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# Physiotherapy intervention for posture improvement in individual with scoliosis: A case study

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## ABSTRACT

**Background:** Scoliosis is a structural spinal deformity marked by an abnormal sideways curvature and a loss of the spine's natural front-to-back alignment, resulting in postural imbalances. This study investigates how physiotherapy interventions improve posture in individuals with scoliosis.

**Methods:** This qualitative descriptive-analytic case study utilized physiotherapy interventions such as stretching exercises, Pilates, core stability training, myofascial release, and manipulation therapy. Outcome measures included a scoliometer (spinal curvature), goniometer (lumbar range of motion), McGill's Torso Muscular Endurance Test Battery (core endurance), volumetric exerciser (lung capacity), measuring tape (limb length), Clarke's angle method (foot arch assessment), and Zebris FDM (body force pressure and center of pressure movement during stance).

**Results:** Physiotherapy improved postural alignment, reducing spinal curvature from 9 degrees to 3 degrees and increasing lumbar flexion from 61 degrees to 75 degrees. Core endurance increased, as evidenced by a 1.06-second improvement in the flexion-extension ratio and a 0.90-second bilateral increase in side-bridge endurance. Limb length discrepancy decreased from 2.5 cm to 0.5 cm, enhancing symmetry in both true and apparent lengths. Foot arch asymmetry also improved, with the right arch increasing from 45 degrees to 46 degrees and the left from 39.7 degrees to 42.5 degrees. Conversely, lung capacity declined from 1363 mL to 1238 mL. Force pressure distribution became more asymmetrical in most cases, particularly affecting the longer limb in individuals with scoliosis, and center of pressure movement increased from 51.5 mm to 76.5 mm, indicating altered balance and postural control.

**Conclusion:** Over two months, physiotherapy effectively improved postural alignment and musculoskeletal function in individuals with scoliosis.

**Keywords:** Body force pressure, core endurance, posture, scoliosis, and spinal curvature.
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## INTRODUCTION

Scoliosis involves a spinal deformity in the coronal plane and a loss of normal sagittal curvature, causing lateral deviation and axial rotation.[1] It's measured using a scoliometer and, while it can affect all ages, adolescents aged 10-18 are most susceptible due to rapid bone growth and hormonal changes during puberty. Notably, women have a tenfold higher risk of progressive scoliosis compared to men. Poor eating and exercise habits during adolescence may also increase the likelihood of developing spinal deformities.[2,3]

Data from the American Academy of Orthopaedic Surgeons indicates that 93% of the approximately 1.26 million patients with spinal disorders are diagnosed with scoliosis. Of these scoliosis patients, 85% have idiopathic scoliosis, with 60-80% occurring in women.[4] While exact national figures are unavailable, research in Jakarta from 2018-2019 found a scoliosis prevalence of around 10% (1.48 million people) out of the city's 10.18 million residents.[5,6]

Ideal posture, defined as the optimal alignment for efficient daily activities with minimal energy, is not always achievable. In individuals with scoliosis, postural issues like asymmetrical shoulders, scapular protrusion, pelvic asymmetry, lateral trunk lean, and limb length discrepancies can contribute to the progression of the condition.[7,8] Environmental conditions and lifestyle significantly influence scoliosis severity.[9] For instance, carrying excessively heavy backpacks, a practice the American Chiropractic Association recommends limiting to 10-15% of body weight, can be detrimental.[10] Prolonged sitting, asymmetrical backpack use, and increased screen time may also contribute.[11] Given that spinal development occurs and can worsen rapidly in young individuals, early intervention is crucial.[12]

The literature describes various therapeutic methods for improving postural problems associated with scoliosis, including stretching exercises, Pilates, core stability exercises, myofascial release, and manipulation therapy. Stretching exercises aim to increase muscle flexibility and joint range of motion, potentially reducing muscle spasms on the concave side and improving spinal curvature.[13,14]

Pilates is a mind-body exercise focusing on core stability, flexibility, posture control, and breathing.[15] Previous research indicated its effectiveness in reducing pain and the angle of scoliosis.[16] Furthermore, Pilates is reported to increase trunk flexibility and improve poor posture.[17] Core stability exercise aims to increase muscle strength and stabilize the trunk.[13] It has a positive effect on reducing spinal curvature and strengthening supporting muscles.[18] Strengthening exercises aim to enhance muscle strength by progressively increasing resistance and reducing fatigue.[19] They can activate weak muscles and improve spinal stability. Furthermore, targeting weak muscles on the convex side can correct the body's line of gravity and improve muscle balance.[14]

The myofascial system comprises solid (muscle, bone, cartilage, adipose tissue) and liquid (blood, lymph) components, with contractile muscles and connective tissue transmitting movement to bones.[20] Trauma to muscle fibers can create trigger points—hyperirritable spots within taut muscle bands—causing localized pain.[21] Myofascial release, a therapeutic technique involving applied pressure, softens and stretches this complex to restore muscle length, reduce pain, and improve function.[22]

The International Federation of Orthopaedic Manipulative Physical Therapists (IFOMPT) defines manipulation therapy as skilled hand movements aimed at increasing tissue extensibility and joint range of motion, mobilizing soft tissues and joints, inducing relaxation, altering muscle function, modulating pain, and reducing soft tissue swelling, inflammation, or movement restrictions. Spinal manipulation therapy, in particular, may effectively treat scoliosis when combined with other conservative approaches.[23]

Despite various physiotherapy methods for scoliosis-related postural issues, most prior studies have evaluated single therapies like stretching, Pilates, or core stability exercises in isolation. Evidence for scoliosis-specific exercises (SSE) remains limited and hasn't demonstrated clear superiority over other approaches. Furthermore, studies predominantly focus on changes in Cobb angle, often neglecting other crucial biomechanical factors such as force pressure distribution and center of pressure (COP) movement, which significantly impact posture and balance.[24]

Based on the description, researchers are interested in investigating the effects of physiotherapy interventions on posture in individuals with scoliosis through a case study. The study aims to explain how these interventions improve posture in individuals with scoliosis, specifically examining their impact on spinal curvature, joint range of motion, core endurance, leg length, lung capacity, foot arch level, body force pressure, and center of pressure movement during the stance phase.

## CASE REPORT

This qualitative research with a descriptive analytic method and case study design was conducted in the physiotherapy gymnasium at Universitas Muhammadiyah Surakarta, Indonesia from November to December 2023. Participants were recruited using purposive sampling based on inclusion and exclusion criteria, and they provided informed consent. Scoliosis degree, lumbar range of motion, core endurance, lung capacity, leg length, foot arch level, body force pressure, and center of pressure movement during stance were measured at the beginning and end of the study to determine changes.

## METHODS

### Respondents

The inclusion criteria for study participants were a spinal curvature greater than 5 degrees, female gender, and willingness to participate. Exclusion criteria included experiencing trauma in the past six months or withdrawing consent. A search yielded four 13-year-old female respondents meeting these criteria, as detailed in the following Table 1. Initial measurements revealed varying characteristics among them.

Respondent N presented with type C dextra scoliosis (11 degrees curvature), a height of 158 cm, weight of 49 kg, inspiratory volume of 1000 mL, lumbar flexion of 55 degrees, lumbar extension of 20 degrees, apparent leg lengths of 93 cm (both sides), right footprint of 50 degrees, left footprint of 55 degrees (average force on the right), and COP movement of 49 mm.

Respondent R had type C scoliosis sinistra (9 degrees curvature), a height of 156 cm, weight of 55 kg, inspiratory volume of 2000 mL, lumbar flexion of 55 degrees, lumbar extension of 20 degrees, apparent leg lengths of 98 cm (dextra) and 99 cm (sinistra), right footprint of 55 degrees, left footprint of 50 degrees (average force on the left), and COP movement of 44 mm.

Respondent A exhibited type S scoliosis (8 degrees curvature), a height of 151 cm, weight of 54 kg, inspiratory volume of 1225 mL, lumbar flexion of 85 degrees, lumbar extension of 25 degrees, apparent leg lengths of 94 cm (both sides), right footprint of 45 degrees, left footprint of 47 degrees (average force on the right), and COP movement of 66 mm.

Finally, respondent Y also had type S scoliosis (8 degrees curvature), a height of 154 cm, weight of 43 kg, inspiratory volume of 1225 mL, lumbar flexion of 50 degrees, lumbar extension of 25 degrees, apparent leg lengths of 87 cm (dextra) and 88 cm (sinistra), right footprint of 30 degrees, left footprint of 7 degrees (average force on the left), and COP movement of 47 mm.

### Research Instruments

Scoliosis examination involved a scoliometer (Theratools brand) to measure the degree of spinal curvature as the participant bent forward; this method shows good correlation with radiographic measurements ($r=0.7$, $p<0.05$), indicating good to excellent validity (Coelho et al., 2013). A goniometer assessed the range of joint motion with excellent reliability (ICC = 0.971-0.995), although a universal placement standard is lacking.

Core endurance was evaluated using McGill's Torso Muscular Endurance Test Battery, with results recorded per the standardized sheet. Lung capacity (total lung capacity) was measured using a Teleflex Hudson RCI volumetric exerciser. Limb length was measured supine using a tape measure between anatomical points, a method with acceptable validity and reliability for detecting discrepancies. Foot arch level was examined using the footprint method and Clarke's angle, which has 89.8% sensitivity and categorizes arches

**Table 1.** **Results of initial measurements or observations of respondents**

| Variable | Respondents | | | |
|---|---|---|---|---|
| | N | R | A | Y |
| **Inspiratory Volume Capacity** | 1000 mL | 2000 mL | 1.225 mL | 1.225 mL |
| **ROM Trunk** | | | | |
| Flexion | $55^0$ | $55^0$ | $85^0$ | $50^0$ |
| Extension | $20^0$ | $20^0$ | $25^0$ | $25^0$ |
| **Core Endurance** | | | | |
| Flexion: Extension | 1.25 | 0.6 | 0.8 | 0.574 |
| Right-Left Side Bridge | 4.5 | 1.14 | 0.85 | 2 |
| Side Bridge: Extension | S (0.12)<br>D (0.56) | S (0.38)<br>D (0.44) | S (0.50)<br>D (0.43) | S (0.14)<br>D (0.28) |
| **Leg Length** | | | | |
| Bone length (cm) | D (53)<br>S (48) | D (50)<br>S (50) | D (47)<br>S (47) | D (41)<br>S (41) |
| True length (cm) | D (96)<br>S (87) | D (89)<br>S (90) | D (85)<br>S (86) | D (80)<br>S (81) |
| Appearance Length (cm) | D (93)<br>S (93) | D (98)<br>S (99) | D (94)<br>S (94) | D (87)<br>S (88) |
| **Footprint Clark'e Angle Methods** | | | | |
| Dextra | $50^0$<br>(high) | $55^0$<br>(high) | $45^0$<br>(normal) | $30^0$<br>(normal) |
| Sinistra | $55^0$<br>(high) | $50^0$<br>(high) | $47^0$<br>(high) | $7^0$<br>(flat) |
| **Average Force** | | | | |
| **Fore foot** | | | | |
| Left | 42 | 43 | 36 | 35 |
| Right | 39 | 56 | 39 | 26 |
| **Back foot** | | | | |
| Left | 58 | 57 | 64 | 65 |
| Right | 61 | 44 | 61 | 74 |
| **Total Force** | | | | |
| Left | 45 | 58 | 43 | 53 |
| Right | 55 | 42 | 57 | 47 |
| **COP Path Length, mm** | 49 | 44 | 66 | 47 |

$^0$, degrees; A: 13$^{th}$ Scoliosis 8 degrees, S 151 cm/54 kg; cm, centimeter; COP, center of pressure; D, Dextra; kg, kilogram; mL, milliliter; mm, millimeter; N: 13$^{th}$ Scoliosis 11 degrees, C Dextra, 158 cm/49 kg; R: 13$^{th}$ Scoliosis 9 degrees, C Sinistra, 156 cm/55 kg; S, Sinistra; Y 13$^{t}$h Scoliosis 8 degrees, S 154 cm/43 kg.

as normal (31–<45 degrees), flat (<31 degrees), or high (>45 degrees) (Latifah et al., 2021). Finally, the Zebris FDM system assessed body force pressure and center of pressure during stance to analyze static balance via its pressure platform and software.

This study has received ethical clearance by the Health Research Ethics Committee of the Faculty of Health Sciences, Universitas Muhammadiyah Surakarta with number 139/KEPK-FIK/XII/2023.

### Interventions

Over eight weeks, respondents participated in a supervised integrated exercise program, attending two 90-minute sessions weekly. The program included stretching, Pilates, strengthening, core stability, myofascial release, and therapeutic manipulation, all performed under physiotherapist supervision to ensure correct execution (Table 2).

## RESULTS

This two-month study involved a control group of four 13-year-old women (Figure 1) with spinal curves ≥5 degrees (Figure 2), revealing several factors influencing scoliosis improvement: initial curve degree, joint range of motion, core endurance, lung capacity, leg length, and foot arch level. Initial measurements showed respondent N with the most severe scoliosis (11 degrees) and respondents A and Y with the least (8 degrees). Following physiotherapy, curve reduction ranged from 7 degrees to 4 degrees, with respondent N's type C curve decreasing to 4 degrees, respondent R's type C to 3 degrees, and respondents A and Y's type S curves to 1 degrees and 4 degrees, respectively.

Table 3 indicates that joint range of motion, particularly lumbar flexion (most notably in respondent N, increasing from 55 degrees to 85 degrees), and core endurance (based on flexion:extension ratio, right-side bridge: left-side bridge,

**Table 2. Integrated exercise program**

| | |
|---|---|
| Stretching Exercise | Pelvic tilt |
| | Pelvic elevation |
| | Bound angle pose |
| | Stretching hamstring |
| | Stretching quadriceps |
| | Stretching hamstring |
| Pilates Exercise | Side lying stretch on the ball |
| | Side lying stretch on the ball with stick |
| Core Stabilization Exercise | Plank |
| | Side plank |
| | Lying knee raises |
| | Crunch with flexion knee |
| | Bridge |
| | Bridge with knee extension |
| | Dynamic neuromuscular stabilization |
| Strengthening Exercise | Barbel row |
| Myofascial Release | Massage deep friction |
| | Dry needling |
| | Gun massage |
| Manipulation Therapy | Cervical, thorax, lumbal, ankle |

and side-bridge:extension ratio) (Figure 3) improved in all participants post-intervention. Lung capacity changes were variable: an increase in respondent N, a decrease in respondents R and Y, and no change in respondent A. Leg length measurements (bone, true, and appearance length) showed minimal post-intervention changes, with respondent A exhibiting no change (Figure 4).

Foot arch analysis (Table 3) showed a trend towards normalization in most participants, although some asymmetry remained. Pre- and post-intervention body force measurements (Zebris FDM, Table 3) indicated varied weight distribution, potentially linked to scoliosis type and leg length differences. Center of pressure movement (Table 3) decreased in respondent Y, suggesting improved static postural balance, while no significant

**Table 3. The results of joint range of motion, core endurance, limb length, footprint characteristics, average Zebris stance force, and Zebris stance center of pressure before and after physiotherapy intervention**

| Variable | Respondents | | | |
|---|---|---|---|---|
| | N | R | A | Y |
| **ROM Trunk** | | | | |
| Pre-test | S = $20^0$ - $0^0$ - $55^0$ | S = $20^0$ - $0^0$ - $55^0$ | S = $25^0$ - $0^0$ - $85^0$ | S = $25^0$ - $0^0$ - $50^0$ |
| Post-test | S = $20^0$ - $0^0$ - $85^0$ | S = $20^0$ - $0^0$ - $60^0$ | S = $25^0$ - $0^0$ - $85^0$ | S = $25^0$ - $0^0$ - $70^0$ |
| **Core Endurance** | | | | |
| **Flexion: Extention** | | | | |
| Pre-test | 1.25 | 0.6 | 0.8 | 0.57 |
| Post-test | 1.68 | 2.05 | 0.9 | 0.58 |
| **Right-Left Side Bridge** | | | | |
| Pre-test | 4.5 | 1.14 | 0.85 | 2 |
| Post-test | 1.025 | 0.76 | 0.53 | 1.06 |
| **Side Bridge: Extention** | | | | |
| Pre-test | S (0.12)<br>D (0.56) | S (0.38)<br>D (0.44) | S (0.50)<br>D (0.43) | S (0.14)<br>D (0.28) |
| Post-test | S (1.81)<br>D (1.86) | S (2.7)<br>D (2.1) | S (1.6)<br>D (0.85) | S (0.84)<br>D (0.89) |
| **Leg Length** | | | | |
| **Bone length (cm)** | | | | |
| Pre-test | D (53)<br>S (48) | D (50)<br>S (50) | D (47)<br>S (47) | D (41)<br>S (41) |
| Post-test | D (52.5)<br>S (52) | D (50)<br>S (50) | D (47)<br>S (47) | D (41)<br>S (41) |
| **True length (cm)** | | | | |
| Pre-test | D (96)<br>S (87) | D (89)<br>S (90) | D (85)<br>S (86) | D (80)<br>S (81) |
| Post-test | D (94)<br>S (87) | D (90)<br>S (90) | D (85)<br>S (86) | D (81)<br>S (81) |
| **Appearance Length (cm)** | | | | |
| Pre-test | D (93)<br>S (93) | D (98)<br>S (99) | D (94)<br>S (94) | D (87)<br>S (88) |

| Variable | Respondents | | | |
|---|---|---|---|---|
| | N | R | A | Y |
| Post-test | D (93)<br>S (93) | D (100)<br>S (100) | D (94)<br>S (94) | D (89)<br>S (89) |
| **Footprint Clark'e Angle Methods** | | | | |
| **Dextra** | | | | |
| Pre-test | $45^0$<br>(normal) | $50^0$<br>(high) | $55^0$<br>(high) | $30^0$<br>(normal) |
| Post-test | $45^0$<br>(normal) | $45^0$<br>(normal) | $45^0$<br>(normal) | $34^0$<br>(normal) |
| **Sinistra** | | | | |
| Pre-test | $47^0$<br>(high) | $55^0$<br>(high) | $50^0$<br>(high) | $7^0$<br>(flat) |
| Post-test | $42^0$<br>(normal) | $50^0$<br>(high) | $45^0$<br>(normal) | $38^0$<br>(normal) |
| **Average Force** | | | | |
| **Fore foot** | | | | |
| **Left** | | | | |
| Pre-test | 42 | 43 | 36 | 35 |
| Post-test | 46 | 47 | 27 | 44 |
| **Right** | | | | |
| Pre-test | 39 | 56 | 39 | 26 |
| Post-test | 68 | 55 | 37 | 45 |
| **Back foot** | | | | |
| **Left** | | | | |
| Pre-test | 58 | 57 | 64 | 65 |
| Post-test | 54 | 53 | 73 | 56 |
| **Right** | | | | |
| Pre-test | 61 | 44 | 61 | 74 |
| Post-test | 32 | 45 | 63 | 55 |
| **Total Force** | | | | |
| **Left** | | | | |
| Pre-test | 45 | 58 | 43 | 53 |
| Post-test | 86 | 57 | 52 | 51 |
| **Right** | | | | |
| Pre-test | 55 | 42 | 57 | 47 |
| Post-test | 14 | 43 | 48 | 49 |
| **COP Path Length. mm** | | | | |
| Pre-test | 49 | 44 | 66 | 47 |
| Post-test | 61 | 64 | 157 | 24 |

$^0$, degrees; A: $13^{th}$ Scoliosis 8 degrees, S 151 cm/54 kg; cm, centimeter; COP, center of pressure; D, Dextra; kg, kilogram; mL, milliliter; mm, millimeter; N: $13^{th}$ Scoliosis 11 degrees, C Dextra, 158 cm/49 kg; R: $13^{th}$ Scoliosis 9 degrees, C Sinistra, 156 cm/55 kg; S, Sinistra; Y $13^{th}$ Scoliosis 8 degrees, S 154 cm/43 kg.

improvement was observed in the other three respondents.

## DISCUSSION

Several risk factors can influence scoliosis, including gender, age, muscle imbalance, postural habits, and limb length differences. Research indicates that females have a 5 to 10 times higher risk of curve progression than males.[25] Adolescence is a critical period due to rapid musculoskeletal changes that can worsen existing scoliosis.[26] Biomechanical factors like pelvic asymmetry, muscle imbalance, and abnormal leg posture also contribute.[27] Furthermore, daily habits such as prolonged sitting and heavy backpack use can increase spinal stress and exacerbate scoliosis.[28]

The four respondents in this study were selected to represent a diverse range of scoliosis risk factors, including curve shape, severity, and biomechanical factors like leg length and posture. Despite the small sample size, this case study aimed for an in-depth analysis of physiotherapy interventions across varying scoliosis conditions. The findings offer an overview of physiotherapy's effectiveness in treating scoliosis with diverse characteristics.

Despite varying scoliosis curve types, all respondents received the same physiotherapy interventions to assess their effects on each curve. The combined interventions resulted in significant

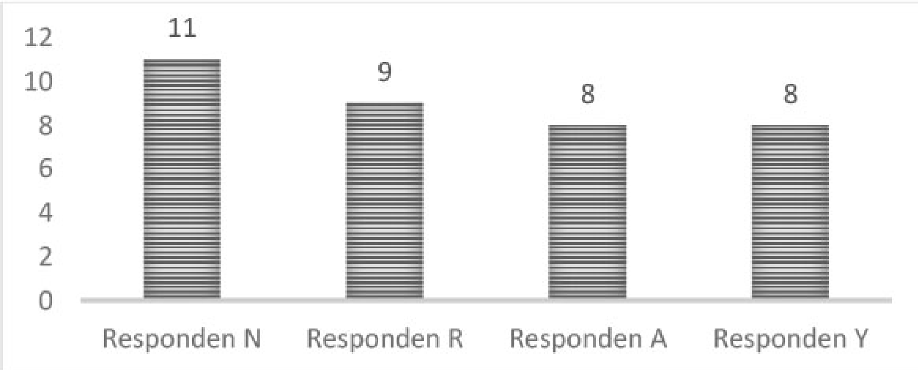


**Figure 1.** Pre-test scoliosis degree of respondents.

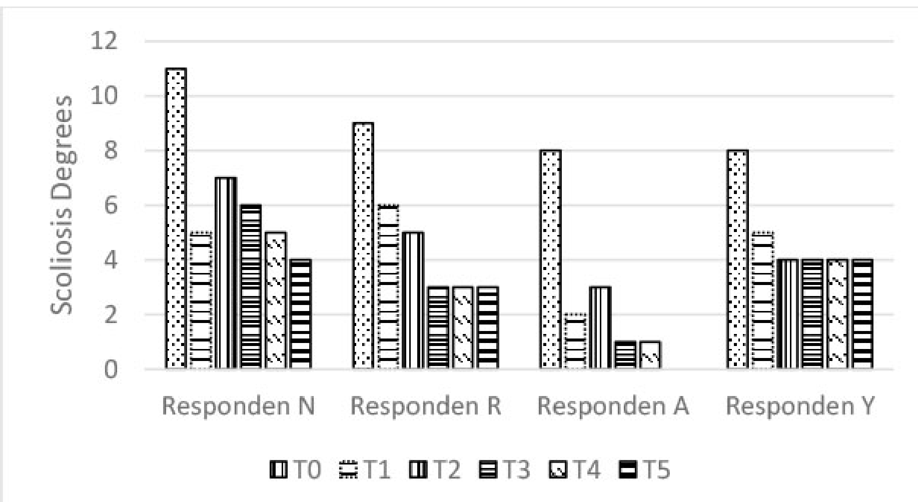


**Figure 2.** The development of the respondent's degree of scoliosis before and during the provision of physiotherapy interventions.

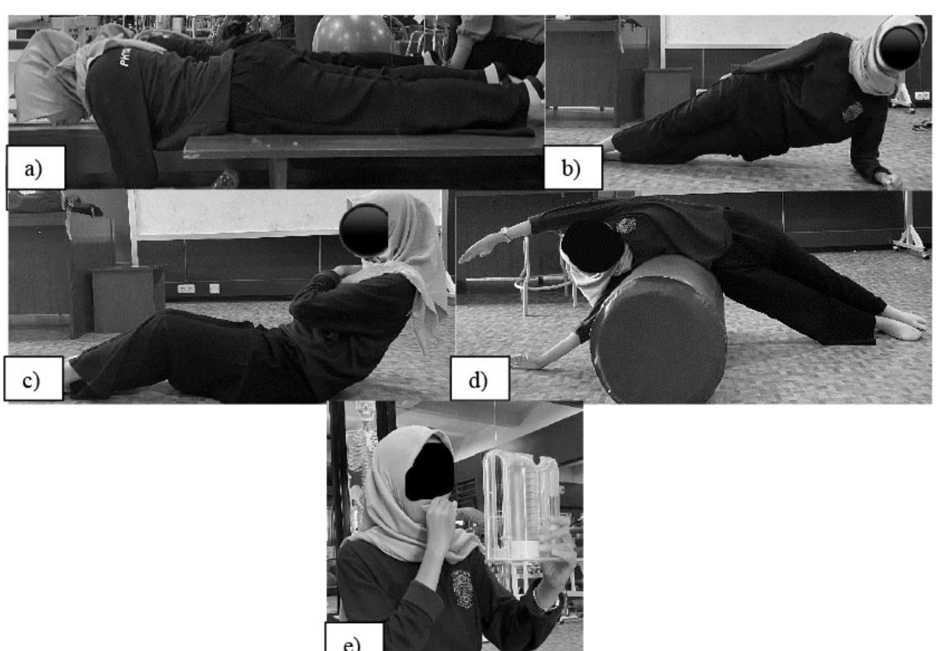


**Figure 3.** a) Trunk extensor endurance test, b) Trunk flexor endurance test, c) Side bridge test, d) Strech on the ball performed, e) Volumetric exerciser.

improvement for all, as evidenced by a decrease in each respondent's scoliosis degree (Figure 2). The physiotherapy focus differed for each respondent, targeting their specific weaknesses and tightness.

Stretching relaxes tense muscles and increases joint flexibility, making it a crucial first-stage intervention for scoliosis. By reducing stress on the concave side and enhancing joint mobility, stretching facilitates gradual curve correction.[14] Subsequently, Pilates exercises, such as stretches on a ball, can further improve trunk rotation by increasing thoracic vertebrae mobility and balancing asymmetrical body segments.[29] Core stabilization and strengthening exercises, particularly on the weaker side, can address body imbalances. Strengthening the convex side of the spinal curve, such as with side planks, may help reduce the scoliosis curve angle by counteracting the tendency of the spine to bend towards the stronger side. This often results in weaker muscles on the convex side compared to the concave side.[30]

Studies by Park et al. (2016) showed that core exercises can reduce scoliosis angles and increase back muscle activity.[31] Additionally, Aly et al. (2019) found that a 6-month integrated program of manual therapy, myofascial release, core stability exercises, yoga, and Pilates improved posture and reduced high spinal curve degrees in individuals with scoliosis.[32]

This study found that Pilates-based exercises can improve lumbar joint range of motion by activating core muscles like the multifidus and transversus abdominis, thereby enhancing spinal control and flexibility.[15] Similarly, previous research indicates that Pilates can improve lumbar extensibility by increasing lumbar motion and hamstring flexibility through controlled, decompressive movements.[33] An eight-week study by Park (2014) demonstrated that a program incorporating stretching and Pilates-based exercises significantly reduced scoliosis and increased joint range of motion.[34]

Stretching and strengthening exercises can enhance core endurance. This study observed an increase in core endurance in all respondents, likely due to improved neuromuscular control and the enhanced strength and endurance of trunk and pelvic

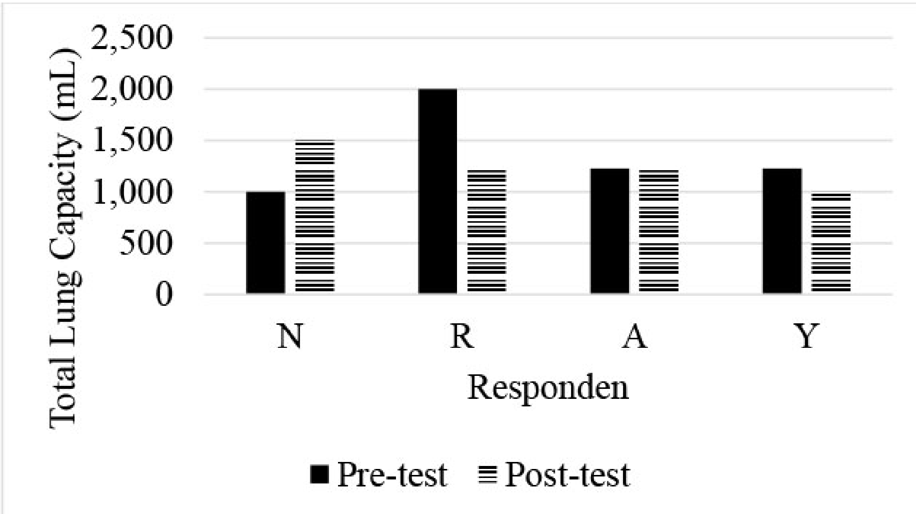


**Figure 4.** The results of measuring the total inspiratory volume of respondents before and after physiotherapy intervention.

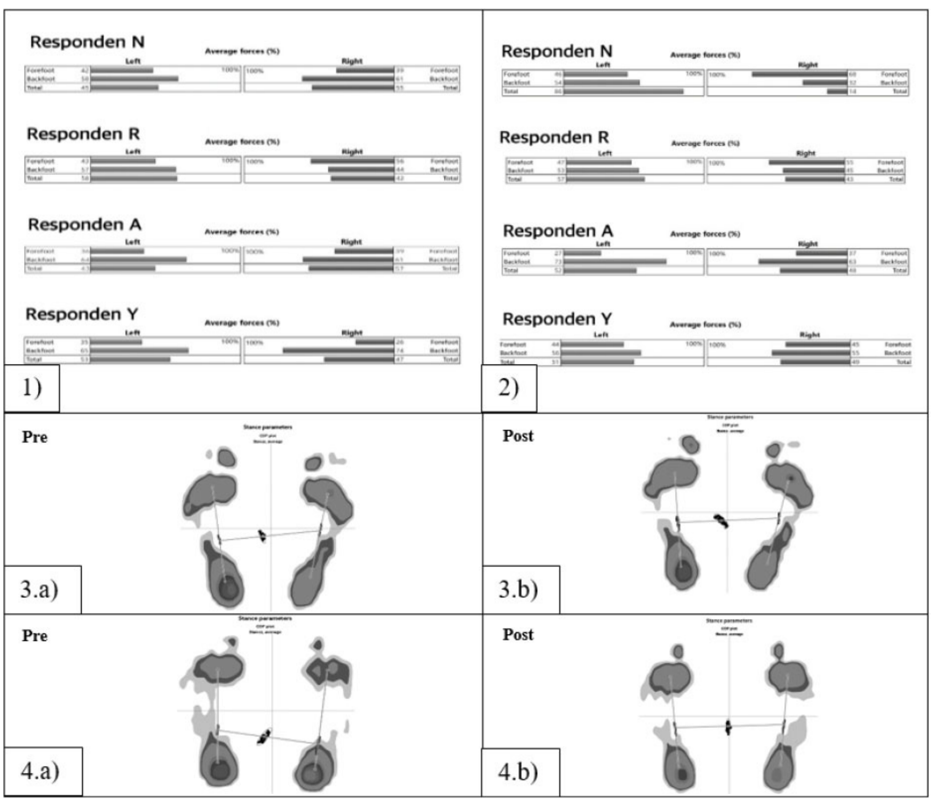


**Figure 5.** 1) Pre-test force average of respondents, 2) Post-test force average of respondents, 3 a & b) COP movement in respondents who did not experience a decrease in COP movement before and after physiotherapy intervention. 4 a & b) COP movement in respondents who experienced a decrease in COP movement before and after physiotherapy intervention.

floor muscles, which contribute to spinal stability. Strengthening these muscles aids in distributing spinal load evenly, reducing pressure on the scoliosis' concave side, and increasing the core muscles' resistance to fatigue.[31]

Due to the varying scoliosis curve types among respondents, exercise adjustments were necessary. For instance, respondent N presented with a dextro-convex C-curve, left-side hypertonicity, and right-side hypotonicity, while respondent R had a levo-convex C-curve with right-side hypertonicity and left-side hypotonicity. Both received strengthening and stretching exercises, with a greater emphasis on strengthening the hypotonic side. Park et al. (2016) found that 10 weeks of core strengthening exercises increased back muscle strength and core endurance in scoliosis patients.[31] Similarly, Ozrudi (2021) demonstrated that 8 weeks of targeted stretching and strengthening exercises in the central body strengthened weakened and stretched shortened muscles, thus improving core endurance.[35]

Spinal curvature can disrupt pelvic balance. Apparent leg length, measured from the umbilicus to the medial malleolus, is one method to assess this balance.[36] EOS imaging evaluation has revealed significant functional or apparent leg length differences in scoliosis patients.[37] This study suggests that reducing limb length discrepancy can aid in decreasing spinal curvature. Spinal stretching exercises may contribute to this by alleviating muscle tightness on the concave side, enhancing flexibility and vertebral mobility, and fostering better pelvic alignment and weight distribution in the lower limbs. Improved muscle balance around the pelvis, achieved through stretching, lessens asymmetrical tension that contributes to limb length differences. Furthermore, core strengthening enhances trunk stability, further supporting postural correction and minimizing compensatory pelvic shifts.

Scoliosis-induced changes in chest wall structure and rib alignment impair respiratory function by affecting thorax stiffness and size. Loss of elasticity in costovertebral joints and the spine further disrupts respiratory mechanics.[14] Dursun et al. (2023) noted that scoliosis curve angle, loss of normal spinal kyphosis, and spinal rotation contribute to decreased respiratory function. The exercises given in this study also have an impact on increasing lung capacity, especially total inspiratory volume (total lung capacity). Such as the provision of pilates exercises that can stimulate plasticity and the development of trunk symmetry[38].

As part of the kinetic chain linking the lower extremities to the spine via the pelvis, the foot is crucial for static posture stabilization and plantar load distribution during gait.[39] Foot posture influences plantar pressure in the midfoot and rearfoot of individuals with scoliosis. Based on the medial longitudinal plantar arch, foot arches are categorized as cavus (high) or planus (low).[40] Clinically, Barsotti et al. (2021) demonstrated that both cavus and planus feet affect plantar pressure distribution in scoliosis patients, potentially contributing to postural imbalance.[41]

Static evaluation with the Zebris FDM tool showed that respondents with cavus feet exhibited maximum force in the rearfoot (Figure 5). Post-physiotherapy, the decrease in scoliosis degree correlated with improved foot arch (Table 3), likely due to weight-bearing redistribution and muscle rebalancing from postural correction. This scoliosis reduction also lessened the body force difference between legs, potentially from reduced curve and leg length discrepancies, enhancing kinetic chain efficiency.[42]

The Center of Pressure (COP), the midpoint of the ground reaction force vector, is a common measure in gait analysis.[43] As shown in Figure 5, the COP is represented by the black dot between the feet. Greater COP movement (sway) indicates poorer postural stability, as increased displacement suggests a greater reliance on compensatory balance mechanisms. Because the extent of COP movement reflects static postural imbalance, individuals with scoliosis often exhibit larger COP shifts due to spinal curvature asymmetry and altered weight distribution. This postural imbalance arises from the asymmetry of the concave and convex spinal curves, leading individuals to employ compensatory strategies through the vestibular and somatosensory systems.[44] In this study, not all respondents experienced a decrease in COP movement, which may be influenced by factors such as adjustment to changes in spinal curvature.[45]

This study's limitations include its small and homogenous sample of four 13-year-old females with severe scoliosis, limiting the generalizability of findings. The absence of a control group makes it difficult to definitively attribute improvements to the physiotherapy intervention. Additionally, while the scoliometer correlated well with radiographic measures and the goniometer showed excellent reliability, the former is an indirect assessment, and the latter lacks a universal placement standard, potentially introducing measurement variability. The study also did not control for external factors like daily activities and lifestyle. Furthermore, despite using the Zebris FDM system, postural balance was not a specific focus or reported outcome. Finally, the eight-week intervention period might have been too short to capture the full long-term effects. Future research should address these limitations by including larger and more diverse samples, incorporating control groups, controlling for lifestyle factors, and specifically investigating postural balance to enhance our understanding of physiotherapy's impact on scoliosis.

## CONCLUSION

A two-month physiotherapy program incorporating stretching, Pilates, core stability, strengthening exercises, myofascial release, and manipulation therapy improved posture in individuals with scoliosis. This was evidenced by a decreased spinal curve, increased joint range of motion and core endurance, a reduced difference in limb length and arch level, and a shift in body force pressure. However, the respondents' lung capacity decreased, and most did not experience improved postural balance during stance, as indicated by COP movement.

## CONFLICT OF INTEREST

No conflict of interest in this study.

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## ETHICAL CONSIDERATION

This study has received ethical clearance from the Health Research Ethics Committee of the Faculty of Health Sciences, Universitas Muhammadiyah Surakarta with approval number 139/KEPK-FIK/XII/2023. Informed consent was obtained from all participants prior to their involvement in the study.

## AUTHOR CONTRIBUTIONS

AFN designed the study, collected and processed the data, and wrote the initial manuscript. AS, PK and AAF contributed to the study design and manuscript revision.

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