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Conservative treatment of adolescent idiopathic scoliosis: the effectiveness of rigid bracing

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Abstract

Background The use of rigid braces and specialized exercises for the treatment of adolescent idiopathic scoliosis (AIS), is the most common non-surgical approach used to prevent curvature progression. The study aims to assess the efficacy of a rigid brace (the Chêneau brace), in conjunction with SEAS (Scientific Exercise Approach to Scoliosis), as a conservative approach to the treatment of AIS.

Methods The study involves a retrospective analysis of data collected prospectively from 119 patients with AIS who underwent treatment with the Chêneau brace and SEAS. Patients with AIS were eligible for treatment if they had a Cobb angle between 20° and 40° (at the time of initial treatment) and significant residual spine growth (Risser grade 0–2). It was recommended that patients wear the brace for a minimum of 22 h per day. The effectiveness of the treatment was assessed based on changes in the Cobb angle measurements. To evaluate the patients' perception of treatment outcomes, the Scoliosis Research Society-22 revised (SRS-22r) was administered before and after treatment. A multivariable logistic regression analysis was used to identify factors that may independently predict treatment success.

Results The use of the Chêneau brace, in combination with SEAS gymnastics, was effective for 99 patients (83.2%). Only six patients (5.1%) achieved a Cobb angle of the major curve greater than 45°. There were no significant differences in treatment success based on the location of the curve. In the group of patients who followed the recommended wearing time for the brace and SEAS exercises, the rate of curvature progression was significantly lower than in the overall group (0% versus 16.8%, $p = 0.004$), and the group that partially or poorly followed the treatment protocol (0% versus 28%, $p < 0.001$).

Conclusions The SRS-22r showed improvements in satisfaction with treatment from the start to the end of brace use, with an average score of 4.62 ± 0.54. The use of the Chêneau brace in combination with SEAS gymnastics has been shown to reduce the risk of spinal curvature progression in individuals with AIS.

Keywords Adolescent idiopathic scoliosis, Brace treatment, Chêneau Brace, Conservative treatment, SEAS gymnastics, SRS-22r questionnaire

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Introduction

Idiopathic scoliosis is a common orthopedic condition [1]. According to the definition of the Scoliosis Research Society, this condition entails a lateral curvature of the spine in the frontal plane that is characterized by a Cobb angle of 10° or more and is invariably accompanied by vertebral rotation. At the same time, it is not associated with any congenital, positional, or, in some cases, neuromuscular pathologies [2]. In approximately 90% of all cases, idiopathic scoliosis is diagnosed during adolescence [3]. A curvature with a Cobb angle greater than 50° is correlated with clinical manifestations, such as back pain, discomfort, and shortness of breath during exercise [4]. Surgical correction is necessary due to the high risk of gradual deterioration in adulthood at a rate of approximately 1° per year [5]. In addition to the adverse impact of adolescent idiopathic scoliosis (AIS) on overall quality of life, it is also important to consider its impact on adolescents' self-perception and mental well-being [6].

Despite extensive research efforts, the precise etiology of AIS has not yet been determined [7]. The treatment for this complex three-dimensional deformity requires careful consideration of several factors, including the Cobb angle, measurement of vertebral rotation according to Raimondi, the results of the Risser sign test, and the rate of scoliotic progression. Based on these indicators, it is possible to determine whether conservative treatment alone is sufficient or whether surgical intervention is required [8].

Given the relatively high prevalence of AIS and the multifaceted nature of its pathogenesis, a comprehensive treatment approach is warranted. At present, there is a lack of clear delineation between the transition from non-surgical to surgical management. The selection of an AIS treatment strategy depends on the specifics of each individual case. However, certain criteria guide both conservative and surgical approaches [3]. According to available data, conservative treatment can be effective for patients with adequate growth potential. This potential is typically indicated by a Risser sign score of up to 3 and an angle of primary curvature equal to or less than 45 ° [9]. Conservative treatment for scoliotic spinal deformities may include specific exercise regimens (such as Schroth's method, SEAS (Scientific Exercise Approach to Scoliosis), BSPTS (Barcelona Scoliosis Physical Therapy School), the FED method (Fixation, Elongation, Derotation), Functional Individual Therapy of Scoliosis (FITS), Lyon, Side Shift, and the Dobosiewicz method, or DoboMed) and the application of rigid corrective braces [10]. To reduce the progression of curvature during growth and avoid surgical treatment, it is recommended to wear a corset for spinal curvature of 20°–40° [11]. In cases where conservative treatments are not effective, surgical intervention involving vertebral stabilization and spinal fusion may be utilized to halt the progression of the curvature. However, given the high incidence of postoperative complications (up to 22% of cases) and the potential reduction in the quality of life and functionality of patients, conservative management strategies are increasingly favored if possible and when a satisfactory outcome is anticipated [12].

Treatment with rigid braces, such as thoracolumbar sacral orthosis (TLSO), is the most commonly used nonsurgical intervention to prevent the progression of spinal deformity. There are various types of orthoses available, but their common goal is to restore normal spinal contours and alignment through the application of external forces [13, 14].

Treatment with braces is recommended for patients with a curvature between 20 and 40° and a Risser grade of 0 to 2, in order to prevent the progression of scoliosis during spinal growth [15]. As a general rule, braces are worn for a certain period of time each day for several years, until bone growth is complete. This typically occurs at the age of 16 for girls and 18 for boys. According to research, the use of a brace does not affect curvature beyond 40°. However, in this patient group, bracing may potentially slow the progression of curvature and delay the need for surgical correction of scoliosis until spinal maturity, avoiding repetitive surgeries [16]. Based on available data, it is estimated that in approximately 70% of patients who use a brace experience a halt in the progression of their curvature, potentially avoiding the need for surgical intervention [17]. However, the failure rate continues to be relatively high, ranging from 12 to 39% [18]. Several studies have demonstrated that brace therapy, in conjunction with specific exercises for scoliosis, yields better outcomes than simply wearing a brace [19–21].

The success of treatment for AIS requires a high degree of cooperation from patients and their families, including parents, siblings, and friends, as well as orthopedic surgeons and orthotic specialists. Failure to adhere to the prescribed brace wear schedule by patients can often hinder successful treatment outcomes [22, 23].

In Kazakhstan, there is a lack of studies on the effectiveness of rigid braces in combination with SEAS (Scientific Exercise Approach to Scoliosis) therapy as a conservative treatment option for AIS. This study aims to assess the efficacy of rigid Chêneau braces combined with SEAS as a conservative approach to AIS treatment. The data were analyzed in terms of the severity of scoliosis prior to and after the treatment, as well as the duration of brace use.

Materials and methods

Research cohort

This research is based on a clinical observational study conducted as a retrospective analysis of data

prospectively collected from patients with AIS who used Chêneau braces combined with SEAS between 2019 and 2024 at Kinetik, a rehabilitation center in Astana, Kazakhstan. The study received approval from the National Commission on Bioethics of the Republic of Kazakhstan and followed the ethical standards outlined in the 1964 Helsinki Declaration. The patients received detailed information about the study, and their parents/guardians signed a consent form regarding the use of their clinical data for research purposes.

The study included a total of 119 patients (90 female, 29 male), with an average age of 11.8 ± 2.4 years. All patients had never received brace treatment before. An additional criterion for inclusion was the availability of spine radiographic images in the anterior-posterior and lateral views prior to bracing, as well as during subsequent monitoring. To evaluate the treatment outcomes, patients were categorized into four groups based on the location of their scoliosis: thoracic (Th) with a coronal apex between Th3 and Th9 ($n = 14$); thoracolumbar (Th/L), with an apex between Th10 and L1 ($n = 19$); lumbar (L), with an apex between L2 and L4 ($n = 11$), and combined (S), with a double S-curve ($n = 75$).

Bracing

Indications for the bracing of patients with AIS included a Cobb angle between 20° and 40° (at the time of initial treatment) and significant residual spine growth. The aim was to prevent further progression of the scoliotic curve and avoid the need for surgical intervention. The orthopedic specialist was responsible for fitting the patient with a brace and providing information to both the patient and their parents regarding its use. All patients were fitted with Chêneau braces manufactured by the same orthotist. It was advised that the brace be worn for at least 22 h per day. For 21 consecutive days, patients individually received 45-minute SEAS gymnastics sessions, which were supervised by a rehabilitation physician. In the presence of myofascial conditions, massage and physiotherapy (treatment with paraffin and ozokerite) were administered. The patients were monitored by the orthopedic specialist of the clinic, including clinical and radiological examinations. The patients did not receive regular physical therapy, but it was essential to continue SEAS exercises at home for 20–25 min per day at least 5 days a week. They attended the clinic every 6 months throughout the duration of the brace treatment period. At each appointment, clinical monitoring of brace fitting accuracy in growing patients was performed. To evaluate the effectiveness of the treatment, additional radiographic images of the entire spine without a brace were taken. If the Risser grade remained within the range of 0 to 2 and there were substantial modifications in the curvature or growth of the patient's spine, an additional brace was fabricated to facilitate further treatment until reaching skeletal maturity. At each appointment, the duration of daily brace wear was adjusted according to changes in the severity of curvature. If the major curve remained unchanged or worsened, the daily wear time of the brace remained at 22 h. If the curve improved, the wear time could be reduced to between 18 and 20 h. Upon reaching skeletal maturity, brace treatment was discontinued. Skeletal maturity was indicated by an increase in body height of no more than 1 cm over the past 6 months, or grade 4–5 on the Risser scale. Braces could be removed for sports and personal hygiene purposes. The study's outcome was determined based on the criteria used in the BRAIST study [7]. The effectiveness of bracing and the final outcome were assessed based on the Cobb angle of the major curve measured through serial radiographic examinations of the spine. Radiographic examinations were conducted at the initial clinical visit prior to wearing the brace, during the initial assessment of the brace in the clinic, and at the final clinical follow-up. Patients with a progression or regression of the major curvature of ≤ 5° were considered stable [24]. Accordingly, a reduction in the Cobb angle of the major curve by > 5° indicated an improvement in scoliosis severity, and an increase of > 5° was seen as progression. An increase in the Cobb angle ≤ 5° indicated successful treatment. After discontinuation of bracing, all patients underwent follow-up at 6, 12 and 24 months after the end of treatment.

Radiology

A standardized form was utilized to collect clinical and radiographic data. Prior to bracing, all patients underwent a spinal MRI scan to exclude abnormalities in the spinal cord. Complete radiographic images of the spine were obtained using a low-dose biplanar imaging device, EOS (EOS-imaging®, Paris, France), or conventional radiography. Radiographic imaging was conducted before the application of a brace, during brace use, and after the conclusion of brace treatment. The images were taken in standing and lateral projections. Analysis of the images involved the use of Surgimap software (Surgimap®, New York, New York, USA). The radiographic measurements were independently assessed by two experienced radiologists who were unaware of the design of the study. Skeletal maturity was assessed based on the Risser sign (US staging methods) and bone age assessment of the left arm (the Greulich and Pyle method). The radiological parameters included:

(1) Coronal parameters: the primary Cobb angle of the major curve, the secondary Cobb angle of the compensatory curve, coronal alignment (Calignment), C7-plumbline (C7PL).

(2) Sagittal vertebral and pelvic parameters: thoracic kyphosis (TK) Th1–Th12, TK Th4–Th12, lumbar lordosis (LL) L1–S1, pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), sagittal-vertical axis C7-S1 (SVA), Th1-slope of the spine (Th1 SPi), Th9-slope of the spine (Th9 SPi).
(3) Axial plane parameters: apical vertebral rotation (AVR) of the major curve (Raimondi 1).

Curve measurements were conducted by an orthopedic surgeon specializing in scoliosis treatment, under the supervision of a radiologist. The Cobb method was employed using both manual and digital examinations. All subsequent measurements were compared to the initial curvature at the start of the brace treatment period. In this study, the error in the Cobb angle measurements was within the specified limits of 3°, which is in line with the SOSORT/SRS guidelines.

Patient adherence to the treatment plan

The study analyzed the effect of patient adherence to the treatment plan on its effectiveness, without considering the location of scoliosis. The methodology proposed by Karavidas et al. [21] was employed to assess the adherence to the recommendations regarding bracing duration and performing SEAS exercises at home. The following scale was used to assess the adherence to the plan: A = strict adherence, B = partial adherence, and C = poor adherence. Full adherence to the brace treatment corresponded to wearing the brace for 90–100% of the recommended time, partial adherence corresponded to 70–90%, and poor adherence corresponded to less than 70%. Similarly, full adherence to the SEAS exercise plan was defined as performing the prescribed set of exercises 5 days per week, partial adherence implied 3 to 4 days per week, and poor compliance was defined as less than 3 days per week. Adherence to the treatment plan was evaluated independently by the patients' parents. They completed an independent assessment form and maintained a daily log, which they submitted to the researchers on a monthly basis.

For ethical reasons, the study avoided the formation of control groups consisting of patients who did not receive treatment with braces or who received treatment with braces alone, without SEAS therapy. All patients who were eligible for brace treatment received it, and all were advised to perform SEAS at home. However, when analyzing statistical and clinical data, a group of patients who demonstrated poor adherence to the brace treatment and the SEAS exercise recommendations was considered a control group. Thus, the control group included 25 patients who did not comply with the prescribed duration and frequency of SEAS sessions and did not wear the brace for the recommended time (indicators B-B, B-C, C-B and C-C). Indicators from group A-A were compared to those of the entire cohort and those of the control group, and indicators from the control group were compared to the entire cohort.

Questionnaires

The study used specialized questionnaires to evaluate the patients' perception of their clinical outcomes. Thus, upon the conclusion of bracing use, all participants completed the Pediatric Quality of Life Inventory (PedsQL) and the Scoliosis Research Society-22 revised (SRS-22r). The PedsQL score ranges from 0 to 100, with higher scores indicating better quality of life. The SRS-22r consists of 22 items grouped into 5 categories (domains): functionality, back pain, self-image, mental health, and satisfaction with treatment. Each item is rated on a scale from 1 to 5, with 1 being the lowest rating.

Statistical analysis

Statistical analysis was performed using SPSS 25 (IBM®, Armonk, New York, USA). Data are presented as mean ± standard deviation (SD). A paired t-test was employed for intergroup comparison. The significance threshold was set at $p < 0.05$. Multivariate analysis was used to identify risk factors independently predicting the success of the brace treatment. This involved calculating the odds ratio (OR) and its 95% confidence interval (CI).

Results

Evaluation of the effectiveness of the chêneau brace in combination with SEAS gymnastics

Among 119 patients with AIS who completed the treatment program, the triradiate cartilage was found to be open at the beginning of treatment in 50 patients (42%), and closed in the remaining 69 (58%). Of the entire cohort, 44% of patients ($n = 52$) had Risser grade 0 at the start of treatment, 31% had Risser grade 1 ($n = 37$), and 25% had Risser grade 2 ($n = 30$). The mean Risser score was 0.8 at the beginning of treatment (range 0–2) and 4.5 at the end (range 3–5). Curvature progression assessment showed that 68 patients (57.1%) maintained stability of the major curve. A reduction in the major curve > 5° was observed in 31 patients (26.1%), while an increase of > 5° occurred in 20 patients (16.8%). At the same time, 6 patients (5.1%) had a Cobb angle of > 45° in the major curve, suggesting the need for surgical intervention to correct scoliosis. Therefore, treatment with Chêneau braces in combination with SEAS exercises was successful in 99 patients (83.2%).

In the group of patients with S scoliosis, the mean Cobb angle was 30° before bracing (range: 23–37°) for the larger curve and 22° (16–25°) for the smaller curve. In the first brace radiograph, the indicators were 17° (range: 12–32°) for the larger curve and 11° (8–23°) for

Table 1 Patients with AIS who have undergone Brace treatment in combination with SEAS gymnastics

	S scoliosis ($n=75$)*	Th scoliosis ($n=14$),	Th/L scoliosis ($n=19$)	L scoliosis ($n=11$)
Pre-Brace Cobb Angle	30° (range: 23–37°)/ 22° (16–25°)	32° (range: 22–37°)	29° (range: 24–40°)	26° (range: 22–38°)
First Brace Cobb Angle	17° (range: 12–32°)/ 11° (8–23°)	18° (range: 10–32°)	16° (range: 12–30°)	20° (range: 14–34°)
Last Follow-up Cobb Angle	26° (range: 18–34°)/ 19° (13–24°)	26° (range: 18–34°)	23° (range: 16–34°)	21° (range: 19–32°)
Mean Improvement in the Cobb Angle	3.9°/3.2°	4.2°	5.4°	3.8°
Triradiate Cartilage	Open: 33 Closed: 42	Open: 5 Closed: 9	Open: 8 Closed: 11	Open: 4 Closed: 7
Risser grade at start of bracing	0.7 (range: 0–2)	0.8 (range: 0–2)	0.9 (range: 0–2)	0.5 (range: 0–2)
Risser grade at end of bracing	4.4 (range: 3–5)	4.5 (range: 3–5)	4.6 (range: 3–5)	4.3 (range: 3–5)
Age at start of bracing; years	11.4 (range: 10.2–14.2)	11.6 (range: 10.2–15.6)	12.1 (range: 10.4–15.3)	11.7 (range: 10.4–15.4)
Age at end of bracing; years	17.4 (range: 15.2–18.4)	16.6 (range: 14.8–18.1)	17.1 (range: 13.8–17.6)	16.4 (range: 14.3–18.2)
Duration of brace treatment; years	3.6 (range: 2.6–4.5)	3.0 (range: 2.5–4.8)	3.3 (range: 2.6–5.2)	3.5 (range: 2.4–4.4)
Follow-up period; years	2.8 (range: 2–3.3)	2.5 (range: 2–3.0)	2.5 (range: 2–3.0)	2.7 (range: 2–3.2)

Note: *- for patients with S scoliosis, the table shows the Cobb angle of the larger and smaller curves

the smaller one. At the last follow-up visit, the mean Cobb angles were 26° (range: 18–34°) for the larger curve and 19° (13–24°) for the smaller one, with an average improvement of 3.9° ($p=0.03$) and 3.2° ($p=0.04$), respectively, during treatment.

In the group of patients with Th scoliosis, the mean Cobb angle was 32° before bracing (range: 22–37°). According to the first brace radiograph, the angle was 18° (range: 10–32°). At the last follow-up, the mean Cobb angle was 26° (range: 18–34°), with an average improvement of 4.2° ($p=0.04$) during treatment. In the group of patients with Th/L scoliosis, the mean Cobb angle was 29° before bracing (range: 24–40°). The first brace radiograph showed that the angle was 16° (range: 12–30°). At the last follow-up, the mean Cobb angle was 23° (range: 16–34°), with an average improvement of 5.4° ($p=0.02$) during treatment. In the group of patients with L scoliosis, the mean Cobb angle was 26° before bracing (range: 22–38°). The first brace radiograph demonstrated that the angle was 20° (range: 14–34°). At the last follow-up, the mean Cobb angle was 21° (range: 9–32°), with an average improvement of 3.8° ($p=0.03$) during treatment.

The average age of patients was 11.8 years (range 10.2–15.6) at the start of the brace therapy and 16.7 years (range 13.8–18.2) at the end of the treatment. The average duration of treatment with a brace was 3.3 years (range 2.4–5.2), while the average follow-up period after the conclusion of treatment was 2.6 years (range 2-3.2) (Table 1).

Therefore, patients who received brace treatment combined with SEAS gymnastics had a statistically significant improvement in the Cobb angles. Additionally, there was a significant reduction in the TK (Th1–Th12) curve in these patients (before bracing compared to post-treatment period: 32.4 ± 7.3 vs. 28.6 ± 9.3; $p=0.03$). Other measured sagittal parameters and Raimondi angles in the axial plane showed no significant change. There were also no significant differences in treatment success for Chêneau bracing combined with SEAS, regardless of the curvature location.

Table 2 Predictors of successful Brace treatment (curvature progression ≤ 5°)

Characteristics	Odds Ratio	95% Confidence Interval	*p*-Value
Scoliosis in close family	1.335	1.086–1.936	0.035
Single major curve	1.155	1.063–2.031	0.025
Major curve at the start of bracing	1.093	1.068–2.068	0.03
Major curve reduction during the first in-brace PA spine radiograph	1.467	1.121–2.232	0.02
Risser grade	1.346	1.064–2.342	0.03
Triradiate cartilage	1.575	1.173–2.503	0.03
Post-menarche status	1.752	1.212–2.614	0.02
Adherence to therapy	1.223	1.079–1.928	0.02
Treatment time (months)	1.158	1.051–1.632	$p<0.001$

Predictors of successful brace treatment (curvature progression ≤ 5°)

Multivariate analysis was used to identify predictors of successful brace treatment outcomes. The analysis demonstrated that the predictors of successful Chêneau brace therapy are the absence or presence of scoliosis in family members (OR = 1.335, 95% CI: 1.086–1.936; p = 0.035); single major curve (OR = 1.155, 95% CI: 1.063–2.031; p = 0.025); major curve at the start of bracing (OR = 1.093, 95% CI: 1.068–2.068; p = 0.03); major curve reduction during the first in-brace PA spine radiograph (OR = 1.467, 95% CI: 1.121–2.232; p = 0.02), high Risser grade (OR = 1.346, 95% CI: 1.064–2.342; p = 0.03), closed (not opened) triradiate cartilage (OR = 1.575, 95% CI: 1.173–2.503; p = 0.03), post-menarche status (OR = 1.752, 95% CI: 1.212–2.614; p = 0.02), adherence to therapy (OR = 1.223, 95% CI: 1.079–1.928; p = 0.02), treatment time (months) (OR = 1.158, 95% CI: 1.051–1.632; $p<0.001$) (Table 2).

Adherence to the treatment plan and its effect on the success of treatment

Overall, the patients demonstrated a good level of adherence to the treatment plan. Specifically, A-A indicators (adherence to recommendations regarding the timing of brace wear and SEAS exercise, respectively) were observed in 71 (59.7%) of patients, A-B in 12 (10.1%) of patients, A-C in 8 (6.7%) of patients, B-A in 3 (2.5%) of patients, B-B in 6 (5%) of patients, B-C in 4 (3.4%) of patients, C-A in none of the patients (0%), C-B in 5 (4.2%), and C-C in 10 (8.4%). Accordingly, 25 patients with B and C indicators according to both criteria were classified as a control group. Indicators from group A-A were compared to those from the entire cohort and control groups, and indicators from the control group were compared to the entire cohort.

According to the analysis of 71 patients in group A-A, 49 patients (69.0%) showed no change in the Cobb angle of their major curve, 22 patients (31.0%) had a decrease in the angle, and none of the patients experienced an increase in curvature. The rate of curvature progression in this group was significantly lower than in the entire cohort (0% versus 16.8%, $p = 0.004$). In the group of 25 patients who did not fully or adequately follow the treatment plan (either B or C for both parameters), 12 patients (48%) had a stable Cobb angle in the major curve, 6 patients (24%) had a decrease in the angle, and 7 patients (28%) had an increase in curvature of > 5°. Three patients (12%) reached a Cobb angle > 45° in the major curve. The rate of curvature progression was significantly higher than in the entire cohort (28% vs. 11.5%, $p = 0.02$) and the A-A group (28% vs. 0%, $p < 0.001$).

Quality of life and adverse events

Among 119 patients who received brace therapy, 94 completed the PedsQL at the following time points: before starting brace use, during therapy, and after discontinuing brace wear. The mean PedsQL scores of these patients prior to and during brace use did not differ significantly: 79.6 and 77.8, respectively ($p = 0.97$). Conversely, the mean PedsQL scores after discontinuation of brace wear were statistically significantly greater than those prior to brace initiation (85.4, $p = 0.027$). The SRS-22r questionnaire was completed by 86 patients. The results revealed post-treatment improvements in indicators functionality, self-image, mental health, with an average level of treatment satisfaction of 4.62 ± 0.46 (Table 3).

There were no significant differences in the percentage of patients experiencing any adverse events ($p = 0.46$) or back pain ($p = 0.12$) prior to and during the treatment period. Side effects on the skin area covered by the brace were reported by 14 out of 119 patients (approximately 8%) who used the brace during the study.

Table 3 SRS-22r results for 86 patients with AIS

Indicator	Patients ($n = 86$)		p
	Pre-treatment	Post-treatment	
Functionality	3.67 ± 0.43	4.24 ± 0.71	< 0.001
Back pain	3.62 ± 0.36	3.78 ± 0.32	0.12
Self-image	3.47 ± 0.46	3.92 ± 0.15	0.008
Mental health	3.58 ± 0.37	3.87 ± 0.14	0.01
Satisfaction with treatment	-	4.62 ± 0.46	-

Discussion

The current study has demonstrated the high efficacy of conservative treatment for AIS using Chêneau braces in combination with the SEAS exercise regimen. Among the patients involved in this study, 83.2% experienced no curvature progression (57.1% maintained stability, 26.1% demonstrated regression of curvature). Only 6 patients (5.1%) had a Cobb angle exceeding 45° in the major curve by the end of therapy.

Bracing, as a conservative treatment option, is widely used for AIS. Given the high risk of curvature progression in adolescents with AIS, bracing is highly advisable and has undeniable benefits over other treatments. The BRAIST study has confirmed the efficacy of bracing. According to the results, the treatment was successful in 72% of cases, and the treatment prevented the progression of scoliosis to a 50° angle. As a result, the patients managed to avoid surgical intervention. Additionally, only 48% of the cases in which bracing was not utilized resulted in AIS progressing to 50° [23]. Nevertheless, bracing is less effective for patients with curvature greater than 40°, and its outcomes remain insufficiently explored [24]. Currently, there is a wide variety of braces, and the outcomes of curvature correction vary [25, 26]. The classification of scoliosis braces developed by the International Society on Scoliosis Orthopedic and Rehabilitation Treatment (SOSORT) is based on the following criteria: primary action, rigidity, location, primary corrective plane, and construction [27]. According to recent studies, rigid braces typically have a higher rate of effectiveness compared to more elastic options [28].

There are various approaches to brace treatment depending on the duration of use: permanent, intermittent, and nighttime. At present, there is conflicting data on the efficacy of permanent versus nighttime-only corset use. Thus, Weinstein et al. [29] have reported that the efficacy of the treatment decreases when the duration of wearing the brace is less than 17 h per day. On the other hand, a systematic review and meta-analysis have not revealed a significant difference in the treatment outcomes between permanent and nighttime braces [30].

In this study, we investigated the outcomes of using the Chêneau brace in combination with a specific set of scoliosis exercises (SEAS) for adolescents with IS. The Chêneau brace is one of the most frequently prescribed

options for adolescents with IS. This brace consists of asymmetrical thoracolumbar sacral orthosis with anterior openings and expansion voids in concavities. The design of the brace is based on three-dimensional (3D) correction of spinal deformities, which may be combined with specific scoliosis exercise therapy to optimize overall treatment outcomes [31]. The patients were recommended to use the brace for at least 22 h per day. In our study, similar to the BRAIST study [7],, the criterion for the efficacy of brace therapy was the reduction in scoliosis progression by less than 5°. Of the 119 patients with AIS who received brace therapy, the increase in the curvature of the major curve was greater than 5° in only 20 patients (16.8%).

A single-center prospective study conducted by Pepke et al. [32] in Germany involved adolescents diagnosed with AIS and presenting with curvature angles ranging from 20 to 45 degrees. The prescribed wearing duration for the brace was 23 h per day, with radiographic assessments conducted at 6- and 12-months following the cessation of brace wear (the criterion for cessation was growth plate closure or an increase in the major curve exceeding 45°). A notable finding from a study on the topography of scoliotic curvatures in specific subgroups revealed variations among them. The group experiencing primary worsening of the Cobb angle following C-brace therapy predominantly comprised patients with thoracic scoliosis, accounting for 78% of cases. Conversely, the group exhibiting primary post-treatment improvement in the Cobb angle featured a higher proportion of individuals with thoracolumbar (33%) and lumbar (28%) scoliosis [32].

A study conducted by Weniger et al. [33] examined 159 cases of Adolescent Idiopathic Scoliosis (AIS) with curvature angles ranging from 20 to 45°. Treatment involved the use of Chêneau braces. Specifically, the patients wore permanent brace orthoses daily for up to 23 h. The mean Cobb angle before treatment initiation was recorded at 28.39°±9.44°, which decreased to 27.7°±12.34° upon the completion of treatment. Notably, stabilization of scoliosis (< 5°) was achieved in 136 patients (85.5%). However, during the final follow-up, progression of the Cobb angle exceeding 5° was observed in 23 cases, leading to secondary surgery in 19 instances. The study concluded that brace treatment is an effective approach for managing curvatures within the range of 20–40°.

Tsaknakis et al. [34] conducted a study on the treatment of 88 cases of AIS, which also included 22 cases of neuromuscular scoliosis. The initial treatment criteria were consistent with those of previous studies, with the average scoliotic curvature angle at the beginning of brace therapy measured at 30.4° ± 12.5°. The primary brace intervention resulted in a reduction of the scoliotic curve by 31%, bringing it down to 20.9°. Interestingly, children and adolescents with lower maturity status demonstrated greater success with brace therapy compared to patients with higher Risser's signs. Furthermore, the researchers found that obese children exhibited less success during bracing treatment compared to those of normal or underweight status.

Negrini et al. [19] studied the effectiveness of AIS treatment for 48 patients who used Lyon or Sforzesco-SPoRT braces in conjunction with SEAS. They found that the treatment was successful for 96% of these individuals with no patients reaching a curvature level of 45° or more. Kwan et al. [20] conducted a study of 24 patients who received treatment based on the use of the Boston brace and a set of PSSE exercises. The treatment resulted in a success rate of 79%.

A prospective study led by Karavidis et al. [21] focused on conservative treatment of idiopathic scoliosis utilizing PSSE gymnastics in conjunction with a permanently worn Chêneau brace. According to the findings, of the sixty-two patients studied, 65.3% remained stable, with the curvature angle exhibiting a change of less than 5°. In turn, 23.2% experienced a curvature improvement of more than 5°, and 11.5% showed progression of scoliosis. The Chêneau brace demonstrated a correction rate of 49.7% for the thoracic region and 61.7% for the lumbar region. Curvature progression assessment revealed that the Chêneau brace correction (31.7% for thoracic and 34.4% for lumbar) and compliance (81.8% for Chêneau brace C, 63.6% for PSSE C) fell below the average. Notably, the group of patients who used the brace for more than 20 h (65.3%) exhibited significantly superior outcomes, with 70.9% remaining stable, 29.1% showing improvement, and 0% experiencing progression.

The SRS recognizes compliance as a critical aspect of the final outcome and recommends ensuring adherence to the prescribed treatment plan when using braces [2]. Brox et al. [35] in their study of a cohort of 459 patients with AIS, found that the risk of progression was significantly reduced for those who followed the recommendations for brace use compared to those who did not. The current study demonstrates the effectiveness of the Chêneau braces as part of a treatment regimen that includes a set of SEAS exercises. At the same time, compliance with the treatment plan, including wearing the corset for the recommended time and performing the SEAS exercises as prescribed, was essential for achieving positive outcomes.

Using multivariate logistic regression models, previous studies have shown that the degree of scoliotic angle, Risser grade, and vertebral rotation have a predictive effect on bracing [18, 22, 36]. The study has shown that the effectiveness of bracing for patients with AIS is higher for patients having closed triradiate cartilage, post-menarche status, a Risser grade of 2 or lower, or a

smaller Cobb angle at the start of treatment, aa well as for patients showing good adherence to the therapy.

The patient's perception of the treatment is another indicator of treatment effectiveness. To evaluate this parameter, this study utilized two questionnaires, specifically the Pediatric Quality of Life Inventory (PedsQL) and the Scoliosis Research Society-22 revised (SRS-22r). At the final follow-up, patients who completed bracing (with or without surgery for scoliosis) reported high levels of satisfaction. This was linked to normal functionality, positive self-esteem, and decreased pain after treatment for scoliosis.

This study has some limitations. These include the lack of monitoring of patient compliance with the brace wearing requirements using sensors installed on the device. The SRS guidelines support this practice and suggest that the effectiveness of brace treatment can be assessed based on the actual success rate in managing scoliosis and preventing surgery, regardless of patient adherence to the treatment plan [17].

Conclusions

The study confirmed that the non-surgical treatment for AIS with Chêneau braces combined with a specific set of exercises known as SEAS can reduce the risk of spinal curvature progression. Using multidimensional regression models, the study demonstrated that predictors of success with the Chêneau brace treatment include the presence or absence of scoliosis in family members, closed triradiate cartilage, post menarche, Risser grade, smaller initial scoliosis angle, adherence to treatment, and treatment duration (months).

These findings underscore the importance of personalized therapy tailored to the unique characteristics of each individual patient in order to avoid over-treatment. Patient adherence to the treatment regimen (including recommendations regarding the duration of brace wear and SEAS exercise) contributes to enhancing the efficacy of treatment. At the conclusion of treatment, patients reported restored functionality, improved self-image, reduced pain, and high levels of satisfaction. The findings may assist in monitoring the effectiveness of corset therapy in patients with AIS.

Author contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by AA, DK, AK, SD. The first draft of the manuscript was written by VT. All authors read and approved the final manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

All methods were performed in accordance with the principles of the Declaration of Helsinki. The study was approved by Local Ethics Committees of NSC Astana Medical University (Protocol No. 3 of 10.11.2023).

Competing interests

The authors declare no competing interests.

Conflict of interest

This research has no conflict of interests.

Informed consent

Written informed consent was obtained from the parents.

Consent to publish

Not applicable.

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