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Which Respiratory Training is More Effective in Individuals with Ankylosing Spondylitis: 360-Degree Expansion Diaphragm Exercises or Standard Diaphragm Exercises? Randomized Controlled Trial

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ABSTRACT

Objective: Respiratory complications, though often asymptomatic, are a significant cause of morbidity and mortality in individuals with Ankylosing Spondylitis (AS). Despite the proven benefits of exercise in managing AS, limited evidence exists comparing conventional diaphragmatic breathing to novel, multidimensional approaches targeting full thoracic expansion. This study aimed to address this gap by evaluating the effectiveness of standard versus 360-degree expansion diaphragm breathing exercises delivered with sensor-based feedback in improving respiratory function, disease activity, and physical capacity in AS.
Material and Methods: Fifty individuals diagnosed with AS were randomized to either a standard diaphragm breathing group (DG) or a 360-degree expansion diaphragm group (360DG). Both groups received supervised exercise interventions twice weekly for six weeks. Outcomes included pulmonary function tests, maximal inspiratory and expiratory pressures (MIP/MEP), and AS-specific indices.
Results: Both groups demonstrated significant improvements in functional indices and respiratory parameters, with no statistically significant intergroup differences (p>0.05). Notably, FEV1/FVC improved in the DG group (p=0.017), while FVC showed a significant increase in the 360DG group (p=0.007). Respiratory muscle strength (MIP and MEP) improved significantly in both groups (p<0.05).
Conclusion: This randomized controlled trial is among the first to evaluate 360-degree expansive diaphragm breathing in AS. The findings suggest that both standard and sensor-guided breathing exercises are safe and effective in improving respiratory and functional outcomes. These results underscore the clinical relevance of incorporating tailored respiratory training into rehabilitation programs for AS, offering physiotherapists and clinicians flexible, evidence-based strategies to improve patient care.
Keywords: Functional capacity, mobility, respiration, rheumatic disease.

Ankilozan Spondilitli Bireylerde Hangi Solunum Eğitimi Daha Etkilidir: 360 Derece Ekspanse Diyafram Egzersizleri mi, Standart Diyafram Egzersizleri mi? Randomize Kontrollü Çalışma

ÖZET

Amaç: Solunum komplikasyonları genellikle asemptomatik olsa da Ankilozan Spondilit (AS) hastalarında önemli bir morbidite ve mortalite nedenidir. Egzersizin AS yönetimindeki kanıtlanmış faydalarına rağmen, geleneksel diyafram nefesi ile göğüs kafesinin tamamını hedefleyen çok boyutlu, yenilikçi yaklaşımların karşılaştırıldığı sınırlı sayıda çalışma bulunmaktadır. Bu çalışma, standart diyafram nefesi ile sensör destekli 360 derece ekspanse diyafram nefesi egzersizlerinin solunum fonksiyonu, hastalık aktivitesi ve fiziksel kapasite üzerindeki etkilerini değerlendirerek bu boşluğu doldurmayı amaçlamıştır.
Gereç ve Yöntem: AS tanısı almış 50 birey, standart diyafram nefesi grubu (DG) veya 360 derece ekspanse diyafram nefesi grubu (360DG) olmak üzere rastgele iki gruba ayrılmıştır. Her iki gruba da altı hafta boyunca haftada iki kez denetimli egzersiz uygulanmıştır. Değerlendirilen sonuçlar arasında solunum fonksiyon testleri, maksimal inspiratuvar ve ekspiratuvar basınçlar (MIP/MEP) ve AS'ye özgü indeksler yer almıştır.
Bulgular: Her iki grupta da işlevsel indeksler ve solunum parametrelerinde anlamlı iyileşmeler gözlemlenmiş, ancak gruplar arası farklar istatistiksel olarak anlamlı bulunmamıştır (p>0,05). Özellikle, DG grubunda FEV1/FVC oranında anlamlı bir artış (p = 0,017), 360DG grubunda ise FVC değerinde anlamlı bir artış (p = 0,007) saptanmıştır. Solunum kas gücü (MIP ve MEP) her iki grupta da anlamlı şekilde artmıştır (p<0,05).
Sonuç: Bu randomize kontrollü çalışma, AS'de 360 derece ekspanse diyafram nefesi egzersizlerini değerlendiren ilk çalışmalardan biridir. Bulgular hem standart hem de sensör destekli nefes egzersizlerinin solunum ve fonksiyonel sonuçları iyileştirmede güvenli ve etkili olduğunu göstermektedir. Bu sonuçlar, fizyoterapistler ve klinisyenler için kişiye özel solunum eğitiminin AS rehabilitasyon programlarına entegre edilmesinin klinik önemini vurgulamakta ve hasta bakımını geliştirmek için esnek, kanıta dayalı stratejiler sunmaktadır.
Anahtar Kelimeler: Fonksiyonel kapasite, mobilite, romatizmal hastalık, solunum.

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1. Introduction

Ankylosing spondylitis (AS) is a chronic inflammatory disease primarily affecting the sacroiliac joint and the axial skeleton. Progressive loss of mobility, postural deformities, and gait disturbances are the most common symptoms of AS (1). While the main focus of AS treatment was previously on the axial skeleton, a more holistic approach has become prevalent as nearly 40% of patients exhibit at least one extra-articular manifestation (2). Although pulmonary findings in AS are often asymptomatic, respiratory diseases are the third most common cause of death in AS (3). Restricted chest wall mobility, the natural disease course, and side effects of medications can lead to pulmonary findings such as fibrosis in the upper lobes, interstitial lung disease, spontaneous pneumothorax, mycetoma associated with secondary infections, emphysema, bronchiectasis, and respiratory dysfunction (4). Exercise therapy plays a major role in the management of both the articular and extra-articular manifestations of AS (2). Respiratory exercises, which are intended to strengthen the respiratory muscles and improve chest expansion-important components of AS management-usually include deep breathing and anterior abdominal wall inflation (5, 6). The diaphragm is the major inspiratory muscle, whose contraction during inspiration increases the volume of the thoracic cavity (7). In a normal breathing pattern, a costodiaphragmatic breathing pattern is observed at rest, during which lateral costal and abdominal expansion predominate over superior thoracic expansion, allowing maximum lung expansion and gas exchange (8, 9). The flattening of the diaphragm dome results in changes in the volume and shape of the thoracic cage, causing cylindrical expansion of the thoracic wall in all directions (360-Degree) (10). One of the major challenges in AS is reduced thoracic expansion, which can significantly impair pulmonary function. Therefore, respiratory exercises for AS patients should be designed to specifically promote thoracic expansion. Standard diaphragmatic breathing exercises, which involve placing a hand on the abdomen and pushing the anterior abdominal wall outward (11), do not fully achieve this effect. This technique primarily focuses on anterior abdominal movement, limiting the engagement of the lateral and posterior thoracic regions, which are essential for comprehensive lung expansion.

This study aims to evaluate and compare the efficacy of standard diaphragmatic breathing and sensor-based device-assisted breathing exercises in enhancing thoracic expansion, improving pulmonary function, and reducing disease activity in patients with AS.

2. Material and Method

2.1. Research Type and Sample of the Research

A total of 50 volunteers (mean age: 44.94 ± 11.60 years) diagnosed with AS according to the 1988 Modified New York Criteria (12), with Bath Ankylosing Spondylitis Disease Activity Index (BASDAI) (13) scores of 3 or 4, were enrolled in this prospective, randomized controlled trial. The diagnoses and referrals were made by a rheumatologist at Dokuz Eylul University Hospital.

Participants were excluded if they had any neurological or pulmonary comorbidities that could independently affect chest wall mobility or pulmonary function, such as chronic obstructive pulmonary disease (COPD) or asthma. Individuals who had participated in regular structured exercise therapy within the preceding three months were also excluded to eliminate prior training effects. Furthermore, during the intervention period, participants who missed four consecutive supervised sessions or required modifications to their standard treatment regimen were withdrawn from the study to preserve the internal validity of the findings (Figure 1).

2.1.1. Sample Size

Since there was no directly comparable study in the literature on the subject of our research, the sample size calculation in our study was based on the FVC (Forced Vital Capacity) value from a study by Drăgoi et al. (14) comparing conventional training with inspiratory respiratory muscle training. This guarantees, with a power of 95% and using 80% test strength as α = 0.05 by estimating, by software named "G*Power 3.1.9.4", that each group has 25 participants.

2.1.2. Randomization

Two lists of numbers- one with 50 numbers- were generated through the "Research Randomiser" website. The random numbers were placed in individual sealed envelopes, one number per envelope. After the participants had been checked for inclusion criteria, each participant was asked to pick one envelope. According to the number inside the envelope, participants were assigned to either Group 1 or Group 2.

2.2. Data Collection

2.2.1. Data Collection Tools

The sociodemographic characteristics of the participants, age, weight, height, education level, smoking status, medical history, presence of comorbidities, and year of diagnosis, were recorded using an evaluation form. The main outcome measure in the current study was spinal mobility, which was measured by means of the Bath Ankylosing Spondylitis Metrology Index (BASMI). The secondary outcome measures included disease-related functional status, disease activity, and respiratory functions.

2.2.2. Primary Outcome

The Bath indices played a significant role in capturing patient-reported data of AS. Therefore, spinal mobility and clinical differences in spinal movements were measured by BASMI, which consists of five measurements: cervical rotation, tragus-to-wall distance, lateral lumbar flexion, anterior lumbar flexion, and intermalleolar distance. BASMI scores range from low to high; the lower the score, the better the spinal mobility (13). The Turkish validity and reliability of BASDAI were determined by Akkoc et al. in 2005 (15).

2.2.3. Secondary Outcomes

2.2.3.1. Disease Activity

Disease activity, progression, and prognosis were assessed with the use of BASDAI. This index comprises five questions, and the final score is the average score of all the questions, but the last two questions are averaged to yield a single score (13). The Turkish validity and reliability of BASDAI were determined by Ay et al. in 2004 (16).

2.2.3.2. Functional Assessment

Functional status of the participants was assessed by using the Bath Ankylosing Spondylitis Functional Index (BASFI), which is formed by 10 questions. Of these, there are eight questions assessing the physical status of patients and two questions related to coping with daily life. Answers are scored on a 10 cm visual analogue scale, ranging from 0 (easy) to 10 (impossible). The Turkish validity and reliability of BASFI were determined by Özer et al. in 2005 (17).

2.2.3.3. Respiratory Muscle Strength Measurement

Maximal inspiratory pressures (MIP) and Maximal expiratory pressures (MEP) were measured using a non-invasive mouth pressure device (RP Check, MD Diagnostics Ltd., Maidstone, UK).

MIP Measurement: Maximum expiration was performed by the subjects in a seated position, followed by maximal inspiration for 1-3 seconds, occluding the airway with a valve. The pressure recorded, reflecting the pressure required to open alveoli at residual volume, was noted as a negative value.

MEP Measurement: The subjects in a seated position were asked to execute maximal expiration for 1-3 seconds after maximal inhalation.

In MIP and MEP measurements, at least three maneuvers lasting over 1.5 seconds must be conducted, separating the maneuvers with a one-minute rest. The highest value was recorded (18, 19).

2.2.3.4. Respiratory Function Test

Pulmonary function tests were conducted using an ATS and ERS-criteria compatible portable spirometer (MIR, Spirobank II, Rome, Italy) in a seated position. The following parameters were recorded in liters and as a percentage of the predicted values (20): Forced expiratory volume in the first second (FEV1), FVC, Ratio of FEV1 to FVC (FEV1/FVC), Peak expiratory flow (PEF), Forced expiratory flow at 25-75% of FVC (FEF25-75%), Vital capacity (VC).

2.3. Implementation of the Research

2.3.1. Intervention

Those who were diagnosed with AS and who fulfilled the inclusion criteria were then randomly assigned to the 360 DG Group and the DG Group.
360 DG Group: Participants were subjected to 360-degree expanded diaphragmatic breathing exercises using the Ohmbelt device along with physiotherapy exercises.
DG Group: Participants were subjected to conventional diaphragmatic breathing exercises along with physiotherapy exercises.
Treatment in both groups was provided once a week for six weeks. Each session was 35 minutes in length, including 15 minutes of exercises to improve breathing and 20 minutes of physiotherapy exercises. All participants received educational instructions regarding the breathing exercises and physiotherapy exercises to which they were assigned. They were also taught to continue the exercises as part of a home exercise program, performing them twice per week, with 10 repetitions and 2 sets, and were asked to mark the exercises on an exercise tracking sheet (21).

2.3.1.1. 360-Degree Expanded Diaphragmatic Breathing Exercises

Participants in this group were taught 360-degree expanded diaphragmatic breathing exercises using the Ohmbelt device (Nilus Medical LLC, OHMBELT, Redwood City, CA, USA). The Ohmbelt is a Core360 belt equipped with OhmTrak sensors (11). Two Ohmbelt devices were used in this study, and they were positioned on the body as described in the literature (11, 22, 23).

Participants were seated on a backless chair with their hips and knees flexed at 90° with both feet on the floor. The Ohmbelt devices were positioned on the participant's torso as follows: anterior sensor placed in the inguinal cavity to visualize the anterior abdominal wall expansion; posterior sensor positioned on the contralateral upper lumbar triangle to visualize the posterior wall expansion. They were instructed to maintain the pressure on the sensors during inspiration and expiration. The sequence of breathing through the nose for inspiration and expiration, each for 6 seconds, was repeated. The exercises were repeated 10 times in 3 sets with a rest of 1 minute between the sets (6). They were also asked to perform 360-degree expanded breathing exercises with an elastic band as the exercise program in their house, and to write about the exercises they performed in their exercise log.

2.3.1.2. Standard Diaphragmatic Breathing Exercises

The participants of this group were instructed on normal diaphragmatic breathing. Lying supine with a pillow to elevate the head and knees for support, they were instructed to close their eyes in order to focus. Instructions of exercise: "Place one

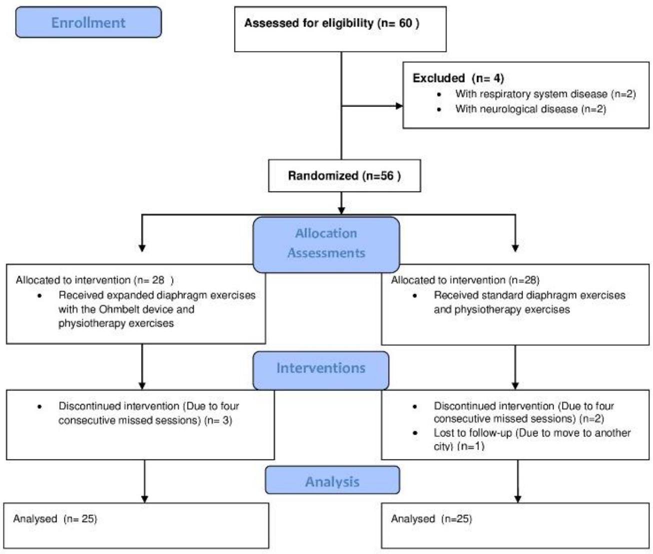

Figure 1. Flow diagram for the study

hand on your chest and the other on your abdomen. Inhale slowly through your nose, allowing the air in as much as possible towards the hand on the belly. Visualize inflating a balloon in the abdomen and ribs. Now, exhale all the air through your mouth very slowly." The breathing exercise protocol was to inspire and expire through the nose for 6 seconds. Exercises were conducted for 10 repetitions in 3 sets, resting for 1 minute between sets of exercises (6). These diaphragmatic breathing exercises were recommended to be conducted at home and recorded in an exercise log.

2.3.1.3. Physiotherapy Exercises

Both groups' participants were individually subjected to a three-dimensional functional exercise program recommended by evidence-based guidelines for patients with AS (24, 25). The protocol included warm-up, mobility, stretching, flexibility, and cool-down periods, lasting approximately 20 minutes. Participants were instructed to perform the functional exercises at home as part of the exercise program and to record their progress in an exercise log (Appendix 1).

2.3.2. Analysis of Research Data

Data analysis was done by means of the Statistical Package for Social Science software, version 29.0 (SPSS Inc., Chicago, Illinois, USA). Normality was confirmed for all variables except age, based on histogram inspection, skewness and kurtosis values, and the Shapiro-Wilk test. Descriptive analyses were used to present demographic data, questionnaire results, and measurement parameters as mean±SD and percentiles. Comparisons within groups for continuous data meeting parametric assumptions were conducted with paired t-tests and chi-square tests for categorical data comparison. Treatment group differences in change from baseline to endpoint were examined using an ANCOVA model. The level of statistical significance considered for all these analyses was p<0.05.

2.4. Ethical Aspects of the Research

The study was conducted between March and December 2024 at the Izmir University of Economics. Ethical approval was obtained for the study from the Izmir University of Economics Health Sciences Research Ethics Committee (Approval No: B.30.2.IEUSB.0.05.05-20-279). The participants were informed both verbally and in writing. Informed consent was taken based on principles of the World Medical Association Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Participants. We adhered to the CONSORT guidelines and completed the checklist. The study is registered on Clinicaltrials.gov under the registration number NCT06490796. Volunteers aged 20–60 years who fulfilled the selection criteria were included in the study.

3. Results

Fifty patients completed the study without experiencing any adverse events or side effects. Demographic data for the study group are summarized in Table 1. No statistically significant differences were observed between the groups in terms of age, gender, BMI, disease duration, BASFI, BASMI, alcohol consumption, or smoking status (p>0.05).

Table 1. Demographic properties of the groups in baseline

	Diaphragm Group (n=25) Mean + SD	360 DG (n=25) Mean + SD	p
Age (years)	43.12 (±10.31)	46.76 (±12.72)	0.236
BMI	25.25 (±3.84)	28.42 (±4.98)	0.656
BASDAI	0.01 (±0.05)	0.01 (± 0.01)	0.046
BASFI	2.79 (±2.16)	2.65 (± 1.94)	0.625
BASMI	3.37 (±1.47)	3.27 (±1.60)	0.849
Disease Duration (years)	12.04 (±6.45)	11.28 (±8.5)	0.430
	n (%)	**n (%)**	**X2**
Gender Female	14 (56.0%)	10 (40.0%)	0.258
Smoker	10 (40.0 %)	9 (36.0%)	0.771
Non-drinkers	17 (68.0%)	16 (64.0%)	0.765

Independent Samples T Test #p<0.05 within groups; Chi square test for categorical data comparison, BMI: Body Mass Index; BASDAI: Bath Ankylosing Spondylosis Disease Index; BASFI: Bath Ankylosing Spondylitis Functional Index; BASMI: Bath Ankylosing Spondylosis Metrology Index.

3.1. Primary outcomes

Both the DG and the 360 DG group demonstrated significant improvements in BASMI, BASDAI, and BASFI scores following the intervention. These findings indicate that both exercise programs effectively improved disease activity and functional status, with no statistically significant differences in outcomes between the two groups (Table 2).

3.2. Secondary outcomes

Both groups showed improvements in pulmonary function and respiratory muscle strength parameters post-intervention. Table 3 summarizes the results of intergroup comparisons.

Patients in the DG group showed significant improvements in FEV1/FVC (p=0.017), while those in the 360 DG group demonstrated significant increases in FVC (p=0.007) after the 6-week multidimensional functional mobility exercise program. However, intergroup comparisons revealed no statistically significant differences in changes for FVC (p=0.265) or FEV1 (p=0.148).

The FEV1/FVC ratio improved in both groups, but the intergroup difference was not statistically significant (p = 0.548).

For PEF, a non-significant decrease was observed in the DG group (p=0.360), while the 360 DG group demonstrated a slight but non-significant increase (p=0.683). However, the between-group difference was not statistically significant (p=0.135). Significant post-intervention improvements were observed in both MIP and MEP within both groups. In the DG group, changes in MIP (p=0.001) and MEP (p=0.001) were statistically significant, as were changes in the 360 DG group for MIP (p=0.042) and MEP (p=0.020). However, intergroup comparisons for both MIP and MEP showed no statistically significant differences.

Overall, both interventions effectively enhanced pulmonary function and respiratory muscle strength. The magnitude of improvement was comparable between the two groups, with no statistically significant differences observed in intergroup analyses.

4. Discussion

The findings of this study demonstrate that both the DG and 360 DG multidimensional functional mobility exercise programs were effective in improving disease activity, functional status, pulmonary function, and respiratory muscle strength in patients with AS. To our knowledge this is the first controlled study investigating 360-degree expansive diaphragm exercises with a

Table 2. Intergroup comparison of the initial and last assessment differences of disease related scales

	Diaphragm Group (n=25) Mean±SD			360 DG (n=25) Mean ±SD					Post-intervention between group comparisons
	Before	**After**	**p value**	**Before**	**After**	**p value**	**df**	**F**	**p value**
BASMI	3.37 (±1.47)	2.22 * (±1.25)	<0.000	3.27 (±1.61)	1.92* (±1.09)	0.001	1	1.761	0.191
Δ		-1.15 (±0.56)			-1.35 (±1.04)				0.388
BASDAI	3.77 (±2.49)	2.61* (±1.73)	0.001	3.98 (±2.22)	2.92* (±2.20)	0.003	1	1.27	0.27
Δ		-1.16 (±1.53)			-1.05 (±1.60)				0.805
BASFI	2.79(±2.16)	1.89* (±1.32)	0.012	2.65 (±1.94)	2.17* (±1.73)	0.038	1	1.373	0.247
Δ		-0.89 (±1.65)			-0.48 (±1.09)				0.300

Paired sample test *p<0.05 between groups; ANCOVA #p<0.05 within groups; Δ: variable difference between pre-treatment and post- treatment, BASMI: Bath Ankylosing Spondylosis Metrology Index BASDAI: Bath Ankylosing Spondylosis Disease Index; BASFI: Bath Ankylosing Spondylitis Functional Index; VAS (rest): Visual Analog Scale at Rest; VAS (act): Visual Analog Scale at Activity non-invasive device used for feedback. Participants in the study demonstrated full compliance with the use of this device and reported no discomfort or adverse effects.

Pulmonary function tests results of all participants were within normative ranges for their age and sex. Consequently, the aim of this study was not to address existing symptoms but to evaluate the pulmonary effects of multidimensional exercise programs in individuals with AS.

These results provide further evidence supporting the role of structured exercise interventions in managing conditions associated with impaired mobility, reduced respiratory capacity, and functional limitations.

4.1. Disease Activity and Functional Outcomes

Both groups in this study showed significant improvements in BASFI, BASMI, and BASDAI scores, indicating enhanced functional status and reduced disease activity.

This loss of spinal mobility is a cardinal feature of AS (26), and addressing it through targeted exercises is crucial. Mobility and breathing exercises have shown promise in enhancing functional status and reducing disease activity in individuals with AS (27, 28).

The findings of this study are consistent with previous research emphasizing the benefits of targeted exercise programs in alleviating stiffness, reducing pain, and mitigating overall disease burden in individuals with AS (1, 5, 14, 27, 28). Importantly, the lack of statistically significant differences between the DG and 360 DG groups indicates that both exercise interventions are comparably effective. This insight is valuable for customizing exercise programs to accommodate individual patient needs, preferences, or logistical considerations.

In support of these findings, a recent network meta-analysis by Luo et al. examined the effectiveness of various exercise interventions for managing AS symptoms (29). This study compared different exercise modalities to non-exercise therapies, aiming to identify the most effective strategies for improving outcomes in AS patients. The results of the meta-analysis provide valuable guidance for healthcare practitioners, enabling the development of tailored treatment plans that address the unique needs and preferences of each patient while optimizing therapeutic benefits (28, 29).

Similarly, the systematic review by Saracoğlu et al. concluded that disease-specific indices improve with any form of movement-based treatment; however, pulmonary functions require more targeted and specific therapeutic approaches (30).

4.2. Pulmonary Function

The improvement in pulmonary function parameters such as FVC and FEV1/FVC of the participants of the study underscores the impact of multidimensional exercise programs on respiratory health. In particular, the DG group demonstrated significant improvements in the FEV1/FVC ratio, while the 360 DG group showed significant increases in FVC. These findings suggest that both interventions effectively enhance different

Table 3. Intergroup comparison of the initial and last assessment differences of pulmonary function parameters

	Diaphragm Group (n=25) Mean + SD			**360 DG (n=25) Mean + SD**					**Post-intervention between group comparisons**
	Before	**After**	**p value**	**Before**	**After**	**p value**	**df**	**F**	**p value**
FVC (lt)	3.46 (±0.96)	3.54 (±0.96)	0.489	5.28 (±0.96)	5.69* (±0.96)	0.032	1	1.414	0.240
Δ	0.08 (±0.58)			0.40 (±0.89)					0.265
FEV1 (lt)	2.55 (±0.89)	2.72 (±0.79)	0.067	3.04 (±2.56)	2.70 (±0.87)	0.481	1	0.278	0.601
Δ	0.16 (±0.43)			-0.34 (±2.39)					0.148
FEV1/ FVC (lt)	73.10 (±14.48)	78.90* (±7.71)	0.017	74.30 (±13.09)	76.56 (±12.50)	0.312	1	1.493	0.228
Δ	5.80 (±11.37)			2.26 (±10.96)					0.548
PEF (lt)	5.49 (±8.15)	4.01 (±1.16)	0.364	4.19 (±1.70)	4.30 (±1.65)	0.683	1	0.813	0.372
Δ	-1.48 (±8.02)			0.11 (±1.37)					0.135
FEF (lt)	2.52 (±1.15)	2.67 (±0.97)	0.299	2.48 (±1.04)	2.67 (±0.84)	0.216	1	0.012	0.912
Δ	0.15 (±0.70)			0.18 (±0.72)					0.349
VC (lt)	3.35 (±0.98)	3.44 (±0.92)	0.350	3.47 (±0.96)	3.46 (±0.97)	0.921	1	0.444	0.508
Δ	0.80 (±0.42)			-0.01 (±0.39)					0.801
MIP (cm H2O)	59.44 (±21.50)	69.91* (±20.74)	<0.000	67.96 (±29.42)	73.91* (±28.66)	0.042	1	1.31	0.259
Δ	10.47 (±7.14)			5.95 (±13.82)					0.085
MEP (cm H2O)	72.44 (±21.50)	85.61* (±20.74)	<0.000	72.56 (±36.12)	81.65* (±43.78)	0.020	1	0.778	0.382
Δ	13.17 (±13.96)			9.09 (±18.15)					0.368

Paired sample test *p<0.05; ANCOVA #p<0.05 within groups; #p<0.05within groups; FVC, forced expiratory vital capacity; FEV1, forced expiratory volume during the first second; FEV1/FVC forced vital capacity ratio of forced expiratory volume during the first second; PEF, peak expiratory flow rate; FEF, Forced expiratory flow; VC, vital capacity; MVV, maximum voluntary ventilation; MIP, maximum inspiratory pressure; MEP, maximum expiratory pressure.

aspects of pulmonary function, potentially due to the emphasis on mobility, posture, and breathing techniques integrated into the programs. Low FVC is commonly associated with restricted thoracic expansibility, whereas a reduced FEV1/FVC ratio is indicative of airway obstruction, typically seen in conditions such as asthma and COPD. Although AS primarily causes restrictive pulmonary impairments (4), improvements in thoracic and spinal mobility, along with enhanced respiratory muscle strength, have also been shown to positively affect these two parameters (28, 30, 31). However, the lack of significant intergroup differences reinforces the idea that both approaches are equally viable options.

The observed increase in FEV1/FVC and FVC reflects improved lung mechanics and respiratory efficiency, which are crucial for patients with restricted pulmonary function.

Exercise interventions have demonstrated various benefits for individuals with AS, including improvements in respiratory function (30-33). A systematic review by Saraçoğlu et al. (30) examined the effectiveness of specific exercise types, such as Tai Chi, Pilates, and aquatic exercises, on pulmonary function and aerobic capacity. Similarly, Boudjani et al. (34) conducted a meta-analysis investigating the effects of various exercise programs on AS, while Kaya et al. (35) investigated the correlation between respiratory function, exercise capacity, and quality of life. Further studies, including those by Dimofte et al. (36), Yentür et al. (37), and Szewczyk et al. (38), have explored the effects of interventions like respiratory rehabilitation,

Pilates training, and manual therapy combined with stretching on mobility and pulmonary function in AS patients. The common conclusion of these studies is that specific exercises improve pulmonary function and chest expansion more than conventional exercises in patients with AS and are an effective adjuvant therapy to reduce cardiopulmonary complications in addition to medical treatment.

There is robust evidence to support the notion that exercise can be beneficial in the management of AS, with particular respiratory exercises having the potential to contribute to the prevention of pulmonary complications (14, 30, 39). However, there is a scarcity of research focusing on the optimal integration of respiratory exercises into exercise prescriptions. The present study is distinctive in that it maintains a consistent exercise protocol while systematically varying respiratory exercise methods. The findings of the study demonstrate that respiratory exercises are efficacious in enhancing pulmonary function in patients with AS, regardless of the specific type.

4.3. Respiratory Muscle Strength

Significant improvements in MIP and MEP within both groups highlight the positive impact of exercise on respiratory muscle strength. These parameters are critical indicators of respiratory health and are particularly relevant for individuals with chronic diseases affecting pulmonary capacity. The lack of significant intergroup differences suggests that both programs are equally effective in enhancing respiratory muscle performance.

A study by Ortancil et al. found that a six-week home-based exercise program significantly improved chest expansion and maximal inspiratory and expiratory pressures in AS patients (33). Çelik et al. examined the effects of inspiratory muscle training added to a group in an 8-week home-based exercise programme. The study found that conventional exercises positively affected MEP independently of respiratory training. However, the group that received additional respiratory muscle strength training showed significant enhancements in MIP, disease activity, functionality, and MEP (40). These studies showed that even home-based exercises may have a beneficial effect on pulmonary function; however, some other studies showed no improvement in the home-based exercise treatments (1, 31).

Szewczyk et al reported that inspiratory muscle strength improved after 10 consecutive work days of either manual therapy or exercise treatment, even without specific respiratory exercises (38). In a subsequent study, they ascertained that this was attributable to a reduction in thoracic dysfunction with exercise (26).

It is evident from the data obtained that interventions aimed at enhancing thoracic and upper body mobility, in conjunction with the incorporation of respiratory exercises within a supervised programme, would prove favourable in enhancing respiratory muscle strength in patients with AS.

4.4.Clinical Implications

The findings of this study have important clinical implications. First, they highlight the utility of exercise as a non-pharmacological intervention to address both functional and respiratory limitations in patients. The comparable outcomes between the DG and 360 DG programs suggest that clinicians can recommend either approach based on patient preferences, resource availability, and specific therapeutic goals. Additionally, the significant improvements in pulmonary function and respiratory muscle strength observed in this study emphasize the importance of integrating breathing exercises and respiratory training into rehabilitation programs.

4.5. Study Strengths and Limitations

A major strength of this study is its robust methodological design, which included well-matched intervention groups and comparable baseline characteristics. This design strengthens the internal validity of the findings and ensures that the observed improvements can be attributed to the exercise interventions rather than potential confounding variables. However, several limitations should be acknowledged. First, the relatively short duration of the study (six weeks) may be insufficient to fully assess the long-term effectiveness and sustainability of the interventions. Many physiological and clinical outcomes—particularly those related to disease progression, treatment response, and adverse events—may take longer to manifest. Second, the study did not evaluate participant adherence to the home exercise program or satisfaction with the interventions, factors that are crucial for assessing the real-world feasibility, patient engagement, and scalability of such programs. Third, this study is its single-center design, which may reduce the generalizability of the results to broader populations. Future research should aim to replicate the findings in multi-center studies involving more diverse samples. Finally, the study did not include a long-term follow-up period, making it difficult to determine the sustained effects of the exercise intervention. Future studies are encouraged to incorporate long-term assessments to evaluate the durability of treatment outcomes.

5. Conclusion and Recommendations

This randomized controlled trial demonstrates that both standard diaphragmatic breathing and 360-degree expansion diaphragm breathing exercises, when combined with functional mobility training, are effective in improving pulmonary function, respiratory muscle strength, and disease-related functional outcomes in individuals with AS. Notably, the comparable efficacy of these two approaches suggests that clinicians can select either intervention based on patient preferences, available resources, and therapeutic goals, without compromising treatment outcomes.

From a clinical perspective, the findings support the integration of respiratory exercises into routine rehabilitation protocols for AS. These exercises are non-invasive, well-tolerated, and feasible to implement in both clinical and home-based settings, making them a valuable adjunct to pharmacological treatment. Importantly, the use of sensor-guided feedback in 360-degree breathing exercises offers a novel approach to enhancing patient engagement and thoracic mobility, particularly in individuals with pronounced postural and respiratory limitations.

Future studies should explore the long-term sustainability of these benefits, evaluate patient-reported outcomes such as satisfaction and adherence, and investigate the adaptability of these interventions across diverse patient populations, including those with comorbid respiratory conditions or differing severity levels of AS. Additionally, economic evaluations may help determine the cost-effectiveness and scalability of these respiratory training programs in broader clinical practice.

In summary, the results of this study underscore the clinical relevance of incorporating structured, personalized respiratory exercises into rehabilitation programs for AS. These findings provide a foundation for refining physiotherapy strategies aimed at improving quality of life and reducing disease burden in this patient population.

6. Contribution to the Field

This study provides compelling evidence for the integration of respiratory training into routine rehabilitation programs for individuals with AS. Both standard and 360-degree expansion diaphragm breathing exercises, when combined with functional mobility training, were shown to significantly improve pulmonary function, respiratory muscle strength, and disease-related functional outcomes. The clinical value of this finding lies in its flexibility: clinicians can confidently choose between these approaches based on patient preferences, resource availability, and treatment context, without compromising efficacy. Furthermore, the use of sensor-based feedback in 360-degree breathing introduces an innovative and engaging tool to enhance thoracic mobility and patient adherence, especially in individuals with postural limitations. By offering a structured, non-pharmacological, and well-tolerated strategy to manage respiratory dysfunction in AS, this study contributes to the growing body of evidence supporting holistic and individualized rehabilitation models. These findings also encourage the adoption of multidimensional interventions that address both musculoskeletal and pulmonary impairments in chronic rheumatic diseases.

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Conflict of Interest

There is no conflict of interest with any person and/or institution.

Authorship Contribution

Concept: BG, SYY; Design: BG, SYY Supervision: SYY; Funding: None; Materials: None; Data Collection/Processing: BG, SYY, ÖU, IS; Analysis/Interpretation: BG, SYY; Literature Review: BG, SYY; Manuscript Writing: BG, SYY; Critical Review: BG.

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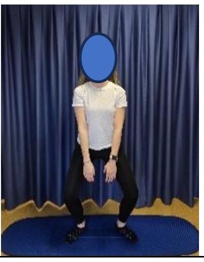
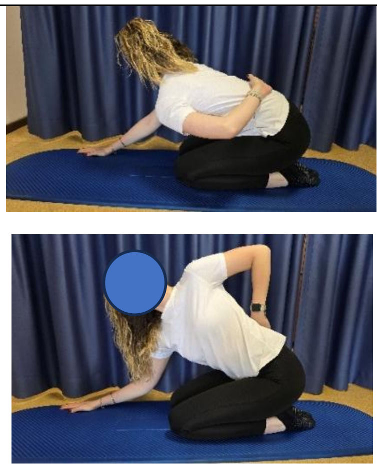
Appendix 1.

Session	Exercise Name	Exercise	Repetition
1-2. sessions	Warm-up / Exercise Preparation-1	 	X3
1-2. sessions	Warm-up / Exercise Preparation-2	 	X3

1-2. sessions	Warm-up / Exercise Preparation-3	 	X3 for each side
1-2. sessions	Warm-up (in different walking styles)	    	X10 for each side

1-2. sessions	Dynamic stretching of the anterior diaphragmatic chain		X10 for each side
1-2. sessions	Dynamic stretching of the posterior static chain		X10 for each side
1-2. sessions	Cat-Cow exercise	 	X5
1-2. sessions	Dynamic and static stretching of the anterior diaphragmatic chain and the anterior internal chain of the scapular girdle-1	 	X7

1-2. sessions	"Dynamic and static stretching of the anterior diaphragmatic chain and the anterior internal chain of the scapular girdle-2	 	X7
1-2. sessions	Dynamic stretching of the anterior diaphragmatic chain and the anterior internal chain of the pelvic girdle		X4 for each side
1-2. sessions	Dynamic stretching of the posterior static chain and the scapular girdle		X8 steps
1-2. sessions	Static stretching of the anterior diaphragmatic chain and the pelvic girdle		X3 for each side
1-2. sessions	Static stretching of the anterior diaphragmatic chain-1		X3

3-4. Sessions (will be added to the programme after the second session.)	Static stretching of the anterior diaphragmatic chain-2		X3 for each side
3-4. Sessions (will be added to the programme after the second session.)	Stretching exercise in pigeon pose		X3 for each side
3-4. Sessions (will be added to the programme after the second session.)	Trunk rotation exercise		X3 for each side
5-6. Sessions (will be added to the programme after the second session.)	Wall Angle Exercise		X7
5-6. Sessions (will be added to the programme after the second session.)	Thoracic Bridge Exercise		X7