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Research article

The relationship between myotonometry parameters and spinal mobility in ankylosing spondylitis patients included in a physical exercise program

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Abstract: Studies showed that the mechanical properties of spinal muscles in patients with ankylosing spondylitis (AS) differ from healthy controls; the continued disease duration alters elasticity and stiffness. Our research focused on analyzing the myotonometry parameters of the longissimus capitis and lumbar erector spinae muscles and spinal mobility in AS patients who followed an 8-week physical exercise program. 34 AS patients were evaluatedevaluated at the beginning of the physical exercise program and after 8 weeks by MyotonPRO (the device measures frequency, stiffness, decrement, relaxation time, and creep) and cervical and lumbar spine assessments. Significantly higher frequency was noted for right and left longissimus capitis muscle after rehabilitation. We recorded statistically significant decreasedstiffness and higher decrement for the right lumbar erector spinae muscle at the second assessment. After the physical exercise program, the cervical spine range of motionmotion improved significantly for all the tested movements. The Schober test had significantly increased values, while the finger-to-floor test decreased significantly. Significant correlations were noted between stiffness and right lumbar rotation and right lumbar lateral flexion at both baseline and 8-week assessments. Improvements in cervical and lumbar spinal motions can be analyzed in relation to mechanical muscles properties in AS pa-tients who have followed a physical exercise program.

Keywords: ankylosing spondylitis, physical exercise, myotonometry, mobility

1. Introduction

Ankylosing spondylitis (AS) is a chronic inflammatory arthritis. AS involves sacroiliac joint inflammation or fusion, and more prevalent spinal fusion and ankylosis in advanced stages of the disease [1]. The functional limitations of the AS patients are typically related to spine pain and immobility. The three best predictors of decreased spinal mobility are cervical rotation, the modified Schober test, and finger-to-floor distance [2,3].

Early in the disease process, decreased spine range of motion is secondary to back pain and muscle spasms, and most dysfunction is mild and self-limited. In severe disease, limitations include thoracic kyphosis and loss of cervical rotation that reduce patients' ability to view activities in front of them and side to side [4].

The benefits of exercise for AS patients are well-documented [5]. American College of Rheumatology, Spondylitis Association of America, and Spondyloarthritis Research guidelines strongly recommend treatment with physical therapy [6]. Fernández-de-las-Peñas et al. evaluated the impact of a 4-month comprehensive protocol of strengthening and flexibility exercises on functional and mobility outcomes. Improvements of the modified Schober test, cervical rotation, lumbar side flexion, and intermalleolar distance were recorded after the exercise program [7]. Aytekin et al. stated that regular home-based exercise therapy should be a part of the main therapy in patients with AS. This category of patients should exercise at least five times a week for at least 30 minutes per session [8]. The review of Ungureanu et al. stated that patients suffering from spondyloarthropathies could benefit from different types of non-pharmacological treatments for quality of life improvement [9].

Myotonometry is a simple method used to assess the condition of muscles, and it is highly reliable [10]. The MyotonPro is a handheld device designed to measure muscle mechanical properties in various research and clinical fields [11]. The device has demonstrated positive results in characterizing the mechanical features of the para-vertebral region when used on asymptomatic patients with cervical and lumbar spinal pain [12]. By applying mechanical stimuli, this device enables the measurement of tone or tension, indicated by the natural oscillation frequency; dynamic stiffness and logarithmic decrement of natural oscillation, which reflects the tissue's overall elasticity; mechanical stress relaxation time and the ratio of deformation and relaxation time, which characterizes creep.

The study of Garrido-Castro et al. showed that the mechanical properties of spinal muscles in patients with axial spondyloarthritis differ from healthy controls. In the patients' group, lumbar and cervical muscles exhibited greater linear elastic properties (frequency and stiffness) and lower viscoelastic properties (relaxation and creep) [13]. The preliminary results of White et al. suggested that with continued disease duration the biomechanical properties of elasticity and stiffness are altered in AS subjects [14].

The objectives of our study were to assess the myotonometry parameters of the longissimus capitis and lumbar erector spinae muscles and spinal mobility in AS patients that have followed an 8-week physical exercise program. The erector spinae group comprises the intermediate layer of the intrinsic muscles of the back. It is a large and superficial group that lies just beneath the thoracolumbar fascia and originates from the erector spinae aponeurosis. This group is made up of three subgroups, divided by location: spinalis (the most medial), longissimus (between spinalis and iliocostalis), and iliocostalis (the most lateral). The longissimus group is the main component of the erector spinae and includes longissimus capitis, longissimus cervicis, and longissimus thoracis.

2. Materials and Methods

Participants

41 patients with definite radiographic ankylosing spondylitis according to the Assessment of Spondyloarthritis International Society 2009 criteria [15] were recruited for the study from the Rehabilitation and Rheumatology Department of the University County Hospital Timisoara, Romania, by personal invitation (on one of the routine visits). We included in the study AS patients who satisfied the diagnostic criteria for axial spondyloarthritis. Exclusion criteria were: grade 4 AS (spinal ankylosis), disk hernia, moderate or severe scoliosis, history of spinal surgery, history of vertebral fracture, psychiatric disorders (dementia or other disorders that affect rationality), neurological diseases (stroke, Parkinson’s disease, etc.), cardiopulmonary disorders that could affect participation in a physical exercise program, body mass index ≥ 35 kg/m2, exercising regularly during the previous 3 months. Patients treated with disease-modifying antirheumatic drugs had to be on a stable dosage for at least three months. Medication was not altered during the study period.

5 patients met the exclusion criteria. We enrolled in the study 36 patients. 2 patients were lost to follow-up. 34 patients completed the physical exercise program and their data were analyzed.

The sample size was calculated using G*Power 3.1.9.7 (Heinrich-Heine-Universität, Düsseldorf, Germany), with a significance level of 0.05, 0.95 power, and an effect size of 0.8. 20 participants represent the minimum sample size [16].

Baseline patients' characteristics were collected: age, body mass index, duration of ankylosing spondylitis, specific disease functioning scores (Bath Ankylosing Spondylitis Disease Activity Index, Bath Ankylosing Spondylitis Functional Index), and medication (Table 1).

Table 1. Baseline patients' characteristics

Characteristics	
Gender	
Males (%)	25 (73.5%)
Females (%)	9 (26.5%)
Age (years), mean (SD)	54.1 (10.9)
Height (cm), mean (SD)	168.6 (10)
Weight (kg), mean (SD)	82.3 (13.3)
BMI (kg/m^2), mean (SD)	29.03 (4.62)
BASFI, mean (SD)	4.31 (2.16)
BASDAI, mean (SD)	1.99 (0.83)
Medication (%)	
NSAIDs (%)	18 (53%)
SSZ (%)	6 (17.6%)
Biologics (%)	4 (11.7%)
SSZ + biologics (%)	4 (11.7%)
NSAIDs + MTX (%)	2 (5.8%)
NSAIDs + SSZ +biologics (%)	2 (5.8%)

SD: standard deviation; BMI: body mass index; BASFI: Bath Ankylosing Spondylitis Functional Index; BASDAI: Bath Ankylosing Spondylitis Disease Activity Index; NSAID: non-steroidal anti-inflammatory drugs; SSZ: Sulfasalazine; MTX: Methotrexate.

The study was conducted between December 2023 and May 2024. Participation in the study was voluntary and written informed consent was obtained from all the participants. The study is in accordance with the Helsinki Declaration and was approved by the Ethics Committee of the "Victor Babes" University of Medicine and Pharmacy in Timisoara (reference no. 33/23.11.2023).

Assessment

All the study participants were assessed twice, at the inclusion in the study and after an 8-week physical exercise program. The same investigator (trained physical therapist) performed both myotonometry and cervical and lumbar spine assessments.

MyotonPRO device (Myoton AS, Tallinn, Estonia) determines the following parameters: tone or state of tension (measured in Hz); biomechanical properties- dynamic stiffness (measured in N/m) and logarithmic decrement (characterizing elasticity or dissipation of natural oscillation); viscoelastic properties- mechanical stress relaxation time (measured in ms), and creep (ratio of relaxation time to deformation time) [8].

The measurements were performed with the patient in a sitting position. The testing muscles were: right and left longissimus capitis muscle (at the level of C4) and right and left lumbar erector spinae (at 2.5 cm to the right and left of L5). The myotonometer probe was placed vertically on the skin surface of the belly of the tested muscle.

The cervical spine was assessed with a conventional manual goniometer in a sitting position (flexion, extension, right and left rotation, right and left lateral flexion) and with a measuring tape (chin to sternum distance, right and left chin to acromion distance, right and left tragus to acromion distance). The lumbar spine was assessed with a conventional manual goniometer in a sitting position (right and left rotation, right and left lateral flexion) and with a measuring tape (Schober test and fingertip to floor test).

Physical exercise program

The AS patients performed the physical exercise program for 8 weeks. In the first 2 weeks, a trained physical therapist supervised the program in the Rehabilitation Department. A home-based exercise program was continued afterward for 6 weeks; it was self-administered as the patients have learnt how to perform correctly the exercise during the 10 supervised session in the Rehabilitation Department. Both the program in the rehabilitation unit and the home exercise program were performed 5 days per week; the session duration was 40 minutes.

The exercise program consisted of motion and flexibility exercises of the cervical, thoracic, and lumbar spine; stretching of the hamstring muscles, erector spine muscle, and shoulder muscles; control abdominal and diaphragm breathing exercises and chest expansion exercises. Strengthening of back and hip extensors was also included. The mobility exercises were performed lying on the back with the knees bent as follows: raising the knees towards the shoulders (10 repetitions); lowering the knees to one side allowing the trunk to rotate (5 repetitions to right side and 5 repetitions to the left); and raising both arms towards the ceiling (10 repetitions). Sitting on a gym ball with a neutral spine position, the patients were asked to turn their heads to look over the shoulder as far as they could and then to tuck their chin in to give themselves a double chin (5 repetitions to right side and 5 repetitions to the left). Stretching exercises were done in a standing upright position and against the wall (corner stretch to open the chest, holding the stretching for 10 seconds, 5 repetitions), and in the quadruped position (keeping the elbows straight, slowly arching the back as high as possible, and then lengthening the neck keeping the nose parallel to the floor and hollow the back; maintain the stretching of the trunk extensors for 10 seconds and then the stretching of the abdominal muscles for 10 seconds; 5 repetitions). The breathing exercises were performed in a standing position (with legs apart, grasping a stick with both hands and raising it above the head in inspiration; in exhalation, the hands come down in front) and seated on a chair (with a pulley in the hands, the hands extended in front: in inhalation, the hands go to the sides, in exhalation back to the initial position). All the mobility and flexibility exercises were of low intensity.

Statistical analysis

All statistical analyses were done using GraphPad Prism 5.0 for Windows. Descriptive statistics were computed for all variables (mean and standard deviation). Before statistical applications, the normal distribution of values in this study was verified by the D'Agostino-Pearson normality test. The intragroup data (myotonometry parameters, cervical and lumbar spine assessments at baseline and after the physical exercise program) were compared with the paired t-test. The relationship between stiffness and spinal mobility (range of motion and distances) was analyzed with the Pearson's rank correlation coefficient. A p-value of less than 0.05 was considered as statistically significant [17].

3. Results

Table 2 includes the results of myotonometer assessment of the longissimus capitis muscle at baseline and after the 8-week physical exercise program. Statistically significant differences were recorded for frequency for both the right and left longissimus capitis muscle, with higher values after the physical exercise program. Both right and left muscles had an increased tone in a resting state after rehabilitation in comparison to baseline assessment. An increased tone of the cervical extensors will help the patient to keep a straight posture of the cervical spine.

Table 2. Myotonometer parameters of the longissimus capitis muscle before and after physical exercise program

Myoton parameters	Right side			Left side		
	Baseline	After 8-week physical exercise program	p	Baseline	After 8-week physical exercise program	p
Frequency (Hz), mean (SD)	17.34 (3.76)	18.24 (4.38)	**0.04**	17.94 (4.19)	19.25 (4.83)	**0.003**
Stiffness (N/m), mean (SD)	374.00 (88.69)	369.1 (97.69)	0.74	397.2 (129.8)	389.2 (136.2)	0.62
Decrement, mean (SD)	1.4 (0.25)	1.43 (0.28)	0.49	1.3 (0.16)	1.28 (0.16)	0.49
Relaxation (ms), mean (SD)	14.03 (2.89)	14.55 (3.56)	0.34	13.45 (2.55)	14.23 (4.17)	0.17
Creep, mean (SD)	0.83 (0.15)	0.89 (0.18)	0.13	0.84 (0.13)	0.87 (0.23)	0.3

SD: standard deviation; Bold values: $p<0.05$ indicates statistical significance.

Table 3 presents the results of myotonometer assessment of the lumbar erector spinae muscle at baseline and after the 8-week physical exercise program. We recorded statistically significant differences in stiffness and decrement for the right lumbar erector spinae muscle. The stiffness decreased, while the decrement increased (lower elasticity) after the exercise program. A lower stiffness of the right lumbar erector spinae can be related to higher right lumbar rotation and right lumbar lateral flexion. The relaxation time was significantly higher for both the right and left lumbar erector spinae muscle at the 8-week assessment; the recovery time for the muscle to return to its normal state after deformation increased after rehabilitation.

Table 3. Myotonometer parameters of the lumbar erector spinae before and after the physical exercise program

Myoton parameters	Right side			Left side		
	Baseline	After 8-week physical exercise program	p	Baseline	After 8-week physical exercise program	p
Frequency (Hz), mean (SD)	14.18 (4.58)	13.88 (4.09)	0.31	14.14 (2.91)	14.39 (3.16)	0.67
Stiffness (N/m), mean (SD)	341.6 (21.6)	302.0 (88.5)	**0.0003**	363.5 (128.9)	327.5 (133.3)	0.09
Decrement, mean (SD)	1.46 (0.46)	1.55 (0.48)	**0.021**	1.58 (0.43)	1.63 (0.49)	0.37
Relaxation (ms), mean (SD)	19.51 (6.85)	21.31 (7.26)	**0.0002**	16.47 (5.57)	18.49 (6.33)	**0.02**
Creep, mean (SD)	1.21 (0.39)	1.28 (0.39)	0.072	1.04 (0.32)	1.12 (0.35)	0.09

SD: standard deviation; Bold values: $p<0.05$ indicates statistical significance.

After the physical exercise program, the cervical spine range of motion improved significantly for all the tested movements (flexion, extension, right and left rotation, right and left lateral flexion). All the assessed distances decreased after rehabilitation, proving an increased mobility of the cervical spine. Moreover, for the chin to sternum distance and left chin to acromion distance, the values were significantly lower after the 8-week physical exercise program (Table 4).

Table 4. Cervical spine assessment before and after a physical exercise program

	Baseline	**After 8-week physical exercise program**	**p**
Flexion (°), mean (SD)	28.2 (8.8)	30.8 (8.8)	**<0.0001**
Extension (°), mean (SD)	26.5 (12.9)	27.9 (13.2)	**<0.0001**
Right rotation (°), mean (SD)	36.1 (15)	38 (15.6)	**<0.0001**
Left rotation (°), mean (SD)	37.4 (12.7)	39.5 (12.5)	**<0.0001**
Right lateral flexion (°), mean (SD)	24.2 (11.5)	24.7 (11.7)	**0.0001**
Left lateral flexion (°), mean (SD)	24.4 (12.4)	25 (12.4)	**0.0003**
Chin to sternum distance (cm), mean (SD)	4.3 (3.4)	3.8 (3)	**<0.0001**
Right chin to acromiom distance (cm), mean (SD)	7.7 (6.4)	7.5 (6.4)	0.22
Left chin to acromiom distance (cm), mean (SD)	8.4 (7.3)	8.2 (7.2)	**0.014**
Right tragus to acromion distance, mean (SD)	8.4 (6.7)	8.2 (6.7)	0.15
Left tragus to acromion distance, mean (SD)	8.4 (6.6)	8.3 (6.6)	0.08

SD: standard deviation; Bold values: $p<0.05$ indicates statistical significance.

The lumbar spine range of motion improved after rehabilitation for all four tested movements (right and left rotation, right and left lateral flexion). Both the right and left rotations were significantly higher after the 8-week physical exercise program. The patients had better mobility after rehabilitation; the Schober had significantly increased values, while the finger-to-floor test decreased significantly (Table 5).

Table 5. Lumbar spine assessment before and after the physical exercise program

	Baseline	**After 8-week physical exercise program**	**p**
Right rotation (°), mean (SD)	27 (9.1)	28.2 (9.4)	**<0.0001**
Left rotation (°), mean (SD)	28.4 (10.1)	29.4 (10)	**<0.0001**
Right lateral flexion (°), mean (SD)	21 (6.2)	21.4 (6.3)	0.26
Left lateral flexion (°), mean (SD)	21.4 (6.3)	21.8 (7.9)	0.49
Schober test (cm), mean (SD)	2.8 (0.8)	3 (0.8)	**<0.0001**
Finger to floor test (cm), mean (SD)	13.7 (9.3)	12.3 (9.1)	**<0.0001**

SD: standard deviation; Bold values: $p<0.05$ indicates statistical significance.

Table 6 includes the correlations between the stiffness of the longissimus capitis muscle and cervical spinal mobility (rotation and lateral flexion) and distances (chin to acromion and tragus to acromion), and the correlations between stiffness of the lumbar erector spinae and lumbar spinal mobility (rotation and lateral flexion). The correlations were recorded for the muscle and the range of motion and distances on the same side. We recorded statistically significant negative correlations between right lumbar rotation and right lumbar lateral flexion at both baseline and 8-week assessments. With the decrease of right lumbar erector spinae stiffness, the range of motion of right lumbar rotation and right lumbar lateral flexion is higher. Although there were no other significant correlations, for most of the compared parameters indirect correlations were noted; the more the stiffness decreases, the better the cervical and lumbar mobility.

Table 6. Correlation of spinal motion and distances with stiffness

Spinal motion/distances	Baseline		After 8-week physical exercise program	
	r	p	r	p
Right cervical rotation	-0.114	0.51	-0.271	0.12
Left cervical rotation	-0.048	0.78	-0.084	0.63
Right cervical lateral flexion	-0.149	0.39	-0.322	0.06
Left cervical lateral flexion	0.013	0.93	-0.025	0.88
Right chin to acromion distance	-0.145	0.41	0.138	0.43
Left chin to acromion distance	-0.198	0.26	-0.11	0.53
Right tragus to acromion distance	-0.192	0.27	0.105	0.55
Left tragus to acromion distance	-0.206	0.24	-0.123	0.48
Right lumbar rotation	-0.41	**0.015**	-0.362	**0.035**
Left lumbar rotation	-0.179	0.3	-0.009	0.95
Right lumbar lateral flexion	-0.41	**0.015**	-0.429	**0.011**
Left lumbar lateral flexion	-0.096	0.58	-0.255	0.14

r: rank correlation coefficient; $p<0.05$ indicates statistical significance.

4. Discussion

Our research focused on assessing the mechanical properties of two muscles that are important for maintaining the extension of the spine, namely longissimus capitis and lumbar erector spinae. We chose as a study group patients diagnosed with AS who have followed an 8-week physical exercise program. We tested the right and left longissimus capitis and the right and left lumbar erector spinae at baseline and after the exercise program.

We recorded a significantly increased frequency of both right and left longissimus capitis after the physical exercise program in comparison to the baseline assessment. The frequency is the expression of the muscle tension or tone in a resting state. All four tested muscles had reduced stiffness after the 8-week physical exercise program. The stiffness reflects the ability of the muscle to resist contraction or external force that deforms its initial shape. However, the values were significantly lower only for the right lumbar erector spinae. After rehabilitation, there were no significant differences in the decrement, except for right lumbar erector spinae (higher values after exercise program). Logarithmic decrement in the amplitude of oscillation describes the ability of the tissue to restore its shape after deformation, characterizing the inverse of the elasticity (the lower the decrement value, the greater elasticity) [18,19].

The relaxation time was higher after physical exercise program for all the assessed muscles, with significantly increase for the right lumbar erector spinae. The relaxation time of stress is the recovery time for the muscle to return to its normal state after deformation. The creep was higher after rehabilitation. However, no statistically significant differences were noted. Creep is the property of progressive deformation while applying constant stress, reflecting the viscosity of the tissue [14].

The studies of Alcaraz-Clariana et al. and Garrido-Castro et al. assessed the mechanical properties of semispinalis capitis and lumbar erector spinae in patients with axial spondyloarthritis [13,20]. Semispinalis capitis muscle is located superficial to the semispinalis cervicis muscle and deep to the splenius capitis and cervicis and trapezius muscles. Sometimes, a small portion of the muscle remains exposed as part of the posterior triangle of the neck.

In the current research, we tested the myotonometry parameters of longissimus capitis and lumbar erector spinae muscles both at the beginning of the physical exercise program and after the 8-week exercise program.

The stiffness of the semispinalis capitis muscle was 314.71 ± 43.87 N/m (Alcaraz-Clariana et al.[20] on 43 patients) and 349.60 ± 44.90 N/m, respectively (Garrido-Castro et al. [13] on 34 patients). In our study on 34 patients, at baseline assessment, the stiffness of the longissimus capitis was 374.00 ± 88.69 N/m for the right side and 397.2 ± 129.8 N/m for the left side. After exercise program, we recorded a stiffness of 369.1 ± 97.69 N/m for right longissimus capitis and 389.2 ± 136.2 N/m for left longissimus capitis. The stiffness of the lumbar erector spinae muscle was 383.13 ± 53.22 N/m (Alcaraz-Clariana et al. [20]) and 393.57 ± 152.24 N/m, respectively (Garrido-Castro et al. [13]). In our study, at first evaluation, the stiffness of the erector spinae was 341.6 ± 21.6 N/m for the right side and 363.5 ± 128.9 N/m for the left side. After the exercise program, we recorded a stiffness of 302.0 ± 88.5 N/m for the right erector spinae and 327.5 ± 133.3 N/m for the left erector spinae.

In contrast to the studies of Alcaraz-Clariana et al. and Garrido-Castro et al. [13,20] that performed the myotonometric assessment with patients lying in a prone position, we tested the patients in a sitting position. The research of Li et al. on patients with chronic low back pain demonstrated that the erector spinae stiffness was significantly increased from prone to sitting, especially on the painful side [21]. We chose to test the patients in a sitting position both for the longissimus capitis and for the erector spinae as the cervical and lumbar spinal assessments were also performed in sitting condition.

Zhang et al. found more collagen fibril accumulation and atrophy in AS patients' paraspinal muscle samples than in healthy controls [22]. In addition, these patients have more fatty degeneration and denervation in paraspinal muscles [23]. The increase in muscle tone of the extensors muscles, such as longissimus capitis and lumbar erector spinae, is important to counterbalance the changes due to the disease course.

The study of Hsieh et al. compared the effectiveness of combined home exercise (range of motion exercises, strengthening of the muscles of the spine and major joints and aerobic exercise) and range of motion home exercise (range of motion exercises of the spine and major joints) in patients with AS. Both programs were performed for 3 months [24].

In our study the AS patients followed an exercise program that included a range of motion, stretching, and strengthening exercises, started in a rehabilitation center, and continued with a home-based program. As the physical activity intervention programs are recognized for bringing benefits for health status [25], we draw attention to the importance of a tailored physical exercise program in AS patients.

The clinical implications of the current study are related to the effects of a short-term physical exercise program on spinal mobility and muscle properties in AS patients. The proposed home-based program is easy to be learnt and performed by the patients without supervision. However, if not performed as recommended (frequency, duration) the effects will not be as expected. That is why the adherence of AS patients to exercise program is extremely important.

The lack of surface electromyography of longissimus capitis and erector spinae muscles and the comparison to healthy controls can be considered limitations of the current study. We are aware that the second evaluation (after an 8-week physical exercise program) is a relatively short-term analysis. We intend to compare the myotonometry parameters and spinal mobility before starting the physical exercise program and after a longer period (6 months and one year). Another future research aims to compare myotonometry data in AS patients who will follow two different types of physical exercise programs. We admit that the absence of a control group of AS patients who did not follow the 8-week physical exercise program is a limitation of our study. The opportunity to compare two groups of AS patients (who will follow a physical exercise program versus without a physical exercise program) is a future research plan. Including different age groups who will follow the same physical exercise program can be also a future direction.

5. Conclusions

In patients with AS, after an 8-week physical exercise program, significant differences were recorded for longissimus capitis muscle frequency, for right lumbar erector spinae stiffness and decrement, and for bilateral lumbar erector spinae relaxation. The stiffness of both muscles was negatively correlated with most spinal mobility parameters. Improvements of cervical and lumbar spinal motions can be analyzed in relation to mechanical muscle properties in AS patients who have followed a physical exercise program.

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