups. AS — ankylosing spondylitis; RA — rheumatoid arthritis; SSc — systemic sclerosis

Oczy otwarte vs. zamknięte p < 0,05 - Open vs. closed eyes p < 0.05
Pionowe słupki oznaczają 95% przedziały ufnosci - Vertical bars indicate 95% CI
Oczy otwarte - Open eyes
Oczy zamknięte - Closed eyes
ZZSK - AS
RZS - RA
TU - SSc
Liczba wychyleń CoP - Number of amplitudes of the CoP
% czasu przebywania CoP w okręgu r = 5 mm - Percentage of time spent by the CoP within a circle of radius R = 5 mm
Długość statokinezjogramu do wielkości pola powierzchni - Sway path compared to size of sway area
średnia częstotliwość - Mean frequency

Appendix

Table S1. Outcomes of descriptive statistics and a[...] of group and eye opening/closing on the results of tests performed on the stability platform

	AS		**RA**		**SSc**		**ANOVA**		
	O	**C**	**O**	**C**	**O**	**C**	p_{group}	**p** O vs. C	$p_{interaction}$
Body balance R/L	1.07 ± 0.36	1.08 ± 0.26	0.99 ± 0.22	1.01 ± 0.29	1.03 ± 0.19	1.07 ± 0.22	0.077	0.51	0.93
Sway path outlined by the CoP [mm]									

In 2D axes	208.5 ± 63.1	285.7 ± 120.9	218.2 ± 71.2	317.1 ± 151.5	204.1 ± 71.6	263.4 ± 133.9	**< 0.05**	**< 0.001**	0.39
In the AP plane	152.2 ± 54	228.5 ± 109.2	166.9 ± 67.5	261.4 ± 144.6	152.1 ± 64.5	211.7 ± 121.2	**< 0.05**	**< 0.001**	0.45
In the ML plane	110.0 ± 34.1	125.5 ± 51.6	105.8 ± 28.7	127.0 ± 51.2	103.9 ± 28.6	115.0 ± 44.5	0.29	**< 0.001**	0.60
Mean amplitude of CoP from point 0 [mm]									
In 2D axes	3.65 ± 1.41	4.11 ± 2.62	3.54 ± 1.49	4.34 ± 3.04	3.08 ± 1.07	3.20 ± 1.50	**< 0.01**	0.21	0.56
In the AP plane	3.07 ± 1.36	3.37 ± 1.69	2.86 ± 1.13	3.52 ± 2.59	2.37 ± 1.03	2.73 ± 1.36	**< 0.001**	**< 0.05**	0.94
In the ML plane	1.44 ± 0.84	1.70 ± 1.97	1.51 ± 1.24	1.76 ± 1.85	1.48 ± 0.74	1.21 ± 0.63	0.80	0.60	0.134
Maximum amplitude in the AP plane [mm]	9.4 ± 3.7	12.0 ± 6.3	10.0 ± 4.1	12.8 ± 7.4	8.8 ± 6.2	10.7 ± 5.7	**< 0.001**	**< 0.001**	0.96
Maximum amplitude in the ML plane [mm]	5.0 ± 2.7	5.7 ± 7.1	5.0 ± 3.2	6.2 ± 4.9	5.4 ± 3.8	5.0 ± 2.7	0.88	0.65	0.30
Mean velocity [mm/s] at which the CoP moved during testing									
In 2D axes	6.9 ± 2.1	9.5 ± 4.0	7.3 ± 2.4	10.6 ± 5.1	6.8 ± 2.4	8.8 ± 4.5	**< 0.05**	**< 0.001**	0.39
In the AP plane	5.1 ± 1.8	7.6 ± 3.6	5.6 ± 2.2	8.7 ± 4.8	5.1 ± 2.1	7.1 ± 4.0	**< 0.05**	**< 0.001**	0.46
In the ML plane	3.7 ± 1.1	4.2 ± 1.7	3.5 ± 1.0	4.2 ± 1.7	3.5 ± 1.0	3.8 ± 1.5	0.29	**< 0.001**	0.58
Sway area outlined by the point of application of foot pressure on the ground [mm^2]	228.8 ± 144.1	359.3 ± 422.7	235.3 ± 158.3	426 ± 481.2	200.1 ± 143.3	254.9 ± 203.2	**< 0.05**	**< 0.001**	0.41

Sway path compared to size of sway area [mm^{-1}]	1.09 ± 0.41	1.11 ± 0.44	1.16 ± 0.47	1.16 ± 0.54	1.22 ± 0.45	1.33 ± 0.58	< **0.05**	0.44	0.64
Mean frequency of CoP [Hz]	0.34 ± 0.13	0.43 ± 0.20	0.37 ± 0.15	0.44 ± 0.18	0.38 ± 0.15	0.48 ± 0.19	0.15	< **0.001**	0.92
Percentage of time spent by the CoP within a circle of radius R = 5 mm	75.6 ± 20.1	72.7 ± 24.4	76.9 ± 19.8	71.4 ± 25.6	84.9 ± 13.8	81.7 ± 17.6	< **0.001**	0.09	0.87
Number of amplitudes of the CoP									
In the AP plane	16.1 ± 10.5	13.1 ± 8.8	20.0 ± 9.8	14.4 ± 9.4	18.3 ± 11.9	81.7 ± 17.6	< **0.05**	< **0.001**	0.40
In the ML plane	13.6 ± 6.4	15.0 ± 10.3	12.7 ± 6.5	16.7 ± 9.8	9.6 ± 6.5	14.9 ± 7.8	0.05	< **0.001**	< **0.05**

$p_{O\ vs.\ C}$ – significance level for the effect of eye **O**pening/**C**losing

Interaction – interaction between the group and the open-eye test/closed-eye test