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Research article

Improvement of pulmonary function parameters in female patients with adolescent idiopathic scoliosis by Schroth rehabilitative therapy

Kyra Stein [a], Fabian Holzgreve [a,*], Fee Keil [b], Panagiotis Diaremes [c], David A. Groneberg [a], Eileen M. Wanke [a], Omar Zabar [a,d], Daniela Ohlendorf [a]

[a] Institute of Occupational, Social and Environmental Medicine, Goethe-University Frankfurt, Frankfurt/Main, Germany
[b] Institute of Neuroradiology, Goethe-University, Frankfurt/Main, Germany
[c] Clinic for Orthopaedics (Friedrichsheim), University Hospital Frankfurt, Goethe University Frankfurt/Main, Frankfurt/Main, Germany
[d] Asklepios Katharina-Schroth-Clinic, Orthopedics, Bad Sobernheim, Germany

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ABSTRACT

Objective: This study investigates if an inpatient rehabilitation therapy (brace therapy and Schroth therapy) for six weeks contributes to an improvement in lung function of the patients.
Design: Retrospective study.
Setting: Scoliosis rehabilitation clinic “Asklepios Katharina-Schroth-Klinik” (Bad Sobernheim, Germany).
Participants: In 253 female patients a lung function examination was performed at entry and at the end of their inpatient rehabilitation stay. Of these, 61 patients underwent Schroth therapy (group 1); 192 patients underwent the combination of brace and Schroth therapy (group 2).
Intervention: Lung function parameters under the influence of Schroth and Schroth and brace therapy within a rehabilitative stay.
Main measures: The parameters of IVC (inspiratory vital capacity), FVC (forced vital capacity), FEV1 (forced expiratory volume in 1 s) and the Tiffeneau index (FEV/FVC) related to patient-specific reference values were evaluated with regard to potential ventilation disorders.
Results: There were significant improvements for IVC +2.56 %, FVC +3.99 %, FEV1 +2.36 % for the first stay (IVC and FVC 2nd, 3rd stay). The comparison of patients with vs. without additional brace therapy showed no significances. For the long-term analysis the parameters approached the reference values of age-matched, healthy female subjects. The greater the Cobb angle in the thoracic region, the significantly worse almost each of the measured parameters are.
Conclusion: An inpatient rehabilitation therapy contributes to an improvement in lung function (IVC, FVC and FEV1). A second, and even a third, follow-up stay still led to a measurable improvement in lung function, albeit to a lesser extent.

Abbreviations: IVC, inspiratory vital capacity; FVC, forced vital capacity; FEV1, forced expiratory volume in 1 s.

* Corresponding author. Institute of Occupational, Social and Environmental Medicine, Goethe-University Frankfurt/Main, Theodor-Stern-Kai 7, Building 9a, 60596, Frankfurt/Main, Germany.
E-mail address: holzgreve@med.uni-frankfurt.de (F. Holzgreve).

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1. Introduction

Idiopathic scoliosis of adolescence (AIS) affects about 2–5% of adolescents aged 10–16 years, depending on the literature [1–5]. In 2007, Kamtsiuris et al. [5] counted a prevalence of 6.5 % in a prevalence study for children in Germany aged 11–13 years; from 14 to 17 years, the prevalence was as high as 11.1 %. Based on these data, the diagnosis as well as the proper initiation of therapy is of social relevance. The prevalence of this structural form of scoliosis is 3.6 times higher in female than in male adolescents [1,3]. The variable courses of the varying degrees of severity can individually lead to impairments in the function and quality of life of the affected patients [6–11]. Multifactorial conditions are taken into account in the causal research of AIS, including genetic factors [1,4,12,13]. For the assessment of the severity of scoliosis, the so-called Cobb angle, the maximum degree of curvature of a scoliosis, is usually determined via standardized radiographs [1,14–16]; this, together with to additional factors, such as age and progression, are used to derive the recommended therapies depended on the Cobb angle [17,18].

Since, depending on the height and extent of the scoliotic curvature, a deformation of the thorax occurs, a secondary restriction of respiratory function may result; this may include a restrictive ventilatory disorder which is reflected by a change in the specific functional parameters of lung function [3,19,20]. Evidence of an altered lung function in scoliosis patients was first established from studies in the early 20th century [7,21,22]. Although maximal negative events such as cor pulmonale or death due to the disease are negligible today, reduced lung function continues to be reported in patients with high-grade scoliosis compared with the healthy population [8,23,24]. Among others, Weinstein et al. [7,25] demonstrated a negative correlation between the severity of thoracic scoliosis and the reduction of forced vital capacity (FVC), corresponding to a restrictive breathing pattern. Furthermore, in a long-term follow-up of 187 scoliosis patients, Ascani et al. [8] described cardiopulmonary limitations in adulthood for thoracic and thoracolumbar curves, whereas they found no abnormalities in lumbar curves. Newton et al. [26] evaluated the direct clinical association between the severity of scoliosis and possible changes in pulmonary function in 631 patients as variable and not always present. Here, even patients with a thoracic Cobb angle of $<50^\circ$ exhibited moderate to severe limitations in FVC, forced expiratory volume in the first second (FEV1) and TLC (total lung capacity). Furthermore, Barrios et al. [27] demonstrated significantly reduced exercise tolerance under maximal exercise in 37 AIS patients (Ø Cobb angle 32.8°) compared with a control group. Here, the respiratory rate increased, ventilatory efficiency (VE) worsened, while the FVC and FEV1 parameters remained within the normal range.

In their preoperative study of 72 patients with right thoracic scoliosis, Wang et al. [28] demonstrated a significant negative correlation between the expected FVC (74.41 % ± 20.25) and the magnitude of the thoracic Cobb angle (67.46° ± 17.26). Restrictive limitation (FVC <80 % of the reference value) could be measured in 45 patients.

For patients with a Cobb angle smaller than 20°, pure physiotherapeutic treatment is recommended, whereas a Cobb angle larger than 20° is an indication for the use of additional brace therapy [17]. The therapeutic goal is to reduce the progression of spinal deformity, especially in the growth phase, and to prevent the impending functional impairment of the patient [11,17,29,30].

A successful form of conservative treatment for scoliosis is Schroth therapy; this consists of various elements of physiotherapy combined with breathing exercises [31]. Schroth therapy is based on the possible controllability of breathing, even though it is pathologically altered [31,32]. During outpatient treatment or several weeks of inpatient scoliosis intensive rehabilitation (SIR®), these exercises are learned under supervision. The goal is to slow the progression of the disease and to maintain as unrestricted a high quality of life as possible in the long term [9,33]. A growing number of studies [32–38] point to the benefits of Schroth therapy, such as an increase in VC or chest expansion [39], both in the outpatient setting and during inpatient intensive rehabilitation. However, according to Kuru et al. [40], inpatient therapy is significantly better than home training alone. The fact that Schroth exercises show positive effects with regard to lung function and vital capacity both with a Risser stage 2 upwards and with a greater Cobb angle of over 40° has been proven in various studies [32,34,41]. Moramarco et al. [32] conducted a study on 36 adolescent AIS patients (average age 13.89 years) with Cobb angles averaging 36.92° thoracic and 33.92° lumbar. All patients received a total 20-h physiotherapy program (Schroth Best Practice® (see 2.3.1)) for five to seven days. FVC improved on average from 2.69 l to 2.80 l and FEV1 increased from 2.28 l to 2.37 l at the end of therapy. Abdel Ghafar et al. [41] investigated an additional hippotherapy to Schroth exercises in 45 adolescents (age 12–18 years) with idiopathic scoliosis. All patients had a thoracic or thoracolumbar primary curve (Cobb angle 10–20°) and Risser grade 2–4. Patients in group 1 received 15 × 30-min sessions of hippotherapy over a period of 10 weeks. Group 2 attended 3 times/week 60-min session of Schroth exercises for 10 weeks. Pre- and post-intervention variables (FVC, FEV1, FEV1/FVC, MVV and 6MWT) revealed significant improvement in both groups ($p < 0.05$). Kim et Hwangbo [34] collected preoperative measurements of VC before and after application of Schroth therapy three times a week for twelve weeks in five AIS patients (average age: 22.60 years). There were thoracic Cobb angles >40° at baseline, which indicated planning for surgical therapy. A significant increase in VC was observed over the course of the study (from 2.83 l ± 1.23–4.04 l ± 1.67). The Cobb angle decreased significantly from 42.40° ± 7.86–26.00° ± 3.65.

Depending on the severity, Schroth therapy is performed in combination with brace fitting. Since scoliosis can affect respiratory function depending on its severity, the question arises of whether combined brace and Schroth therapy has a positive effect on selected pulmonary function parameters (inspiratory vital capacity (IVC), FVC, FEV1 and the Tiffeneau index (FEV1/FVC)), which can indirectly demonstrate respiratory function.

In the context of this retrospective study, how these selected lung function parameters change in adolescent female patients with scoliosis as a result of rehabilitative Schroth therapy and, possibly in combination with brace therapy, was investigated. Since the prevalence for scoliosis is much higher in the female gender than in the male gender, this analysis focuses on female individuals. For this purpose, a lung function analysis at the time of admission and after completion of a stay were compared. In particular, the question of whether there is a certain number of rehabilitative inpatient stays that have a beneficial effect on the course of the disease of the affected persons, was addressed.

2. Material and methods

For the retrospective analysis within the years 2000–2016 (16 years), the patient data of 253 female patients of the Katharina-Schroth-Klinik (Bad Sobernheim, Germany) were evaluated.

2.1. Subjects

Only female patients were selected who were at least 11 and at most 19 years old at the time of their first stay. The mean age of the 253 female patients at initial diagnosis was 12.66 ± 1.25 years, with a mean age of patients at their first stay of 13.83 ± 1.52 years. The length of treatment was 28.2 ± 5.10 days. All 253 patients had a second stay, 101 of whom completed three stays, 39 completed four stays and 15 completed five stays; some patients ($n < 10$) even had up to 8 stays in total.

Furthermore, the 253 patients were divided into two groups: group 1 with $n = 61$ (24.10 %) received Schroth therapy only and group 2 with $n = 192$ (75.90 %) received Schroth therapy and wore a brace. These recommendations [17] state that a brace should be worn if the Cobb angle is < 20°. However, this recommendation could not always be adhered to when classifying the groups. Some patients have a larger Cobb angle but still did not wear a brace for the following reasons: they refused it, the parents were unwilling, they were already fully grown or were about to undergo surgery.

The descriptive display of the Cobb angle of the scoliosis curve in each spinal region isolated for each group is illustrated in Table 1.

If a patient changed groups during the treatment period, the analysis was performed according to the intention-to-treat criteria. Schroth therapy was performed 6 h per day in a standardized manner for all patients. Even though different degrees of severity and scoliosis patterns were present, the focus was on the effect of the therapy before and after, in particular the differences in the pulmonary function parameters before and after.

The included patients were those who were between 11 and 19 years of age at their initial diagnosis and who had pulmonary function tests performed at both admission and at discharge from hospital. All pulmonary function examinations were performed as part of the standardized admission and discharge examination regardless of the severity of scoliosis.

Only those patients who had multiple stays (at least two) in the above-mentioned rehabilitation clinic were used for analysis. Radiographs were taken of each subject before each stay.

We excluded all patients who had undergone any type of spinal surgery or who had a spinal disease, other than AIS or a severe congenital disease that prevented proper diagnostic procedures or rehabilitative therapy.

Since spirometry is a standard examination in German clinics for children with scoliosis, including children with moderate scoliosis, every patient undergoes this standardized examination on admission and discharge of the rehabilitative stay, irrespective of the Cobb angle or curvature pattern. Informed consent was obtained from all subjects and/or their legal guardian(s) which means that all patients have signed that their anonymized data from these routine examinations may be used for retrospective studies. All methods were carried out in accordance with relevant guidelines and regulations.

The Ethics Committee of the Rheinland-Pfalz Medical Association (Germany) proofed that no separate ethics application is required. This is the case, because for the retrospective evaluation of the data no study-related interviews or further study-related examinations outside the regular medical diagnostics are performed.

Table 1
Descriptive display of the Cobb angle of the scoliosis curve in each spinal region isolated for each group. The Cobb angle was measured at the beginning of the first stay. For each range, the number of patients as well as median, 1st and 3rd quartile and minimum and maximum of the cobb angle are given, for the whole group of subjects as well as separately for brace and no brace wearers.

	Group 1: No brace			Group 2: Brace			total		
	Number	Cobb angle Median	Cobb angle 1st Quartile/3rd Quartile Minimum/ Maximum	Number	Cobb angle Median	Cobb angle 1st Quartile/3rd Quartile Minimum/ Maximum	Number	Cobb angle Median	Cobb angle 1st Quartile/3rd Quartile Minimum/ Maximum
High thoracic (TH2-TH6) Cobb angle (°)	2	0	0/14 0/14	13	0	0/0 0/67	15	0	0/0 0/67
Thoracic (Th6–Th11/12) Cobb angle (°)	48	23	14/31 0/60	157	31	18.25/39 0/72	205	29	16/38 0/72
Thoracic lumbar (Th12-L1) Cobb angle (°)	11	0	0/0 0/38	46	0	0/0 0/77	57	0	0/0 0/77
Lumbar (L1/2-L4) Cobb angle (°)	47	19	0/29 0/55	116	23	0/33 0/90	163	21	0/32.5 0/90

2.2. Body plethysmograph

Lung function parameters were measured using the ZAN500 Body plethysmograph (nSpire Health, Oberthulba, Germany). A simple spirometry was recorded and evaluated electronically using the integrated software. The individual patient data (age, sex, height, body weight) were also used as reference values to assign the corresponding target values [42]. According to the manufacturer's specifications, the device's measurement error is approximately 0.05 l.

The measurement of the parameters was standardized according to common clinical practice under the guidance of a healthcare professional. The lung function measurement was performed at the beginning and at the end of each stay. During lung function examination, various static and dynamic lung values were measured with the active cooperation of each patient like IVC, FVC, FEV1 and the Tiffeneau index (FEV1/FVC). Each patient sat 90° upright in the booth of the bodyplethysmograph and initially breathed calmly through the mouthpiece. Thus, the so-called breathing rest position was first established by repeated inhalation and exhalation. The patient was then asked to inhale to the maximum and then to exhale to the maximum. This resulted in the parameters mentioned above. In accordance with this standardised procedure, the, each measurement was repeated three times, and the best result was used for evaluation and documented.

2.3. Statistical analysis procedures

Statistical analysis was performed using the BIAS statistical program (Epsilon Verlag, Darmstadt, Germany). Normal distribution was checked by means of the Kolmogorov-Smirnov test. As the data were not normally distributed, non-parametric tests were used, such as the Wilcoxon-matched pairs test, the Mann-Whitney *U* test or the Kruskal-Wallis-Test, and to analyze the long-term trend, the Friedman test was used. For the latter, the magnitude of change was determined by the difference between the median of the initial and final measurements of each stay (in percent). A positive value indicates an improvement from the beginning to the end of the respective stay, while a negative value describes a worsening. This value represents our actual value of the test person. For our calculations of the percentage variance from the target value (in %) we have used the following calculation: (actual value: target value)* 100. All p-values were Bonferroni-Holm corrected. The p-values were graded using Rosenthal's effect size; this describes a "small" effect for a value < 0.1, a "medium" effect for up to 0.3 and a "large" effect ≥ 0.5.

In addition, the estimated values of the differences and the relative change calculated as a percentage between the values before admission and discharge were determined. The significance level was 5 %.

Since the greatest effects of pulmonary function are expected in those patients who have scoliosis in the thoracic region, group comparisons based on the size of the Cobb angle are performed [3,19,20].

3. Results

3.1. 1st stay

3.1.1. Pre-post comparison of all subjects

For all parameters, a statistically highly significant change between pre-post measured values was found after Bonferroni-Holm

Table 2
Pulmonary function test each in relation to target values at discharge for the first stay (n = 253); % = percent. Significant p-values after Bonferroni-Holm correction are marked with *.

1st Stay Test parameter	Median	1st Quartile	3rd Quartile	Range (Minimum - Maximum)	p-value	Effect size r
IVC						
Receiving (in %)	83.56	74.73	91,75	43.19–114.33		
Discharge (in %)	87.74	78.36	96.57	53.73–136.67		
Difference (in %)	2.56	0.28	8.68	−25.86–36.16		
					<0.001*	0.4
FVC						
Receiving (in %)	81.00	72.75	90.54	44.59–113.57		
Discharge (in %)	86.02	77.27	92.22	51.55–126.23		
Difference (in %)	3.99	−0,32	8.71	−13.25–42.65		
					<0.001*	0.4
FEV1						
Receiving (in %)	87.55	78.11	96.41	47.56–122.76		
Discharge (in %)	89.31	80.91	100.00	47.87–145.04		
Difference (in %)	2.36	−1.97	7.20	−24.19–41.70		
					<0.001*	0.27
FEV1/FVC						
Receiving (in %)	108.06	101.35	114.69	81.58–102.55		
Discharge (in %)	105.42	99.89	111.29	71.33–142.99		
Difference (in %)	−1.85	−5.59	1.69	−33.19–41.79		
					<0.001*	0.23

correction ($p \leq 0.001$) (Table 2). For IVC and FVC there was a medium effect ($r > 0.3$), while for the other parameters there were small effects ($r < 0.3$). The changes in the medians (Table 1) indicate that the lung function tended to improve. Calculated deviations from target values at receiving and discharge showed a positive trend; only FEV1/FVC showed a negative trend.

Before starting rehabilitation, 110 patients had a reduced vital capacity (IVC) of less than 80 % of the target value and at the end of the stay, 78 patients still had this value. The detailed number of those below and above 80 % at the beginning of rehabilitation and their percentage change in IVC is shown in Table 3.

3.1.2. Brace vs. no brace

Within groups 1 and 2 there were significant improvements in the IVC, FVC and FEV1 parameters after Bonferroni-Holm correction ($p \leq 0.01$–0.001) (Table 4). However, for FEV1/FVC there was a significant negative trend in both groups. The effects should be reported in the low to medium range. As a result, IVC and FVC showed a medium effect with $r > 0.37$ in both groups.

The group comparisons of each parameter revealed no significant differences ($p \geq 0.05$).

3.2. 2nd stay

3.2.1. Pre-post comparison of all subjects

IVC and FVC showed positive significant improvement after Bonferroni-Holm correction ($p \leq 0.001$) although with only small effect sizes ($r = 0.16$ and $r = 0.17$, respectively), whereas the parameter FEV1/FVC significantly worsened ($p \leq 0.01$). Between stay 1 and 2, there were 54 subjects who changed groups (Table 5).

3.2.2. Brace vs. no brace

Within group 1, there were no statistically significant differences between values pre-post. In group 2, significant changes were observed in the difference values of the parameters IVC, FVC, FEV1/FVC ($p \leq 0.01$–0.001). In each case, the effect size showed a small effect with values of $r < 0.3$. Regarding the medians, as in the first stay, in both groups (group 1 and group 2) the parameters IVC, FVC and FEV1 improved and the parameter FEV1/FVC worsened, respectively. In addition, the median of the differences for IVC show an increase of 1.58 %, for FVC an increase of 1.74 %, and for FEV1/FVC a decrease of 0.46 %.

The comparison of the two groups per parameter shows no significant differences ($p \geq 0.05$).

3.3. 3rd stay

3.3.1. Pre-post comparison of all subjects

In the pre-post analysis, there were highly statistically significant differences ($p \leq 0.001$) for IVC, FVC and FEV1/FVC, all with a small effect size ($r < 0.3$). While the parameters of IVC and FVC improved, a decrease was observed for FEV1/FVC. No significant change was shown for FEV1. Regarding the medians, all parameters changed with varying degrees; here, the greatest change (from 87.56 % to 90.81 %) was seen for IVC (Table 6).

3.3.2. Brace vs. no brace

For group 1, after Bonferroni-Holm correction was performed, only IVC showed a statistically significant difference between the values at admission and at discharge (median difference pre-post of IVC: +1.88 %, $p = 0.01$; FVC: +1.46 %, $p = 0.03$; FEV1: +1.32 %, $p = 0.37$; FEV1/FVC: -0.6 %, $p = 0.27$). The effect size varied between $r = 0.34$ and $r = 0.40$. In group 2, the pre-post comparisons for IVC +1.31.%, $p = 0.03$), FVC +1.50 %, $p = 0{,}001$) and FEV1/FVC (−1.57 %, $p = 0{,}001$) after Bonferroni-Holm correction showed significant differences. The parameter FEV1 was not significantly changed with $p = 0.12$ (+0.59 %). For all parameters, only a small effect size could be detected in each case ($r < 0.3$).

The comparison of the two groups showed no significant differences in any of the tested parameters.

Follow up from first to last treatment period.

Due to the decreasing sample size with increasing stays (stay 1: $n = 253$; stay 2: $n = 248$; stay 3: $n = 96$, stay 4: $n = 39$, stay 5: $n = 15$), only a comparison of the first three stays was made.

Table 3
Distribution of participants above and below 80 % of the individual target value (IVC) at the beginning of rehabilitation and at discharge of the first stay. Median, minimum and maximum for the parameters age (years), thoracic Cobb angle (°) and difference of the final IVC value subtracted from the initial value (in per cent) are presented.

	Below 80 % of the individual target value at admission of the first stay		Above 80 % of the individual target value at discharge of the first stay	
	Improvement	Deterioration	Improvement	Deterioration
Number of participants	92	18	101	42
Age (years)	14 (11.0/19.0)	14 (12.0/20.0)	14.0 (12.0/22.0)	14.0 (12.0/16.0)
Cobb thoracic (°)	31.5 (0.0/72.0)	28.5 (0.0/60.0)	27.0 (0.0/61.0)	23.0 (0.0/50.0)
Difference End- Initial value (%)	6.7 (0.3/36.2)	−1.8 (−8.7/-0.2)	5.0 (0.0/36.0)	−3.7 (−25.9/-0.3)

Table 4
Pulmonary function examination each in relation to target values and at discharge for the first stay after splitting into subgroups 1 (no brace; n = 61) and 2 (brace; n = 192); % = percent. Significant p-values after Bonferroni-Holm correction are marked with *.

1st Stay Test parameter	Median	1st Quartile	3rd Quartile	Range (Minimum – Maximum)	p-value	Effect size r
Group 1 (n = 61)						
IVC						
Receiving (in %)	86.07	78.45	94.11	54.04–111.49		
Discharge (in %)	92.02	80.82	100.99	62.40–122.03		
					<0.001*	0.37
FVC						
Receiving (in %)	83.61	76.15	93.84	54.34–112.32		
Discharge (in %)	90.82	78.76	98.73	59.66–122.15		
					<0.001*	0.38
FEV1						
Receiving (in %)	91.98	83.93	101.17	53.72–122.76		
Discharge (in %)	95.80	82.68	107.30	69.79–145.04		
					0.01*	0.25
FEV1/FVC						
Receiving (in %)	110.37	104.45	115.33	81.58–120.21		
Discharge (in %)	108.01	102.54	115.03	87.58–118.62		
					0.01*	0.25
Group 2 (n = 192)						
IVC						
Receiving (in %)	81.85	72.72	91.12	43.19–114.33		
Discharge (in %)	86.33	77.71	94.35	53.73–136.67		
					<0.001*	0.40
FVC						
Receiving (in %)	79.88	71.14	88.70	44.59–113.57		
Discharge (in %)	84.19	76.34	93.92	51.55–126.23		
					<0.001*	0.40
FEV1						
Receiving (in %)	85.13	75.88	94.54	47.56–120.14		
Discharge (in %)	87.89	79.55	97.58	47.87–131.99		
					<0.001*	0.28
FEV1/FVC						
Receiving (in %)	106.41	101.17	114.70	81.78–120.55		
Discharge (in %)	104.34	99.35	109.52	71.33–142.99		
					<0.001*	0.22

Table 5
Pulmonary function examination each in relation to target and at discharge for the second stay (n = 248); % = percent. Significant p-values after Bonferroni-Holm correction are marked with *.

2nd Stay Test parameter	Median	1. 1st Quartile	3rd Quartile	Range (Minimum - Maximum)	p-value	Effect size r
IVC						
Receiving (in %)	85.38	76.89	93.42	55.44–140.29		
Discharge (in %)	86.72	78.68	95.37	53.48–120.66		
					<0.001*	0.18
FVC						
Receiving (in %)	84.72	74.07	92.11	52.09–120.33		
Discharge (in %)	85.01	76.74	94.12	48.97–119.73		
					<0.001*	0.20
FEV1						
Receiving (in %)	87.79	77.20	98.78	50.49–131.27		
Discharge (in %)	89.45	79.63	98.14	54.91–127.69		
					0.07	0.09
FEV1/FVC						
Receiving (in %)	106.94	100.09	112.01	83.27–136.12		
Discharge (in %)	105.76	99.38	111.39	79.28–119.30		
					0.01*	0.13

The 96 all-female patients were 13.69 ± 1.19 years old during the first stay, 14.8 ± 1.20 years old at the second stay and 16.42 ± 1.97 years old at the third stay. The length of the stays was 28.57 ± 5.39 days (stay 1), 25.27 ± 0.58 days (stay 2) and 24.70 ± 4.43 days (stay 3).

The relative deviations of the measured parameters from the corresponding target values of the age-matched, healthy reference population were calculated for each stay. The medians of this deviation for stays 1 to 3 were compared using the Friedman test; IVC,

Table 6
Pulmonary function examination each in relation to target values at admission and at discharge for the third stay (n = 96); % = percent. Significant p-values after Bonferroni-Holm correction are marked with *.

3rd Stay Test parameter	Median	1st Quartile	3rd Quartile	Range (Minimum - Maximum)	p-value	Effect size r
IVC						
Receiving (in %)	87.56	76.29	95.47	54.15–122.22		
Discharge (in %)	90.81	76.41	98.91	57.70–121.64		
					0.001*	0.27
FVC						
Receiving (in %)	86.08	75.53	92.63	52.06–135.02.		
Discharge (in %)	87.89	74.96	97.42	58.41–137.74		
					<0.001*	0.29
FEV1						
Receiving (in %)	89.94	77.05	97.40	52.96–132.20		
Discharge (in %)	90.96	80.48	98.29	57.52–131.44		
					0.07	0.14
FEV1/FVC						
Receiving (in %)	103.62	99.78	107.60	99.78–107.60		
Discharge (in %)	102.37	97.67	107.20	58.10–118.27		
					<0.001*	0.27

FVC and FEV1 showed a superior significant p-value ($p \leq 0.05$–0.001) (Table 7). In the multiple pairwise comparisons, significance was observed between the 1st and 2nd stay and the 1st and 3rd stays for IVC, between the 1st and 2nd and the 1st and 3rd stays for FVC, and between the 1st and 2nd stay for FEV1. Only for FEV1/FVC could no significant difference between the stays be found.

In summary, the actual values deviated less from the target values over the course of time from stay 1 to stay 3. This was evident to varying degrees depending on the parameter.

3.4. *Group comparisons based on the size of the Cobb angle*

The group comparison of the thoracic Cobb angle (Table 8) shows that there is a significant group difference at the beginning of the first stay ($p \leq 0.001$–0.05). In the subsequent multiple pairwise comparison including Bonferroni-Holm correction, there are significances between all three groups for FEV1 ($p \leq 0.001$ and 0.04, respectively). The other parameters showed significant differences between group 1 and 3 (($p \leq 0.01$ and 0.05, respectively). FEV1/FVC also showed significant differences between group 1 and group 2 ($p < 0,008$).

At discharge, no significant superior p-value was found for IVC and FVC. For FEV1 and FEV1/FVC there is a significant p-value present ($p \leq 0.001$, respectively). Here, a significant pairwise comparison is shown between group 1 and 2 as well as between group 1 and 3 and also between group 2 and 3 ($p \leq 0.001$ and 0.04, respectively).

All significant pairwise comparisons show that the lung function parameters decrease with increasing thoracic Cobb angle.

4. Discussion

Generally, the Schroth therapy aims in a more effective mobilization of the existing lung segments by the intensive respiratory therapy. For FEV1, a larger volume should be mobilized, however, the flow velocity has not increased sufficiently or equivalently calculated to the first second, which can possibly be attributed to a reduced endurance of the respiratory (auxiliary) muscles due to the

Table 7
Friedman-test (superior p-value) followed by multiple pairwise comparison of the long-term course of the parameters IVC, FVC, FEV1, and FEV1/FVC over the three stays, (n = 96); median (in percent), S1 = Stay 1, S2 = Stay 2, S3 = Stay 3. Significant p-values after Bonferroni-Holm correction are marked with *.

Test parameter	S 1 Median	S 2 Median	S 3 Median	Superior p-value	Multiple pairwise comparison p-value
IVC	4.74	2.17	1.41	0.01	1/2 0.01* 1/3 0.01* 2/3 0.85
FVC	4.19	1.26	1.48	0.01	1/2 0.01* 1/3 0.04* 2/3 0.56
FEV1	1.79	0.32	0.88	0.05	1/2 0.05* 1/3 0.32 2/3 0.33
FEV1/FVC	−2.92	−0.9	−1.33	0.63	1/2 1.00 1/3 1.00 2/3 1.00

Table 8
Group comparison of the Cobb angle in the thoracic region for all parameters at admission and at discharge. Group 1: 0–20° (n = 74), Group 2: 20–40° (n = 119), Group 3: >40° (n = 56). The superior p-value of the Kruskal-Wallis test and the results of the multiple pair comparison are shown.

	Median admission	Superior p-value admission	multiple pair-comparison p-value admission	Median discharge	Superior p-value discharge	multiple pair-comparison p-value discharge
IVC	1.84.54	0.04 eta^2 0.03	1 vs. 3 p ≤ 0.04	1.88.26	0.23	
	2.83.56			2.88.31		
	3.78.48			3.85.15		
FVC	1.80.70	0.05 eta^2 0.02	1 vs. 3 p ≤ 0.05	1.86.90	0.28	
	2.82.13			2.86.23		
	3.78.16			3.82.62		
FEV1	1.89.97	0.001 eta^2 0.06	1 vs. 2 p ≤ 0.04	1.92.99	0.001 eta^2 0.06	1 vs. 2 p ≤ 0.04
	2.86.03		1 vs. 3 p ≤ 0.001	2.89.63		1 vs. 3 p ≤ 0.001
	3.82.64		2 vs. 3 p ≤ 0.04	3.84.52		2 vs. 3 p ≤ 0.04
FEV1/ FVC	1.111.47	0.004 eta^2 0.05	1 vs. 2 p ≤ 0.008	1.108.76	0.001 eta^2 0.09	1 vs. 2 p ≤ 0.001
	2.106.29		1 vs. 3 p ≤ 0.01	2.104.44		1 vs. 3 p ≤ 0.001
	3.104.22			3.101.19		2 vs. 3 p ≤ 0.04

progressive pathological deformity of the spine and thorax [20]. Thus, muscular imbalances or secondarily caused maldevelopment of the muscular compartments associated with the concept of rotational breathing could be reduced or compensated by Schroth therapy through the daily units of the inpatient therapy modules, some of which lasted several hours [31].

In this study all patients showed a significant tendency to improve the lung volume (consideration of the device measurement error of approximately 0.05 l) between admission and at discharge between +2.36 % and 3.99 % (IVC, FVC and FEV1, $p < 0.001$) with an medium effect size. Only the Tiffeneau Index decreases significantly by 1.85 % with medium effect size.

These trend improvements also correspond with the fact that at the beginning of the rehabilitation 110 patients had a reduced vital capacity (IVC) of less than 80 % of the target value and at the end only 78 patients. Regardless of this 80 % threshold, about 76 % of a total of 253 patients have improved. Regardless of this 80 % threshold, about 76 % of a total of 253 patients have improved.

Therefore, within the intragroup pre-post analysis both groups improved between 2 and 8% significantly in the main test parameters (except FEV1/FVC) during the first stay. IVC and FVC improved the most in group 1 with Schroth therapy at 8 % and 7 % respectively and in group 2 with combined therapy at 5 % for both parameters. The reduction in FEV1/FVC may reflect a restriction more likely to occur with a decrease in FVC due to structural anatomic restriction when FEV1 is often unremarkable, whereas obstruction is associated with a predominance of reduced FEV1 [24,43]. Accordingly, it is possible that improvement in the FVC may shift the FEV1/FVC ratio back positively toward normal ventilation. Descriptively, it can also be noted that the entry values of the brace group are approx. 5 % lower than those of the other group. The smaller change in group 2 could, possibly, be attributed to an additional restrictive effect of the brace therapy. At the same time, the number of those with a larger Cobb angle is much higher in the brace group which might influenced this finding (Table 3). Nonetheless, the unequal group size (group 1: n = 61 vs. group 2: n = 192) must be considered here as a potential statistical bias.

A sustained efficacy of the combined therapy with brace is illustrated by the still significant differences in the pre-post comparison in stays 2 and 3; in contrast to group 1, which could not provide any significant differences for stay 2. This statement is limited by the different number of patients in the respective groups as well as the possible group changes which may have occurred after the first stay. This should be taken into account for subsequent studies as, otherwise, a possible difference could be distorted.

With regard to the analysis over several stays (all patients together), there were significances for all lung function parameters except the Tiffeneau index (FEV1/FVC) in the global test. Descriptively, at the beginning of the first stay, IVC had a magnitude of change (difference of the median from the initial and final measurements of each stay) by a deviation of+4.74 % of the first stay, a decrease of +2.171 % at the second stay and a deviation of +1.41 % at the third stay. FVC revealed statistical significances for stays 1 (+4.19 %) and 2 (+1.26 %) as well as for stays 1 and 3 (+1.48 %), respectively. FEV1 showed significances between stay 1 and 2 (S1: +1.79 %, S2: +0.32 %, S3: +0.88 %). FEV1/FVC had no significant differences between the stays (S1: 2.92 %, S2: -0.90 %. S3: -1.33 %).

Furthermore, it is noted that the greater the Cobb angle in the thoracic region, the worse almost all recorded lung function parameters are both at the beginning of the first stay and at its end. In summary, patients (n = 96) who had at least three stays benefited little from the respective stays; this was also shown by the pre-post comparisons which were performed separately for each stay. The extent of improvement decreased with the increasing number of stays, so it can be assumed that further follow-up stays would show a similar trend, insofar as lung function being considered the main parameter IVC. For the other parameters, this linear trend is not so clear. When interpreting the data, it must be taken into account that the changes amount to 2–8%. These changes are not high, but since the values refer to adolescents who have very good lung parameters despite the scoliosis, this is an improvement that has low clinical relevance. However, the surgical indication of a scoliosis is definitely associated with the lung function and an improvement of these parameters can certainly lead to a postponement or avoidance of surgery and thus these small changes also contribute to this. Almost all changes, although statistically significant, are below the threshold for clinically demonstrable changes. Here, further analysis of changes in lung function at the individual level according to curve size or scoliosis location may distinguish between those at risk and those who may benefit from treatment. However, this is a new issue that could be answered by following up on this study.

In the available patient data, it can be seen that changes were made to the therapy between stays, i.e., some terminated their brace therapy outright or started a new brace therapy. Furthermore, interindividual differences in the learning of the physiotherapeutic exercises and therapy adherence have to be considered in the concept of inpatient rehabilitation. The advantage of an early rehabilitation measure can be seen, among other things, in the still continuing spinal flexibility of the spine, even if the progressive course of the scoliosis is yet to take place. Additionally, it has to be taken into consideration that the decreasing number of patients who had further inpatient rehabilitation stays after the second stay must be considered. Since comparable studies on multiple hospital stays are missing in the literature so far, it can be assumed that severely affected patients seek multiple stays rather than those with a smaller curve size. On the other hand, large curvatures are more likely to have an indication for surgery in the course of the disease. However, even in individual cases, orthopedic rehabilitation may follow surgical intervention, albeit to a milder extent, as mobility may be limited depending on the surgical procedure.

A comparison of the significant but clinically small relevant improvements in lung function resulting from the rehabilitation stay with previous studies [32,33,37,38,44] indicates that these studies have also found such small improvements. However, these studies often involved short-term intensive rehabilitation, such as according to the Schroth Best Practice or modifications of it. Rohrböck et al. [44] demonstrated improvements in FVC and FEV1 (FVC: from 3.30 l to 3.36 l; FEV1: from 2.88 l to 2.92 l) following three weeks of inpatient Schroth therapy, which were accompanied by a significantly improved scoliotic curve from 9.05° to 7.81°. Even short-term interventions with Schroth exercises have produced positive effects (an increase of IVC from 2073 ml to 2326 ml; $p < 0.05$ (38) or an increase of IVC after six weeks of outpatient Schroth therapy: 2795 ml–2956 ml; $p < 0.01$ (37)). Kuru et al. [40] and Kwan et al. [45] also demonstrated positive therapy effects, i.e., improvements in the trunk rotation by $-4.23^\circ \pm 4.78$ and the Cobb angle by -2.53° (Kuru et al. [40]) and improvements of >6° in 16 % of the patients compared to 4 % in the control patient group (Kwan et al. [45]); the age ranges were between 10 and 18 years in the study of 39 female and 6 male participants [40] and 12.3 ± 1.4 years in the study of 24 patients (19f/5 m) [45], respectively. However, all of these studies have, in common, the lack of follow-ups and, thus, no long-term effects were published.

Rohrböck [44] also found no significant differences in the comparison of brace wearers (n = 31) vs. non-brace wearers (n = 11). This was confirmed by Schreiber et al. [46] In contrast, Kwan et al. [42] demonstrated measurable improvements (ATR (angle of trunk rotation): $9.43^\circ \pm 3.27$–$8.45^\circ \pm 3.45$) in the comparison of the combination of brace and Schroth therapy vs. brace therapy alone versus no changes in the control group without brace use.

The reason for a restrictive effect by wearing a brace is assumed to be the dysbalance of the compartments involved in respiratory mechanics (diaphragm, intercostal muscles, abdominal pressure) (Danielsson et al. [47], Yagci et al. [48], Bo Ran et al. [49]). Furthermore, the trunk and thorax are forced by the brace into a posture in which the overstretching of individual muscles may occur; deep inhalation and exhalation in the sense of full lung development are no longer possible [50]. A survey of TLC, RV, resistance and compliance, which can only be obtained by complete body plethysmography, may provide an approach to investigate this hypothesis in more detail.

A limitation of the present study is the lack of subgrouping based on the curvature pattern or severity of the scoliosis. However, since the focus of this study was on the general long-term effects, those more differentiated analyses should be performed in follow-up studies. In addition, spirometry should be extended to measure the total lung capacity and, if necessary, the residual volume in order to detect more effectively potential ventilation disorders. Furthermore, the intersubjective variable treatment of patients on the physician's part must be taken into account. However, this aspect is very clearly reduced, since the Katharina-Schroth therapy is standardized and consequently clear instructions for each therapist apply to the patients of this clinic. Even after the rehabilitation stay, the treatment strategy is approximately the same for all patients: every 6 months to the scoliosis-specialized physician, 2 times a week physiotherapy with a certified Schroth therapist and 3 times learned self-exercise of Schroth therapy at home, as well as annual inpatient rehabilitation.

5. Conclusion

Inpatient rehabilitative therapy according to Schroth, practiced for several weeks, was found to contribute to an improvement in the patient's lung function. It should be noted, however, that the improvement (patients without and with brace therapy) is small and thus in line with the results of other studies. Nevertheless, it must be taken into account that these improvements are not necessarily demonstrable for each individual. Follow-up analysis showed that a second, and also a third, follow-up stay led to a minimal improvement (statistically significant, but not clinically relevant), although the extent of the improvement decreased with each additional stay.

Based on these first long-term results of a combined Schroth and brace or only Schroth therapy over three stays, individual changes to the Schroth therapy should be integrated into the evaluation in future analyses.

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Availability of data and materials

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Ethics approval and consent to participate

On September 12, 2017, the Ethics Committee of the Rheinland-Pfalz Medical Association (Germany) certified that no separate ethics application is required. This is the case, because for the retrospective evaluation of the data no study-related interviews or further study-related examinations outside the regular medical diagnostics are performed.

Consent for publication

Not applicable.

CRediT authorship contribution statement

Kyra Stein: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Fabian Holzgreve:** Methodology, Conceptualization. **Fee Keil:** Methodology, Conceptualization. **Panagiotis Diaremes:** Resources, Project administration, Conceptualization. **David A. Groneberg:** Resources, Project administration, Conceptualization. **Eileen M. Wanke:** Supervision, Methodology. **Omar Zabar:** Resources, Methodology. **Daniela Ohlendorf:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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