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Brace treatment of Idiopathic Scoliosis is effective for a curve over 40 degrees, but is the evaluation of Cobb angle the only parameter for the indication of treatment?

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ABSTRACT

Background
The recent literature showed positive results for bracing of patients with idiopathic scoliosis above 45° who refused surgery. However, no one has investigated whether other parameters can affect the results.

Aim
The aim of this study was to evaluate the effectiveness of bracing in idiopathic scoliosis with curves above 40° and to verify the mechanical and biological parameters which go beyond the simple bend value expressed in Cobb degrees.

Design
This is an observational controlled cohort study nested in a prospective clinical on-going database including 1,238 patients with idiopathic scoliosis.

Setting:
Inpatients and outpatients in Rome.

Population:
160 patients with idiopathic scoliosis with curves above 40°.

Methods
This is a prospective study based on an ongoing database including 1,238 patients with idiopathic scoliosis.
The patients studied had idiopathic scoliosis with curves of 40° or more, Risser grade 0-4, and had refused any surgical treatment. 160 patients met the inclusion criteria. Of these, 104 patients had a definite outcome, 28 abandoned treatment and 28 are currently under treatment. The minimum duration of follow-up was 24 months. X-rays were used to obtain Cobb degrees and torsion of the apical vertebrae (Perdriolle's method). Three outcomes were distinguished according to SRS-SOSORT criteria: correction, stabilization and progression.
To achieve the second aim we divided the sample into subgroups according to Cobb degrees (<45°;≥45°), Risser (0-2; 3-4) and rotation (<20; ≥ 20). Furthermore, logistic regression was applied by Stepwise Regression.

Results
The results of our study showed that in 104 patients with a definite outcome the Cobb mean value was initially 47 ± 5.25 SD and 34.19 ±8.45 SD at follow-up. Perdriolle was initially 20.04 ± 5.53 SD and 16.76 ± 7.04 at follow-up.
Overall, 81 patients (78%) obtained a curve correction, and stabilization was achieved in 14 cases (13%). Nine patients experienced curve progression (9%), 16 patients were recommended for surgery because the curve at follow up was over 45°.
The analysis of subgroups shows that with Cobb < 45° at baseline, the average reduction was 11.46° Cobb, while in cases with Cobb ≥ 45 at baseline, the mean correction was 13.74° Cobb. In subgroups with Perdriolle < 20° at baseline, the average reduction was 16.02° Cobb, while in cases with Perdriolle ≥ 20° at baseline, the mean correction was 8.4° Cobb. In subgroups with Risser 0-2 at baseline, the average reduction was 14.7° Cobb, while in cases with Risser 3-4 at baseline, the

mean correction was 6.7° Cobb. The logistic regression model shows significance for the initial value of Perdriolle and Risser.

Conclusion
Our results indicate that an adequate conservative treatment must definitely be considered for patients with scoliotic curves who refuse surgery; the results will be better particularly if the rotation is lower than 20 and Risser is between 0-2.

CLINICAL REHABILITATION IMPACT:
With the simultaneous evaluation of the Cobb angle, the vertebral rotation and the potential vertebral growth, it was possible to predict the final results at the start of treatment.

Key words*:* Scoliosis - Brace - Conservative treatment – Biomechanics - Vertebral rotation

Background

The specific pathological features of adolescent idiopathic scoliosis (AIS) are characterized by a process of evolution of the initial conditions that, if not treated, determines serious consequences such as curve progression, lower back pain, psychosocial problems and minor cardiopulmonary consequences [1–6].

The aim of the conservative treatment in AIS, usually performed in growing patients, is to prevent the progression of the curve.

In the older literature several authors propose that conservative treatment does not represent a truly effective option but only a procrastination of surgery, aimed at limiting the worsening of the curves while waiting for the right age for surgical treatment. Goldberg CJ et al underline that in the North American population, the incidence of surgery in patients treated by standard bracing is the same as that in observation-only patients[7–9].

Despite the lack of data supporting brace treatment, the positivists stated, “The truth is that an effective method of early non-surgical treatment is available. That method is bracing.” [10]. Despite this, several studies attesting to the effectiveness of the brace have been published in recent years by members of the International Society on Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT) [11–17]. Weinstein in the BrAIST study showed that, in the North American Population, the rate of treatment success was 72% after bracing, compared with 48% after observation only [18].
The reasons for the controversy can, still today, be summarized as follows:
-Our insufficient knowledge about the etiopathogenetic factors of scoliosis hinders the search for a causal therapy for idiopathic scoliosis;
-Although the scoliotic curves have a potentially worsening evolution, this is a probabilistic event and the result is due from both biological and mechanical factors;
-The results of conservative treatment are not always the same in the sense that, in relation to the methods and the therapeutic regime employed, the treatment is not completed in all cases. Finally,

the possibility that orthopedic treatments can achieve a recovery of the curve, albeit a partial one, is contested;
-There is still insufficient knowledge about the biomechanical factors that affect both the worsening evolution process and the treatment of the curves. This has led to the empiricism that often characterizes the indication for the type of brace, its manufacture and the clinical management of the different types of treatment [19].
However, the indication to conservative treatment for scoliosis with more than 40° Cobb degree curves remains controversial, even if there have been recent reports of some positive results in bracing patients with idiopathic scoliosis above 45° who refused surgical treatment[20–23].

Aim of the study:
- Evaluate the effectiveness of bracing in idiopathic scoliosis with curves over 40° Cobb, following the guidelines on standards of management of idiopathic scoliosis (SOSORT) [24].
- Verify the mechanical and biological parameters which go beyond the simple bend value expressed in Cobb degrees, and which could be used as indicators to conservative treatment even in cases that are usually included in the "grey area".

Materials and Methods

Design

This is an observational controlled cohort study nested in a prospective clinical on-going database including 1,238 patients with idiopathic scoliosis. Patients were recruited both in public hospitals and in private clinics. Inclusion criteria were: idiopathic scoliosis, at least one curve of 40° or more, Risser stage 0-4, age over 10 years old, and had firmly refused any surgical treatment.

Furthermore the study was conducted using the STROBE guidelines (STROBE Statement—Checklist of items that should be included in reports of ***cohort studies)***

Population

The study was carried out during May 2014. From a database including 1238 patients, we found 160 patients meeting the inclusion criteria; of these, 104 patients had a definite outcome, 28 abandoned treatment and 28 are currently under treatment. The minimum duration of follow-up was 24 months after the end of treatment.

All patients gave written consent for their clinical data management to be used for research purposes; the study respects the statements of the requirements of the *Helsinki Declaration* concerning medical experimentation on human beings.

Bracing

Patients with thoracolumbar and lumbar curves were prescribed the Progressive Action Short Brace (PASB), while the Lyon brace was prescribed for those with thoracic or double curves. Full-time bracing was prescribed for all patients (i.e., max 22 hours daily, min 20 hours daily). The daily number of hours of bracing was defined for each patient according to clinical needs and acceptance. In order to maximize compliance to treatment, patients were always followed by the same doctor. Furthermore, controls were performed every 2 months. Frequent checks allowed verification and implementation of compliance, creating an open and friendly doctor-patient relationship. Close checks were also performed to maximize bracing effectiveness over time. Weaning was started when the beginning of ring-apophysis fusion could be seen on a lateral (LL) radiograph view [25], corresponding to a Risser sign 4 or 5 on an anterior-posterior (AP) standing radiograph view. Weaning consisted of 2 to 4 hours bracing reduction at 2-month intervals.

Endpoints

For the present study, only X-rays performed at conventional times were considered: start of treatment (t_1), 4–6 months after start of treatment (t_2), intermediate time between t_1 and t_4 (t_3), end of treatment (t_4), 2-year minimum follow-up from end of treatment (t_5).

For each patient, AP and LL view standing X-rays of the whole spine were performed. X-rays before treatment (t_1) as well as those at t_4 and t_5 were taken without brace. All other radiographic controls were performed with the patient wearing the brace, in order to assess the corrective action of bracing. The first X-ray was obtained at 4–6 months from the beginning of treatment. All other controls were performed once a year. All radiographs were taken at our Institute, at a distance of 2 meters, using a 36 × 91 cm film. The AP view was used to determine the patient's skeletal age (the European Risser's sign) and to obtain the curve magnitude (C_M: Cobb's method) and torsion of the apical vertebra (T_A: Perdriolle's method). [26,27]. Two independent observers carried out the measurements. The end vertebrae were preselected by the senior author (LA) to reduce inter-observer error but the end-vertebrae can change from one X-ray to another. Curves were classified according to SRS into thoracic, thoracolumbar, lumbar, and double major. SRS-SOSORT criteria for bracing studies were applied [28]. As recommended by the SRS Committee on Bracing and Non-operative Management, outcomes were classified as follows: (1) correction (percentage of patients with ≤ 5° curve progression), (2) stabilization (final Cobb angle not differing more than 5º from its initial value), (3) progression (percentage of patients with ≥ 5° progression at maturity), and (4) percentage of patients with curves exceeding 45° at maturity and of those recommended for or who had undergone surgery. To achieve the second aim we have also divided the sample into subgroups according to Cobb degrees (<45°;≥45°), Risser (0-2; 3-4) and rotation (<20; ≥ 20).

Statistical analysis

Statistical analysis was performed using the Graphpad Prism 6.0.

For all variables, normality of data was verified by the Kolmogorov- Smirnov test. Results were analyzed in relation to C_M t_5-t_1 at follow-up, assuming that C_M t_5-t_1 was not within the Cobb's method ± 5 range of error [27]. Changes in C_M and T_A over time from t_1 through t_5 were assessed via one-way analysis of variance (ANOVA) for repeated measures. Tukey's post-test was applied when needed. The model was fitted for age, type of curve, and type of bracing. All analyses were performed according to the intention-to-treat principle. Missing data at follow-up were managed according to the Last Observation Carried Forward (LOCF) method. All tests were two-sided, with significance set at $p < 0.05$. Results are presented as mean ± standard deviation (SD).

Logistic Regression

Logistic regression was used to determine predictively the individual probability of success in each case using the Statistix 9 program.

A reduction at the last control of more than 11 Cobb degrees compared to the initial value was considered a success (variable = 1); a smaller reduction, stabilization or worsening was considered a failure (variable = 0).

Based on this subdivision, the 104 cases studied showed: Successes 54 cases; Failures 50 cases, Prevalence *of Successes* 53.8%.

Logistic regression was applied by Stepwise Regression, assuming as *dependent variable Success (0 or 1) and as independent starting variables*: sex, age, duration of treatment, initial Cobb and *Perdriolle* degrees, Risser index.

Results:

Analyses of patients with a definite outcome

A definite outcome was recorded for 104 patients, 96 females (93%) and 8 males (7%), mean age 12.88±1.86 years and 17.92±1.65 years at t1 and t4, respectively. The mean duration of treatment was 63.12±17.44 months, with an average length of follow-up of 60.86±57.85 (range 24-276) months.

Curve type distribution was as follows: thoracic (n = 43; 41.3%), thoracolumbar (n = 33; 31.7%), lumbar (n = 12; 11%), double (n = 11; 10.5%) and double thoracic (n = 5; 4.8%). The Progressive Action Short Brace (PASB) was prescribed in 57 patients, and the Lyon brace in 47 patients.

Changes in C_M over time were statistically significant (p for trend < 0.0001) (Figure 1), with a mean value of 47.02±5.25 ° Cobb at start of treatment (t_1) and 34.19±8.45 ° Cobb at follow-up (t_5). A less significant pattern was observed for T_A (p for trend < 0.01) (Figure 2), with a mean value of 20.04±5.53° Perdriolle at beginning (t_1) and 16.76±7.04° Perdriolle at follow-up (t_5).

Overall, 81 patients (78%) obtained a curve correction, while stabilization was achieved in 14 cases (13%). Nine patients experienced curve progression (9%), 16 patients were subsequently recommended for surgery because at follow up the curve was over 45° (Table 1).

The analysis of the total sample shows a significant correlation between rotation at baseline and mean curve correction in Cobb degrees, but not for Cobb at baseline and mean curve correction in Cobb degrees (Figure 3). The analysis of subgroups shows that with C_M < 45° at t_1, the average reduction was 11.46° Cobb, while in cases with $C_M \geq 45$ at t_1, the mean correction was 13.74° Cobb. The multiple comparisons in subgroup <45° were significant between the age at baseline and the mean curve correction in Cobb and Perdriolle degrees (Table 2 and 3). Similar results were reported for $C_M \geq 45$. Significant correlations were observed between Perdriolle at baseline and mean curve correction in Cobb degrees (Figures 4 and 5).

In particular, 36 patients in subgroups with $C_M < 45$ obtained a curve correction with a mean value of 13.75°, stabilization was achieved in 7 cases (mean 1.7°) and 4 patients experienced curve progression (mean 7°). In comparison, 45 patients in subgroups with $C_M \geq 45$ obtained a curve correction with a mean value of 14.88°, stabilization was achieved in 5 cases (mean 0.2°) and 7 patients experienced curve progression (mean 5.14°).

In subgroups with $T_A < 20°$ at t_1, the average reduction was 16.02° Cobb, while in cases with $T_A \geq 20$ at t_1, the mean correction was 8.4° Cobb. The multiple comparisons in subgroups $T_A < 20°$ and $T_A \geq 20°$ were significant between the age at baseline and the mean curve correction in Cobb and Perdriolle degrees (Table 4 and 5). Significant correlations were found between Perdriolle at baseline and mean curve correction in Cobb degrees (Figure 6 and 7).

In subgroups with Risser 0-2 at t_1, the average reduction was 14.7° Cobb, while in cases with Risser 3-4 at t_1, the mean correction was 6.7° Cobb.

Treatment outcomes are shown in Tables 1, 6 and 7.

Logistic Regression

The model discarded, for the non-significance of the coefficients, all the variables except for the initial value of Perdriolle and Risser.

It provided a regression equation for logit L: L = 10.41-0.403 * Initial Pedriolle -1.21 * Risser

The results are detailed in Table 10, By L: Odds = Exp(L); Probab. % = 100* Odds /(1+Odds)

Taking into account a discriminating threshold of 50% probability, the decision-making matrix can be built (Table 8) and gives the diagnostic table (Table 9). The method is highly predictive with an accuracy of 90.4%. It appears particularly suitable for predicting positivity (*VP* +: 92.6%)

ROC analysis

To see how the result could vary according to the decision-making threshold adopted, a ROC curve was constructed using the method described by Galli[29].

For completeness, the ROC curves were also drawn using Perdriolle and Risser as parameters.

The graph in Figure 8 shows how the curve determined with Perdriolle + Risser shows a significantly increased area under the curve (AUC = 0.961) ($p <0.05$) compared to that obtained with the individual parameters, and that they practically do not differ among themselves. Furthermore table 10 shows the sensitivity values (TPF) for some threshold values (FPF = 1-Specificity) and the complementary data obtained from the two-factor curve ROC analysis; in particular the Q point is 90.6% and the Diagnostic Odds Ratio (DOR) is over 90.

DISCUSSION

This study confirmed that brace treatment could be useful for adolescent scoliosis with curves over 40° Cobb. The indication to surgical treatment is greatly decreased by bracing, while the probability of success (reduction of the curve of at least 5°) is deeply influenced by the severity of torsional deformity (Perdriolle degree) and skeletal maturity (Risser degree).

The efficacy of brace treatment has been questioned for many years. Recently, many European studies, in particular the Braist study that included a randomized arm, have shown the effectiveness of bracing in adolescent patients[14,16,23,30,31]. However, no adolescents with curves above 40° have been included in these studies because the only generally accepted therapeutic option for this specific population is surgery. Furthermore, in recent years societies such as SRS and SOSORT have accepted bracing as a therapeutic option in adolescents with curves of 45 degrees and the Braist study considered progression to 50 degrees as conservative treatment failure.

The patients in our study had surgical indication but, despite our explaining to them the advantages of surgery and the poor evidence of the efficacy of conservative treatment for this type of curve, they firmly refused treatment and consequently received the conservative treatment. Nevertheless our patients have the strongest motivation to avoid a spinal fusion, resulting in high compliance rates. Compliance is an important factor in obtaining good results with an efficacious brace.

Moreover the results of this study are in accord with those reported by Lusini for patients with a curve over 45 degrees that showed conservative treatment failure in only 23.5% of patients. [20], However, our results provide new information about the parameters to be evaluated before starting treatments in the “grey area”.

To better explain the results, the importance of the degree of torsion and the rationale of this study, we must clarify some principles of biomechanics.
In particular, studies on the brace-spine interaction and analysis of the instability of the scoliotic spine [32], have underlined that stopping the evolutionary process of the idiopathic scoliosis and, when possible, correcting the deformity and deformations, can be achieved provided that the brace is projected according to precise mechanical requirements and that the biological structure can react in a suitable way to the induced actions [33–35].
Studies on the biological reaction to mechanical actions could provide tools for defining the indications to and limits of conservative treatment, which could be used as well as evaluating the curve in Cobb degrees.
Previous papers observed that a deformed spine has a mobility which reduces the natural "dynamic stability"[33,36]. In a growing subject, this phenomenon induces a progressive increase of the vertebral asymmetry causing a worsening of the curve originally provoked by biological factors [34,37].
The mechanical behavior of the scoliotic spine clarifies the theoretical suppositions concerning brace treatment [38].

The correction can be achieved via forces which can modify the model of distribution of the solicitations. Intervertebral discs are viscoelastic structures that can distort themselves and return to their normal shape. Correct position and good viscoelastic equilibrium are the basic conditions for physiological biomechanics of the intervertebral disc. In fact, a condition of hysteresis of the disc would make the disc unable to transmit the corrective actions of the brace. The twisting component is the element which characterizes the scoliotic curve.

In a scoliotic spine, vertebrae are locked in a permanent twist, which distorts the vertebra and puts the disc in a position of permanent rotation. This “patho”-mechanical setting induces an increase in the stiffness of the spine towards twisting, subsequently leading to hysteresis of the disc. This condition is related to the entity of rotation and the initial value of the G modulus, that changes in relation to its position and to the patient’s age[32].

These results are confirmed by the biomechanical analysis; in fact, over time, the elastic characteristics of the spine undergo considerable variations.

The different degrees of intervertebral disc elasticity explain the different degrees of permeability to external actions and, therefore, to the different evolutionary patterns seen in scoliosis.

In children, the lower value of the torsion modules of the discs can indeed promote a spontaneous evolution toward serious deformity. However, this evolution can be stopped by administering a proper conservative treatment and achieving an effective recovery of the deformity.

Therefore recovery, independent of the initial Cobb degrees, is subordinate to the concomitant presence of two essential conditions.

The growth of vertebrae: a limited residual growth precludes any remodelling of the vertebral geometry. If treatment is started at the end of growth, the curve correction is obtained mainly by deforming the disco-elastic structures, and in fact the correction will vanish when the patient removes the brace.

The disc alteration is located in the elastic-plastic deformity area, therefore allowing low degrees of spinal rotation. The elastic return to zero degrees, after removal of the torsional moment, can only happen if the rotation is sufficiently below the field of linear elasticity and the applied torsional moment rapidly loses its effect. Otherwise a portion of the energy furnished remain in the disc and provoke an increase in rigidity, thus producing the phenomenon of hysteresis.

This explains why, for a scoliosis with a medium grade of rotation, recovery can only be limited due to the partial deformation of the discs. For a scoliosis with a high grade of rotation, the alteration of the discs allows no correction with the brace treatment, only a stabilization of the curve.

Finally, we would like to underline the importance of the increase in the physiological values of G with the advance of age. In fact a scoliotic curve with an important rotation considered not recoverable in the adolescent may be susceptible to meaningful recovery in infants.

Our study has certain limitations:

Some of our cases lack long-term follow-up which could show a progression requiring fusion.

The actual gold standard for treatment for curves over 45 degrees is fusion which excludes being able to perform a randomized controlled study and thus reduces the scientific strength of the study.

CONCLUSION

The indications to conservative treatment in idiopathic scoliosis are normally defined only taking into consideration the lateral deviations on the coronal plane. In fact, Cobb degrees are used to determine the "area" of therapeutic orientation with the determination of a "grey area" and a "surgical area". This type of evaluation has been confirmed as being useful for all patients where conservative treatment can be guaranteed to stop the curve progression. However, this study demonstrates the limits of an evaluation criterion that doesn't adequately take into consideration elements such as residual vertebral growth and the elastic potential of the discs. Their capacity to induce, during conservative treatment, a recovery of the deformity, even partial, determines the different results in the different "areas."

Although the results do not allow a precise definition of new "areas" based upon the convergence of different factors which could change the evolution of the curves, it is likely that the Risser sign and the degree of torsion presented at the first observation are primary elements when considering the indication to conservative treatment and predicting a successful outcome of the treatment. Thus, the conservative treatment of scoliosis, administered in accordance with SOSORT criteria, plays a primary role in the management of this condition, even when patients are in the “grey” or surgical areas.

Finally, this new approach could offer a less controversial interpretation of the different results obtained with similar initial Cobb degrees in different subjects receiving conservative treatment. With the simultaneous evaluation of the Cobb angle, vertebral rotation and potential vertebral growth it is possible to predict the end results at the start of treatment.

List of abbreviations
SRS : Scoliosis Research Society;
AIS : Adolescent Idiopathic Scoliosis;
SOSORT: Society on Scoliosis Orthopaedic and Rehabilitation Treatment;
LL: Latero-lateral
AP: Anterior-Posterior
CM: Cobb’s method
TA: Perdriolle’s method

Competing interests

“The authors declare that they have no competing interests”.

Authors' contributions

AGA participated in the conception, design and coordination, acquisition of data, analysis and interpretation of data and drafted the manuscript. AGA and MG performed the statistical analysis. MG, FF and VG helped to draft the manuscript.
LA participated in the conception, design and coordination and helped to draft the manuscript.
All authors read and approved the final manuscript.

Ethics approval and consent to participate
The study was conducted in respect to the Helsinki Declaration, and all the participants (parents) gave their informed consent to allow the use of clinical data for research purposes.

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Legends

Tables

Table 1. Outcomes of the subgroup.

Table 2. Comparisons between different variables in Cobb subgroups ($C_M < 45$).

Table 3. Comparisons between different variables in Cobb subgroups ($C_M \geq 45$).

Table 4. Comparisons between different variables in Perdriolle subgroups ($T_A < 20$).

Table 5. Comparisons between different variables in Perdriolle subgroups ($T_A \geq 20$).

Table 6. Outcomes of the patients at Follow up

Table 7. Outcomes of the patients in agreement of SRS-SOSORT criteria

Table 8. Decision-making matrix

Table 9. Diagnostic table

Table 10. Model retained by stepwise regression, discarding all other stating variables

Figures

Figure 1. Changes in curve magnitude in Cobb degrees from the beginning of treatment (t1) to 2-year minimum follow-up from end of weaning (t5). Each box depicts the interquartile range, with the median indicated by the the black center line. Error bars show the data distribution, with the whiskers corresponding to the minimum and maximum values.

Figure 2. Changes in apical torsion in Perdriolle degrees from the beginning of treatment (t1) to 2-year minimum follow-up from end of weaning (t5). Each box depicts the interquartile range, with the median indicated by the the black center line. Error bars show the data distribution, with the whiskers corresponding to the minimum and maximum values.

Figure 3. Correlations between mean curve correction in Cobb degrees and Perdriolle at baseline (a) and Cobb at baseline (b).

Figure 4. Correlations between mean curve correction in Cobb degrees and Risser at baseline (a) Cobb at baseline (b) and Perdriolle at baseline (c) in $C_M < 45$.

Figure 5. Correlations between mean curve correction in Cobb degrees and Risser at baseline (a) Cobb at baseline (b) and Perdriolle at baseline (c) in $C_M \geq 45$.

Figure 6. Correlations between mean curve correction in Cobb degrees and Risser at baseline (a) Cobb at baseline (b) and Perdriolle at baseline (c) in $T_A < 20$.

Figure 7. Correlations between mean curve correction in Cobb degrees and Risser at baseline (a) Cobb at baseline (b) and Perdriolle at baseline (c) in $T_A \geq 20$.

Figure 8. ROC Curves (ROC1: Risser+Perdriolle; ROC2: Perdriolle; ROC3: Risser)

Table 1

	Curve Correction (n, %)	Curve Stabilization (n, %)	Curve Progression (n, %)	Surgery Referrals (n, %)
<45° Cobb (n=47)	36 (77%)	7 (14%)	4 (9%)	5 (10%)
≥45° Cobb (n=57)	45 (78%)	5 (13%)	7 (9%)	11 (19%)
<20° Perdriolle (n=55)	53 (96%)	1 (2%)	1 (2%)	1 (2%)
≥ 20° Perdriolle (n=49)	28 (57%)	13 (27%)	8 (16%)	15 (30%)
≥25° Perdriolle (n=22)	3 (14%)	15 (68%)	4 (18%)	18 (81)
Risser 0-2 (n=68)	59 (86%)	6 (9%)	3 (5%)	7 (10%)
Risser 3-4 (n=36)	22 (61%)	12 (33%)	2 (6%)	9 (25%)
PASB (n=57)	47 (82%)	5 (9%)	5 (9%)	5 (9%)
Lyon Brace (n=47)	34 (72%)	9 (19%)	4 (9%)	11 (23%)

Table 2

Cobb <45°

Tukey's multiple comparisons test	Mean Diff	t	Adjusted P Value	95% CI of diff
Cobb t1 vs Cobb t5	11,46	3,950	0,0137	0,7542 to 22,16
C_M t5-t1 vs T_A t5-t1	-8,099	2,711	0,4437	-19,12 to 2,923
Age at baseline vs C_M t5-t1	23,37	8,103	< 0,0001	12,73 to 34,02
Risser vs C_M t5-t1	12,50	4,334	< 0,0001	1,858 to 23,15
P t1 vs P t5	2,287	0,7928	0,9982	-8,357 to 12,93
Age at t1 vs T_A t5-t1	15,28	5,140	< 0,0001	4,308 to 26,24
Risser vs T_A t5-t1	4,403	1,481	0,9789	-6,564 to 15,37

Table 3

Cobb ≥45°

Tukey's multiple comparisons test	Mean Diff	t	Adjusted P Value	95% CI of diff
Cobb t1 vs Cobb t5	13,74	4,796	0,0004	3,174 to 24,30
C_M t5-t1 vs T_A t5-t1	-10,31	3,414	0,0837	-21,45 to 0,8281
Age at t1 vs C_M t5-t1	26,38	9,210	< 0,0001	15,82 to 36,95
Risser vs C_M t5-t1	15,40	5,376	< 0,0001	4,838 to 25,97
P t1 vs P t5	4,073	1,422	0,9982	-6,492 to 14,64
Age at t1 vs T_A t5-t1	20,86	7,119	< 0,0001	10,06 to 31,67
Risser vs T_A t5-t1	5,091	1,737	0,9789	-5,716 to 15,90

Table 4

Pedriolle <20°

Tukey's multiple comparisons test	Mean Diff	t	Adjusted P Value	95% CI of diff
Cobb t1 vs Cobb t5	16,02	5,630	< 0,0001	5,526 to 26,52
C_M t5-t1 vs T_A t5-t1	-10,78	3,714	0,0317	-21,49 to -0,07732
Age at t1 vs C_M t5-t1	27,96	9,871	< 0,0001	17,52 to 38,41
Risser vs C_M t5-t1	16,89	5,963	< 0,0001	6,444 to 27,34
Perdriolle t1 vs Perdriolle t5	4,094	1,439	0,9979	-6,401 to 14,59
Age at t1 vs T_A t5-t1	17,18	5,919	< 0,0001	6,477 to 27,89
Risser vs T_A t5-t1	6,109	2,105	0,8713	-4,595 to 16,81

Table 6

	Begginig of treatment	Follow Up
>45° Cobb	57	22
<40° Cobb	0	65
<30° Cobb	0	38

Table 7

Outcome

	N	%
Progressed 5° or more	3	3
Unchanged	20	19.2
Improved 5° or more	81	77.8
Total	104	

Table 8

	Success	Failure
T+	50	4
T-	6	44
TOT	56	48

Table 9

Sensitivity	89.3%	95% CI: 78.12 – 95.7
Specificity:	91.7%	95% CI: 80 – 97.68
Predicting value (VP) +	92.6%	95% CI: 82.11 – 97.94
Predicting value (VP) -	88%	95% CI: 75.69 – 95.47
Accuracy	90.4%	95% CI: 87.4 – 97.8

Table 10

Logistic regression of success				
Predictor Variables	Coefficient	Std Error	Coef/SE	Significance
Constant	10.41	1.99	5.21	$p<10^{-4}$
Initial Perdriolle	- 0.40	0.08	-4.7	$p<10^{-4}$
Risser	- 1.21	0.34	-3.53	$p<4*10^{-4}$
Deviance = 74.85	p-value = 0.98	Degree of freedom = 101		
Convergence criterion of 0.01 met after 5 iteration				
Cases included = 104; Missing cases = 0				

Table 5

Tukey's multiple comparisons test	Mean Diff	t	Adjusted P Value	95% CI of diff
Cobb t1 vs Cobb t5	8,400	2,964	0,2706	-2,057 to 18,86
C_M t5-t1 vs T_A t5-t1	-7,202	2,372	0,7059	-18,41 to 4,000
Age at t1 vs C_M t5-t1	20,88	7,367	< 0,0001	10,42 to 31,33
Risser vs C_M t5-t1	10,10	3,565	0,0525	-0,3543 to 20,56
Perdriolle t1 vs Perdriolle t5	1,558	0,5533	> 0,9999	-8,831 to 11,95
Age at t1 vs T_A t5-t1	13,68	4,690	0,0006	2,916 to 24,44
Risser vs T_A t5-t1	2,900	0,9945	> 0,9999	-7,860 to 13,66

	Curve Correction (n, %)	Curve Stabilization (n, %)	Curve Progression (n, %)	Surgery Referrals (n, %)
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Table 2. Comparisons between different variables in Cobb subgroups (C_M < 45).

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P t1 vs P t5	4,073	1,422	0,9982	-6,492 to 14,64
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Table 4. Comparisons between different variables in Perdriolle subgroups (T_A < 20).

Pedriolle ≥ 20°

Tukey's multiple comparisons test	**Mean Diff**	**t**	**Adjusted P Value**	**95% CI of diff**
Cobb t1 vs Cobb t5	8,400	2,964	0,2706	-2,057 to 18,86
C_M t5-t1 vs T_A t5-t1	-7,202	2,372	0,7059	-18,41 to 4,000
Age at t1 vs C_M t5-t1	20,88	7,367	< 0,0001	10,42 to 31,33
Risser vs C_M t5-t1	10,10	3,565	0,0525	-0,3543 to 20,56
Perdriolle t1 vs Perdriolle t5	1,558	0,5533	> 0,9999	-8,831 to 11,95
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Table 5. Comparisons between different variables in Perdriolle subgroups ($T_A \geq 20$).

	Begginig of treatment	Follow Up
>45° Cobb	57	22
<40° Cobb	0	65
<30° Cobb	0	38

Table 6. Outcomes of the patients at Follow up

Outcome	N	%
Progressed 5° or more	3	3
Unchanged	20	19.2
Improved 5° or more	81	77.8
Total	104	

Table 7. Outcomes of the patients in agreement of SRS-SOSORT criteria

	Success	Failure
T+	50	4
T-	6	44
TOT	56	48

Table 8. Decision-making matrix

Sensibility	89.3%
Specificity:	91.7%
Predicting value (VP) +	92.6%
Predicting value (VP) -	88%
Accuracy	90.4%

Table 9: Diagnostic table

FPF	Sensitivity	FPF	Sensitivity		AUC	96.1%
2.5	70.3	30	97.5		ES	2%
5	82.9	35	98		Q	90.6%
10	91.1	40	98.4		DOR	92.2+/-1.97
15	94.2	45	98.7			
20	95.8	50	98.9			
25	96.8					

Table 10: Shows the sensitivity values (TPF) for some threshold values (FPF = 1-Specificity) and the complementary data obtained from the two-factor curve ROC analysis.

Tukey's multiple comparisons test	Mean Diff,	Q	Adjusted P Value	95% CI of diff,
t1 vs. t2	2,767	4,373	0,0178	0,3169 to 5,216
t1 vs. t3	3,907	6,176	0,0001	1,458 to 6,357
t1 vs. t4	4,910	7,642	< 0,0001	2,422 to 7,397
t1 vs. t5	3,278	5,089	0,0032	0,7839 to 5,772
t2 vs. t3	1,141	1,799	0,7087	-1,315 to 3,596
t2 vs. t4	2,143	3,328	0,1302	-0,3503 to 4,636
t2 vs. t5	0,5114	0,7921	0,9807	-1,989 to 3,011
t3 vs. t4	1,002	1,556	0,8063	-1,491 to 3,496
t3 vs. t5	-0,6293	0,9747	0,9588	-3,129 to 1,871
t4 vs. t5	-1,632	2,490	0,3979	-4,169 to 0,9055

Figure 2. Changes in apical torsion in Perdriolle degrees from the beginning of treatment (t1) to 2-year minimum follow-up from end of weaning (t5). Each box depicts the interquartile range, with the median indicated by the the black center line. Error bars show the data distribution, with the whiskers corresponding to the minimum and maximum values.

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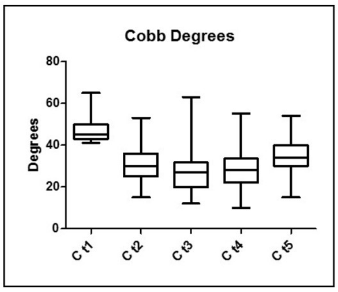
t1 vs. t3	19,44	24,64	< 0,0001	16,39 to 22,50
t1 vs. t4	18,46	23,23	< 0,0001	15,39 to 21,54
t1 vs. t5	12,83	15,89	< 0,0001	9,703 to 15,96
t2 vs. t3	3,212	4,069	0,0338	0,1561 to 6,267
t2 vs. t4	2,234	2,810	0,2738	-0,8441 to 5,312
t2 vs. t5	-3,401	4,211	0,0252	-6,528 to -0,2740
t3 vs. t4	-0,9775	1,230	0,9080	-4,056 to 2,101
t3 vs. t5	-6,613	8,187	< 0,0001	-9,740 to -3,486
t4 vs. t5	-5,635	6,928	< 0,0001	-8,784 to -2,486

Figure 1. Changes in curve magnitude in Cobb degrees from the beginning of treatment (t1) to 2-year minimum follow-up from end of weaning (t5). Each box depicts the interquartile range, with the median indicated by the the black center line. Error bars show the data distribution, with the whiskers corresponding to the minimum and maximum values.



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C t2 vs. C t3	3,212	4,069	0,0338	0,1561 to 6,267
C t2 vs. C t4	2,234	2,810	0,2738	-0,8441 to 5,312
C t2 vs. C t5	-3,401	4,211	0,0252	-6,528 to -0,2740
C t3 vs. C t4	-0,9775	1,230	0,9080	-4,056 to 2,101
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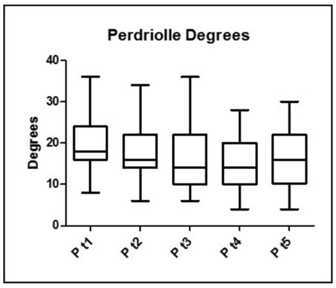

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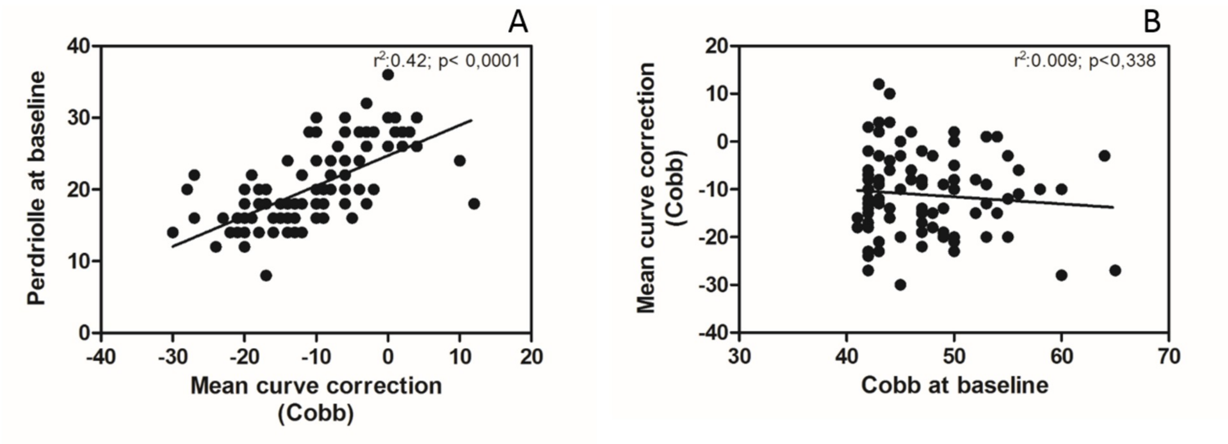
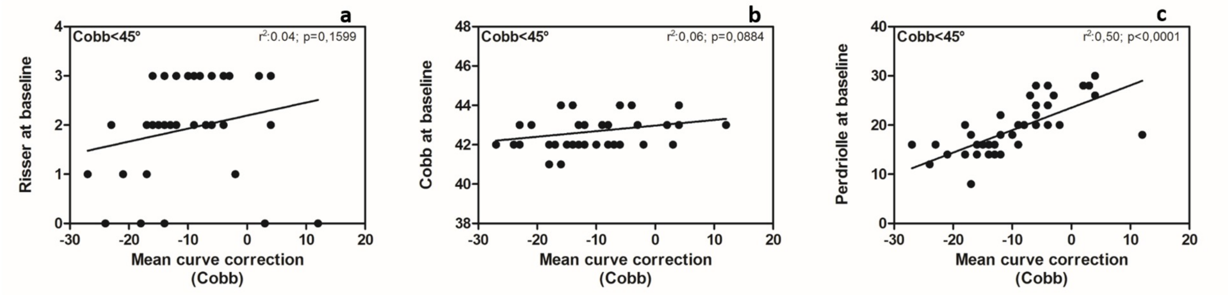
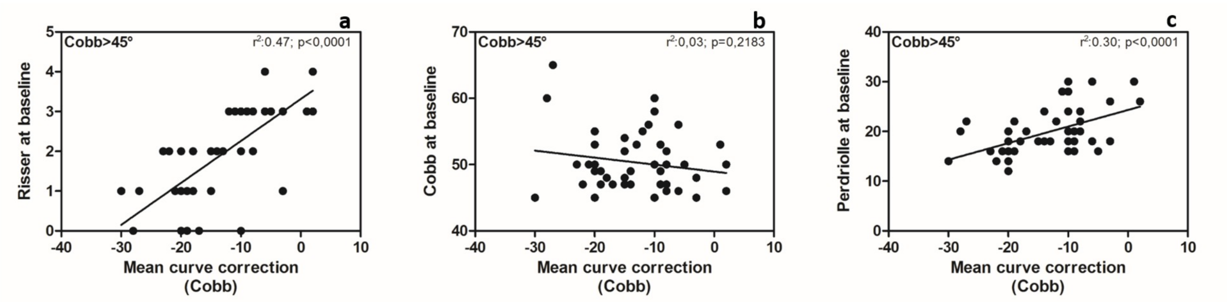
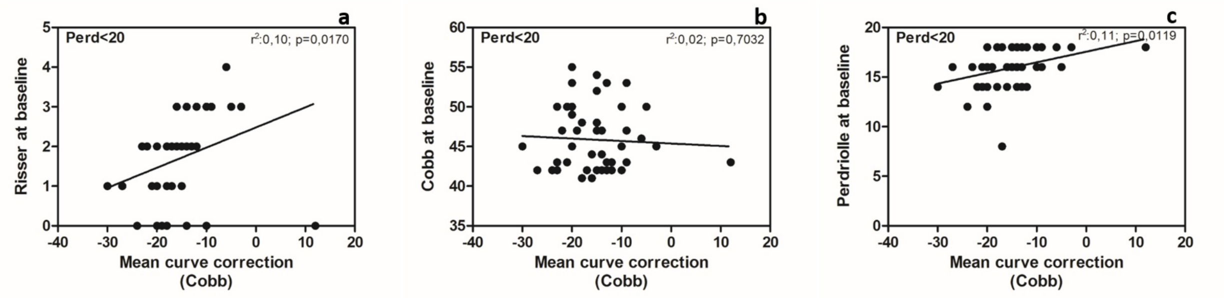
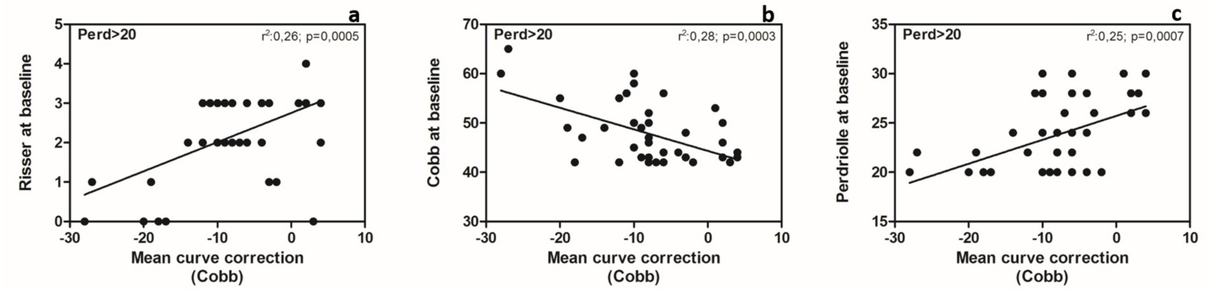
P t1 vs. P t5	3,278	5,089	0,0032	0,7839 to 5,772
P t2 vs. P t3	1,141	1,799	0,7087	-1,315 to 3,596
P t2 vs. P t4	2,143	3,328	0,1302	-0,3503 to 4,636
P t2 vs. P t5	0,5114	0,7921	0,9807	-1,989 to 3,011
P t3 vs. P t4	1,002	1,556	0,8063	-1,491 to 3,496
P t3 vs. P t5	-0,6293	0,9747	0,9588	-3,129 to 1,871
P t4 vs. P t5	-1,632	2,490	0,3979	-4,169 to 0,9055

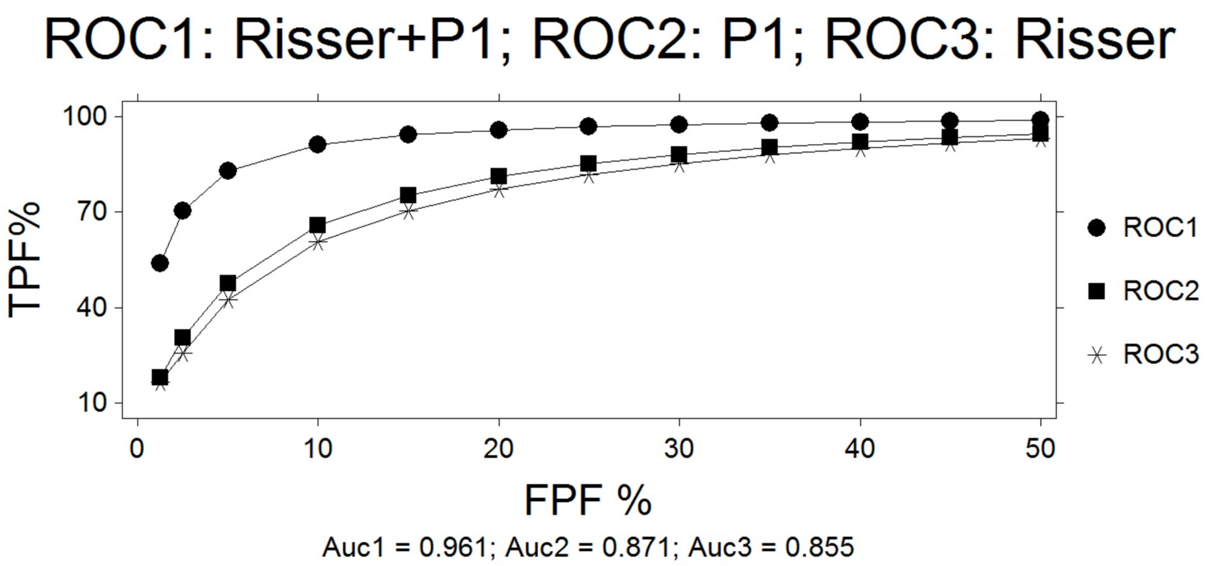

A
r2:0.42; p< 0,0001
Perdriolle at baseline
Mean curve correction (Cobb)
B
r2:0.009; p<0,338
Mean curve correction (Cobb)
Cobb at baseline


a
Cobb<45°
r²:0.04; p=0,1599
Risser at baseline
Mean curve correction
(Cobb)
b
Cobb<45°
r²:0,06; p=0,0884
Cobb at baseline
Mean curve correction
(Cobb)
c
Cobb<45°
r²:0,50; p<0,0001
Perdriolle at baseline
Mean curve correction
(Cobb)


a
Cobb>45°
r²:0.47; p<0,0001
Risser at baseline
Mean curve correction
(Cobb)
b
Cobb>45°
r²:0,03; p=0,2183
Cobb at baseline
Mean curve correction
(Cobb)
c
Cobb>45°
r²:0.30; p<0,0001
Perdriolle at baseline
Mean curve correction
(Cobb)


a
Perd<20
r²:0,10; p=0,0170
Risser at baseline
Mean curve correction
(Cobb)
b
Perd<20
r²:0,02; p=0,7032
Cobb at baseline
Mean curve correction
(Cobb)
c
Perd<20
r²:0,11; p=0,0119
Perdriolle at baseline
Mean curve correction
(Cobb)


a
b
c
Perd>20
r²:0,26; p=0,0005
r²:0,28; p=0,0003
r²:0,25; p=0,0007
Risser at baseline
Cobb at baseline
Perdriolle at baseline
Mean curve correction
(Cobb)


ROC1: Risser+P1; ROC2: P1; ROC3: Risser
100
70
40
10
TPF%
0
10
20
30
40
50
FPF %
ROC1
ROC2
ROC3
Auc1 = 0.961; Auc2 = 0.871; Auc3 = 0.855