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Exercises reduce the progression rate of adolescent idiopathic scoliosis: Results of a comprehensive systematic review of the literature

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Abstract

Background. A previously published systematic review (Ped.Rehab.2003–DARE 2004) documented the existence of the evidence of level 2a (Oxford EBM Centre) on the efficacy of specific exercises to reduce the progression of AIS (Adolescent Idiopathic Scoliosis).

Aim. To confirm whether the indication for treatment with specific exercises for AIS has changed in recent years.

Study design. Systematic review.

Methods. A bibliographic search with strict inclusion criteria (patients treated exclusively with exercises, outcome Cobb degrees, all study designs) was performed on the main electronic databases and through extensive manual searching. We retrieved 19 studies, including one RCT and eight controlled studies; 12 studies were prospective. A methodological and clinical evaluation was performed.

Results. The 19 papers considered included 1654 treated patients and 688 controls. The highest-quality study (RCT) compared two groups of 40 patients, showing an improvement of curvature in all treated patients after six months. We found three papers on Scoliosis Intensive Rehabilitation (Schroth), five on extrinsic autocorrection-based methods (Schroth, side-shift), four on intrinsic autocorrection-based approaches (Lyon and SEAS) and five with no autocorrection (three asymmetric, two symmetric exercises). Apart from one (no autocorrection, symmetric exercises, very low methodological quality), all studies confirmed the efficacy of exercises in reducing the progression rate (mainly in early puberty) and/or improving the Cobb angles (around the end of growth). Exercises were also shown to be effective in reducing brace prescription.

Conclusion. In five years, eight more papers have been published to the indexed literature coming from throughout the world (Asia, the US, Eastern Europe) and proving that interest in exercises is not exclusive to Western Europe. This systematic review confirms and strengthens the previous ones. The actual evidence on exercises for AIS is of level 1b.

Keywords: *Physical exercises, adolescent idiopathic scoliosis, conservative treatment, physiotherapy, rehabilitation*

Introduction

Various types of treatments for AIS (Adolescent Idiopathic Scoliosis), whether conservative or surgical, have been reported. The majority of adolescents with AIS have been treated with conservative care that included bracing, simple observation and/or physical exercises (PEs) [1]. PEs for the treatment of AIS have been used since 500 BC, when Hippocrates [2], followed by Galenus [3], introduced their usage as means to maintain the flexibility of the chest wall. During the past centuries there was a considerable flowering of different approaches to PEs, but only at the beginning of the previous century, mainly in Germany with Klapp and Von Niederhöfer, was it possible to verify the first methods through deep scientific observation [4]. During the same period Katharina Schroth described her method [5]. Later, in many parts of Europe, authors described different methods: Between 1930 and 1950 the 'IOP' method was introduced in Italy, and the 'Psoas' method was produced in the Soviet Union [4]. The 'Lyon' method [6,7] and that of Mézières [8] were described in France during the 1960s. Later, Souchard derived its treatment from Mézières [9], and in Poland Dobosiewics proposed its approach

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[10], while Min Mehta introduced the 'side-shift therapy' [11] to arrive at the actual 'Scientific Exercises Approach to Scoliosis (SEAS),' again created in Italy [12].

Apart from each method, PEs were subjected during the years to various fates [13,14], and today the current evidence regarding the effectiveness of PEs and other conservative treatments for AIS remains insufficient [14–16]. At the moment there is certainty only in regard to the ineffectiveness of electrical stimulation [17]. Despite the fact the rationale for the choice of which conservative treatment should be used is unclear and the effectiveness of exercises has not been proved, in many areas of the world patients are expected to continue treatments that have an impact on their quality of life [14]. We are perfectly aware that exercises also achieve other important objectives [18,19], such as increased neuromotor control and spinal stability, biomechanical reduction of postural collapse and increased respiratory function. Moreover, the effectiveness of PEs in AIS patients has already been shown to improve respiratory function [20,21], strength [22] and postural balance [23]. But a key factor for the scoliosis treating community is to understand whether exercises are truly capable of a positive influence on the deformity [18], and this is the main reason we have conducted, after five years, an update on our previous systematic review [14] about PEs as a treatment to avoid the progression of AIS and ultimately prevent the use of bracing. The goal of this paper is to systematically search the literature for news on the effectiveness of PEs as means to eventually modify, and therefore conclude, our review.

Methods

We followed exactly the same methodology of our previous review [14] so as to add our actual results to the previous ones. We performed an extensive search through all the relevant databases: Medline, Embase, Cinhal, PEDro and Cochrane Library. We searched papers in every available language covering the period from the month we concluded our previous search (December 2002) up to July 2007. Again, we used the Mesh terms 'scoliosis AND (''exercise therapy OR 'rehabilitation'')', and in free text we used 'idiopathic scoliosis' followed by the operator 'AND' and the terms 'exercise,' 'exercises,' 'sports,' 'sport,' 'rehabilitation' and 'physiotherapy.' No restriction was applied in regard to language. We checked the reference list of the retrieved articles and also performed a manual search of the journals listed in Table I. The inclusion criteria remained the same:

Table I. Journals in which the manual search was performed.

Journal	Years searched	Language
Annales de Kinésithérapie	2002–2007	French
Kinésithérapie Scientifique	2002–2007	French
Résonances Européennes Du Rachis	2002–2007	French
Cahiers de Kinésithérapie	2002–2007	French
Ginnastica Medica, Medicina Fisica e Riabilitazione	2002–2007	Italian
Chinesiologia Scientifica	2002–2007	Italian
Atti Gis, Giornate di Patologia Vertebrale	2002–2007	Italian
European Medical Physiology	2002–2007	English
European Spine Journal	2002–2007	English

- Patients: Diagnosis of AIS by a specialist, confirmed through X-rays; we focused on patients in growth years (up to Risser 5) and accepted three studies in which most of the patients were growing, but some older ones were also included;
- Experimental intervention: Patients treated exclusively with PEs, without any other associated intervention;
- Control group: Any kind of patients, either observed or treated;
- Outcome measures: Only Cobb degrees; results could be reported in absolute terms or as percentage of patients improved/worsened;
- Study design: Any study design.

For the methodological evaluation of the studies we considered the following parameters (Table II) [14]: Controlled study, random allocation to experimental and control intervention, prospective versus retrospective study, recruitment modality described, patient characteristics described, intervention described, blinded assessment of outcomes, identification of possible confounding factors, statistical control for the confounding factor.

The results are herein reported in methodological and clinical terms. In the clinical section we will look for the duration of the studies and number of patients included, but also the characteristics of patients as well as the PE techniques used. Accordingly, the clinical presentation will be divided for:

- Methodology (randomized controlled trial – RCT – versus others): Obviously good methodology papers can be trusted more than the others;
- Type of rehabilitation (Scoliosis Intensive Rehabilitation – SIR – versus outpatient rehabilitation exercises – [OR]): Inpatient treatment is totally different in many respect (possible efficacy but also costs) from outpatient one;

Table II. Methodological quality of retrieved studies.

Study			Controlled study	Random allocation	Prospective study	Allocation criteria described	Recruitment modality described	Patient characteristics described	Intervention described	Blinded assessment of outcomes	Confounding factors	
Author	Year	Ref									Identification	Statistical control
Wan	2005	31	Y	Y	Y	Y: random	Y	Y	Y	N	N	N
Weiss	1997	14	N	N	Y	Na	N	Y	N	N	N	N
Weiss	1992	40	N	N	N	Na	N	Y	Y	N	N	N
Weiss	2003	16	Y	N	Y	N	N	Y	Y	N	Y	N
Rigo	1991	17	N	N	N	Na	N	Y	Y	N	N	N
den Boer	1999	19	Hc	N	Y	Na	Y	Y	Y	N	Y	N
Mamyama	2002	20	N	Na	Y	Na	N	Y	Y	N	N	N
Maruyama	2003	21	N	Na	N	Na	N	Y	Y	N	N	N
Otman	2005	18	N	Na	Y	Na	Y	Y	Y	N	N	N
Mollon	1986	27	Y	N	N	N	N	Y	N	N	Y	Y
Ferraro	1998	29	N	N	Y	Na	Y	Y	Y	N	N	N
Ducongé	2002	28	Y	N	N	N	N	Y	N	N	N	N
Negrini	2006	30	Y	N	Y	Y: patient's decision	Y	Y	Y	N	N	N
Mooney	2000	23	N	N	Y	Na	N	Y	Y	N	N	N
Durmala	2003	26	N	Na	Y	N	N	Y	Y	N	N	N
McIntire	2006	24	N	Na	Y	Na	N	Y	Y	N	N	N
Stone	1979	22	Hc	N	Y	Na	Y	Y	Y	N	N	N
Klisic	1985	32	Y	N	N	Y: patient's decision	N	N	N	N	N	N
Negrini	2006	31	Y	N	Y	Y: patient's decision	Y	Y	Y	N	N	N

Y, yes; N, no; NA, not applicable; HC, historical control.

- Type of autocorrection (AC) exercises proposed (extrinsic: obtained mainly through the arms and/or trunk muscles; or intrinsic: focused mainly on contraction of paravertebral spine muscles; or no AC); autocorrection has been proposed by SOSORT Consensus [18] as the key to a proper rehabilitation protocol;
- In cases where the AC (i.e., asymmetrical by definition) [18] was not used, we will differentiate between symmetric and asymmetric exercises.

Results

The electronic search allowed us to find 192 articles, but through the manual search we did not find relevant papers. In this way the papers considered, including those coming from the previous review, [14] amounted to 616. Reading the titles and abstracts we excluded 586 papers, while we searched 30 full texts for further evaluation as probably relevant. They were all retrieved: Ten were excluded because they did not fulfil all the inclusion criteria, and the final review included 19 papers.

Characteristics of the included studies

The 19 relevant studies (Tables III, IV and V) encompassed 2342 AIS patients, 1654 of whom had been treated exclusively with PEs for an average time of 23 ± 18 months. The age considered in the studies was on average 13.4 ± 2.8 years, and the scoliosis curvature was $23.6 \pm 8.9^{\circ}$ Cobb. The control groups included for observation [24–28] or alternative treatments (other kinds of exercises [29–31], and in one case bracing [11]). We excluded any paper that considered results other than Cobb degrees: Two studies [31,32] did not report clinically on the worsening or improvement of the patients, while three [25,28,33] did not include the final curvatures obtained. One study [30] reported on the usefulness of exercises in enhancing the efficacy of bracing [34,35].

Given the heterogeneity of the studies and their weak methodologies, we did not attempt a real meta-analysis. Nevertheless, a general purview of all studies was possible. First, all groups treated with exercises had better clinical results than the five observed control groups (Figure 1). Generally, it seems that at the beginning of adolescence and the start of puberty, when the risks of progression are

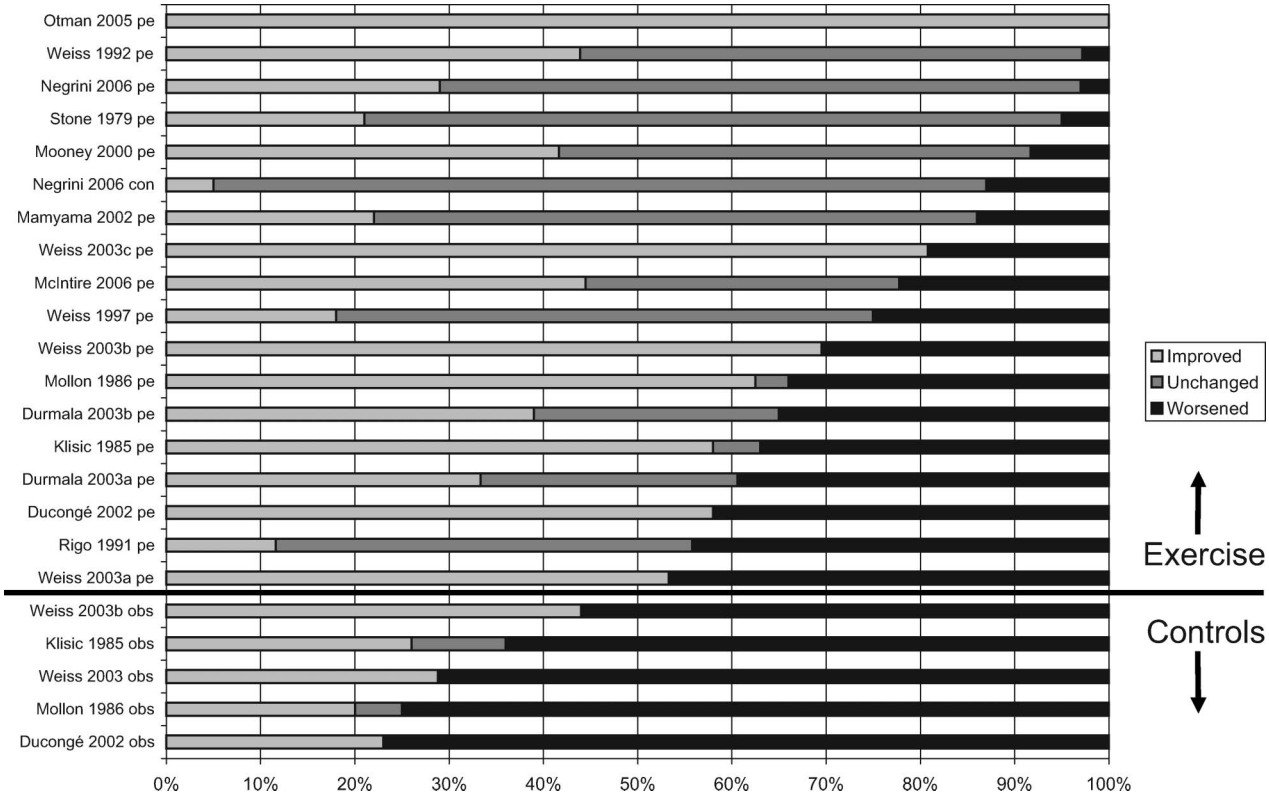

Figure 1. The clinical results (patients improved, unchanged or worsened) reported in all exercises groups in the studies considered in this review are better than those reported in the observational groups. All the observational groups (obs) are listed under the black line, all the exercise groups (ex/con) over this line. The exercise groups include also a control group (con) that performed usual physiotherapy.

higher, patients with lower-degree curvatures are usually treated, and the results show a slow progression and rarely a decrease in curvature, while in patients of older ages success is achieved more easily and in greater curvatures (Figure 2). In any case, the studies with the biggest numbers of patients tend to show good results (stability) but such results are generally not as significant as those with reduced samples (Figure 3).

Methodological quality

The results of quality assessments of the included studies are shown in Table II. The quality of the studies was found to be weak. Only one study was a randomized controlled trial [31], but its methodological quality was poor: The method of sequence generation and of allocation concealment was not described, the outcome assessor was not blinded, and none was lost at follow-up. Six studies were subjected to concurrent controls [25–30], and two had historical controls [11,24]. Only three out of the six studies with concurrent controls were prospective [25,29,30]. In the two studies with historical controls the experimental group was evaluated prospectively. The allocation criteria (other than random criteria) were described only in three [28–30] of the six controlled studies, and were based on the patient's decision. The other 12 included studies that were uncontrolled and involved only one evaluation of the outcome measure before and after treatment. Seven of these studies were prospective [22,32,33,36–39]. The recruitment modality was described in seven of the 19 studies included [11,24,29–32,37]. The characteristics of patients were described in all the studies, whereas the description of the intervention was reported in 16 of 19 studies. Only three studies attempted to identify the possible confounding factors [11,25,26], and only one [26] adjusted the results accordingly.

Clinical results

RCT (Randomized controlled trial)

Wan [31], in 2005, published the first RCT about PEs for the treatment of AIS in 80 Chinese patients (40 per group) of 15 ± 4 years of age and $24 \pm 12^{\circ}$ of curvature: All patients received electrostimulation on lateral body surface as well as traction and postural training; and patients in the treatment group underwent specific asymmetric

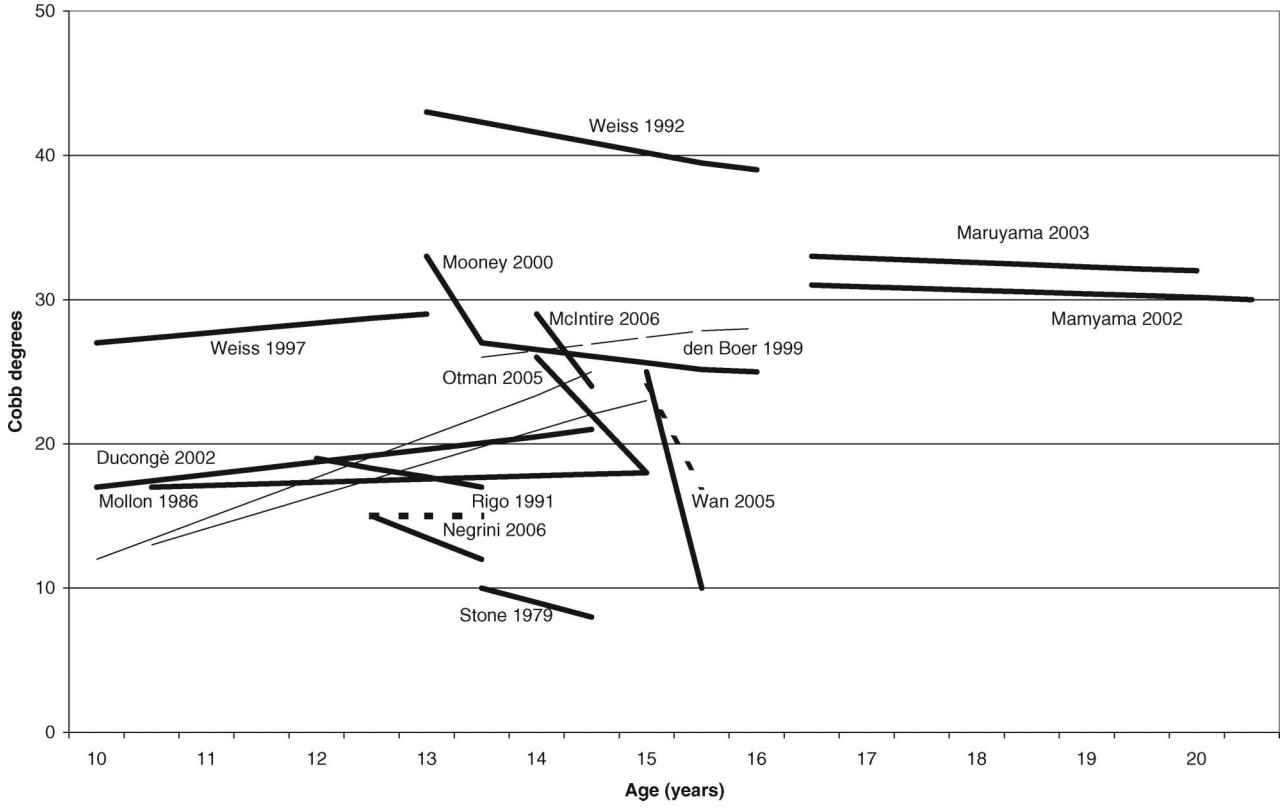

Figure 2. Results in terms of Cobb degrees of the studies included in this review according to the age of the treated patients. In this graph, the thick black lines represent the treated patients, the thick dotted lines (Wan 2005 and Negrini 2006) the control exercise groups, the thin dotted lines (Mollon 1986 and Ducongè 2002) the control observational groups, and the thin dashed lines (den Boer 1999) the only control braced group.

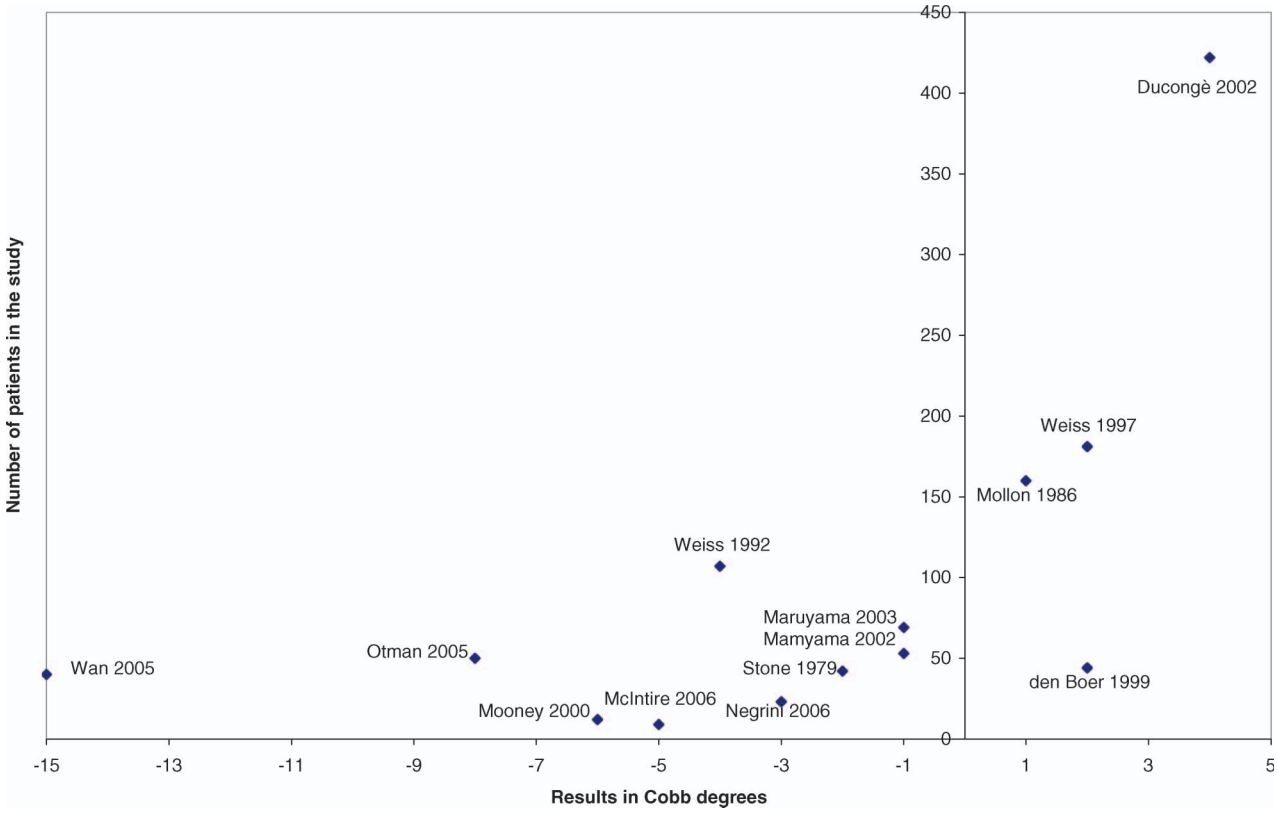

Figure 3. The papers with the biggest number of patients have results of stability of the curves (±5°).

Table III. Characteristics of the included studies: Populations and follow-up. The study by Weiss et al. has been divided into two age groups according to the original study.

Study			Population									Duration of treatment		
			Number of patients			Age			Cobb degrees			Months		
Author	Year	Ref	Total	Exercises	Controls	Average	SD	Range	Average	SD	Range	Average	SD	Range
Wan	2005	36	80	40	40	15	4					6		
Weiss	1992	15	107	107		21.6		10.9–48.8	43		10–114	1.5		1–1.5
Weiss	1997	14	181	181		12.7			27			33		
Weiss	2003	25a	94	30	64	10		4–11	21		5–52	35	23	
Weiss	2003	25b	102	59	43	13		12–14	29.5		5–68	34	37	
Rigo	1991	17	43	43		12			19.5			19.5		3–?
den Boer	1999	19	164	44	120	13.6		10–15	26		20–32	26		4–?
Mamyama	2002	20	69	69		16.3		11–27	31.5		13–74	50		14–132
Maruyama	2003	21	53	53		16.3		13–27	33.3		20–74	41		12–132
Otman	2005	18	50	50		14.1		11–17	26.1		20–35	12		
Mollon	1986	27	210	160	50	10.8		10–15	16			53		
Ferraro	1998	29	34	34		11.6		8–14	14.9		10–24	24		7–51
Ducongé	2002	28	591	422	169	10.1		7–16	15.6			55		
Negrini	2006	30	48	23	25	12.4			15.1			12		
Mooney	2000	23	12	12		13.1		11–16	33.5		20–60	4		
Durmala	2003	26	136	136				6–18				12		
McIntire	2006	24	9	9		14	1.7		29	6	20–37	4		
Stone	1979	22	99	42	57			12–15	10		4–22	12		9–15
Klisic	1985	32	150	100	50	11		5–15	14			36		12–84
Negrini	2006	31	110	40	70	13.4		10–15	30.9			5		

strengthening PEs once daily for correction of scoliosis. With six months of treatment the changes of Cobb angle in the thoracic and lumbar segments were significant, but in the PE group the improvement (15°) was greater than in the control group (7°).

Table IV. Characteristics of the included studies: Exercises performed and compliance.

Study			Exercises			
Author	Year	Ref	Type	Aims	Characteristics	Compliance
Wan	2005	13	Gymnastic exercise and postural training (Na)	Correction of essential S-shaped scoliosis and maintaining symmetrical posture during normal activities	Once daily	
Weiss	1997	14	Schroth method (E)	actively straightening, auto-correction	intensive in-patient exercise programme	
Weiss	1992	15	Schroth method (E)	actively straightening, auto-correction	intensive in-patient exercise programme	
Weiss	2003	16	Schroth method (E)	actively straightening, auto-correction	intensive in-patient exercise programme	
Rigo	1991	41	Schroth method (E)	actively straightening, auto-correction	three times a week with physio	
Den Boer	1999	11	Side shift therapy (E)	side shift, posture	instruction from physio, side-shift in daily living	95%
Mamyama	2002	38	Side shift therapy (E)	Lateral shift-trunk during standing and sitting	Not reported	Not reported
Maruyama	2003	42	Side shift therapy (E)	Lateral shift-trunk during standing and sitting		
Otman	2005	18	Scroth method (E)	Active extension, active-correction, realignment of trunk	Outpatient rehabilitation for the first 6 weeks (4 hours day for 5 days) and later same program at home	68 patients recruited, 18 not compliant excluded from the analysis
Mollon	1986	26	Lyon method (I)	posture control, strengthening, balance	twice a week with physio and other times at home	75%
Ferraro	1998	29	Many methods (I)	active postural correction	twice a week with physio and other times at home	see text
Ducongé	2002	27	Lyon method (I)	posture control, strengthening, balance	twice a week with physio and other times at home	71%
Negrini	2006	29	SEAS.02 (I)	Active-self correction learning	Individually adapted exercises at a super-specialized structure (1.5 h session every 2–3 months), prosecution at home	Not reported
Mooney	2000	23	MedX Rotary Torso Machine (Na)	strengthening	Daily	
McIntire	2006	24	Trunk rotational strength training (Na)	Increase trunk strength, stabilize or decrease curve size	2 training session per week (tot 32)	Not reported
Durmala	2003	33	Asymmetric mobilization of the trunk (Na)			
Stone	1979	22	Milwaukee method (Ns)	mobilization, strengthening, posture	instructions from physios, exercises performed at home	about 50%
Klisic	1985	32	(Ns)			
Negrini	2006	31	SEAS.02 (Ns)	Active-self correction learning	Individually adapted exercises at a super-specialized structure (1.5 h session every 2–3 months), prosecution at home	Not reported

Abbreviations: E: extrinsic autocorrection; I: Intrinsic autocorrection; Na: No autocorrection, asymmetric exercises; Ns: No autocorrection, symmetric exercises.

Table V. Results of the retrieved studies.

Study				°Cobb			Clinical change				
Author	Year	Ref	Groups	Start	End	P	Variation considered	Improved	Unchanged	Worsened	P
Wan	2005	13	Specific exercises	25	10						
			Postural exercises	24	17						
Weiss	1992	15	Exercise	43	39		5	44%	53%	3%	
Weiss	1997	14	Exercise	27	29		5	18%	57%	25%	
Weiss	2003	16a	Exercise	21				53%		47%	
			Observation	5–30°				29%		71%	
Weiss	2003	16b	Exercise 1	29				70%		31%	
			Exercise 2	42				81%		19%	
			Observation	5–30°				44%		56%	
Rigo	1991	17	Exercise	19	17		5	12%	44%	44%	
den Boer	1999	19	Exercise	26	28						NS
			Brace	27	25						
Mamyama	2002	20	Exercise	31	30		5	22%	64%	14%	
Maruyama	2003	21	Exercise	33	32						
Otman	2005	18	Exercise	26	18		5	100%	0%	0%	
Mollon	1986	27	Exercise	17	18		3	63%	4%	34%	
			Observation	13	23			20%	5%	75%	
Ferraro	1998	29	Exercise	15							
Ducongé	2002	28	Exercise	17	21		3	58%		42%	
			Observation	12	25			23%		77%	
Negrini	2006	30	Exercise	15	12		5	29%	68%	3%	
			Usual physiotherapy	15	15			5%	82%	13%	
Mooney	2000	22	Exercise	33	27		5	42%	50%	8%	
McIntire	2006	39	Exercise	29	24		5	44%	33%	22%	
Durmala	2003	26	Exercise: double curves					33%	27%	39%	
			Exercise: single curves					39%	26%	35%	
Stone	1979	24	Exercise	10	8		4	21%	74%	5%	
Klisic	1985	28	Exercise	15				58%	5%	37%	
			Observation	13				26%	10%	64%	
Negrini	2006	30	Exercise	30	25		5	58%	41%	1%	
			Usual physiotherapy	31	28			46%	44%	10%	

Exerc, exercises; Ctrl, controls. Ref. No. 16 (Weiss et al.) has been divided, according to the original study, into two different age groups (a) and (b); the group (b) included two sub-groups (1) and (2): This presented the worst curvatures.

Other studies

SIR (Scoliosis intensive rehabilitation)

This sub-group includes three studies, 484 AIS patients 14.3 ± 5 years old, with 30 ± 9° Cobb, in which 377 had been treated for 26 ± 16 months. All the studies reported on this kind of approach have been proposed by Weiss [25,36,40], using the intensive physiotherapy protocol originally proposed by Katharina Schroth (4–6 weeks of treatment, 6–8 hours per day, then at home for 90 min per day). The Schroth method (Figure 4) is based on sensorimotor and kinaesthetic principles. Exercises comprise the correction of scoliotic posture (through elongation, realignment of trunk segments, positioning of the arms and muscle contraction), and the use of specific breathing patterns with the help of proprioceptive and esteroceptive stimulation and mirror control.

The authors first proposed two case series: In 1992 [40] they proved in 107 patients of various ages (ranging from 10.9–48.8 years) with curvatures of 43° (ranging from 10–114°) the efficacy of SIR in the short term (4–6 weeks), with an improvement in 44% and a worsening in 3%; in 1997 [36] 181 adolescents (12.7 years) with 27° curvatures did not progress in 33 months (end of treatment: 29° – 25% worsened, 18% improved). Finally, in 2003 [25] the authors proposed a prospective cohort controlled study in two sub-groups matched for sex and age (first subset, ten years of age 21° curves; second one, 13 years old, 29.5° curves). In both SIR groups the authors found in 35 months of treatment better results than in control groups: The youngest had 53% improvement versus 29% in controls, the oldest 70% versus 44%, respectively.

OR (Outpatient rehabilitation exercises)

Extrinsic autocorrection. This sub-group includes five studies, 379 AIS patients 14.4 ± 1.8 years old, with 27 ± 5° Cobb; 259 have been treated for 32 ± 16 months. Two papers used the Schroth method as an outpatient approach. In the retrospective study by Rigo [41], 43 patients 12 years old with 19.5° curves exercised twice a week following a two-hour program

for a minimum of three months: 11.6% worsened and 44.2% improved. Recently, Otman [37] followed prospectively a series of 50 adolescents 14.1 years old (ranging in age from 11 – 17) as outpatients for the first six weeks (four hours per five days a week) who continued exercising at home for 90 min per day: During the treatment he observed a progressive improvement of Cobb degrees from an average angle of 26.1 – 17.8° at one year, when all patients showed improvement.

Another method that is very common (and has been studied by several authors) is the 'side-shift therapy' (Figure 5) originally proposed by Min Mehta. This is a kind autocorrection, first through a lateral shift of the trunk applied as an exercise and then in the activities of daily living. The oldest study

Figure 4. Example of a Schroth therapy exercise (extrinsic autocorrection). Permission has been given by Dr. Weiss to reproduce this figure.

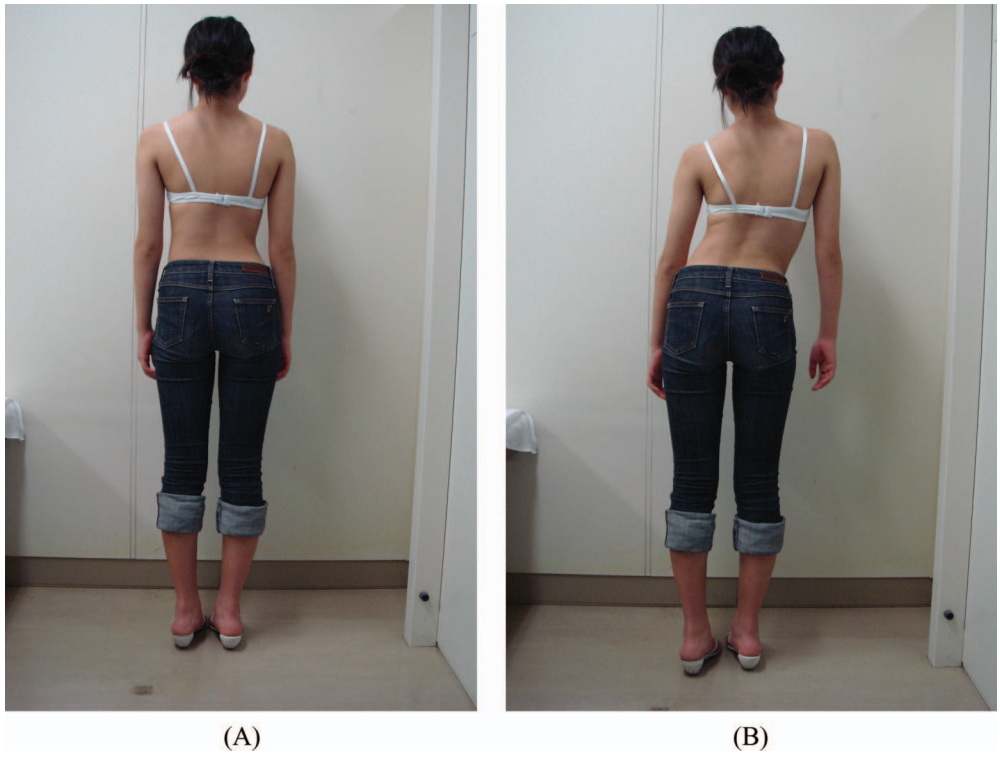

Figure 5. Side-shift exercise (extrinsic autocorrection). A: neutral position; B: end of side-shift moevement. (Courtesy Dr. T. Maruyama)

has been proposed by den Boer [11], who compared prospectively PEs (44 patients) with bracing (120 adolescents) in adolescents 13.6 years old with 20–32° Cobb curvatures. The authors found no statistically significant differences or the intention to treat or determine efficacy between the two groups. Mamiyama, in 2002 [38], prospectively followed a series of 69 patients 16.3 years old with 31.5° curvatures who started exercising after skeletal maturity (Risser grade IV or V, postmenarche after more than two years): After an average follow-up period of 4.2 years the authors observed that 22% of the curves had progressed while 14% improved (4% of 10° or more). One year later Maruyama [42] retrospectively confirmed these results in a sample of 53 patients of similar clinical characteristics treated for 41 months.

Intrinsic autocorrection. This sub-group includes four studies, 883 AIS patients 11.2 ± 1.0 years old, with 15 ± 0.5° Cobb, in which 259 had been treated for 36 ± 21 months. This intrinsic AC approach is based on the former Lyon School proposals, which were based on the auto-elongation exercise [6,7] (Figure 6). According to the new knowledge in the literature, this have been reinterpreted in terms of three-dimensional AC in the SEAS (Scientific Exercises Approach to Scoliosis) by ISICO (Italian Scientific Spine Institute) [12] (Figure 7).

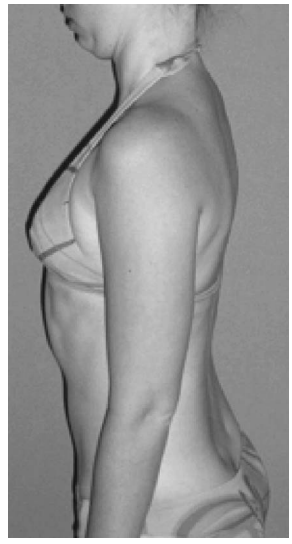

Figure 6. Auto-elongation according to the Lyon School (intrinsic autocorrection). Copyright permission has been granted by ISICO to reproduce this figure.

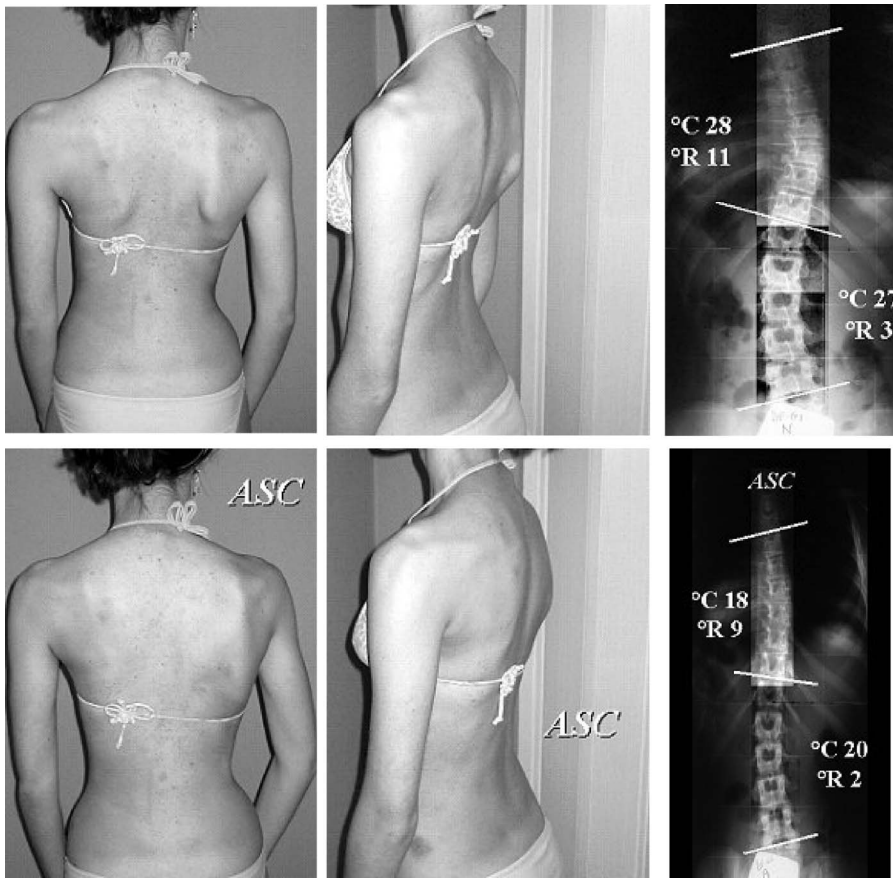

Figure 7. Active autocorrection according to the SEAS protocol proposed by the ISICO School (intrinsic autocorrection). Copyright permission has been granted by ISICO to reproduce this figure.

The oldest retrospective controlled study has been proposed by Mollon and Rodot [26], which studied the entire growth period of 210 AIS patients 10.1 years old recruited throughout Europe: These 50 controls and 160 patients had been treated with PEs consisting of posture control, strengthening and balance training according to the Lyon method [6,7], based on the neuromotor control to be increased though external input, mainly proprioceptive. At the end of treatment (four years) the authors found statistically significant differences, with 62.5% of treated patients improved (44% worsened), while in the control group these percentages were 20% and 75%, respectively. More than ten years later, Ducongé [27] confirmed these results in a similar sample with the same methods: 42% of the 422 treated patients worsened versus 77% of the 169 controls. A similar treatment has been applied in Italy by Ferraro [32], who treated 34 outpatients twice a week (plus personalized home sessions). When compared to the minimal compliance (<10 min/day), the maximal participation (>30 min/day) slowed down or even halted the progression of scoliosis (difference between the groups: 9°).

More recently, Negrini [29] compared to usual physiotherapy in a prospective study the SEAS protocol, which is based on active three-dimensional self-correction (Figure 7) and aims at improved spinal stability, developing balance reactions and preserving/improving the physiological sagittal spinal curvatures. In this one-year prospective controlled study of 48 patients 12.4 years old, with 15° curves, the number of braced patients (failure of treatment) was statistically significantly reduced by specific exercises (4.3% versus 20%), while SEAS caused 28.9% improvements versus 5% in controls.

No autocorrection, asymmetric exercises. Some authors did not apply the autocorrection principles but instead used asymmetric exercises according to different theories. This sub-group includes three studies. Durmala [33] followed prospectively (for 12 months) 136 AIS patients ranging in age from six to 18 years, treated with asymmetric trunk mobilization and reported a 31–39% decrease in Cobb angle according to the segment of the spine considered. Two pilot studies proposed PEs performed with the aid of a rehabilitation device, the MedX Rotatory Torso Machine for trunk rotation strength training, starting with the idea that there is increased activity on the convex side of scoliosis, particularly in patients with progressive curvatures. Mooney [22] performed a pilot study and obtained in a period of four months, in 12 patients 13.1 years old with 33.5° curvatures, an improvement in 41.6%, while only one worsened. Six years later another pilot study by McIntire [39], who proposed, to nine patients aged 14 years with 29° curvatures, two training sessions per week for four months and reported a statistically significant reduction of 5°.

No autocorrection, symmetric exercises. Finally, there is the group of authors who neither applied the autocorrection principles nor used asymmetric exercises. This sub-group includes three studies, the oldest ones (and the only one negative) and one of the last, which relate to a particular possible aim of PEs, being increased brace correction. In 1979, Stone [24] proposed to 42 patients ranging in age from 12–15 years with 10° curvatures (range 4–22), a 12-month home program of mobilization, strengthening and posture control according to the Milwaukee method, but obtained no differences between the prospective PE group and 57 retrospective controls. Contrastingly, in 1985 Klisic and Nikolic [28], through PEs (no details of protocol given) obtained an improvement in 58% of 100 patients 11 years of age with 14° curvatures, while 37% worsened versus 26% and 64%, respectively, in 50 controls. Finally, one paper explored the usefulness of PEs in preparation for bracing [30]: The SEAS protocol of general and localized mobilization demonstrated its efficacy in increasing the brace correction at five months in 40 patients versus 70 control patients 13.4 years old with curvature of 30.9°. Of these, there was a 58% improvement rate and 1.5% worsening in the PE-treated versus 45.8% and 10.3%, respectively, in controls.

Discussion

This review adds a lot of new data to the previous one we performed five years ago [14]. In this period an RCT [31] and seven more papers of different methodological quality have been published [29,30,33,37–39,42]. All results are consistent with the previous ones [14,15,43], and confirm a possible efficacy of PEs in contrasting the progression of AIS. The evidence is not of the highest level (1b, according to the Oxford Centre for Evidence-Based Medicine) [44], but it is better than the previous existing evidence of level 2a [14].

The RCT is the strongest research design on the basis of which to draw valid conclusions regarding the effectiveness of a therapeutic intervention because, if well conducted, it minimizes the risk of bias. Nonetheless there are many clinical settings in which RCTs are difficult, impractical or unethical. In such situations a controlled non-randomized study, an observational controlled study or an uncontrolled study could constitute a valid alternative, providing that confounding factors and sources of bias are carefully analyzed [45]. Rehabilitation is among the medical fields in which a researcher attempting to

conduct an RCT is most likely to encounter difficulties [46]: It is often difficult to collect a homogenous patient sample large enough to obtain adequate power of the study. Additionally, it is often difficult to find a suitable placebo intervention, and it is sometimes impossible for ethical and practical reasons to include a 'no intervention control group'. Moreover, it may often be impossible to distinguish between the specific effect of the intervention (PEs, physical therapies or other) and the therapeutic effect (psychological) of the patient-therapist relationship. Equally, the specific effect of the intervention could be modified by the therapist's expertise and faith in the given technique. Finally, it is almost always impossible to establish a double-blind condition. Nonetheless, it is possible to evaluate the effectiveness of rehabilitative intervention through good-quality studies. There are, in fact, many published studies that try to overcome the difficulties associated with the field of rehabilitation. The Cochrane Library, for example, contains many systematic reviews on various rehabilitative interventions, which include RCTs of acceptable quality that try to overcome said difficulties [47].

Only one of the retrieved studies regarding the effectiveness of PEs in AIS was randomized. Twelve of the included studies were uncontrolled and involved only one evaluation of the outcome measure before and after treatment. This kind of design produces results that are impossible to interpret, because one cannot reasonably conclude that the improvement observed was causally determined by the intervention: The positive change could have occurred naturally or might have been the result of other aspects of therapy being conducted contemporaneously [45]. Six studies were controlled with concurrent controls, and two had historical controls. Moreover, the controlled and uncontrolled studies gathered in the authors' search failed to meet some methodologic criteria for observational studies. It is therefore impossible, on the basis of the data contained in these studies, to draw strong conclusions on the effectiveness of PEs in AIS. Further randomized controlled trials or properly conducted observational prospective studies with adjustments for confounding factors should be realized.

Another topic to be considered when deciding whether a treatment can be applied is the kind of adverse effect: In all these studies (nor in any other we know) the adverse effects of the exercises performed have been documented. Eventually, the only problem is in terms of dropouts and compliance with treatment over the long term; moreover, these aspects have not been well documented. In any case, this is a key factor for rehabilitation studies that has not been thoroughly discussed in most of the studies reported in this review.

According to the previous review [14], it was possible to imagine that PE as a form of treatment was confined mainly to Western Europe, because papers arrived mainly from Germany [25,36,40] and France [26,27], but also from Holland [11], Italy [32] and Spain [41]; exceptions appeared from the former Yugoslavia [28], and a couple of papers from the US, even if these included the only one negative [24] and a pilot study [22]. On the contrary, these new data (apart from Italy [29,30]) include the whole world: Asia (Japan [38,42] and China [31]), Eastern Europe [33] and the US (but again a pilot study) [39].

Another aspect we considered, but which must be looked at carefully, is the result versus patient age and the duration of treatment (Figure 2). When applied at the start of puberty – when it is very well known that the rapidity of progression is greater than later in the patient's growth – PEs seem able to halt or at least reduce the negative evolution. In older ages, even with very significant curvatures, the results are positive. Some papers show dramatic reductions made within very short periods of time but should be regarded with caution because they are mainly pilot studies. Another point to consider carefully is that Figure 2 reports the average results in the average patients in the average time of treatment: Variability is not taken in account, while it is better illustrated in Figure 1. Moreover, the papers with the largest numbers of patients have results of stability of the curves ($\pm 5^{\circ}$) (Figure 3). Again, this seems to point to the attention given the quality of the studies, because the size of the sample is a key factor.

In this review it was possible to divide the exercises according to the different application (methods) proposed by the authors. Sub-grouping in systematic reviews should always be made with caution, even if it is a big temptation for clinicians. It can be stated that the only negative paper is clinically the most stable in many respects; the intrinsic autocorrection samples generally looked at younger patients with lower degrees of curvature than the extrinsic autocorrection ones. Moreover, asymmetric exercises did show positive results, and a real conclusion regarding the possible different methods is very difficult to reach with the actual state of research.

Conclusions

The clinical conclusion is that exercises can be recommended according to level-1b evidence with the aim of reducing scoliosis progression. At the actual stage it is not possible to state anything regarding the types of exercises to be proposed nor in regard to the kind of autocorrection to be performed. A patient of younger age could expect an average

degree of stability even if a great variability should be accepted, as well as in the latter stage of puberty and the first stages of adulthood, when on average reductions can presumably be achieved.

The research conclusion is that solid data coming from RCTs and long-term observational studies will be required. Moreover, it is necessary to make a comparison between different techniques or, even better, to use a common language in overcoming the concept of 'techniques' and arrive at that of 'aims of treatment' and 'kind of exercises.' No data exists regarding exercises when braces are used (only one paper discusses exercises as a means to prepare for bracing), and again this is important. Finally, for the future we strongly suggest the use of a primary outcome such as 'brace prescription' together with the secondary outcomes 'Cobb degrees' and 'progression.' Along the same line, the evaluation of QOL (Quality of Life) during treatment should be done [46,48,49].

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