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RESEARCH

The "Idiopathic Scoliosis Graphical Representation of Worsening Trend of Natural History" (IS-GROWTH) communication tool provides a reliable prediction useful to manage long-term treatment during growth. 2025 SOSORT award winner

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Abstract

Purpose Effective communication with patients regarding long-term conservative treatment for idiopathic scoliosis necessitates an understanding of its natural history. Existing predictive models have limitations in this regard. Our study aimed to develop and evaluate the reliability and utility of the Idiopathic Scoliosis Graphical Representation Of Worsening Trend of Natural History (IS-GROWTH) communication tool.

Methods IS-GROWTH development and validation involved consecutive untreated patients with radiographs taken at and prior to the first consultation. To construct the model, we calculated the minimum and maximum progression of patients grouped by 10° Cobb angle range and growth phases. IS-GROWTH is developed for each patient, incorporating the expected progression of each growth phase into the preceding one. For temporal validation, we included patients whose data were obtained after the development of IS-GROWTH, comparing IS-GROWTH predictions with natural history. We calculated the percentage of correct predictions and applied the chi-square test. We also examined the distribution of natural history within IS-GROWTH. Finally, we piloted the tool's usefulness for communication with patients among a group of physicians using it for several years.

Results To develop IS-GROWTH, we analysed 3,184 radiographs from 1,818 participants, spanning from infancy to adolescence. For validation, we included 552 patients and found an accuracy of 95% (95% Confidence Interval, 93-97%) after adjusting for the 5° radiographic measurement error. Nineteen physicians (7.3±5.8 years' experience) reported using IS-GROWTH in 30% of their patients (range 5-95%) and found it most useful during follow-up (84%) to motivate patients (79%).

Conclusion IS-GROWTH is reliable and useful. We now regularly use it to deepen our understanding of individual natural history and enhance communication with patients.

Keywords Idiopathic scoliosis · Natural history · Shared decision-making · Patient-physician communication

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Introduction

Idiopathic Scoliosis (IS) management is dictated by the severity of the spinal curvature, with treatment strategies broadly classified into conservative (rehabilitation) and surgical approaches [1]. Rehabilitation is preferred in low to medium-degree curves and involves long-term therapy spanning several years until skeletal maturity. A recent study involving 1,938 adolescents reported an average treatment duration of approximately 3.8 years [2]. Additionally, many patients present before adolescence, leading to an extended observation period [2].

Rehabilitation typically consists of a series of interventions, including bracing and/or scoliosis-specific exercises [3, 4]. Adherence to therapy is a critical determinant of success [5] but poses significant challenges, as these treatments are often demanding and require sustained patient compliance. Strategies to improve adherence [6], including shared decision-making [2], require good communication with patients and parents.

A thorough understanding of the natural history of IS is crucial for effective communication, accurate prognosis, and optimized treatment strategies. However, past studies highlighted the unreliability of classical natural history data. Di Felice et al. [7] found that traditional prognostic information was inconsistent, necessitating more robust studies. Subsequent advancements led to the development of prognostic models like the BrAIST Calc [8], specifically focused on patients aged 9–16 years with IS curves between 15–44° and Risser stages 0–2. BrAIST Calc restitutes the final result in terms of the probability of reaching the threshold of 45°, but does not describe other details relevant to long-term treatments.

Parent et al. [9] developed predictive models based on a large dataset of 2,317 untreated patients aged 6–25 years, with a median prediction error of 4.5° and an accuracy rate of 80–84% within a 10° range. Unfortunately, the model is linear, whereas untreated IS progression is not [10]. For this reason, Negrini et al. [11] refined these models, showing different progression in three growth phases: before (ages 6–10), during (ages 11–Risser 2), and after puberty (Risser 3 onward). They achieved an accuracy of 74% within a 5° margin, and up to 95% within a 10° to 15 ° margin. However, both studies provided only a short-term view, ranging from two to three years [11] to up to five years [9], which is insufficient to capture the entire treatment period, particularly for juvenile or infantile scoliosis. For these reasons, although clinicians can utilise them to predict the short-term evolution of untreated IS, they have limited effectiveness in communicating with patients, especially once treatment commences.

We produced this study to address these limitations and provide a comprehensive tool that can show the natural course of scoliosis progression throughout the entire growth period, facilitating communication with patients. The primary objectives of our study were to (1) develop the tool, which we called Idiopathic Scoliosis Graphical Representation of Worsening Trend of Natural History (IS-GROWTH), (2) perform a temporal validation, and (3) conduct a preliminary evaluation of its clinical utility.

Materials and methods

Methods

Study design

The study was performed in three phases: (1) development of IS-GROWTH; (2) retrospective temporal validation of IS-GROWTH; (3) cross-sectional clinical utility evaluation through a survey of long-term expert users. The setting was a tertiary-level institute specialized in idiopathic scoliosis rehabilitation treatment. The study was approved by the ethical committee (Comitato Etico Milano Area 2, approval number 801_2015 bis). We did not have external funding. We reported results using the STROBE checklist [12].

Development of the prediction tool

Participants According to a previously described methodology [9], we included only natural history information of never-treated patients of all ages using the following inclusion criteria: idiopathic scoliosis defined as a radiographic curve above 10° [13, 14]in at least one of the considered radiographs, acceptance of blind data management for research purposes, at least two available frontal AP full-spine radiographs performed (1) at the first consultation at our Institute and (2) before the consultation. We excluded patients with previous brace treatment and any sign suggesting a secondary scoliosis or other disease.

Variables We collected all frontal full-spine radiographs obtained at and before the first consultation at our Institute. We retained multiple radiographs from the same patient to maximise the available data. We considered the following variables: sex, age and European Risser sign (from now on reported as Risser) at the time of the radiographs, and Cobb degrees of the major curve. The data collection was con-

ducted in May 2017, including all patients from September 2006 onward.

Development of IS-GROWTH To build the IS-GROWTH model, we standardized growth phases among individuals and between sexes by defining key periods: before (up to age 10), during (within one year of reaching Risser 1), and after the growth spurt (beyond Risser 1). We calculated scoliosis progression rates between consecutive radiographs of each patient, using the changes in Cobb angles specific to their growth phases. Patients were grouped by Cobb angle ranges of 10 degrees and by their respective growth phases. For each group, we calculated the minimum and maximum progression rates to establish a comprehensive understanding of potential scoliosis evolution. IS-GROWTH is individually tailored, incorporating both the minimum and maximum expected progression for each phase, added to the Cobb degree range attained in the prior phase. This approach allows for a dynamic representation of each patient's scoliosis trajectory, adapting as they progress through their growth stages. The model visually illustrates predicted developments against critical thresholds for surgical intervention and functioning in adulthood based on Cobb angle measurements. All details on IS-GROWTH development are reported in Appendix 1.

Temporal validation of the prediction tool

Participants As needed for temporal validation studies [15], we included all consecutive patients of all ages who came to our Institute after the development of IS-GROWTH in May 2017, adhering to the same inclusion criteria used for the development of IS-GROWTH. After May 2017 we expanded our natural history radiograph information as part of another research project [9, 11].To increase the strength of the validation process through the inclusion of more participants, we also utilized these new data not available at the time of IS-GROWTH development. The final data collection was performed in October 2023.

Variables We considered the same variables used to develop IS-GROWTH. At this stage, we added (1) the length of observation and (2) the "IS-GROWTH percentage". This last variable is calculated by considering the position of the Cobb degrees of the patient at the last radiograph relative to the range of IS-GROWTH predictions: 100% corresponds to the worst IS-GROWTH prediction, and zero corresponds to the lowest. When the actual natural history of the patient fell outside the range of IS-GROWTH, the "IS-GROWTH percentage" was either below zero or above 100%.

Analysis We calculated the IS-GROWTH from the first available radiograph of all included patients and checked if their natural history fell within the boundaries of their personalized IS-GROWTH prediction range. We also took into account the measurement error of the radiographs [3] because it could influence the results. For this reason, we considered three IS-GROWTH predictions: (1) unadjusted and adjusted for (2) the ±3° intra-examiner and (3) the ±5° inter-examiner radiographic errors [3]. We calculated the reliability in terms of the percentage of patients within the boundaries of IS-GROWTH predictions with a 95% confidence interval (95CI) and applied the chi-square test for statistical comparisons.

We also examined the distribution of patients within the IS-GROWTH prediction in terms of the percentage of patients in each quartile of their prediction (e.g., if the IS-GROWTH percentage was below 25% or above 75%, the patient was considered to be in the 1 st or 4th quartile of their prediction, respectively). For the variables sex, starting Cobb degrees, age, and Risser stage, we verified (1) the correlations with the IS-GROWTH percentage and (2) if they influenced the IS-GROWTH percentage and the distribution of patients within the different predictions.

Clinical utility assessment

We performed a cross-sectional observational study with a survey. It involved all physicians in our institute who have regularly used IS-GROWTH in their clinical practice since 2017. The questionnaire for physicians included questions regarding the usefulness of IS-GROWTH for communication, with two sections addressing its utility for them as clinicians and their perception of its utility for patients and their families.

Results

To develop IS-GROWTH, we considered 3184 radiographs of 1818 participants: 2404 radiographs from 1344 adolescents, 756 from 459 juveniles, and 24 from 15 infantile idiopathic scoliosis patients, respectively. We excluded 321 pairs of radiographs, crossing the considered growth phases and 143 outliers. Figure 1 reports the example of IS-GROWTH in four different cases.

For validation, we included 552 patients, (74% females) aged 12.4±2.0 and 14.7±1.7 with a curve of 19±9° and

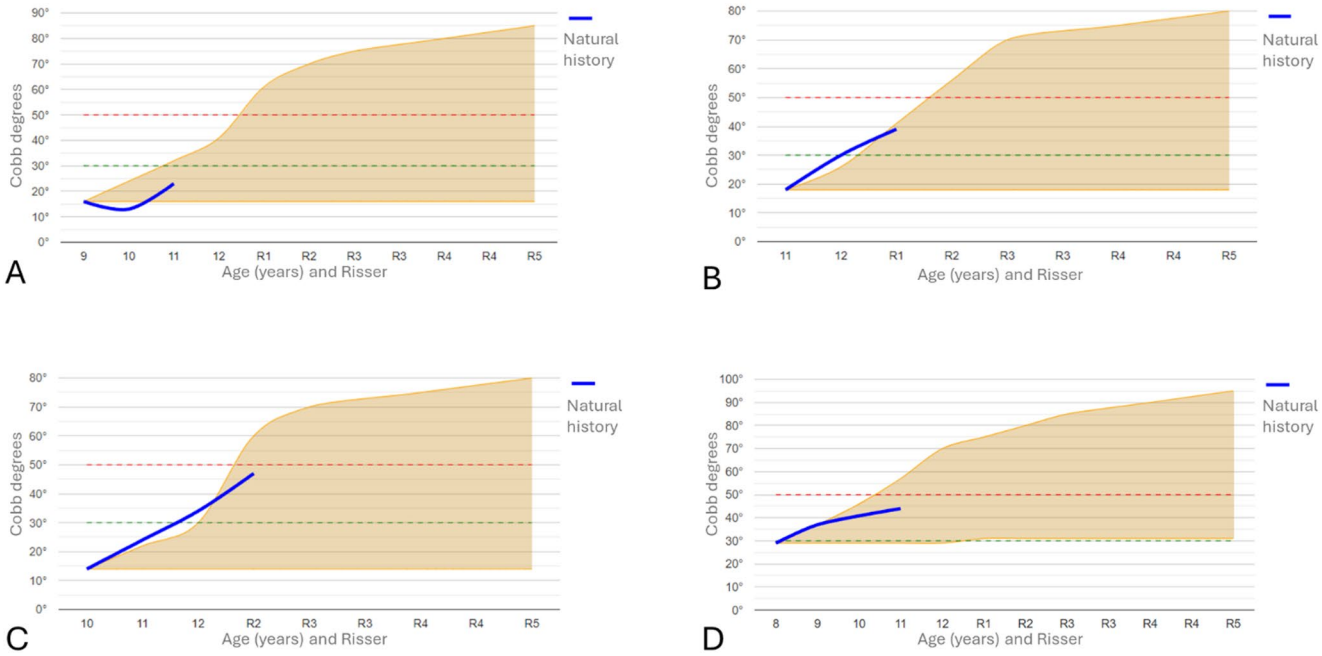

Fig. 1 Example of four different natural histories (2 juveniles and 2 adolescents) reported in their IS-GROWTH predictions. IS-GROWTH is reported from the start of observation (first radiograph) as a brown area gradually enlarging between the best and worst possibilities calculated as reported in the text; a blue line shows the recorded evolution. (**A**) Patient with three radiographs at Risser 0 and age 9, 10 and 11, respectively. (**B**) Patient with two radiographs at Risser 0 age 11 and 12, and one at Risser (1) **C**. Natural history of a patient with two radiographs at Risser 0 age 10 and Risser (2) **D**. Natural history of a patient with three radiographs at age 8, 9 and 11

Table 1 Characteristics of the patients included in the Temporal validation study at the first and last radiograph performed

		First radiograph		Last radiograph		*P*
		Av	SD	Av	SD	
Cobb degrees		19	9	26	11	<0.001
Age		12.4	2.0	14.7	1.7	<0.001
Risser stage	*0*	283		0		<0.001
	1	109		70		
	2	87		151		
	3	66		175		
	4	7		112		
	5	0		44		
Progressed	>5°			271		
Unchanged	±5°			272		
Improved	<5°			9		

26±11° at the start and end of observation, respectively (Table 1). Unadjusted IS-GROWTH predicted the natural history in 74% (95CI 70–78) of cases. Adjusting for the radiographic measurement errors of ±3° and ±5°, the accuracy improved statistically significantly to 90% (88–92) and 95% (93–97), respectively (Table 2). The distribution of patients within the possible predictions showed a tendency to concentrate in the lowest level of the prediction, with the 3rd quartile (75% of patients) in the lowest 50% for all predictions (Table 2). Completely failed predictions (i.e., outside the IS-GROWTH boundaries of more than 5°) were more common in patients who progressed above the maximum prediction than below the minimum: 26 out of 48 (54%), 30 out of 33 (91%) and 3 out of 4 (75%) for the prediction model unadjusted, or adjusted±3° and ±5°, respectively (Fig. 2). We found no correlation of the IS-GROWTH percentage with the baseline data, but with increasing Cobb degrees, age and Risser stage and with decreasing observation time quartiles, there was a decrease in IS-GROWTH percentage (Table 3). We did not find differences for sex (Table 4).

Nineteen physicians with 7.3±5.8 years of experience in the field responded to the survey (95% response rate). They all used IS-GROWTH regularly and reported using it in 30% of patients (range 5–95%). They found it useful mostly during follow-up (84%) to understand the patients'

Table 2 Accuracy of IS-GROWTH predictions (unadjusted, and adjusted for the ±3° intra-examiner and ±5° inter-examiner radiographic measurements errors) and distribution of natural history cases within the IS-GROWTH prediction. N: number

	Adjusted±5°		Adjusted±3°		Unadjusted	
	N	%	*N*	%	*N*	%
Predictions						
Correct	527	95%	495	90%	410	74%
Partial failure (within 5°)	21	4%	24	4%	104	19%
Complete failure (over 5°)	4	1%	33	6%	38	7%
Distribution of cases within the IS-GROWTH prediction						
1 st quartile	21%		18%		6%	
3rd quartile	50%		50%		47%	
95th percentile	79%		78%		86%	

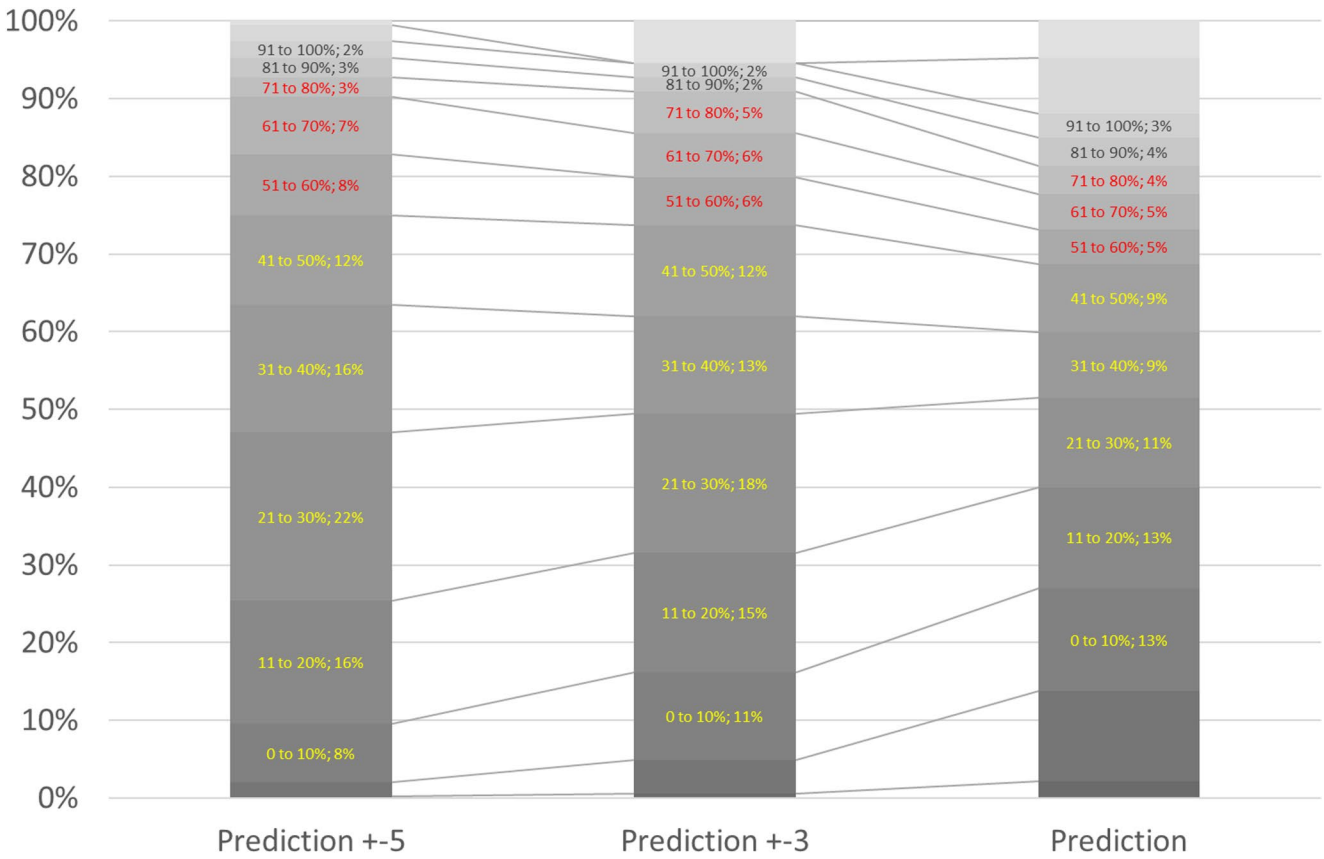

Fig. 2 Distribution of natural history cases within the IS-GROWTH prediction (unadjusted, and adjusted for the ±3° intra-examiner and ±5° inter-examiner radiographic measurements errors). Yellow numbers: IS-GROWTH percentage below 50%; red numbers: IS-GROWTH percentage above 50%; black numbers: IS GROWTH percentage above 80%

evolution (63%), to motivate patients (79%) and inform on results (68%) and prognosis (53%) (Table 5).

Discussion

We developed IS-GROWTH using unconventional methods, with the sole aim of facilitating communication with patients and overcoming the current difficulties of prediction models in describing the potential evolution of individual patients at all ages and throughout growth. This paper demonstrates that the IS-GROWTH is reliable and provides valuable insights into the potential evolution of individual patients' scoliosis. Moreover, it proved to be valid for clinical use for understanding the evolution and communicating with patients.

Since achieving a complete correction of the IS is usually unfeasible, the primary goal of treatment is to alter the natural history, possibly slightly improving and sometimes only stopping or minimizing the curve's progression during growth [3]. IS can be more or less aggressive, and its natural history varies greatly from case to case [9]. Due to

Table 3 Influence of starting Cobb degrees, chronological and bone age (Risser) and length of observation on IS-GROWTH percentage (see text for definition)

	1 st quartile	2nd quartile	3rd quartile	4th quartile	Significant differences
Cobb degrees					
Quartiles	*5–12*	*13–16*	*17–23*	*24–52*	
IS-GROWTH percentage	38±31%	28±33%	24±28%	22±29%	1 vs. 2, 3, 4
Age					
Quartiles	*5.9–10.8*	*10.9–12.5*	*12.6–13.7*	*13.8–17.7*	
IS-GROWTH percentage	31±27%	32±32%	27±33%	22±30%	4 vs. 1, 2
Risser					
Quartiles	0	1	2	3>	
IS-GROWTH percentage	33±30%	29±32%	27±32%	7±17%	4 vs. 1, 2, 3
Length of observation					
Quartiles	0.1-1	1.1–1.7	1.8-3.0	3.1–10.0	
IS-GROWTH percentage	15±27%	32±32%	31±32%	33±28%	1 vs. 2, 3, 4

Table 4 Influence of sex on IS-GROWTH percentage (see text for definition)

	Females	Males	*P*
Number	74%	26%	
Cobb	20±9	17±8	<0.05
Age	12.1±1.9	13.1±2.2	<0.001
Length observation	2.3±1.7	2.5±1.8	NS
IS-GROWTH percentage	28±30%	28±32%	NS

Table 5 Moments and reasons to use IS-GROWTH according to physicians using the instruments regularly since 2017

		To help physicians	To help patients
When do you use IS-GROWTH?	At follow-up	84%	63%
	At first consultation	26%	42%
	In other moments	21%	16%
	At difficulties with compliance	-	42%
	At the end of treatment	-	37%
For what do you use IS-GROWTH?	To understand the pathology	63%	-
	For other reasons	26%	-
	To decide treatments	21%	-
	To motivate patients	-	79%
	To inform on results	-	68%
	To inform on prognosis	-	53%

ethical concerns, untreated IS is rarely studied. The current evidence favoring the efficacy of bracing for IS [16, 17] makes natural history studies even more challenging than before [9] due to the lack of equipoise concerning the at-risk population and the impossibility of leaving patients untreated. Therefore, we do not anticipate further natural history studies employing classical methodologies (prospective observation).

Effective communication with adolescents and their parents is the foundation of adherence and the outcomes of AIS treatment [2]. Setting realistic and achievable goals can motivate individuals with IS and their parents to initiate and sustain rehabilitation despite its challenges. Clinicians often need to explain that stabilizing in Cobb angle, or even a slight worsening, is still a positive outcome for scoliosis with high evolutionary potential (Fig. 3).

This concept is challenging for patients who lack a comprehensive and personalized understanding of their disease's natural history. Figure 3 presents four examples of IS-GROWTH use in four different patients, including their basic clinical and prognostic information, as well as the treatment performed. The available IS-GROWTH models can aid in prognostic discussions and the interpretation of the achieved results.

Several tools have been proposed in the literature over the last few years to predict the natural history of patients with scoliosis [8, 9, 11, 18]. Comparing IS-GROWTH to the main studies on the topic can help understand the strengths and weaknesses of this tool (Fig. 4). Parent et al. [9] model presents three key limitations: a relatively short-term prediction (up to 5 years), a large error margin with accuracy not reaching 95% (up to 91%) even within 15° of the prediction, and a linear development that does not correspond with the knowledge on scoliosis natural history. Negrini et al. [11] addressed the linearity problem by segmenting scoliosis progression into three distinct growth phases: prepuberty, puberty, and post puberty. The model achieved greater predictive accuracy at the cost of further shortening the observation period, limiting predictions to an average of 2 years at puberty and 3 before and after puberty. Moreover, these models can be used only once, before treatment, losing the possibility to provide information at follow-up. IS-GROWTH provides a comprehensive representation of the entire natural history of scoliosis from early childhood to skeletal maturity offering long-term guidance for clinicians and patients. The increased longitudinal knowledge (all growth) comes at the cost of a gradual and progressive weakening of the predictions due to the expansion of the area of IS-GROWTH. Consequently, the model's utility lies not in the accuracy of its predictions (even if this also applies to the previous models with shorter observation times) but in its effectiveness in counselling and communicating with

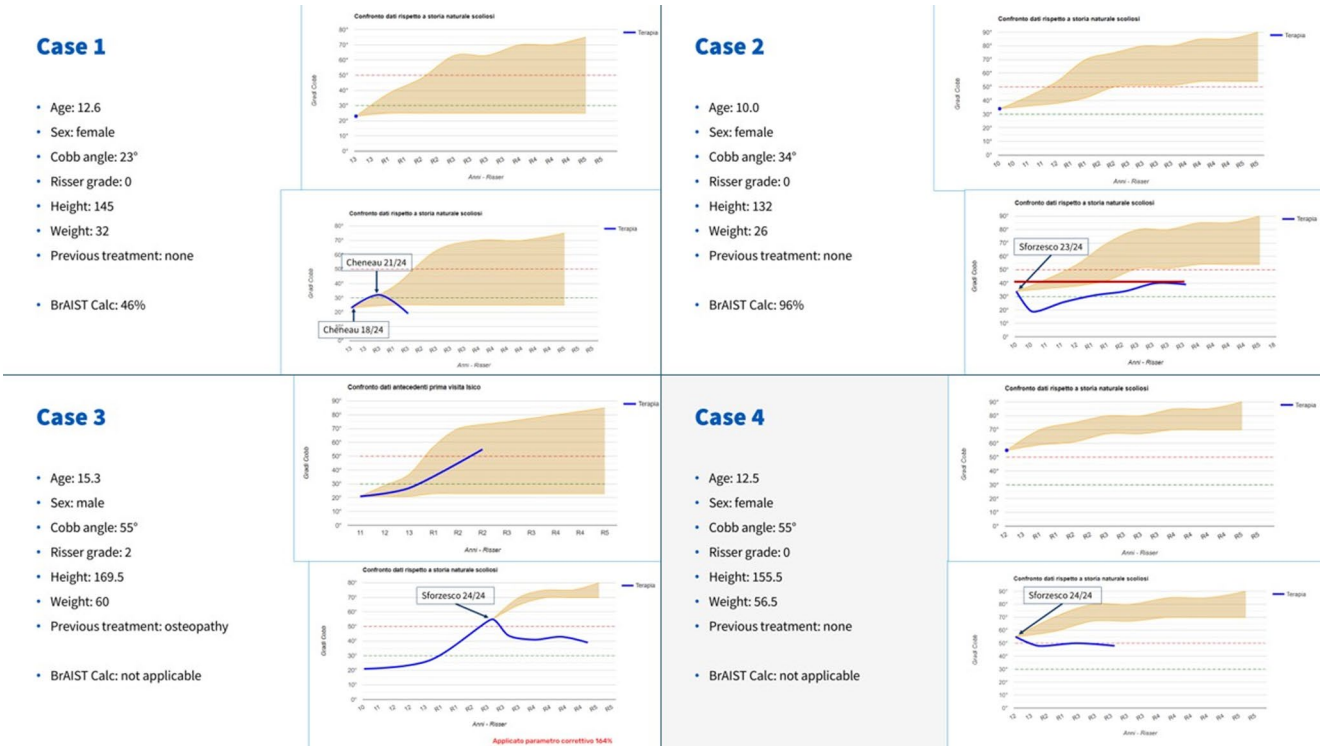

Fig. 3 Four clinical scenarios providing examples of IS-GROWTH implementations. For each case, clinical information is on the left, the starting IS-GROWTH graph is on the top-right, and the evolution of the clinical case with the treatment proposed is on the bottom right. Case 1 illustrates the necessity of increasing bracing hours to achieve a favorable outcome in a challenging clinical scenario at the upper level of potential evolution despite treatment. Case 2 illustrates how IS-GROWTH can alter the interpretation of achieved results, even in the face of progression compared to the start of treatment. Cases 3 and 4 demonstrate a favorable response to treatment, with case 3 exhibiting a previous natural history in the highest part of the graph, characterized by aggressive scoliosis

patients and their families. The preliminary clinical utility study confirms that clinicians rarely use IS-GROWTH as a prediction tool during the first consultation; instead, they use it at follow-up, particularly to motivate and inform one-third of their patients about the results.

Recently, a Machine Learning tool was developed to evaluate the natural history of 887 female patients with AIS [18]. They evaluated the progression at the third consultation but did not provide information on the length of observation. They also had to exclude all braced patients at the first or second consultation, which may have introduced a selection bias, possibly excluding the most aggressive curves. In the future, machine learning may prove useful in developing more accurate prediction models. Nevertheless, we would need large populations and numerous variables to evaluate. Unfortunately, such conditions cannot be expected due to the impossibility of observing patients without treatment in light of the strong efficacy of available treatments in the population at risk [4, 16, 17].

IS-GROWTH confirms the wide variability in the natural history of idiopathic scoliosis [8, 9, 11]. The area representing individual potential evolution expands significantly and progressively in IS-GROWTH, which does not allow for precise predictions; however, this is unavoidable with all current models [8, 9, 11, 18]. At the first consultation, IS-GROWTH can be used to provide patients with an overall idea. Nevertheless, at subsequent consultations, superimposing the actual results on IS-GROWTH enables us to gather more personalized information and gain a deeper understanding of individual courses, providing a valuable tool for communication. Information can be completed using other tools, such as BrAIST-Calc [8].

The paper's strength lies in its comprehensive approach, using a large natural history dataset to develop IS-GROWTH, a tool that visualizes scoliosis progression across the entire growth period. It enables the visualization of personalized, long-term predictions and facilitates enhanced patient-clinician communication. Validation efforts, including adjustments for radiographic errors and positive feedback from clinical users, further reinforce its real-world applicability. The main limitation is the unconventional method used to develop IS-GROWTH. Another limitation, albeit inevitable, is the use of the Risser stage instead of other, more robust skeletal age signs because the study was based on the available radiographs before admission at our Institute. The complexity and variability of scoliosis progression raise

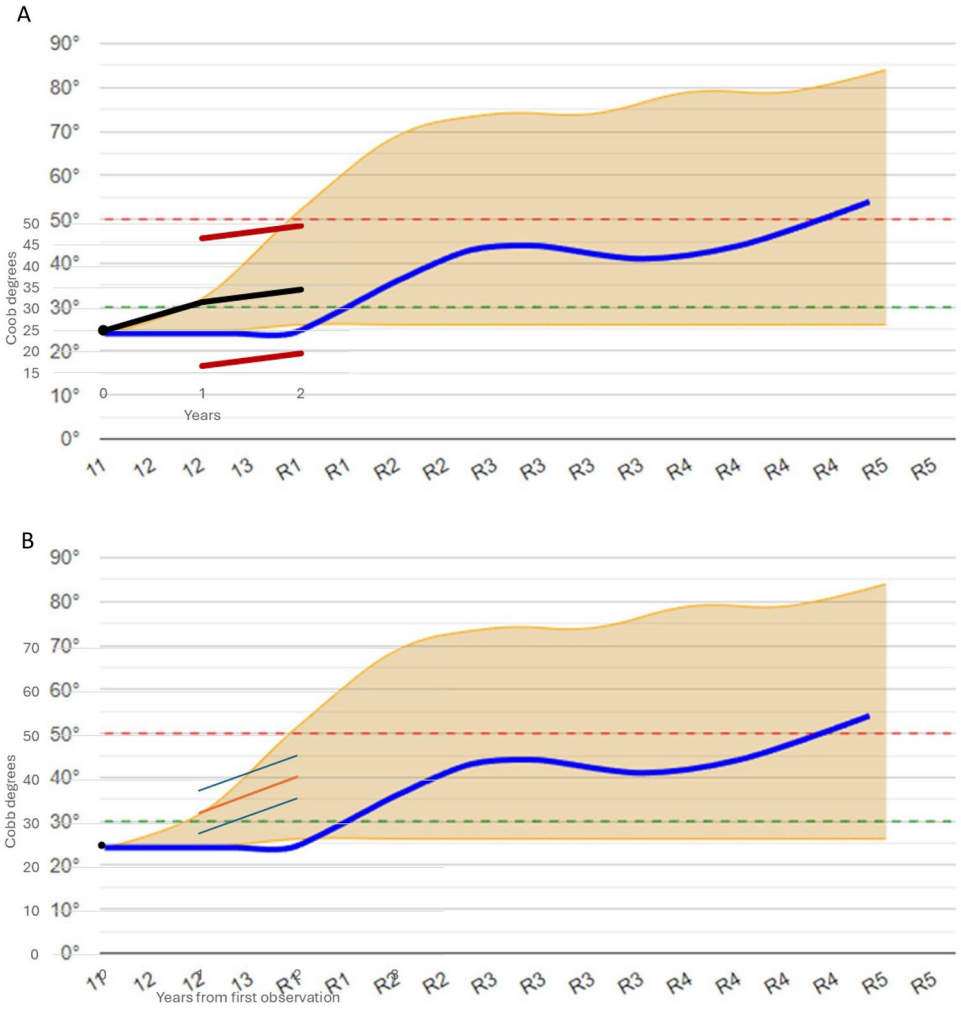

Fig. 4 Superposition of IS-GROWTH and the prediction available using data from the existing natural history models. A: general prediction model according to Parent et al. [9]; B: puberty specific prediction model according to Negrini et al. [11]; The BrAIST Calc [8] do not provide a graph but restituted a risk of progression to surgery of 68%

challenges in predicting individual trajectories, and the IS-GROWTH graph represents large predictions that can over- and under-predict. Furthermore, the results of the clinical utility evaluation should be regarded as preliminary because they are based on clinicians from the same Institute where the tool was developed, even though they were not required to use IS-GROWTH (in fact, they were cautioned that it was not validated and should be considered only as an overall indication): the clinical utility should be further assessed in other settings by clinicians from different Institutes. Finally, while promising, IS-GROWTH needs further external validation across diverse clinical settings to confirm its generalizability and refine its predictive accuracy.

Appendix 1. Development of IS-GROWTH

To standardize the growth phases among individuals and between males and females, we considered three distinct periods: before and after the growth spurt, identified through bone maturity, and the transition phase between the two. Since we had only the chronological age and the spinal frontal radiographic data for each patient, we used the Risser to identify bone maturity. According to Duval-Beaupére [10], we identified the growth phases as follows: (1) "before growth spurt": up to age 10; (2) "after growth spurt": above Risser 1; (3) the transition phase "at growth spurt: within one year of Risser 1, because we wanted to focus only on the rapid growth spurt (and potential rapid scoliosis progression) that, according to previous studies [10, 11], can last between a minimum of 12 and a maximum of 18 months.

We considered the progression rate between each pair of available radiographs of the same patients, calculated using the same numerator (difference of Cobb degrees between the two radiographs) but different denominators per each growth phase: "before growth spurt" the difference in chronological age; "after growth spurt" the change in Risser. We included only pairs of radiographs for the transition phase ("at growth spurt"), with the more recent at Risser 1 and the previous within one-year maximum from the other. For the "after growth spurt" phase, since the Risser provides only

an ordinal scale (by definition, with different time lapses), we considered only pairs of radiographs that changed the Risser of 1 point (e.g., from 2 to 3, but not from 1 to 3).

We provide some examples of the calculation performed: for one patient with three radiographs at ages 6, 8, and 9 showing 10°, 14°, and 18° Cobb, respectively, we calculated two yearly progression rates for the "before growth spurt" growth phase: between age 6 and 8 of (14°−10° Cobb)/(8−6 years of age)=2° Cobb per year and between age 8 and 9 of (18°−14° Cobb)/(9−8 years of age)=4° Cobb per year, respectively. In the case of a patient with radiographs at age 10 (Risser 0), 11 (Risser 1) and another at Risser 2, with Cobb degrees values of 15, 25 and 30, respectively, we calculated two progression rates: one for the "at growth spurt" phase of (25°−15° Cobb)/1=10° Cobb, and another for the "after growth spurt" phase (30°−25° Cobb)=5° Cobb between Risser 1 and 2. Due to this method, we excluded pairs of radiographs if they were (1) in two different growth phases, as we could not use the same denominator; (2) in the "growth spurt" phase but with a time lapse between the two radiographs greater than one year.

We then grouped patients according to their Cobb angle at the first consultation every 10° (from 1°−10° to over 50°). We calculated the minimum and maximum progression rate per group at each growth stage to produce individual IS-GROWTH prediction curves. To mitigate potential issues due to measurement errors and other non-controllable factors, we arbitrarily excluded outliers from each class, defined as all patients within 10% of the maximum and minimum variations. Moreover, in line with current knowledge [3], we excluded the possibility of spontaneous improvement if it remained within the radiographic measurement error of 5°.

The IS-GROWTH is individually developed, adding year by year or Risser in the "before" and "at growth spurt" phases and Risser by Risser in the "after growth spurt" phase the minimum and maximum expected progression to the starting Cobb degrees (first year/Risser possible progression), or to the range of Cobb degrees reached in the previous stage. As an example, Table 6A reports the range of Cobb degrees used for the scope during adolescence. Similar tables are produced for all growth phases. Since (1) it is not possible to know beforehand neither the timing of Risser 1 achievement nor the length of each Risser stage, and (2) there is no reliable data in the literature on these timings, we decided to produce individual IS-GROWTH setting the passages arbitrarily according to our clinical experience as follows: (1) between Risser 0 and 1 at age 12 for females and 13 for males, and (2) between the Risser stages at an interval of 1 year, except for Risser 3 to 4 where we considered 2 years. This remains valid until, during patients' follow-up, they reach these passages: IS-GROWTH is then adapted to the correct individual timing.

Table 6 Range of progression rates for adolescent patients at different growth stages for each group used to develop IS-GROWTH

Cobb degrees at first radiograph	From age 10 to 11 at Risser 0			From Risser 0 to 1			From Risser 1 to 2			From Risser 2 to 3			From Risser 3 to 4		
	Mn	Mx	*N*	Mn	Mx	*N*	Mn	Mx	*N*	Mn	Mx	*N*	Mn	Mx	*N*
1–10	−5	2	16	NA			NA			NA			NA		
11–20	−2	6	88	−2	7	24	−4	6	18	−5	5	22	−5	0	7
21–30	1.3	12	87	2	20	22	−1	7	13	−1	9	23	−4	5	27
31–40	3.5	16	49	4	18	11	1	8	9	0	10	18	−1	14	18
41–50	5.6	23	27	5	14	5	15	17	0	1	9	10	−1	8	13
Above 50	9	32	15	4	24	9	2	15	6	NA			3	10	5

Similar tables are produced for all growth phases.In the final IS-GROWTH, we excluded the possibility of spontaneous improvement (see text). Mn: minimum; Mx: maximum; N: number of patients; NA: not available

IS-GROWTH is finally represented in a graph with Cobb degrees versus the considered time lapse for each growth phase (years until Risser 1, and then the Risser stages until the end of growth) (Fig. 1). The graph reports the individual prediction from the start of observation (first radiograph) as a brown area that gradually enlarges between the best and worst possibilities, as calculated above. A blue line represents the recorded evolution, whether with or without treatment. Two dotted lines, red and green, show the thresholds of possible surgery (50° Cobb) and of expected normal functionality in adulthood (improbable health issues due to scoliosis) (30° Cobb), respectively [19, 20].

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Author contributions AN and SN conceptualized the paper and methodology, were responsible for the statistical analysis, data investigation and curation and project administration. All authors were involved in data collection. All authors contributed to the interpretation of the data and critically revised it for important intellectual content. SN and FN drafted the original version of the manuscript. All authors reviewed, edited, and approved the final manuscript. All the authors have read and agreed to the published version of the manuscript.

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Data availability The data that support the findings of this study are openly available in Zenodo at https://doi.org/10.5281/zenodo.15118191.

Declarations

Conflicts of interest AN and SN own stock of ISICO. FN is related to AN and SN. The other authors have no conflict of interest to declare.

Ethics committee approval and trial registration The local Ethical Committee (Comitato Etico Milano Area 2, Via F. Sforza 28, 20122 Milan Italy– approval number 801_2015bis, 15-12-2015) approved the study protocol.

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