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SYSTEMATIC REVIEW

Effects of the Schroth exercise on idiopathic scoliosis: a meta-analysis

Joo-Hee PARK [1], Hye-Seon JEON [2] *, Ha-Won PARK [3]

[1]Department of Physical Therapy, Graduate School, Yonsei University, Wonju, South Korea; [2]Department of Physical Therapy, College of Health Science, Yonsei University, Wonju, South Korea; [3]Department of Rehabilitation Medicine, Seoul National University, Bundang Hospital, Seongnam, South Korea

*Corresponding author: Hye-Seon Jeon, Department of Physical Therapy, Graduate School, Yonsei University, 1 Yonseidae-gil, Wonju, South Korea.
E-mail: hyeseonj@yonsei.ac.kr

ABSTRACT

INTRODUCTION: The purpose of this study was to examine the effects of the Schroth exercise on idiopathic scoliosis. The overall effect size was analyzed in 15 primary studies and a subgroup analysis of the standardized mean differences of effect sizes from 15 primary studies was also conducted.
EVIDENCE ACQUISITION: We used PUBMED, MEDLINE, NDSL, EMBASE, and Web of Science. The key terms used in these searches were "Schroth," "scoliosis-specific exercise," "scoliosis," and "idiopathic scoliosis."
EVIDENCE SYNTHESIS: Cobb's angle, asymmetry, angle of trunk rotation (ATR), strength of back extensor, strength of trunk flexor, quality of life (QOL), balance, chest expansion, and pulmonary function were coded as outcome measures for computing effect sizes. Potential moderating variables of the Schroth exercise included: 1) pre-intervention severity of the scoliosis; 2) duration; and 3) specific types of Schroth exercise.
CONCLUSIONS: The overall effect size of the Schroth exercise is high (g=0.724). In addition, Schroth exercise may be more beneficial for scoliosis patients who have a 10 to 30° Cobb's angle than for those with a greater than 30° Cobb's angle. Patients should practice the exercise for at least one month to have a better effect. Thus, therapists should consider patients' initial curve status and exercise duration before prescribing the Schroth exercise program. Core muscle strength was most influenced, and structural deformity also changed after the Schroth exercise. In sum, the Schroth exercise is a recommended treatment method for scoliosis patients.

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KEY WORDS: Meta-analysis - Exercise - Scoliosis.

Introduction

Various surgical (instrumentation and fusion) and nonsurgical (exercise and brace) interventions have been implemented to improve symptoms of idiopathic scoliosis.[1-3] Physiotherapeutic scoliosis-specific exercises (PSSE) are one of the currently promoted non-surgical treatments for scoliosis.[1, 4-6] PSSE is a curve specific, individualized physical rehabilitation exercise program that varies according to an individual's scoliosis curve characteristics determined by medical and/or physiotherapeutic evaluations. Previous studies revealed that the effectiveness of PSSE was superior to general exercise, such as yoga, Pilates, and routine physiotherapy, because PSSE is an individualized exercise program based on findings from a thorough medical and physical evaluation.[4, 7] The scientific exercise approach to scoliosis (SEAS), Schroth Method, Barcelona scoliosis physical therapy (BSPT), Dobomed, Side shift, Functional individual therapy for scoliosis and the Lyon approach can all be considered PSSE-based approaches.[1]

Since the Schroth method was first developed by a German, Katharina Schroth, in the 1920's, it has been widely used.[8] This method focuses primarily on the three-dimensional scoliotic curve pattern, a combination of lateral, frontal, and rotational deviations. The individualized treatment program is designed to shift an individual's specific spinal curve toward a normal pattern.[9, 10] Correction of the

curve pattern is achieved through combinations of stretching, strengthening, and breathing in reverse directions of all existing abnormal curvatures, based upon a patient's unique spinal deformation.[1, 11] In order to enhance body awareness and facilitate self-postural corrections, mental imagery, external stimuli, and mirror control are also employed in this method.[11, 12] Each patient learns about her or his own body and what she/he has to do in order to reverse and control abnormal posture so that improved posture becomes a habit. Furthermore, the Schroth method encourages patients to consciously maintain the proper posture learned during the therapeutic exercise periods in routine daily living.

Previous review articles [5, 6] reported that a majority of scoliosis studies were conducted by surgeons and the interest in scoliosis treatment was primarily focused on the effects of surgical approaches. Thus, there was insufficient evidence regarding non-surgical methods, and the quality of the few published studies was low.[1] However, unlike previous studies, more recent studies (published in or after 2012) were well-designed and used objective outcome measures, such as Cobb's angle, questionnaires, special instruments, and function tests. Among the 20 published Schroth studies,[8, 13-31] 15 studies were published in 2012 or later.[8, 13, 14, 16-23, 25-27] A previous systemic review article [32] published in 2011 reported that Schroth exercise was effective for treating scoliosis. However, this review article did not contain studies published in 2012 or thereafter. Therefore, it is necessary to verify the effect of Schroth exercises on idiopathic scoliosis patients based on recently published studies.

This meta-analysis aimed to examine: 1) the efficacy of the Schroth exercise method for idiopathic scoliosis patients by calculating the overall effect size to draw more evidence-based conclusions; 2) which outcome of Schroth exercise was the most effective; 3) whether the effectiveness of Schroth exercise was moderated by the intervention, by the severity of the pre-intervention scoliotic curve, types of Schroth exercise, and intervention duration using subgroup analysis.

Evidence acquisition

Search strategy and inclusion criteria

To identify relevant literature that were screened, then full papers were reviewed to examine whether each study met the following criteria: 1) experimental studies using Schroth exercises; 2) included subjects with a minimum Cobb's angle greater than 10 degrees; 3) provided sufficient information to compute effect sizes; 4) written in English or Korean; 4) pre-post study design; and 5) included only non-surgical idiopathic scoliosis treatments.

Initially, 287 studies were extracted by searching the databases; 134 studies were duplicates and 111 studies did not meet the inclusion criteria after screening title and abstract. Of the remaining 42 studies, 27 studies were excluded when the full text articles were reviewed. Thus, 15 studies were included in this meta-analysis (Table I).[8, 14-27] A flow chart for inclusion (Figure 1) indicates the number of studies excluded and the reasons for exclusion.

Coding of studies

Data were extracted from the included studies. First, all studies were grouped by age (10-19 years old, or ≥20 years old) and gender (male and female or female only) to compare the effectiveness of Schroth exercise according to those characteristics. Second, we compared effect sizes according to study design (with or without a control group) to determine if study design influenced effect size or not. Third, Cobb's angle, asymmetry, angle of trunk rotation (ATR), strength of back extensor, strength of trunk flexor, quality of life (QOL), balance, chest expansion, and pulmonary function were coded as outcomes of Schroth exer-

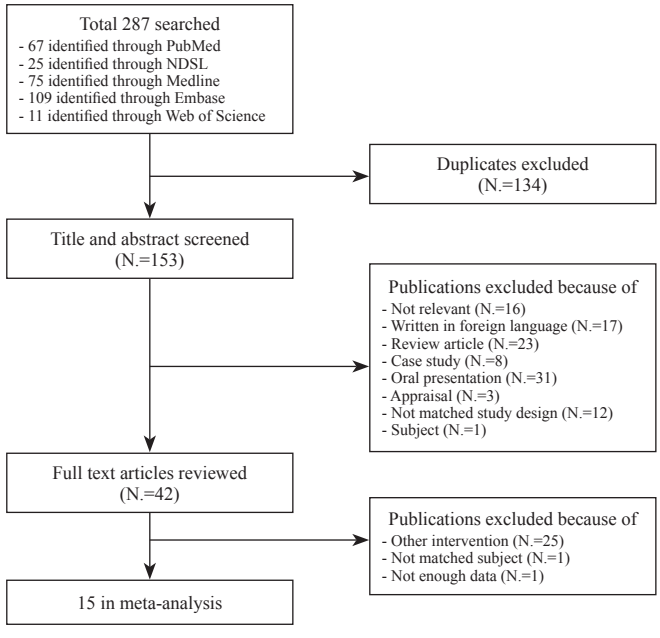


Figure 1.—Flow chart of the study.

TABLE I.—*Characteristics of studies included in the analysis.*[8, 14-27]

Study	ES	N. (C/E)	Program type	Outcome type	Cobb's angle	Age	Exercise time per day	Duration	Published
Borysov (2016) [17]	0.701	23	Schroth best practice	ATR	20-88°	10-18	2 h	1 month	Published
Hwangbo (2015) [18]	0.730	36 (18/18)	Schroth exercise *vs.* Pilates exercise	Cobb's angle ATR Pulmonary function Asymmetry Quality of life Foot balance (weight distribution: concave)	≥20°	E: 15.14±1.70 C: 14.38±1.75	1 h	12 weeks	No
Jung (2014) [14]	0.734	20	Schroth exercise	Cobb's angle Balance (left-right variance) Foot balance (foot pressure)	10-40°	21.6±1.9	2 h	12 weeks	Published
Kim (2015) [19]	1.092	30	Schroth exercise *vs.* Ball&sling	Cobb's angle Trunk flexor strength Balance Flexibility	10-30°	13-18	90 min	8 weeks	Yes
Kong (2014) [20]	0.376	36	Schroth exercise *vs.* Asymmetric scoliosis exercise group	Cobb's angle Asymmetry (right/left trunk muscle volume) Back extensor strength	10-20°	17-21	1 h	3 months	No
Kuru (2015) [21]	0.581	30 (15/15)	Schroth 3D exercise treatment *vs.* Control (no treatment)	Cobb's angle ATR Asymmetry Quality of life	10-60°	10-18	90 min	6 weeks 3 months 6 months	Yes
Lee (2013) [15]	0.138	10	Schroth 3D exercise	Cobb's angle ATR Foot pressure	≥10°	14.5±1.6	1 h	8 weeks	Yes
Lee (2014) [22]	0.264	16 (8/8)	Schroth exercise *vs.* Sling exercise	Cobb's angle Chest expansion Balance (one leg standing) ATR	10-40°	N/A	1 h	8 weeks	Yes
Lee (2015) [16]	0.370	35	Schroth exercise	Cobb's angle Asymmetry (hip internal rotation)	≥10°	18.07±5.85	2 h	12 weeks	Yes
Moramarco (2016) [23]	0.420	36	Schroth best practice	Cobb's angle ATR Chest expansion Pulmonary function	10-50°	10-19	3-4 h	5-7 days	Yes
Otman (2005) [24]	1.844	50	Schroth 3D exercise treatment	Cobb's angle Vital capacity Muscle strength (trunk flexor, back extensor) Quality of life	20-35°	11-17	4 h	6 weeks 6 months 1 year	Yes
Park (2012) [25]	0.291	20 (10/10)	Schroth 3D exercise treatment *vs.* Corrected exercise program	Cobb's angle Pulmonary function Chest expansion	10-30°	>20	1 h	8 weeks	No
Park (2014) [26]	0.530	40 (20/20)	Schroth exercise *vs.* Conventional scoliosis exercise	Cobb's angle ATR Vital capacity Chest expansion Back extensor strength	≥10°	E: 15.50±1.79 C: 16.65±1.66	1 h	8 weeks	Yes
Pugacheva (2012) [27]	2.286	21	Schroth best practice	Asymmetry (lateral asymmetry angle)	28-50°	13-15	3-4 h	6 months	Yes
Schreiber (2015) [8]	1.167	50 (25/25)	Schroth exercise *vs.* Standard care	Quality of life Back extensor strength	10-45°	10-18	1 h	3 months 6 months	Yes

N. (C/E): number of subjects in the control and experimental groups; ATR: angle of trunk rotation.

cise in order to compute effect sizes. For moderator analysis, categorical moderators included: 1) pre-intervention scoliosis severity (whole range, 10-30°, 30 - 50°, and >50° Cobb's angle); 2) duration of the Schroth exercise intervention (under 1 week, 1-3 months, 3-6 months, 6 months to 1 year, and >1 year); and 3) specific types of Schroth exercise studied (Schroth best practice, Schroth 3D treatment, Schroth general). Two physical therapists individually coded all the characteristics of the selected studies for this meta-analysis. All differences between the two coders were resolved by discussion prior to data analysis. Supplementary Tables I-II (online content only) illustrate all data from the 15 studies included.[8, 14-27]

Statistical analysis

All statistical analyses were conducted using Comprehensive Meta-analysis (CMA) software v. 2 (Biostat, Englewood, NJ, USA).

Calculating effect sizes

The Schroth exercise effect was measured using the standardized mean difference (*d*) with/without control groups.[33] The formula to estimate *d* is in the Supplementary material. *d* was calculated for each study, with positive *d* indicating better therapeutic effects seen post-test compared to pre-test. The pooled *d* was computed by averaging the available effect sizes across all individual outcomes of Schroth exercise in each study. According to Hedges and Olkin,[34] *d* has a slight bias in estimating the population effect size, especially in small samples. Therefore, *d* was converted into Hedge's *g* using the following formula:

$$g = (1 - \frac{a}{4df - 1}) \times d$$

Homogeneity

In this study, we first examined the homogeneity among studies by checking the width of confidence intervals, statistical significance of the Q-statistic (Figure 2), and the I^2 index to estimate the variation in effect sizes across studies. For this meta-analysis, a random model was used for the main effect and subgroup analyses, because the result of the homogeneity test was statistically significant (Q=41.10, *df*=10, P=0.00), and the I^2 index was greater than 75% (I^2=75.671).

Subgroup analyses

Among the 15 studies analyzed, we coded 69 effect sizes to compute subgroup analyses. Subgroup analysis was conducted for categorical moderators; Cobb's angle range

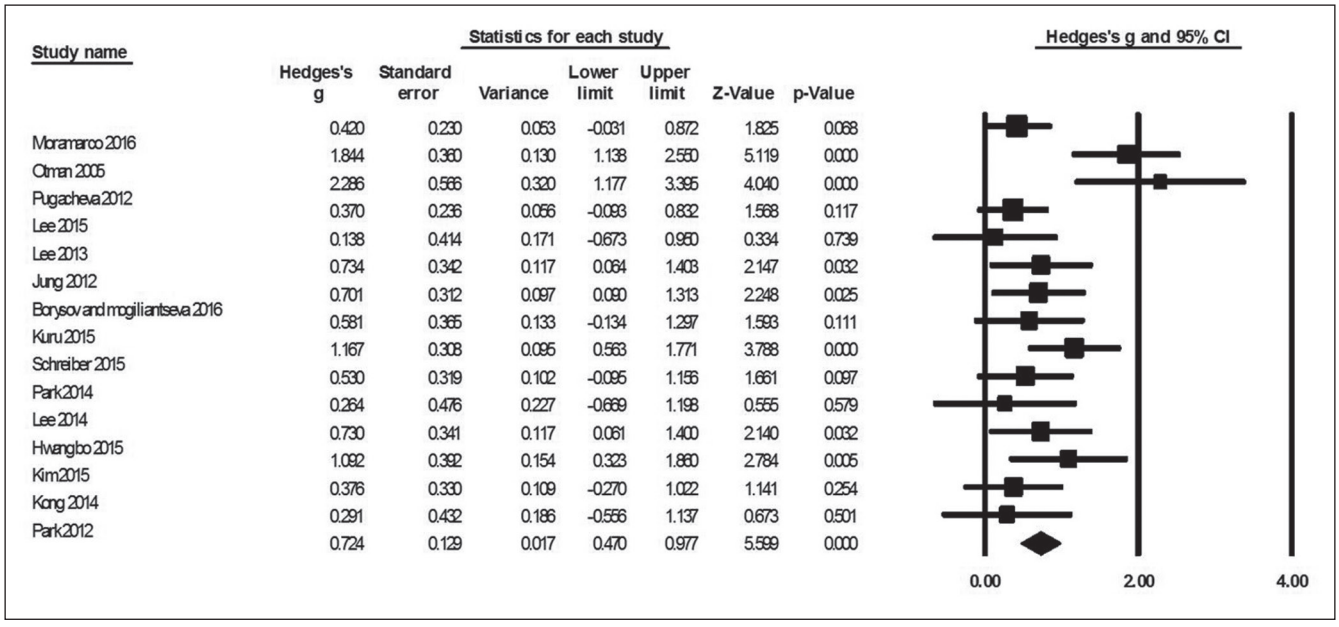


Figure 2.—Forest plot the the 15 included studies.

(whole range *versus* 10-30° *versus* 30-50° *versus* over 50°), treatment duration (under 1 week *versus* 1-3 months *versus* 3-6 months *versus* 6-12 months *versus* over 1 year), and specific types of Schroth exercise (Schroth best practice *versus* 3D treatment versus general).

In general, each primary study in a meta-analysis is assumed to be independent, and using multiple effect sizes from one study can violate this assumption. However, Cooper [35] suggested "shifting units of analysis," such that a study represents a unit of analysis when pooled effect sizes are estimated, and effect sizes represent a unit of analysis when a subgroup analysis is conducted. Thus, even though using multiple effect sizes in one study can violate the assumption of independence, we decided to use effect size as a unit of analysis, while subgroup analyses were conducted to prevent loss of beneficial information.[36]

Evidence synthesis

This synthesis provided 69 standardized mean difference effect sizes from 15 primary studies, with an average of 4.6 effect sizes per study. Supplementary Table III (online content only) shows the type of design and study quality of the 15 studies.[8, 14-27]

There was no missing data in Trim and Fill methods and Egger's regression intercept test was not significant (P=0.17). Thus, publication bias does not appear to affect the studies on Schroth exercise effects.

Overall effect size is calculated by many outcomes included in 15 studies. Under a random effects model, the overall effect size of Schroth exercise treatment was 0.724 (Figure 2). According to Cohen's guideline,[37] Schroth exercises have a medium effect (small effect ≥0.20, medium effect ≥0.50, large effect ≥0.80), however, 0.724 was almost 0.80. Thus, Schroth exercises have a large effect on idiopathic scoliosis patients.

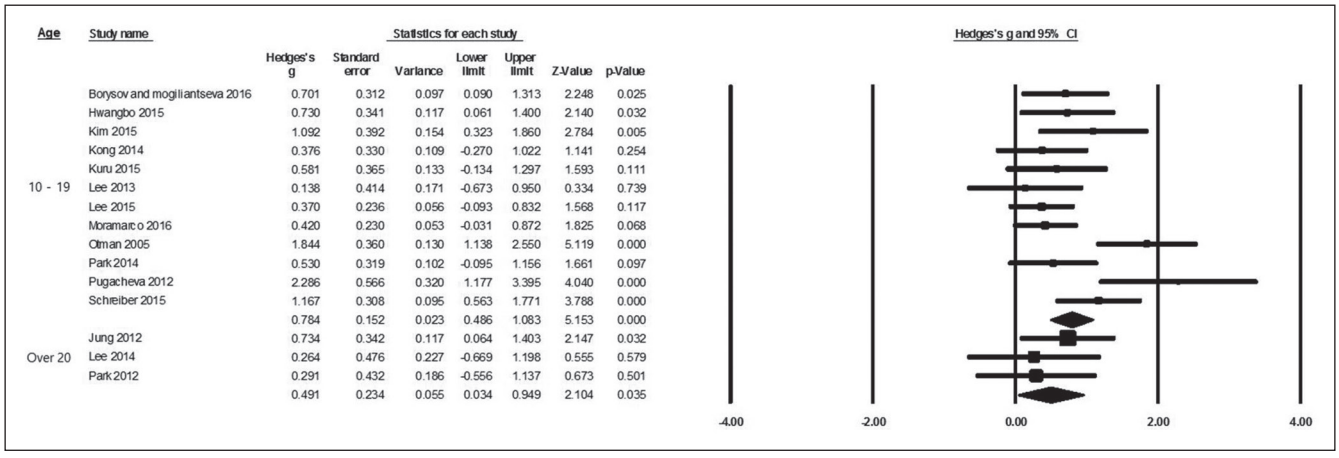
The effect of age, gender, and study design on Schroth exercise is shown in Figures 3 to 5. Twelve of 15 studies recruited adolescent subjects and 3 studies recruited adult subjects. The effect size for the adolescent subjects group (g=0.784) was higher than that for the adult subjects group (g=0.491), but there was no significant difference between age groups (Q=1.10, P=0.29).

Among the 15 included studies, 12 studies recruited subjects from both genders and the remaining studies recruited only female subjects. No significant difference was found between gender groups (Q=0.44, P=0.50), and pooled effect size for both male and female groups was 0.678, and the female only studies pooled effect size was 1.031.

Seven studies were conducted without a control group, and 8 studies utilized a control group. There was no significant difference between study designs.

The result of a random-effects categorical analysis by outcome (Table II) revealed that Schroth exercise influenced the outcome variables differently. In particular, the effect sizes of strength and chest expansion were large, the effect size of Cobb's angle, asymmetry, ATR, QOL, balance, vital capacity, and foot pressure were medium, and the effect size of pulmonary function was small.

Subgroup analyses were conducted according to the following categories: initial Cobb's angle range, treatment duration, and specific types of Schroth exercise (Table III).



Age	Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Borysov and mogilliantseva 2016	0.701	0.312	0.097	0.090	1.313	2.248	0.025
	Hwangbo 2015	0.730	0.341	0.117	0.061	1.400	2.140	0.032
	Kim 2015	1.092	0.392	0.154	0.323	1.860	2.784	0.005
	Kong 2014	0.376	0.330	0.109	-0.270	1.022	1.141	0.254
	Kuru 2015	0.581	0.365	0.133	-0.134	1.297	1.593	0.111
10 - 19	Lee 2013	0.138	0.414	0.171	-0.673	0.950	0.334	0.739
	Lee 2015	0.370	0.236	0.056	-0.093	0.832	1.568	0.117
	Moramarco 2016	0.420	0.230	0.053	-0.031	0.872	1.825	0.068
	Otman 2005	1.844	0.360	0.130	1.138	2.550	5.119	0.000
	Park 2014	0.530	0.319	0.102	-0.095	1.156	1.661	0.097
	Pugacheva 2012	2.286	0.566	0.320	1.177	3.395	4.040	0.000
	Schreiber 2015	1.167	0.308	0.095	0.563	1.771	3.788	0.000
		0.784	0.152	0.023	0.486	1.083	5.153	0.000
	Jung 2012	0.734	0.342	0.117	0.064	1.403	2.147	0.032
Over 20	Lee 2014	0.264	0.476	0.227	-0.669	1.198	0.555	0.579
	Park 2012	0.291	0.432	0.186	-0.556	1.137	0.673	0.501
		0.491	0.234	0.055	0.034	0.949	2.104	0.035

Figure 3.—Effect size grouped by age (10-19 years and ≥20 years).

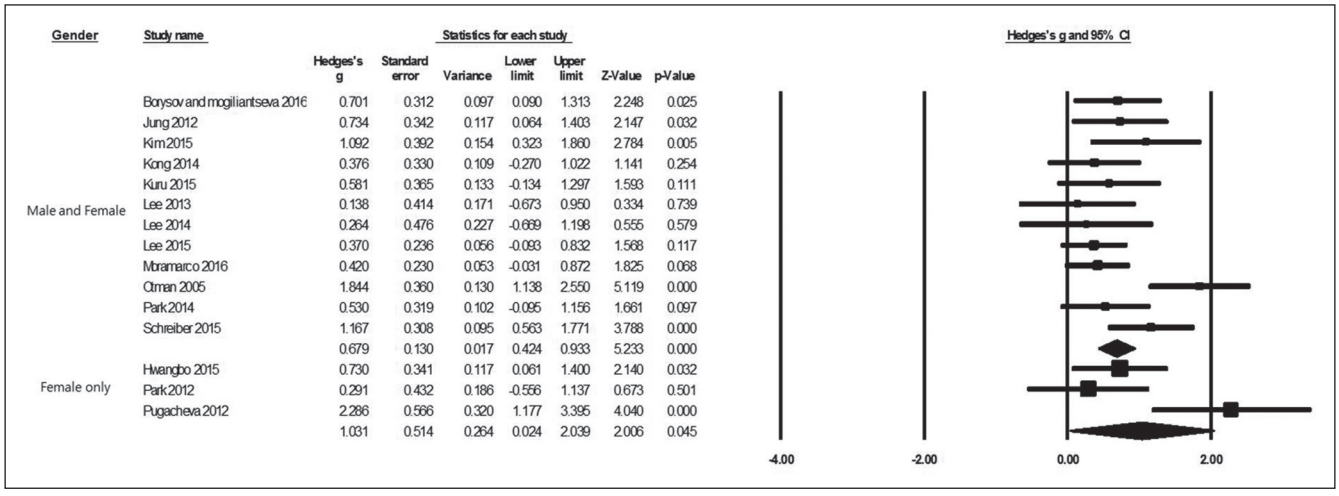


Figure 4.—Effect size grouped by gender (male and female, and female only).

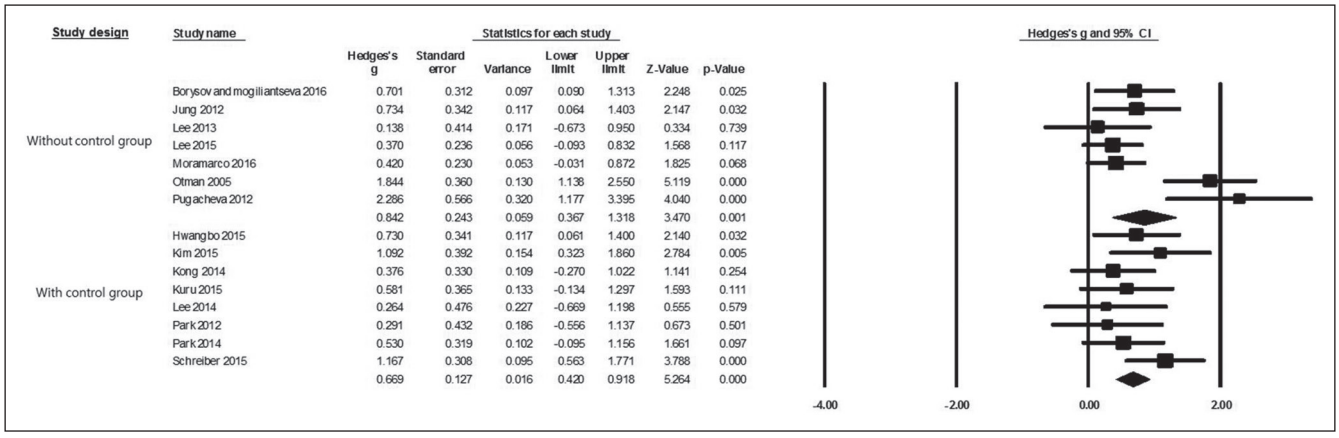


Figure 5.—Effect size grouped by study design (without and with control group).

Initial Cobb's angle range

Cobb's angle is the most frequently used value to quantify spinal deformities, especially to represent or diagnose the severity of scoliotic curves. To measure Cobb's angle, the angle between a line parallel to the superior endplate of the most tilted vertebra at the top of the curve and a line parallel to the inferior endplate of the most tilted vertebra at the bottom of the curve is calculated. Scoliosis is clinically diagnosed when the Cobb's angle is greater than 10°.

We divided effect sizes into four categories according to the pre-intervention Cobb's angle range:[38] 10-30°, 30-50°, above 50°, and whole range. When specific ranges of pre-

TABLE II.—*Effect sizes by outcome.*

Outcomes	κ	ES	95% CI	SE
Cobb's angle	11	0.65	0.32 to 0.99	0.16
Asymmetry	4	0.70	0.38 to 1.37	0.34
Angle of trunk rotation	7	0.53	0.26 to 0.80	0.13
Strength of back extensor	4	1.17	0.19 to 2.15	0.50
Strength of trunk flexor	2	1.69	-0.21 to 3.60	0.97
Quality of life	3	0.76	0.39 to 1.14	0.19
Balance	3	0.63	0.16 to 1.09	0.23
Chest expansion	4	0.84	0.42 to 1.25	0.20
Vital capacity	3	0.62	0.19 to 1.04	0.21
Pulmonary function	3	0.13	-0.31 to 0.53	0.04
Foot pressure	3	0.65	0.06 to 1.24	0.09

κ: number of effect sizes; ES: effect size; CI: confidence interval; SE: standard error.

TABLE III.—*Effect sizes by subgroup: pre-intervention Cobb's angle, duration, and type of Schroth exercise.*

Subgroup	Categories	κ	ES	95% CI		SE	$Q_{between}$	Inter-study variance
Pre-intervention Cobb's angle	Whole range	29	0.59	0.41	0.76	0.08	15.71	0.00*
	10-30°	27	1.07	0.76	1.38	0.15		
	30-50°	10	0.67	0.32	1.03	0.18		
	> 50°	3	0.59	0.07	1.12	0.26		
Treatment duration	<1 week	9	0.38	0.14	0.62	0.12	77.93	0.00*
	1-3 months	26	0.57	0.37	0.77	0.01		
	3-6 months	20	0.62	0.44	0.80	0.09		
	6 months - 1 year	10	1.35	0.87	1.83	0.24		
	>1 year	4	2.58	1.23	3.92	0.68		
Types of Schroth exercise	Schroth best practice	11	0.53	0.22	0.84	0.15	5.43	0.00*
	Schroth 3D treatment	28	1.01	0.71	1.30	0.15		
	Schroth general	30	0.66	0.47	0.84	0.09		

κ: number of effect sizes; ES: effect size; CI: confidence interval; SE: standard error; Q test: homogeneity statistics; NA: not answered.
*P<0.05.

intervention Cobb's angles were not clearly reported by the author, the effect sizes were classified as whole range (10-88°) (Table I). The homogeneity revealed significant differences between categories of initial Cobb's angle ($Q_{between}$=15.71, P<0.05). Effect sizes tended to decrease as the pre-intervention Cobb's angle range increased. The effect size of patients with 10-30° pre-intervention Cobb's angle was large, however, the effect size of 30-50° and over 50° pre-intervention Cobb's angle were moderate.

Duration

A statistically significant difference was observed between the categories of treatment duration with $Q_{between}$=77.93 (P<0.05). Schroth exercise revealed a large effect when it was provided longer than 6 months; the greatest effect was found when the exercise continued beyond one year. However, under 1-week exercise had small effect size.

Specific types of Schroth exercise

In four among the 15 selected papers, the writers clarified specific types of Schroth Exercise protocol. Two applied Schroth 3D treatment and the other 2 applied Schroth best practice. Schroth 3D treatment includes breathing, hanging, mobilization, shaping, stretch & strengthening,[21, 24, 25] and Schroth best practice, the newly developed and intensive Schroth exercise protocol, includes a physiologic program, corrections of the ADL, 3D made easy exercise, and new power Schroth exercise.[13, 23, 27] Studies that did not mention any specific protocol were categorized as Schroth general. The effect size was significantly different between the types of exercise, with $Q_{between}$=5.43 (P<0.05) under a random-effects model. Schroth 3D treatment showed large effect sizes; Schroth general and Schroth best practice protocols had moderate effect sizes.

Discussion

Decreasing and preventing scoliotic spinal deformity is the major goal for surgeons and therapists who treat scoliosis patients. Thus, many clinicians and researchers have tried to find novel approaches to decrease spinal deformity and clarify the efficiency of these interventions. Recently, various exercise approaches have been introduced to improve spinal deformity from scoliosis, and several supportive research findings about PSSE on scoliosis patients have been published.[1, 2, 4, 6] However, evidence regarding the efficacy of these interventions is limited and there was no conclusive confirmation about the effects of Schroth exercise, a form of PSSE.[1, 6] Thus, in this study, we investigated the effect of Schroth exercise on scoliosis patients through a meta-analysis. We included 15 studies related to Schroth exercise, and found that the overall effect size was large (g=0.724). This result implied that the Schroth exercise is significantly effective among scoliosis patients.

Traditionally, Cobb's angle has been used as a clinical guideline for orthopedic surgeons and physical therapists in setting intervention goals and plans for clients with idiopathic scoliosis. North America Standard suggests that physicians wait and observe curve changes before starting active treatment for patients with a Cobb's angle of 10-25°; conservative treatments, such as a brace and exercise, are recommended for patients with a curve between 25° and 45°; a surgical correction is recommended for cases with a

Cobb's angle over 45°.[39] According to referral guidelines for patients with scoliosis, scoliosis patients with a Cobb's angle under 40° are encouraged to pursue non-surgical treatment, such as a brace, but patients with a Cobb's angle over 40° are encouraged to seek surgical treatment.[37] Even though slight differences exist between the two guidelines, it is suggested that patients with Cobb's angles under 40° adopt conservative treatment. We conducted subgroup analyses to examine whether the Schroth exercise influence varied by scoliosis severity. The effect size was very large for a 10° to 30° Cobb's angle; however, it was medium when the Cobb's angle was greater than 30°. Our study demonstrated that Schroth exercise, a conservative treatment, was more beneficial for patients presenting with a Cobb's angle less than 30° compared to those with a Cobb's angle greater than 30°. Other interventions such as surgery should be considered for more severe scoliosis cases with a Cobb's angle greater than 50°.

The duration of therapeutic exercise is a critical factor that influences the outcome of the intervention. Previous studies reported that rotator cuff surgery patients should perform at least 6 weeks of exercise to improve muscle activation and range of motion,[40] and a previous meta-analysis reported that body composition changed after 6 weeks of exercise.[41] Our results support previous studies which reported at least 1-3 months of continuous exercise was necessary to obtain the positive effects of exercise. The effect size became larger as the Schroth exercise duration increased. However, with 6 months as center, the effect size clearly showed less than 6 months exercise had a medium effect size, but over 6 months exercise had large effect size. The effect size decreased to 0.38 (a small effect) when the duration was shorter than a week. Based on the above results, to achieve positive changes with Schroth exercises, patients should be involved in a treatment program lasting at least 6 months.

Schroth best practice is a newly developed intensive program designed to promote self-correction of an individual's scoliotic curve.[13, 23, 27] According to Borysov and Mogiliantseva,[17] Schroth best practice is the most effective treatment method among PSSE treatments. Contrary to our expectations, the effect size of the Schroth 3D treatment program was relatively larger than that of the Schroth best practice program. Among 15 studies, eight studies investigated general Schroth exercise, four studies investigated Schroth 3D treatment, and three studies investigated Schroth best practice. All 4 Schroth 3D treatment studies [15, 21, 24, 25] had a greater than 6 months intervention period; however, only 1 Schroth best practice study investigated 6 months of Schroth treatment.[27] Two other studies investigated Schroth best practice treatment for 1 month [17] and under 1 week.[23] Thus, the present study's results suggest that no matter how fancy and well-designed a program is, exercise duration is the more important factor.

A scoliosis guideline published by the Scoliosis Research Society stated that "*alternative treatment to prevent curve progression […] such as chiropractic medicine, physical therapy, yoga, etc. have not demonstrated any scientific value in the treatment of scoliosis*." However, the effect sizes for Cobb's angle and asymmetry, which represent the structural status of scoliotic curves, were moderate. This suggested that Schroth exercise was effective at inducing changes in the scoliotic curve. The effect size of the trunk flexion strengthening was the largest among the outcome variables. In the Schroth approach, it is believed that core muscle training is a key element for achieving stability, such that in almost every posture of the Schroth method, core muscle activation is stressed. The effect size of QOL was also considered large, which suggests that improving curvature, strength, balance, and appearance may improve self-image, function, satisfaction, and pain, all of which are included in QOL. The effect size of pulmonary function was small because this exercise was primarily designed to improve structural asymmetries and chest expansion not increase pulmonary function or breathing.

Limitations of the study

There were several limitations in our study. First, a scoliosis treatment traditionally lasts at least 2-3 years. According to recommendations from SOSORT-SRS, the follow-up for scoliosis exercise treatment should be longer than 12 months at least. However, most of the included studies in this meta-analysis were relatively short-term compared to SOSORT-SRS's recommendation, and this might make our findings relatively weak. Further studies need to be carefully conducted and should include long-term follow-ups over 2-3 years. Second, additional well-structured higher-level studies are required for a more powerful conclusive meta-analysis in the future.

Conclusions

In this study, we attempted to clarify the effect of exercise therapy, specifically Schroth exercise, on scoliosis patients using a meta-analysis. The high overall effect size seen for

Schroth exercises provides evidence that Schroth exercise has a significant influence on idiopathic scoliosis patients. In addition, scoliosis patients who have 10° to 30° Cobb's angles may benefit more than those who have a greater than 30° Cobb's angle, and exercise should continue for longer than one month to have a better effect. Thus, therapists should consider patients' initial curve status and ability to maintain exercise longer than 6 months before prescribing the Schroth exercise program. Core muscle strength was most influenced, and structural deformity also changed after Schroth exercise regimens. This study is the first meta-analysis regarding the effect of therapeutic exercise on scoliosis patients, and provides the foundation for an evidence-based approach to Schroth exercise for scoliosis patients. In sum, Schroth exercise is a recommended treatment method for scoliosis patients.

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SUPPLEMENTARY MATERIALS

The standardized mean difference effect sizes (*d)* were computed from studies with/without control groups. The sample estimate of d is calculated using the following formula:

$$d = \frac{\bar{Y}_{diff}}{S_{within}} = \frac{\bar{Y}_1 - \bar{Y}_2}{S_{within}} \quad .$$

$\bar{Y}_1$ and $\bar{Y}_2$ are the posttest and pretest means of participants' outcomes, respectively. The formula for calculating S_{within}, the within group standard deviation, is:

$$S_{within} = \frac{S_{diff}}{\sqrt{2(1-r)}} \quad .$$

S_{diff} was used to compute *d* from the standard deviation, where:

$$S_{diff} = \sqrt{S_1^2 - S_2^2} - 2 \times r \times S_1 \times S_2$$

where *r* estimates the pretest-posttest correlation for Schroth exercise. Because there is no primary study that reported pretest and posttest correlations, we used r=0.5 to calculate S_{diff}. Where n is the number of subjects, the variance of *d* is:

$$V_d = \frac{1}{n} + \frac{d^2}{2n} \times 2(1-r) \quad .$$

The standard error (SE) of *d* is:

$$SE_d = \sqrt{V_d} \quad .$$

SUPPLEMENTARY TABLE I.—*Data of pre/post design studies without control group.*

Study	Outcome	Pre data	Post data	N.	Cobb's angle	Duration
Moramarco (2016) [23]	Anterior trunk flexion (°)	11±5.45[b]	8.55±5.19	3	10-30°	<1 week
		9.95±4.44	7.66±4.31	24	30-50°	<1 week
		11±5.45	8.55±5.19	9	>50°	<1 week
	Chest expansion (cm)	8.16±0.76	9.63±1.00	3	10-30°	<1 week
		7.62±1.19	11.49±12.54	24	30-50°	<1 week
		6.94±0.86	8.03±0.99	9	>50°	<1 week
	Pulmonary function (L)	32.12±8.88	33.14±7.71	3	10-30°	<1 week
		27.21±8.55	28.20±8.37	24	30-50°	<1 week
		24.68±4.37	25.56±4.25	9	>50°	<1 week
Otman (2005) [24]	Cobb's angle (°)	26.1±4.69	23.45±5.09	50	10-30°	1-3 months
		26.1±4.69	19.23±3.86	50	10-30°	6 months - 1 year
		26.1±4.69	17.85±3.58	50	10-30°	>1 year
	Vital capacity (L)	2.79±0.40	2.95±0.42	50	10-30°	1-3 months
		2.79±0.40	3.12±0.41	50	10-30°	6 months - 1 year
		2.79±0.40	3.21±0.42	50	10-30°	>1 year
	Strength of trunk flexor (score)	3.63±0.54	4.35±0.42	50	10-30°	1-3 months
		3.63±0.54	4.93±0.18	50	10-30°	6 months - 1 year
		3.63±0.54	5±0	50	10-30°	>1 year
	Strength of back extensor (score)	3.10±0.58	3.53±0.41	50	10-30°	1-3 months
		3.10±0.58	4.43±0.35	50	10-30°	6 months - 1 year
		3.10±0.58	4.93±0	50	10-30°	>1 year
Pugacheva (2012) [27]	Asymmetry (°)	30±5.1	18±5	21	30-50°	1-3 months
Lee (2015) [16]	Asymmetry (°)	31.94±9.43	35.46±7.46	35	Whole range	3-6 months
	Cobb's angle (°)	32.17±14.45	27±15.7	35	Whole range	3-6 months
Lee (2013) [15]	Cobb's angle (°)	16.45 ±5.14	14.65±5.38	10	Whole range	1-3 months
	ATR (°)	8.35±1.48	7.65±1.45	10	Whole range	1-3 months
	Foot pressure (%)	4.25±6.74	2.38±2.42	10	Whole range	1-3 months
Jung (2012) [14]	Cobb's angle (°)	25.1±8	18.6±7.64	20	10-30°	3-6 months
	Balance (score)	3.49±0.35	3.07±0.42	20	10-30°	3-6 months
	Foot pressure (score)	8.88±4.4	10.42±3.58	20	10-30°	3-6 months
Borysov (2016) [17]	Cobb's angle (°)	9.52±3.06	7.33±2.97	23	10-30°	1-3 months

Data presented as mean±SD.

SUPPLEMENTARY TABLE II.—*Data of pre-post design studies with control group.*

Study	Outcome	Experimental group			Control group			Cobb's angle	Duration
		Pre	Post	N.	Pre	Post)	N.		
Kuru (2015) [21]	Cobb's angle	33.4±8.9°	32±8.78°	15	30.3±6.6°	32±7.59°	15	Whole range	6 months - 1 year
	ATR	11.9±5.2°	7.4±4.65°	15	8.4±2.9°	9.16±2.96°	15	Whole range	1-3 months
		11.9±5.2°	7.6±5.03°	15	8.4±2.9°	9.8±3.2°	15	Whole range	3-6 months
		11.9±5.2°	7.66±5.24°	15	8.4±2.9°	10.5±4.24°	15	Whole range	6 months - 1 year
	Asymmetry, cm	2.18±0.95	1.81±0.84	15	1.54 ±0.95	1.57 ±0.92	15	Whole range	1-3 months
		2.18±0.95	1.62±0.65	15	1.54 ±0.95	1.7±0.98	15	Whole range	3-6 months
		2.18±0.95	1.42±0.58	15	1.54 ±0.95	1.72±0.97	15	Whole range	6 months - 1 year
	QOL score	3.9±0.6	4.2±0.6	15	4.1±0.4	4.2±0.4	15	Whole range	1-3 months
		3.9±0.6	4.3±0.6	15	4.1±0.4	4±0.4	15	Whole range	3-6 months
		3.9±0.6	4.4±0.6	15	4.1±0.4	4.1±0.4	15	Whole range	6 months - 1 year
Schreiber (2015) [8]	QOL score	4.25±0.07	4.29±0.07	25	4.15±0.07	4.18±0.07	25	Whole range	3-6 months
		4.25±0.07	4.4±0.07	25	4.15±0.07	4.15±0.07	25	Whole range	6 months - 1 year
	Strength of back extensor, second	117.38±12.19	149.63±12.4	25	120.96±12.3	125.77±12.97	25	Whole range	3-6 months
		117.38±12.19	154.1±12.58	25	120.96±12.3	113.09±12.83	25	Whole range	6 months - 1 year
Park (2014) [26]	Cobb's angle	24.7±11.85°	19.9±14.33°	20	19.35±10.37°	18.85±11.56°	20	Whole range	1-3 months
	ATR	9.1±3.76°	7.55±4.26°	20	7.5±3.54°	7.1±3.9°	20	Whole range	1-3 months
	Vital capacity, L	1.94±0.28	2.46±0.43	20	2.26±0.34	2.3±0.37	20	Whole range	1-3 months
	Chest expansion, cm	4.18±0.87	5.99±0.61	20	5.28±0.68	5.93±0.69	20	Whole range	1-3 months
	Back extensor, %MVC	40.32±20.25	35.78±16.82	20	43.69±17.91	42.53±20.18	20	Whole range	1-3 months
Lee (2014) [22]	Cobb's angle	19.52±9.31°	13.95±8.73°	8	16.88±18.4°	50.25±44.15°	8	Whole range	1-3 months
	ATR	4.03±18.32°	5.79±17.89°	8	2.5±16.28°	5.74±15.38°	8	Whole range	1-3 months
	Balance, second	5.45±1.75	9.02±1.84	8	3.66±1.67	5.69±2.09	8	Whole range	1-3 months
	Chest expansion, cm	16.22±16.44	41.31±26.66	8	16.88±18.4	50.25±44.15	8	Whole range	1-3 months
Hwangbo (2015) [18]	Cobb's angle	35.07±6.81°	22.27±6.14°	18	33.2±3.65°	28.73±3.22°	18	30-50°	3-6 months
	ATR	10.95±2.31°	5.1±1.12°	18	9.98±1.9°	6.18±1.04°	18	30-50°	3-6 months
	Vital capacity, L	2.83±1.23	4.04±1.67	18	2.92±1.69	3.82±1.85	18	30-50°	3-6 months
	Pulmonary function, L	2.05±0.5	2.26±0.5	18	2.05±0.6	2.19±0.47	18	30-50°	3-6 months
	QOL score	24.73±3.17	13.93±1.39	18	23.73±2.09	15.6±1.18	18	30-50°	3-6 months
	Foot pressure, %	43.21±2.09	47.26±1.65	18	44.51±1.65	45.29±1.94	18	30-50°	3-6 months
Kim (2015) [19]	Cobb's angle	18.01±1.11°	12.96±1.9°	15	14.99±0.95°	13.88±1.29°	15	10-30°	1-3 months
	Strength of trunk flexor score	13.73±1.92	18.8±1.73	15	15.6±1.64	18.87±1.64	15	10-30°	1-3 months
	Balance, second	5.87±0.98	15.48±3.43	15	9.18±1.9	20.43±2.09	15	10-30°	1-3 months
Kong (2014) [20]	Cobb's angle	12.05±2.41°	8.48±1.95°	18	11.89±2.78°	9.71±2.11°	18	17-21	3-6 months
	Strength of back extensor, %MVC	65.7±18.52	72.78±17.16	18	60.67±11.9	80.56±15.82	18	17-21	3-6 months
	Asymmetry, %	23.34±4.55	23.58±4.64	18	23.24±4.78	24.38±4.23	18	17-21	3-6 months
Park (2012) [25]	Cobb's angle	24.6±4.07°	20.7±4.07°	10	27.5±5.64°	24.9±5.32°	10	>20	1-3 months
	Chest expansion, cm	30.6±7.65	35.8±9.93	10	27±3.8	30.9±4.2	10	>20	1-3 months
	Pulmonary function, L	4.3±1.25	6.3±1.49	10	4.4±1.35	5.3±1.42	10	>20	1-3 months

Data presented as mean±SD.
ATR: anterior trunk flexion; QOL: quality of life, MVC: maximum voluntary contraction.

SUPPLEMENTARY TABLE III.—*Study quality assessment.*

Study	Reporting										External validity				Internal validity - bias						Internal validity - selection bias						Power		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Kuru (2015) [21]	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	U	Y	U	U	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	N	22	88	
Moramarco (2016) [23]	Y	Y	Y	Y	N	Y	Y	N	N	Y	U	U	Y	N	N	Y	N	Y	U	Y	N	Y	N	N	N	N	12	48	
Otman (2005) [24]	Y	Y	Y	Y	Y	Y	Y	N	N	N	Y	U	U	N	N	Y	N	Y	U	Y	N	Y	N	N	N	N	13	52	
Pugacheva (2012) [27]	Y	Y	Y	Y	N	Y	Y	N	N	N	U	U	U	N	N	U	N	N	U	Y	N	U	N	N	N	N	7	28	
Schreiber (2015) [8]	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	U	Y	N	Y	Y	N	Y	Y	Y	Y	U	Y	N	Y	Y	Y	22	88	
Kong (2014) [20]	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	U	U	U	U	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	N	19	76	
Kim (2015) [19]	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	U	U	U	U	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	N	19	76	
Park (2014) [26]	Y	Y	Y	Y	P	Y	Y	N	N	N	Y	U	U	U	U	Y	Y	Y	U	Y	Y	U	U	N	Y	N	N	14	56	
Park (2012) [25]	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	U	Y	U	U	Y	Y	Y	Y	Y	Y	Y	U	N	Y	N	N	19	76	
Lee (2014) [22]	Y	Y	Y	Y	N	Y	Y	N	N	Y	Y	U	U	U	U	Y	Y	Y	Y	Y	Y	U	Y	N	U	N	N	15	60	
Hwangbo (2015) [18]	Y	Y	Y	Y	Y	Y	Y	N	N	N	Y	U	U	U	U	Y	Y	Y	Y	Y	N	Y	Y	N	Y	N	N	17	68	
Lee (2015) [16]	Y	Y	Y	Y	P	Y	Y	N	N	Y	U	U	U	N	N	Y	N	Y	Y	Y	N	U	N	N	N	N	N	12	48	
Lee (2013) [15]	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	U	U	N	N	Y	N	Y	Y	Y	N	U	N	N	N	N	N	14	56	
Borysov (2016) [17]	Y	Y	N	Y	N	Y	Y	N	N	Y	N	U	Y	N	N	U	N	U	U	Y	U	U	N	N	N	N	N	8	32	
Jung (2014) [14]	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	U	U	N	N	Y	N	Y	Y	Y	N	U	N	N	N	N	N	14	56	

Y: yes; N: no; U: unable to determine; P: partially.
Reporting (1-10):
1. Is the hypothesis/aim/objective of the study clearly described?
2. Are the main outcomes to be measured clearly described in the Introduction or Methods section?
3. Are the characteristics of the patients included in the study clearly described?
4. Are the interventions of interest clearly described?
5. Are the distributions of principal confounders in each group of subjects to be compared clearly described?
6. Are the main findings of the study clearly described?
7. Does the study provide estimates of the random variability in the data for the main outcomes?
8. Have all important adverse events that may be a consequence of the intervention been reported?
9. Have the characteristics of patients lost to follow-up been described?
10. Have actual probability values been reported (*e.g.* 0.035 instead of <0.05) for the main outcomes except where the probability value is less than 0.001?

External validity (11-14):
11. Were the subjects asked to participate in the study representative of the entire population from which they were recruited?
12. Were those subjects who were prepared to participate representative of the entire population from which they were recruited?
13. Were the staff, places, and facilities where the patients were treated, representative of the treatment the majority of patients receive?

Internal validity-bias (15-20):
14. Was an attempt made to blind study subjects to the intervention they have received?
15. Was an attempt made to blind those measuring the main outcomes of the intervention?
16. If any of the results of the study were based on "data dredging," was this made clear?
17. In trials and cohort studies, do the analyses adjust for different lengths of follow-up of patients, or in case-control studies, is the time period between the intervention and outcome the same for cases and controls?
18. Were the statistical tests used to assess the main outcomes appropriate?
19. Was compliance with the intervention/s reliable?
20. Were the main outcome measures used accurate (valid and reliable)?

Internal validity-confounding (selection bias) (21-26):
21. Were the patients in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited from the same population?
22. Were study subjects in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited over the same period of time?
23. Were study subjects randomised to intervention groups?
24. Was the randomised intervention assignment concealed from both patients and health care staff until recruitment was complete and irrevocable?
25. Was there adequate adjustment for confounding in the analyses from which the main findings were drawn?
26. Were losses of patients to follow-up taken into account?

Power:
27. Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is less than 5%?
28. Assessment score.