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ORIGINAL ARTICLE

An effective active self-correction in standing without external aids is possible in adolescents with idiopathic scoliosis: a cross-sectional study

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Abstract

Purpose To verify the effect of an Active Self-Correction (ASC) according to the SEAS (Scientific Exercise Approach to Scoliosis) PSSE school on the radiographic Cobb angle and apical vertebral rotation compared to habitual standing in adolescents with AIS.

Methods this is a cross-sectional study nested in a prospective database of a tertiary outpatient referral institute. Inclusion criteria were AIS, 10–18 years old, Cobb angle ≥ 10°, coronal full-spine standing radiography performing Active Self-Correction. The exclusion criterion was no x-ray in habitual standing within two months of ASC x-ray. Curves were divided into single primaries and double primaries and blindly measured using Cobb and Raimondi degrees. Descriptive statistics, Pearson and Spearman correlation analysis were used.

Results Twenty-six adolescents, mean Cobb angle 32 ± 11°, were included. The mean difference between not ASC and ASC x-ray was clinically significant in both Cobb and Raimondi degrees in single primary curves (5.8° and 1.7°, respectively) and in Raimondi degrees only in double primaries (1.8°). Very-weak correlations were found between Cobb and Raimondi degrees variations ($r = 0.1$).

Conclusions Active Self-Correction without external aid is able to improve the scoliosis deformity. The results highlight the effect of ASC in reducing Cobb degrees in single primary curves, but suggest that double curve management can still be improved. Future research should investigate which aspects of ASC do impact SEAS treatment efficacy.

Keywords Scoliosis · Physiotherapy · Rehabilitation · SEAS · Conservative treatment

Introduction

Adolescent idiopathic scoliosis (AIS) is a three-dimensional deformity of the spine and trunk of an unknown origin. It occurs in 2% to 3% of the general population between 10 years and skeletal maturity [10]. When AIS spinal curvature exceeds the 30° Cobb Angle, the risks of deformity progression in adulthood and higher back pain incidence become real [13]. Conservative treatment for AIS includes observation, physiotherapeutic scoliosis-specific exercises (PSSEs), and bracing [10, 13]. Conservative treatment aims to reduce curve progression, decreasing the risk of back pain and disability, and achieving the best possible aesthetics and quality of life [12].

PSSEs include all forms of outpatient physiotherapies with evidence of having an effect on some scoliosis outcomes [10]. Primary studies [11, 14] and several systematic

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reviews, including a Cochrane review, reported the effectiveness of PSSE in improving measures of spinal deformity in AIS, but highlighted the need for higher-quality studies [1, 4, 6, 16, 22]. PSSEs consist of curve-specific exercise protocols individually adapted to each patient in different ways according to various schools [3]. According to SOSORT (Scientific Society on Scoliosis Orthopaedic and Rehabilitation Treatment) experts, PSSEs are based on 3D auto-correction and its stabilization and integration in daily life [10, 24]. All the existing PSSE schools base their exercise protocols on these principles, but they differ in how to reach these aims [3].

Since self-correction plays a crucial role in PSSE,[10] it is essential to understand its real effect on AIS's misalignment. One study checked the in-exercise Schroth correction in 36 AIS patients using 3D ultrasound in fourteen different positions, and found that a good correction was achieved [21]. A pilot study on ten pairs of x-rays showed a decrease of 6 Cobb degrees between normal standing and Schroth trained position [18]. Another study conducted on 16 AIS patients showed an x-ray reduction of thoracic curve deformity while performing a guided autocorrection after three manual corrections applied by a Global Postural Re-education (GPR) trained therapist [7]. A case study showed no self-correction effect at the beginning of the Barcelona Physiotherapic School (BSPTS) therapy and a positive impact on the thoracic curve with a worsening of the lumbar one after one year [25]. These studies evaluate the effect of different types of self-corrections (Schroth, GPR, BSPTS), all having in common the performance with external aids (supports, postures, specific positions, spine manipulation maneuver). No studies have yet evaluated the effect of an active, not aided and standing self-correction to understand if (1) such an active self-correction (ASC) is really possible and (2) how much this correction is comparable to the one obtained in other ways.

According to the latest systematic reviews, [6, 22] the two PSSE schools with stronger evidence are Schroth and SEAS (acronym for "Scientific Exercise Approach to Scoliosis"). SEAS exercises are based on autocorrection and stabilization, as in the other PSSE exercise programs. Nevertheless, unlike all the other schools, SEAS autocorrection is an ASC performed by the patient to directly counteract the misalignment, without any external aid [17, 19]. Nevertheless, currently there are no proofs that an ASC can really be obtained without external aids and in a standing position.

The aim of this study was to verify if an ASC according to the SEAS school can be effective on radiographic Cobb angle and apical vertebral rotation reduction compared to habitual standing in AIS.

Materials and methods

Study design and setting

This was a cross-sectional study. Data were collected from a prospective clinical database that included all individuals with spinal deformities who visited a tertiary outpatient referral institute in Italy from March 2003 to December 2020. The local Ethics Committee provided consent to the study (948_2022, October 10, 2022), which is available at clinicaltrials.gov (NCT05598021).

Participants

We included all patients diagnosed with AIS, 10–18 years old, Cobb angle ≥ 10°, Risser sign 0–4 who had been scanned with coronal full-spine standing radiography in normal standing and in ASC. The latter was performed due to (1) prescription of their physician, (2) mistake of the patients/radiologist or (3) autonomous decision of the parents. We excluded all patients with (1) the standing x-ray more than two months apart from the ASC radiography, because a reliable comparison was not possible; (2) patients treated with PSSE according to SEAS school for less than three months and who had less than three physiotherapy sessions with an expert therapist. Participants could be in brace treatment if needed according to SOSORT guidelines [10]. TLSO braces used included Sforzesco very rigid braces, and Lyonese and Cheneau-Sibilla rigid braces. Normal standing and ASC x-rays were always taken at the end of the prescribed daily weaning period.

Intervention

The self-correction tested in this study was the ASC according to SEAS Italian school. ASC is learned and gradually improved during physiotherapy sessions every one to three months. The expert physiotherapist chooses the best ASC based on scoliosis and patient characteristics. The personalized ASC is then taught and adapted according to patient's neuromotor abilities in achieving it. The movements of ASC can be performed in all spatial planes and always in an overall anti-gravitational direction.

- The movement in the coronal plane is named translation. It aims to reduce the curvature's Cobb angle and is always performed obliquely upwards, to counteract the postural collapse.
- The sagittal plane movements aim to recover physiological sagittal curves: kyphotization if thoracic kyphosis is decreased, increasing lumbar lordosis if decreased.

In AIS rarely happens the opposite (i.e. kyphosis or lordosis increase) [10].

- The movement in the horizontal plane is named derotation and aims to reduce spine torsion [17].

Corrective movements can be performed all together or only some of them, simultaneously or in sequence, and are continuously adapted according to changes in both the characteristics of scoliosis and the patient's abilities. The ASC performed by the patient is not the best possible, but the one that the patient can achieve and maintain at best at that moment.

The ASC learning process is a crucial part of every physiotherapy session. In the first session, it includes:

1. The explanation to the patient about his scoliosis characteristics by looking at the x-rays;
2. The theoretical explanation of the corrective movements that allow the x-ray curves to improve;
3. Mirror observation by the patient to look for a correspondence between what he saw in the x-ray and his real trunk;
4. The practical learning of the corrective movements previously studied on x-rays, with the help of the mirror and of physiotherapist's hands;
5. The training in performing ASC movements with less help from the therapist until the patient gets to perform it in complete autonomy and without the mirror's help.

The first session's ASC learning process is replaced by ASC refinement from the second session. After the ASC learning or refinement phase, the exercise program is set up to train the ability to maintain ASC in increasingly complex activities. The patient performs exercises daily at home for about 20 min between sessions. To make the patient independent at home, the physiotherapist records the explanation of ASC and each exercise execution by the patient via video.

Outcomes

Coronal full-spine x-rays in habitual standing and performing ASC were compared to verify the effect of SEAS ASC (Fig. 1). The outcomes measured were Cobb angle and apical vertebral rotation according to Raimondi. The Raimondi ruler was used to read the width of the apical vertebral body and the pedicle shadow offset, then related with a proportion and converted to degrees of rotation. Measurement of vertebral rotation with Raimondi ruler has been shown to be easier and slightly more reproducible compared to Perdriolle torsiometer [23]. The Scoliosis Research Society suggests that scoliosis diagnosis is confirmed when the Cobb angle is 10° or higher and axial rotation can be recognized [10]. When more than one curve with at least 10° Cobb was present, if a single curve had more than 4° Raimondi, this was considered the primary curve. In the presence of more curves with rotation greater than 4° Raimondi, these were considered double primary if the Cobb degree difference between them was less than 10°. The 4 Raimondi degrees threshold was used as the inter-rater error of 3.6° was considered [23]. Three experts (2 experienced, with more than ten years of practice, and 1 inexperienced, in the first year of practice) blindly measured the outcomes. After a preliminary internal study, the intra-rater errors of measurement were set at 3° for Cobb angle [9] and 1° for Raimondi [23].

Statistical methods

Descriptive statistics were used to analyze the sample. Mean (standard deviation), 95% Confidence Interval and Pearson correlation coefficient were calculated for normally distributed variables, median, interquartile range, and Spearman correlation coefficients for non-normally distributed variables. Statistical analysis was performed using Stata 14 SW (StataCorp LP, College Station, TX, USA).

Results

Twenty-seven adolescents met the inclusion criteria. One was excluded due to the time distance between the two x-rays greater than two months. The study group consisted of 23 females (88%) and 3 males diagnosed with AIS, mean age 13.9 ± 1.6 years, 6 (23%) Risser 0–2 and the remaining 3–4, mean Cobb angle (largest curves) 32 ± 11°. Twenty-three (88%) were braced, 18.5 ± 3.7 h per day. Ten adolescents were classified with double primary curves, sixteen with single primary curves. The latter all had a secondary compensation curve greater than 10° Cobb (21 ± 8°). Considering all curves, 29 were thoracic, 16 lumbar, and 7 thoracolumbar.

The mean difference between not ASC and ASC x-ray was greater than the error of measurement in both Cobb and Raimondi degrees in single primary curves. In double primary curves, the mean difference was greater than the error of measurement in Raimondi degrees but not in Cobb degrees (Table 1).

Most of the single primary curves (81%) improved in Cobb degrees, and none got worse (Fig. 2). In the same patients, secondary curves remained stable in 31%, worsened in 18%, and improved in 50%. Considering double primary curves, Cobb and Raimondi degrees improved in at least one curve in 60% and 80% of patients, respectively.

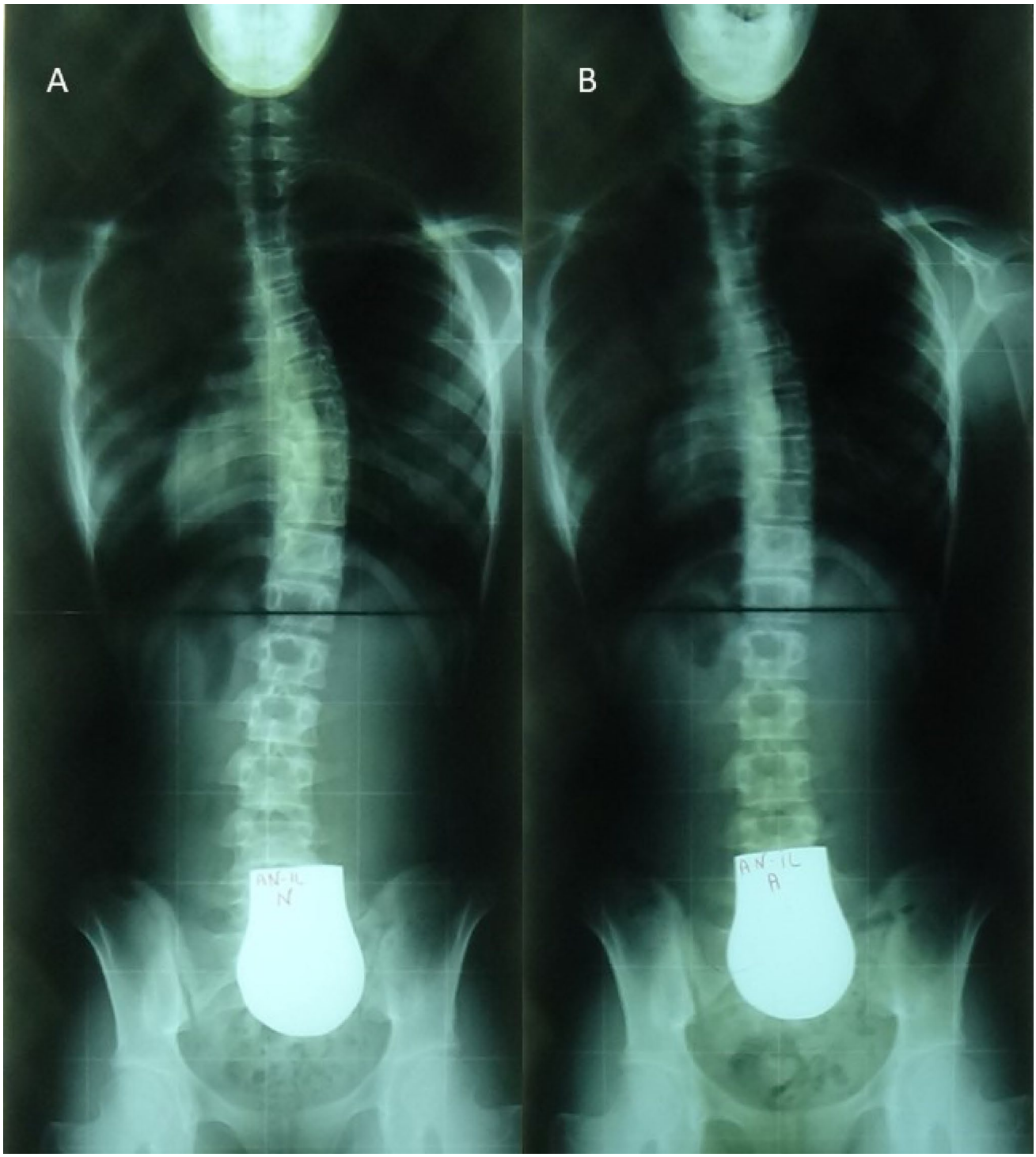

Fig. 1 Coronal full-spine x-rays in habitual standing (Fig. 1a) and performing Active Self Correction (Fig. 1b) of a patient. In habitual standing and in Active Self Correction Cobb angle was 27° and 20°, and apical vertebral rotation was 20° and 13°, respectively

No patients worsened Cobb or Raimondi degrees in both curves (Table 2).

The median of the days between the last physiotherapy session and the ASC x-ray was 28 (interquartile range, IQR = 60), with the longest time of 5 months.

Very-weak correlations were found between Cobb and Raimondi degrees variations ($r = 0.1$), and between the number of physiotherapy sessions before ASC x-rays and the variation in Cobb and Raimondi degrees ($r = -0.1$, $r = 0.1$, respectively).

Table 1 Mean [95% confidence Interval] of Cobb and Raimondi degrees in both habitual standing (not active Self-Correction, ASC) and performing ASC x-rays, mean difference and percentage of reduction in adolescents with single primary curve and double primary curve scoliosis

		Not ASC	ASC	Difference	% reduction
Single primary curves (n = 16)	Cobb	31.3° [25°- 27.6°]	25.5° [19.9°- 31.1°]	5.8° [4.2°- 7.4°]	19 [14.2 - 23.8]
	Raimondi	14.1° [10.3°- 17°]	12.4° [7.4° - 17.4°]	1.7° [(−1°) - 4.4°]	15 [(−7.9) - 37.9]
Double primary curves (n = 10)	Cobb	29.6° [22.9° - 36.3°]	28.3° [20.6°- 36°]	1.3° [(−0.2°) - 2.8°]	6 [0.4 - 11.6]
	Raimondi	9.7° [5°- 14.4°]	7.9° [3.6°- 12.2°]	1.8° [0.4°- 3.2°]	18 [5.4 - 30.6]

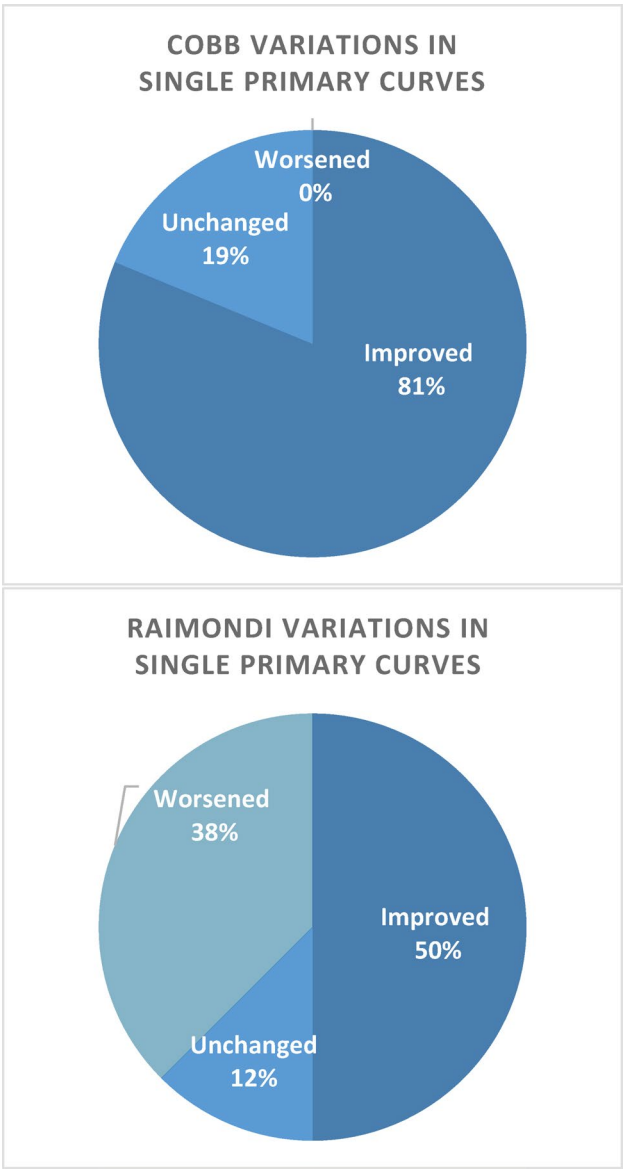

Fig. 2 Representation of improved, unchanged, and worsened percentage in Cobb and Raimondi angles in the single primary curve group. The cut-off for the definition of improvement or worsening was set at 3° Cobb angle and 1° Raimondi, as the intra-rater error of measurement was used

Table 2 Percentage variation of Cobb and Raimondi degrees in patients with double primary curves. The cut-off for the definition of improvement or worsening was set at 3° Cobb angle and 1° Raimondi, as the intra-rater error of measurement was used

	Cobb	Raimondi
Improved	**60%**	**50%**
Improved in one curve	30%	20%
Improved in both curves	30%	30%
Unchanged	10%	10%
Worsened	**30%**	**10%**
Worsened in one curve	30%	10%
Worsened in both curves	0%	0%
Improved in one curve/worsened in the other	0%	30%

Discussion

This cross-sectional study was the first to verify the effect of an unaided, standing self-correction (ASC according to SEAS school) in AIS. The ASC and not ASC coronal x-rays were compared by measuring the Cobb angle and the apical vertebral rotation according to Raimondi. ASC clinically significantly reduced both Cobb and Raimondi degrees in single primary and Raimondi degrees only in double primary curves.

In the SEAS approach, ASC is the best possible 3D alignment the patient can achieve, maintain, and manage during everyday life. This type of ASC is considered by the SEAS school a better tool to attain a reflex improved posture [17], possibly driving to a reduced self-deformation vicious cycle [20] and consequent scoliosis progression. This study shows that there the biomechanical premises allowing to develop the exercises proposed in this school. The results go beyond the specific school, and allows all physiotherapists dealing with AIS patients to introduce this corrective movement beyond the school they follow.

These results are in line with those of the previous studies on self-correction according to other approaches [7, 18, 21, 25]. Fully-corrected exercises in the Schroth PSSE school has been shown to improve curve angle, axial vertebral rotation, and apical vertebral translation using 3D ultrasound imaging. Thirty-six adolescents with double curves (mean thoracic and lumbar Cobb angle 16 ± 8° and 18 ± 9°, respectively) were scanned in standing fully-corrected positions with external aids [21]. A real comparison between the two PSSE approaches' self-correction is not possible due to the different measurement tools, outcome measures,

and mean baseline curve angles, with curves in this study twice as large as those in the Schroth study. Unlike Schroth self-correction, with no main curve correction leading to the secondary one worsening, ASC worsened Cobb angles in 18% of secondary curves and one of the two curves in three patients with double primary curve. The apical rotation also was more difficult to control, worsening almost 40% of single primary curves and 20% of double primary curves. Differences between SEAS and Schroth self-correction results could be due to the substantial difference in execution between the two but also to the evaluation instruments used. ASC according to SEAS is performed without external aids and in a neutral position. According to Schroth approach, as in the other PSSE schools, external aids and asymmetrical positions are used to achieve the best possible self-correction. Nevertheless, the usage of ultrasound in the Schroth study instead of the radiographic gold standard could impact their measurements and results' validity.

Another study conducted on 16 AIS patients showed a thoracic Cobb angle reduction performing self-correction according to the Global Postural Re-education method [7]. Adolescents (mean thoracic Cobb angle 33 ± 9°) were x-rayed after three passive mobilizations in the corrective direction of ten seconds each, and a self-correction learning with a trained therapist. The mean Cobb angle reduction was 11° and only one curve worsened, with lumbar compensations remaining stable. The authors also reported posture compensation in self-corrected x-rays, such as decreased sagittal curves and an increase of the coronal shift. The large correction obtained could be due to the mobilization, possibly neurophysiological facilitation and learning process that occurred just before the x-ray. ASC in our study was instead scanned at a different time than the ASC learning process during the physiotherapy session.

A case study on BSPTS PSSE school showed a difference in the coronal self-correction between baseline and one-year follow-up. [25] A 13-year-old female with AIS (47 lumbar and 30 thoracic Cobb degrees) was x-rayed both in habitual standing and performing BSPTS self-correction at the beginning of exercise treatment and at one-year follow-up. The baseline x-ray performing the corrective exercise showed no change from the habitual standing, while the x-ray at one year showed an improvement of the thoracic curve and a worsening of the lumbar one. In our study, the cross-sectional design did not allow to evaluate any change in the ability to perform ASC over time. However, no correlation between the number of physiotherapy sessions (every 1 to 3 months) before the ASC x-ray and the effect of ASC was found.

A 2023 prospective study by Cheung et al., show an apparent contrast with the results of this study [5]. Authors compared x-rays of 198 patients performed in two different conditions: non-directed, asking the patients to stand naturally, and directed, asking the patients to stand as straight as possible. The study showed that the major curve Cobb angle was smaller in non-directed than directed positioning. While at a first glance it seems that staying straight can worsen radiographic correction, it really shows that a generic order to stay straight is not enough to obtain a correction, in contrast to ASC.

Another interesting result to be verified with further studies is the percentage of worsening of the rotation. Firstly, according to our preliminary evaluation of the intraobserver measurement errors of the expert raters in our study, we used a measurement error (1°) that is significantly lower than what is reported in the literature (3–5°) [2, 8, 15, 23]. Setting the thresholds for worsening to 3° and 5° leads to percentage changes from 38% to 31% and 6% for single curves and from 19% to 5% and 0% for double curves, respectively. There are many other potential explanations not mutually exclusive, including: the ASC does not require external help to be performed, and as such only the internal body anatomical constraints play a role in its determination; the activation of the spinal deep muscles responsible of the ASC is by definition asymmetrical, and due to the omplex anatomy of these muscles, not necessarily perfectly controlled; the population we explored is mixed (patients braced and not, with different curve types, at different treatment stages, etc.) and this could also explain the results (e.g. the percentage of rotation worsening in single curves is reduced compared to the doubole ones); finally, therapists chose ASC individually, and monitor it according to the external changes of the trunk - this is the first study showing the internal radiographic changes, and it is perfectly possible that improvements of the ASC should be searched with other non-invasive evaluations (the only one implementable on a regular basis to individually check ASC), such the recently developed ultrasound imaging systems.

This was the first study showing that SEAS Active Self-Correction without any external aid is possible. These results highlight the effect of ASC in reducing Cobb degrees in single primary curves, but suggest that spinal rotation control and double curve management can still be improved. ASC appears to be qualitatively inferior to that achieved with external aids and quantitatively lower to that performed immediately after a facilitating mobilization and a learning process. Although self-correction is considered an essential element in PSSE treatment,[10] the real weight of the quantity (i.e., the magnitude of measures variation) and quality (i.e., the precision in improving one aspect without worsening another) of self-correction on PSSE efficacy is still unknown. For a better understanding, future research on AIS conservative treatment should investigate which aspects of ASC really impact SEAS treatment efficacy.

Limitations

Results should be considered in the context of the study limitations. The study design was retrospective (even if embedded in a prospective data collection), but no alternative designs could (and will) be considered for ethical reasons with an invasive procedure like x-rays. The data collection was spread in two decades, and even in this case the sample size remained small. Sample heterogeneity could be another limitation, as some patients were braced and others not, and patients were at different stages of skeletal maturity. Selection bias due to the physician's choice in prescribing ASC x-ray may have occurred, even if this was not always the case: unfortunately it was not possible to exactly recollect this information. The evaluator's blindness controlled detection bias. An exhaustive assessment of ASC was not possible due to the lack of lateral x-rays. Sagittal measurements were therefore not available, although their importance in assessing overall a three-dimensional self-correction. Another important limitation is that this study only demonstrates the value of ASC while performing the self-correction effort, but does not provide evidence on its effect on long-term curve progression. Future prospective studies could investigate whether the degree of radiographic self-correction achieved is associated with long-term outcomes, by following these patients until skeletal maturity. This would help to better understand the prognostic value of x-ray correction during ASC and its real impact on scoliosis progression over time.

Conclusions

The present study was the first to check the real efficacy of an active, unaided standing Self-Correction on AIS curves. Self-correction is a key part of all PSSE schools, but only a few studies evaluated its real effect on AIS misalignment. The present study showed that an ASC without external aids is possible. ASC in curves averaging 32° Cobb improved both Cobb degrees and apical rotation in single primary curves and apical rotation in double primary ones. A real comparison between the PSSE approaches' self-correction was not possible due to the studies' heterogeneity. Future research should compare them and investigate which aspects of each self-correction have the greatest impact on AIS treatment results.

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Authors' contributions SN was responsible for the conception and design of the study. FN and AN were involved in the processing and statistical analysis of data; SRR was involved in the drafting of the manuscript; and all authors contributed to the interpretation of the data for the work and revising it critically for important intellectual content. All the authors finally approved the manuscript for publication.

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Declarations

Conflict of interest AN and SN owns stock of ISICO. SRR and FN are related to AN and SN. GF has no conflict of interest to declare.

Ethics committee approval and trial registration The study was approved by the local Ethics Commettee Comitato Etico Milano Area 2 and it has been registered within ClinicalTrials.gov (NCT05598021).

Patient involvement statement Study participants were not involved in the design, conduct, interpretation, or translation of the current research.

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