Reference Manual for the ARTbrace
Acknowledgments

I would like to express, my gratitude to the late Cyril Lecante, whose expertise, understanding, and patience, added considerably to my medical experience. Cyril will not see the end of the ARTbrace project, but every time a brace is fitted, a small part of him is living again. This book is dedicated to him.

A very special thanks goes out to Stéphane Lecante who continued the work of his brother Cyril at the head of The Lecante Group. He organised the first training sessions that gave birth to this book. I would like to also thank the other members of the team and especially Sophie Pourret, Frédéric, Didier, Jonathan, Alith and the numerous others who worked on this project who unfortunately cannot all be named here. I must also acknowledge Pascal Genevois, who has been able, with his whole team, to finalise the new sensor “Orten full body” specifically adapted to the ARTbrace, in less than six months.

Thanks also goes out to my secretary, Marina Catherin, who has the difficult task of organising appointments for patients and support them administratively in this “obstacle race” that is currently the French Medicine. Appreciation also goes out to the Radiology Department of the Clinique du Parc, which for many years has been at the forefront of technology with the EOS system.

The digital cast was born in 2013 during the SOSORT Chicago meeting that I had the honour to chair. The brace is the fruit of 10 years of research within the SOSORT and I am very proud that the acronym ARTbrace was created by my friend Stefano Negrini.

I would also like to thank my family for the support they gave me through my entire life and in particular, I must acknowledge my wife Alice. Without her love, encouragement and patience, I would not have finished this book. My daughter Agnes who from London, corrects my English.

In conclusion, I recognise that this research would not have been possible without the patients who sometimes come from so far and who do their utmost to follow the instructions and protocols. A special thanks to Christine Chenot, President of the french “Scoliose et Partage” Association, who agreed to assess the psychological feeling of this brace.

Dr Jean Claude de Mauroy
The ARTbrace is the latest evolution of the Lyon adjustable brace already used 200 years ago by Charles Gabriel Pravaz. It benefits from the most modern technology with digital cast, digitizer “whole spine” and use of Europlex'O of 3 or 4 mm that combines rigidity, lightness, transparency, thermal insulation and efficiency. The in-brace reduction in ARTbrace reaches 70% on average and is the largest to date. We currently know that the end result depends on the initial in-brace correction.

The name ARTbrace is the acronym for its main biomechanical actions: Asymmetry, Rigidity and (de)Torsion. It is currently the only brace of detorsion for both the child and the adult.

Digital cast offers many more possibilities than the old Cotrel EDF (Elongation Derotation Flexion) plaster cast. Associated with the hyper-correction of the brace, it achieves at best the plastic deformation and a real adjustment of the paravertebral ligamentary tensions. The block superposition technique allows an exclusive optimal correction of the sagittal plane on which the scoliosis evolution in adulthood depends. It is the simultaneous correction of the frontal plane and the sagittal plane for each of the blocks that automatically causes detorsion by the law of coupled movements.

The Lyon brace is the only one to be associated with one of the 7 specific PSSE methods: the Lyon method.

After a first evaluation phase by the inventors: Jean Claude de Mauroy, Sophie Pourret and Cyril Lecante until the publication of the final results in 2019 (SOSORT San Francisco), the changes were minimal. We are now entering a second phase of spreading the method.

The third edition of this manual illustrates the global bracing solution for scoliosis that we are currently performing. All elements of the brace management to its evaluation by on-line questionnaire will be available soon.

This manual contains the main tables and didactic algorithms. Most of the chapters are illustrated by an online video.

After a period which can be referred to as ‘highly surgical’, the interest to conservative treatments whose effectiveness has been scientifically proven by BraIST study, is noted again. The high rigidity PMMA Lyon brace (in-brace reduction
40-50%) has demonstrated its effectiveness for scoliosis including adolescents and scoliosis over 40°. The new Lyon ARTbrace takes much of this legacy even if it use the most modern techniques. In fact, the new ARTbrace concentrates a maximum of technological innovations explaining a double in-brace correction than polyethylene ones.

The book is published in .pdf or .epub format. For practical reasons, the multimedia documents; figures, videos and bibliographical references require an internet connection to be used. Some regular updates will be published according to feedback received during training sessions.

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1. History of ARTbrace

Old Lyon Brace & new ARTbrace

The Lyon Bracing Management has evolved since 1947 as a cooperative effort between Pierre Stagnara MD and Bouillat & Terrier CPO.

The Lyon management protocol requires curve reduction with a plaster cast for one to four months, after which the brace is moulded and fitted. The brace is a highly adjustable under arm design and does not have a superstructure.

Very early braces were made from a combination of steel and leather. Following World War II, Régis Lecante, CPO, discovered a Messerschmitt cockpit near his country house. Made of a very durable plastic, it could be easily machined, tapped and screwed. The use of PMM (polymetacrylate of methyl) or Plexidur™ was born, revolutionising modern brace materials and design.

Evolution of the Lyon brace

The Lyon Brace, created in 1947 by Pierre Stagnara, is designed to be:
- Adjustable: It is easily modified, accommodating up to 7 cm of growth, while also being more cost effective, requiring fewer and less frequent changes.
- Active: The rigidity of the PMM structure stimulates the child to initiate...
an active axial auto correction which decreases superficial pressures.

- **Decompressive:** As a consequence of the “Adjustable” feature, the effect of extension between the two pelvic and scapular girdles also decreases the pressure on the intervertebral discs and promotes more effective pushes.
- **Symmetrical:** In addition to being more aesthetically pleasing, the brace is much easier to build.
- **Stable:** The stability of both shoulder and pelvic girdle facilitates the intermediate corrections.
- **Transparent:** Skin pressures are easily observed and direct control of the pushes, stops, drives and reliefs is possible. Complementary pads are rarely needed.

The Lyon Brace is always constructed after the completion of the reductive plaster casting protocol using a Cotrel EDF frame. The results of the Lyon Brace Management have been validated by numerous teams in Europe. However, the plaster cast process is quite involved for the patient and physician. Consequently, many teams looked for more convenient and expedient solutions without preliminary plaster cast reduction.

http://scoliosisjournal.biomedcentral.com/articles/10.1186/1748-7161-6-4

It was only in 2013 that advances in computer technology with the latest generation software (OrtenShape) allowed the superposition of different CAD/CAM moulds and a segmental 3D reconstruction. The aim was to use this new software to replace the plaster cast with a new Lyon brace: the ARTbrace. The Regional moulding is one of the fundamental innovations of the ART brace. The overcorrection is performed in the frontal plane and the sagittal plane precisely and individually for each child at three levels: pelvis, lumbar spine and thoracic spine. The detorsion is obtained by untwisting the whole spine.

Like the historical Lyon brace, the ARTbrace is **ADJUSTABLE.** Both axillary and pelvic clamps are adjustable with a precise wrench and a bolt system and an anterior ratcheting buckle.

Like the historical Lyon brace, the SAGITTAL PLANE is fixed by the posterior bar. But the sagittal plane is determined by the regional mould and the superposition of the 3 mouldings. In additional it is the lack of support at the sternoclavicular level and at the abdominal level that avoids lumbar delordosis and thoracic flat back.

The initial aim was to avoid the plaster cast, but very quickly, the ARTbrace appeared to be a much more effective solution compared to the former casts and it was even better tolerated. Following the early successes of in-brace correction (40 % better in-brace correction), the whole treatment was continued with the same brace.
**DELIVERY**

- Orthotist
- Definitive trim-lines on the patient
- Signature by the patient of the orthosis acceptance document

**Check-up**

- Physiatrist
- 3 days after delivery
- In-brace X-Ray
- Modifications

**Successive Controls**

- MD + CPO
- X-ray without brace (elasticity)
- After the end of Total Time
- 4 months with BrQ questionnaire
- every 6 months till growth end then progressive weaning mangement

**Cloud documents**

- Educational booklet
- Parents instruction
- Guidelines & Education documents
- BrQ Questionnaire for 4 months control
- Video of home exercises

**Certification**

- PT
- MD
- CPO
- MOOC & Residential

**Telemedecine**

- On-line expertise
3. New biomechanical concepts

**Mathematical Basis: Circled Helicoid**
The mathematical basis of the torso column is the circled helicoid with horizontal generating circle described by the French mathematician Robert Ferréol. For a circled helicoid, the Cartesian parameterisation is the parameterisation of the circle with diameter carried by Ox, with a center \((a,0,0)\), with a radius \(b\), forming an angle \(\alpha\) with the horizontal. For torso column \(\alpha = 0\).

The aim is to get not only a straight spine, but a reverse torso moulding opposite to scoliosis i.e. overcorrection of the scoliosis curvature. This overcorrection is possible only if the vertebral bodies are not distorted. Otherwise, we favour the correction accentuating the asymmetry of pressure on the vertebral body.

**Global Detorsion vs 3 points system (Solid Geometry)**
Given the multiplicity of planes, the corrections by the 3 points system only operate in a limited number of planes. This is why the ARTbrace works in an overall untwisting.

The Global detorsion is performed with a fixed sagittal plane. Axial elongation brings the vertebral bodies near the central axis in the frontal plane, and by untwisting the scoliotic spine between the pelvis and the shoulder the horizontal plane is corrected. So both geometrical detorsion and mechanical detorsion of the cylinder are working together.

The EOS 3D system automatically calculates the rotation for each vertebral segment. The twist (Torsion) is the sum of all the segmental rotations. We can calculate the overall in-brace untwisting.
Fixed Sagittal Plane

Usually conventional braces with 3 points systems decrease lordosis and thoracic kyphosis. Untwisting the spine with ARTbrace is done maintaining the curvatures in the sagittal plane. Indeed, the screw is not straight, but curved. However, curving the screwdriver is useless. The new solution is the moulding in frontal bending which respects lordosis and kyphosis and allows untwisting whilst retaining the curvatures in the sagittal plane. The spine in the sagittal plane is fixed as physiologically as possible. Only the frontal and horizontal planes are mobile.

Soft Contact (dynamic, sliding effect...)

The Soft Contact concept is that of the squeeze attachment for cylindrical hay bales. Pressures are spread over the entire cylinder surface; this is contrary to the principle of the push and counter-push of the historical Lyon brace or other three point braces. As usual in the correction of 3D deformities of the scoliotic spine, room should be provided for migration of lateral curvature, rotated vertebrae and breathing exercises. In this design, actually various 3-point pressure systems are provided to correct the lateral curvature and vertebral rotation from different anatomical planes. In the ART brace the shape of the brace is not a straight spine like the Sforzesco or the old Lyon brace, but an overcorrected spine with reverse scoliosis. This is possible thanks to the superposition of two corrective bending mouldings.

Mayonnaise Tube Effect

The translation along the vertical axis is a fundamental step of untwisting. The concept of elongation has progressed during the last century.
1. Simple cervical traction against gravity: it is more of a stretching
2. With Milwaukee, this elongation is between the head and the pelvis which provides elongation.
3. With the Lyon brace, elongation occurs between shoulder and pelvic belts.
4. With Boston, it is the effect “cherry stone” that is privileged with the idea that correcting the bottom of the column will help to correct the upper part of the spine.
5. Finally with ARTbrace, there is a real extrusion by bringing together the two pieces (hemi-shells).

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1 SOSORT guideline: “It is recommended that the brace proposed for treating a scoliotic deformity on the frontal and horizontal planes should take into account the sagittal plane as much as possible.”
Axilla Baby lift concept and corkscrew effect
The feature of the ARTbrace is an untwisting that occurs in the frontal plane in the armpits, like when wearing a child.

Wrench & Bolt concept
The principle of the wrench and bolt is to “unscrew or untwist” scoliosis. For instance, the Chêneau brace uses the principle of pressure and expansion in many precise areas. For a double major curve in the ARTbrace, the thoraco-lumbar area is the fixed point with unscrewing between this fixed point and the pelvis for lumbar curvature and the shoulder girdle for thoracic curvature. For a thoraco-lumbar curve, the fixed points are at the cranial and caudal parts of the spine and the unscrewing is done at thoracolumbar level. The pelvis is the «bolt head» which is stabilised by a symmetrical pelvic base like a key. Lumbar and thoracic segments above act as a wrench for the detorsion of scoliosis.

Very High Rigid Europlex‘O
Even if the old Lyon brace in polymethacrylate was very rigid, the credit for VERY HIGH RIGIDITY goes to the Italian team of ISICO with the Sforzesco brace, which has proven to be effective by avoiding plaster casts for scoliosis over 45°. The acronym ART brace (Asymmetrical Rigid Torsion brace) was created by Stefano Negrini. The merit of the ART brace is the addition of overcorrection to the high rigidity with a global detorsion. It is this overcorrection for small curvatures which explains the average improvement of the in-brace correction.
4. Principles of ARTbrace

4D Global correction of the ARTbrace

The mechanical action of the ART brace is carried out:

- Along the vertical axis of the spine, in the three sagittal, frontal and horizontal planes of the spine. In the ART brace, the reference plane is the horizontal plane at the thoraco-lumbar junction. The anterior and posterior muscle chains in the frontal plane intersect at this level. The middle brace closure with ratcheting buckle must be strict. The elongation along the axis of the spine is carried out during the first moulding. The spring effect moves the apical vertebrae near the spinal axis. This is the correction of the internal geometric vertebral torsion.

- This classical elongation in braces such as the Milwaukee brace has the disadvantage of reducing the curvatures also in the sagittal plane. Segmental mouldings in the lumbar and thoracic areas overcome this disadvantage, and reproduce physiological curvatures in the fixed sagittal plane.

The correction in the horizontal plane is on the whole external surface of the trunk.

In the case of a double curvature, there is a first untwisting between the pelvis and the reference thoraco-lumbar plane, and a second untwisting between the reference plane and the shoulder girdle.

The correction in the frontal plane is also exerted on the entire external surface of the trunk. It is the shift that is achieved with mouldings 2 and 3 which allows this correction. The translation is at the apical vertebra level and not below, as in the old Lyon brace. For a single thoraco-lumbar curve, it is the reference thoraco-lumbar plane which ensures derotation of the entire trunk, between both pelvic and scapular planes. The lever arm is more important and the curve is therefore better corrected. In the frontal plane, it is also the reference thoraco-lumbar plane that will translate between both scapular and pelvic girdles. Lumbar and thoracic shifts take place in the same direction.

The 4D global correction of ARTbrace occurs during the day and the movement is obtained by balancing among both frontal and horizontal anatomical planes. The inversion of the curvatures automatically creates an expansion in the concavity that allows the 4th dynamical dimension, i.e. Contact during movement and breathing.

The best or nothing

The guidelines N° 16 of SOSORT can be confusing: “It is recommended to use the least invasive brace in relation to the clinical situation, provided the same effectiveness, to reduce the psychological impact and to ensure better patient compliance.” More rigid does not mean more invasive. The strategy of “step by step” i.e. a less corrective brace for a small angulation and a very rigid brace for a larger angulation, is not used in current practice of Lyon management. The risk
of failure culture with progression to braces more and more rigid is often mis-perceived by children and parents. The use of the brace immediately the most effective with partial time wearing was preferred. For the same effectiveness, the psychological impact is reduced by partial time wearing and compliance is improved.

5. Brace prescription

The goal of the Lyon bracing management is to allow non-operative treatment of scoliosis by preventing progression of the scoliosis in the growing child. A better understanding of the natural history of idiopathic scoliosis has refined the indications for brace treatment. Brace treatment begins when the probability of the progression of scoliosis is high. The patient with a mild curve near the completion of growth is unlikely to have further progression of the scoliosis and probably does not benefit from wearing a brace.

**Chaotic & Linear Scoliosis**
Below 20°, scoliosis is more often a deviation which can be reversible. For now it is impossible to predict the evolution. This stage is called chaotic scoliosis. Beyond 20°-25°, there is a structural deformation during growth which will cause the vicious circle of scoliosis described by Ian Stokes. The linear evolution of the scoliosis has been described by Ms. Duval Beaupère. To avoid over treatment, we do not brace in chaotic phase.

The preadolescent with a moderate scoliosis (curvature >30°) is at significant risk concerning the progression of the scoliosis and may derive a great benefit from wearing a brace (Virtuous Bone circle).

The adolescent with a 45-degree curvature and growth remaining may achieve curve control with bracing or can be served by surgical treatment. In general, for the adolescent with a curvature of 25-45° degrees and growth remaining, Lyon bracing management is indicated and will stop progression of the curvature in 55% of patients, it will improve curvature in 35% and curve progression will continue in spite of bracing in 10%. Bracing large curves in the younger child may delay surgery and allow further spinal growth before fusion. In juvenile idiopathic scoliosis, brace wear is initiated when the curvature exceeds 20°. In the adolescent or late onset idiopathic scoliosis, the following guidelines are suggested by SRS:

**Approximate guidelines for brace treatment of Adolescent Idiopathic Scoliosis** (Juvenile curves should be braced much earlier- probably if over 20°)

<table>
<thead>
<tr>
<th>Curve Range</th>
<th>Treatment Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0° - 20°</td>
<td>Observe for progression</td>
</tr>
<tr>
<td>20° - 25°</td>
<td>Brace if substantial progression documented</td>
</tr>
<tr>
<td>25° - 30°</td>
<td>Brace if progressive and growth remains</td>
</tr>
<tr>
<td>30° - 40°</td>
<td>Brace if growth remains</td>
</tr>
<tr>
<td>40° - 45°</td>
<td>If growth remains, consider bracing</td>
</tr>
<tr>
<td>&gt; 45°</td>
<td>If family refutes surgery</td>
</tr>
</tbody>
</table>
Curve Location
The Lyon brace makes it possible to treat all curves, except primary high thoracic curves for which we advise the use of the orthotic device of Milwaukee. Fortunately this pattern of scoliosis is less evolutive than others.

Hypokyphosis and Thoracic Lordosis
The restoration of thoracic kyphosis requires:
- The stability of the lumbar spine in lordosis,
- The anterior xiphoidian stop,
- Bending of the posterior and anterior bars

Contra indications to bracing
1. **Severe thoracic lordosis** (thoracic kyphosis < 0°) is a contra indication to brace. All braces that apply transverse forces with posterolateral push on the spine via a rib articulation may worsen the lordotic spine. Surgical Treatment is recommended for progressive curves with true thoracic lordosis.
2. **No participation from patient and family** The Lyon brace remains an elitist treatment. When the child and his family accept the plaster cast or ART full time, (in approximately two thirds of the cases) the part time bracing which follows will be well accepted. It appears useless to us to spend money for a brace not worn, and when the scoliosis evolves, it is better to consider surgical treatment.
3. **Morbid obesity** may make effective bracing for scoliosis impossible. The brace is designed to grip the pelvis bony prominences and large amount of growth remains, otherwise observe (night time bracing).
4. **Psychological Reaction**
5. **In-brace reducibility <20%**
6. Digital Cast

Biomechanical Basis: Coupled Movement
The biomechanical basis according to Panjabi is the coupled motion behaviour of the spine. The moulding is 2D but the correction is 3D. The direction of rotation may differ depending on the incurvation of the spine in the sagittal plane. When there is a flat back, the initial scoliotic rotation may be increased by the correction in the frontal plane. Restitution of physiological curves in the sagittal plane seems to decrease the scoliosis rotation (Harrison Fryette’s laws)

Principle I: When the spine is in a neutral position, sidebending to one side will be accompanied by horizontal rotation to the opposite side.
Principle II: When the spine is in a flexed or extended position (non-neutral), sidebending to one side will be accompanied by rotation to the same side.

Although these laws have not been described in the context of scoliosis, we often see an accentuation of the rotation during pre-surgical bendings in supine position.

Specific Device with Visual Control of Alignment
To obtain a torso column on the opposite side of the scoliosis, the superposition of three electronic instantaneous full 3D mouldings is necessary. These mouldings were made with the full 3D instantaneous raster stereography digitiser Orten. Markers are placed on the optical jersey:

- On the front at the upper and lower part of the sternum and at the antero-superior iliac spine.
- On the back on a point on each vertebral spinous process.

A visually monitored control with a posterior and profile view is mandatory to obtain the ideal posture.

Sagittalometer Assessment
The basic use of sagittalometer is the calculation of the pelvic incidence. Pelvic incidence is a constitutional factor and does not vary according to the movements in the sagittal plane. Depending on the angle of pelvic incidence, sagittalometer indicates the theoretical value of the sacral slope (mould 1), lordosis (mould 2) and kyphosis (mould 3).

1st mould (self-elongation & pelvic tilt modifier)
7. Processing & Brace construction

Modelling of the trunk shape with shapes overlay
These modifications are made using the software OrtenShape. In the frontal plane moulding 2 is superimposed on moulding 1, then moulding 3. Similarly in the sagittal plane, the second moulding is superposed on the first one, then on the third moulding. Changes are made at constant volume and detorsion which is a result of both corrections in the frontal plane and the sagittal plane.

The ARTbrace is constructed with 2 rigid asymmetrical lateral pieces of Europlex’O. They are connected posteriorly at the midline by a duraluminium bar like the historical Lyon brace. All metal parts are similar to those of the old Lyon brace. Both anterior and lower ratcheting buckles are rigid, the upper third is velcro. The brace is not in complete contact with the body: there is an expansion in the concavity which is there to allow room for the body’s expansion during inhalation.

Specific design and curve pattern
A specific classification is not used, indeed most classifications were developed for surgery. For bracing, a specific classification was developed by Rigo for the specific needs of the RSC brace.
- For the ARTbrace, the sagittal plane, pelvic tilt and axial balance are strictly controlled. The only modifications concern the frontal plane:
  - For a single thoracic curve, the second moulding is used only if the lordosis of the first moulding is incorrect and if this is the case we do not need the frontal shift.
  - For a single thoraco-lumbar curve, both thoracic and lumbar shifts will be made in the same direction.
  - For a double curve, the horizontal plane of overlay is at the level of the transitional vertebra, usually at the lumbosacral junction.
  - For a double thoracic curve, we give priority to the main rib hump, mainly the lower curve and in this case, the plastazote pad will be used to control the upper curve.

If the shoulders are unbalanced, it is also possible to make the upper end of the brace asymmetric at the axillary level like the historical Lyon brace. No specific segmental derotation is required as the ARTbrace causes a global helical untwisting.
**The special case of Infantile Scoliosis**

The ARTbrace was created to replace the plaster cast in the Lyon management for AIS. It was therefore tempting to use it to replace the serial casting for infantile scoliosis. Infantile scoliosis are rare and a study of two cases is the most useful to illustrate the problems infantile scoliosis might cause. The first problem has been the miniaturisation of the brace with a use of a 3mm Europlex’. The posterior metal bar was reduced in proportion so as the anterior closures. The second problem is the impossibility of achieving the regional moulding for children under 3 years which cannot maintain asymmetric postures. The problem is solved by using the mirror technique. The first moulding is realised in passive axial elongation, meaning reducing the curvature by pulling the child by the upper limbs. During the superimposing step, we invert the image, creating a reverse torsion of the initial scoliosis. Thus a major expansion in the concavity is performed for asymmetrical correction of scoliosis and breathing.

**The story of Olympe**

Early Onset Scoliosis was discovered at the age of 2 years with a right thora-columbar curve. At the age of 3 years the curve is 30°. Olympe was not compliant with the first Milwaukee that was quickly replaced by an asymmetrical polyethylene TLSO well-worn during 3 years. Despite bracing, the scoliosis is still progressing to 42° without brace and in-brace correction is 25°. At 8 years old, it was possible to achieve the classic regional moulding in 3 steps. The in-brace correction is complete at 5°. At six months follow-up, the angulation without a brace is 17°, a little better than under the TLSO. Olympe prefers the Europlex’O.

**The story of Adele**

Adele two and a half years old, lives in a North West town of France. At the age of three months, her left infantile scoliosis is discovered. Her Scoliosis is highly progressive because the curve T6-T12 reaches 95° on May 31, 2015. A serial casting from May to July was realised, and then a TLSO brace adapted. MD and CPO are doing their best, but the correction is limited to 60°. The CAD/CAM Mirror technique was used. The in-brace angulation is reduced at 36° (62%), the child is well balanced in the frontal plane and the kyphosis is corrected in the sagittal plane.

Until now, there were not many alternatives to sequential and repetitive surgery for infantile scoliosis. The 3mm Europlex’O seems to be able to replace the Min Mehta’s serial casting and the polyethylene TLSO.

By comparing the results obtained in the same infantile scoliosis by a conventional TLSO and the ART, it is possible to better appreciate the technology differences. In both cases, the results seem to be better for the 3mm Europlex’O.

**Adult Scoliosis**

Scoliosis is a major demographic health issue in the adult population with pain, imbalance and angular curve progression. In a series of 158 adult scoliosis treated by classical polyethylene brace and reviewed on average 8 years after the start of treatment, the natural angular evolution of scoliosis is halted in 80% of cases. However, it appears that current braces fail to stop the kyphotic evolution of adult scoliosis and justifies the improvement of existing braces. As the high rigidity of the ART 4 mm Europlex’O is better tolerated by children than the conventional polyethylene; it was logical to use the new concepts of “baby lift” and overall untwisting for adults. The first encouraging results justify this presentation especially as there is to date no other solution. As with adolescent scoliosis, we use the regional moulding. The third mould is made in maximal inspiration, because the expansion in the concavity is lower than for children. The visual control of the instantaneous 3D scan allows a perfect alignment in the frontal and sagittal plane. The superposition of the three mouldings is carried out by the specific OrtenShape software. The usual wearing protocol of the brace is of 4 hours a day. As adult patients are evolving in kyphosis, the posterior axillary support is lower than for children. Similarly, the anterior abdominal expansion due to the restoration of lordosis improves tolerance. An ARTbrace was performed in 32 adult patients from February to November, 2015. Although there are difficulties for the camptocormia, all patients appreciate the anterior closing by the ratcheting buckle of the ART. One of our patients, passing from polyethylene to Europlex’O, sums up the situation; “Before, I carried the brace, now the brace carries me”.

Our first case is a lady born in April 1931. She has a thoraco-lumbar scoliosis (T11-L3 52°) and especially a high thoracic kyphosis of 88° with significant walking difficulties. The result is: kyphosis in-brace correction at 48° and scoliosis at 38°. Unfortunately, the brace is worn less than 4 hours per day as she has leukaemia.

Our second case is an aging patient treated by the former polyethylene bivalve brace with sterno clavicular support. She presents a scoliosis T5-T12 80° / T12-L4 60°. Since an accident in 2013, the former brace is no longer suitable. A hip flexion and a pelvic retroversion are compensating partially the high thoracic kyphosis. The ART adult is completed in March 2015. From the beginning, twisting sensation disappears, less lumbar pain, she is able to climb three floors without breathlessness. At the 6-month follow up, the brace is worn every morning, is very well tolerated and the high thoracic kyphosis is improving at 45°.

In conclusion, the adult ARTbrace has the advantage of correcting scoliosis as well as kyphosis. The lateral thoracic support is better tolerated than the sternoclavicular support of a sagittal 3 points system. The anterior closure is a benefit to patients. The absence of abdominal compression limits the bladder and digestive complications.

**Fitting and fabrication of the ARTbrace**
Trim Lines
The anterior space between the two pieces is about 2 cm. The cutting at the breast level is wide, to avoid compression. The anterior inferior cutting is higher than for the old Lyon brace. It is at the level of the Antero-Superior Iliac apophysis. The posterior cutting allows the opening of the brace like a book. However, the opening is always partial, because the two hinges are not in the same frontal plane. The cutting is wider in the concavity, i.e., in the opposite direction of scoliosis, which facilitated the opening and allows some manual control for the physiotherapist. The posterior-inferior cutting is at the level of the acetabular roof. The posterior-superior cutting is very high, especially in case of flat back. From a lateral view, the axillary line is inclined from 10° to 20° on the horizontal, the posterior part being higher than the anterior.

Management of the patient with an ARTBrace brace

How to check the brace
Clinically, the height of the child in brace is measured, because the gain in height is an average of 1.58 cm due to the untwisting of the spine. This is an excellent clinical indicator of the effectiveness of the brace. In the sagittal plane, alignment of Tragus – Acromion - Trochanter - Ankles is checked. Frontal and sagittal X-rays are performed 3 to 4 days after fitting the brace with the ultra-low dose EOS system which also allows a 3D reconstruction if necessary. The metal bar must be vertical in the frontal plane and the C7 axis well balanced. Adjusting the brace is made in the supine position. The middle ratcheting buckle is checked at the chondro-costal level. The tightening of the lower ratchet closure does not compress the abdomen, but stabilizes trochanters. Upper Velcro closure must be tight enough to prevent the tingling in the upper limbs. It is always possible to add on a plastazote pad inside the Europlex’O, but in practice this is an exception. Indications of the sitting posture are given with feet behind the chair, buttocks in front of the seat, Europlex’O touching the edge of the table and forearms on the table.

In the ARTbrace, the fixed point is the lower part of the thorax at the thoracolumbar junction. The dynamic movement of the posterior part of the spine is better in this posture. It is the fourth dimension of the brace. The child will relax in the listening posture on the back of the chair. Alternating these two extreme postures seems to be more dynamic.

Follow-up and Management

1 - First initial Control 6 months after the end of full time
   Curve STABLE --> Decrease during the day by blocks of 4 hours
   Curve Unstable (elasticity of more than 10°) --> No Change
   Curve Worsening of more than 5° --> No change + 1 month full time every year

2 - Next Control every 6 months
   Same protocol till reaching 8 h/24 = Night time

How to determine the weaning time?
The Risser test is not a very good test when the brace regularly presses on the iliac crest. We use more simply, the measurement of standing height, barefoot. When the size no longer changes, the weaning time depends on the maximum reached by the scoliosis angle.
1. Below 30 °: removal at the end of linear growth
2. Between 30 ° and 40 °: removal 1 year after the end of growth in stature.
3. For more than 40 °: removal 18 months after the end of growth in stature.

A 6 months test ablation during the summer is then programmed in general at the end of the school year in June for Europe (heat). The child is followed in January of the following year. If the elasticity is below 10°, we confirm the final ablation. If the elasticity is greater than 10°, a recovery of the brace during night time for a further 6 months may be considered.

Physical therapy management
Physiotherapy has remained the same, but the brace asymmetry and preparation for segmental moulding are closer to asymmetric methods and probably the current protocol will be adapted in the future.
8. Manufacturing

1. Thermoforming
   Thermoforming of the two hemi-valves on the positive polurethane. The two pieces must exceed the trim lines drawn on the positive plaster cast.

2. First assembly
   The thermoformed hemi-valves are positioned on the positive polyurethane. The metal bars are curved and a first provisional assembly is carried out. The final trim lines and the final adjusting of the two pieces will be carried out at the time of the initial fitting.

3. Without fitting
   When precise measurements of height and circumference have been made during the digital cast, it is possible to carry out the final construction directly.

4. Used material
   The rigid asymmetrical lateral pieces of Europlex'O are connected posteriorly at the midline by a duraluminium bar like the historical Lyon brace. The posterior metal bar is curved in the sagittal plane by following the positive polyurethane. All metal parts are similar to those of the old Lyon brace. Both anterior and lower ratcheting buckles are rigid, the upper third is Velcro.
9. Fitting

1 – Handing the Tee Shirt
During the fitting session the special seam- less T-shirts are delivered. the patient is explained the need to wash it once before the final placement of the brace. It takes about 3 weeks for the regulation of perspiration with an increased risk of skin allergy during this period.

2 - Fitting directly on the skin
The transparency of the Europlex’O is usually used during the fitting, which will be done directly on the skin.

3 - Progressive tightening with adhesive tape
The 2 hemi-valves are positioned on the iliac crest and blocked at sub-axillary. With the aid of an adhesive tape, the two hemi-valves are brought together, which will press against the trochanter.

The adhesive tape bypasses the patient with the objective of making it grow according to the principle of the mayonnaise tube. The space between the two hemi valves will gradually decrease.

When the adhesive tape reaches the upper part, the tightening is resumed.

Similarly, when the tape arrives at the bottom again, the tightening is resumed and the space between the two hemi-valves decreases again.

Gradually, the child realizes a self-elongation of the trunk.

4 - Trimlines
The orthotist draws trim-lines with a large cut at the chest level.

The lower cut is made 2 cm below the anterior superior iliac spine, which allows a 90° sitting position.

The anterior cut is about 2 cm, knowing during the control, there is usually a superposition.

The fitting at the lower part requires a new tightening with inferior overlapping of about 3 cm.

The postero-inferior cut is normal, but the upper cut is much higher to promote kyphosisation of the thoracic region.

Vertical posterior cuts are also 2 cm apart. An additional quarter-moon cut is made at the concavities to facilitate the detorsion sitting or lying down, especially at the lumbar level. These cuts facilitate the check-up of the brace.

The under axillary cutting is very high. It will take about 3 weeks for the shoulders to lower as the spine is untwisted, according to the principle of "corkscrew
effect”

5 - Adult Trimlines
The cuts will be different in the adult who presents most of the time a thoracic kyphosis. In this case the postero-superior cut is located at the apex of the kyphosis. The tip of the shoulder blades will be free, which facilitates the corrective movement. Laterally the sub-axillary cut is inclined at 20 ° upwards and forwards, what is the opposite as for a adolescent scoliosis.

10. Delivery

1 - Brace presentation by the orthotist
2 - Explanation of setting-up: how to set-up the brace.
3- Setting up on the patient
4 - Adjusting in supine position
5 - Transfer from the lying position to the sitting position by pivoting on the ischium
6 - First walking tests
7 - Self-elongation by pushing down the brace to release the sub-axillary supports (duck dance)
8 - Closures Demonstration: how to use the ratcheting buckles
9 - Testing the Sitting position: from 90° to 120° for trunk-thigh angle
10 - Removal for first finishing
11 - In general, slight decrease in axillary height
12 - Setting up washable axillary felting
13 - Protection of metal parts
14 - Demonstration of the use of washable axillary foam
15 - The patient puts by herself the brace
16 - Last supine control of the abdominal space
17 - Final signature of the certificate of convenience
11. Checking

1 - How to remove the shoes

2 - Measuring height and weight in brace

3.- Frontal ans sagittal balance with the plumbline

4 - Transfer Standing -> Supine

5 - Manual adjustment of the anterior median closing at the base of the thorax

6 - Drawing a new reference line (white pen on black closure)

7 - Control of the hips flexion at 90°

8 - Control the absence of abdominal pressure

9 - Transfer from decubitus-> standing position by pivoting on the ischium

10 - Axillary baby lift Control (thickness of a finger between Europlex'O and skin)

11 - Walking control of frontal and sagittal balance

12 - Control of spirometry without and in-brace (upper closure open)

13 - Sitting Control with 10 cm between the brace and the seat

14 - Sitting control in listening & writing position

15 - Put on the shoes without external help
12. Lyon Method of Physiotherapy

Lyon method
“The treatment of a confirmed scoliosis is a perpetual and disagreeable lesson of humility” wrote Roederer a hundred years ago and unfortunately this sentence is still relevant today. The increasing number of seemingly contradictory methods adds to the confusion and doubt. The Lyon method was developed 60 years ago by Pierre Stagnara with the Lyon brace (Stagnara 1978 & Dubousset 1996). It has been validated by many physiotherapists including Georges Mollon (1986) and Paul Ducongé (2002). The Lyon method is not intended to provide the physiotherapist an original technique and specific exercises, but rather a way of approaching and understanding scoliosis.

Stage I: Assessment in terms of Lyon method

Three elements are important to guide therapy:

1. The patient age.
   - When the patient is less than 10 years old, it is usually an Early Onset Scoliosis (EOS). We know there is a maturation delay in the systems of balance and posture. Physical therapy will be based on exercises favouring coordination and balance in a fun way, such as ball games.
   - During pubertal growth, growth occurs at the bone level and is inhibited by the paravertebral myofascial structures. The readjustment of myofascial tension occurs globally by symmetrical range of motion exercises. The hypotonia of the musculature is also a characteristic of this period. We must insist on the maintenance of muscle tone over time by endurance exercise in aerobic metabolism.

2. Postural Imbalance.
   Multiple postural defects may be associated with scoliosis. The problem is that it is very difficult to determine what is a defect or compensation. In doubt, examine the child walking; if the head is projected at the polygon of the feet, there is no need to act on segmental pelvic or scapular girdles correction. Similarly, if one leg is shorter on the side of the rib hump, it is likely that compensation by heel lift will increase the rib hump and in this case, we will not use the shoe lift.

3. Cobb angle.
   - Below 25°, it is impossible to predict the evolution of scoliosis and it behaves like a chaotic system described by de Mauroy (2008). It is essential to explain to parents that physical therapy cannot prevent the scoliotic earthquake but is an earthquake-resistant construction that will limit the damage.
- Above 25°, the linear mechanism with vicious circle of evolutivity has been described by Stokes. The pressure on the vertebral body and disc is playing a major role. This pressure must be reduced by exercising, sitting position, sport ...

**Stage II: Awareness of trunk deformity**

The child has never seen his back. We must therefore make them aware of corrective possibilities while avoiding dramatizing the situation. Scoliosis is not a disease but is an adaptation of the spine. This correction will be made by the orthopaedic mirror or using a camcorder and a screen. The feedback from the squared mirror is very useful during exercises of auto-elongation or walking with small sand bag on the head. We must stimulate the perception of horizontality and verticality.

At this stage, we must also check and change the sitting position. It’s the writing position that will focus our efforts. The feet are placed behind the chair; the buttocks in front of the seat, awnings chondrocostal spurs just touch the front edge of the table and both forearms lie on the horizontal work plan. This position reduces stress on the disks and prevents excessive inflexion of the spine. (figure 1)

![Fig. 1. Usual sitting position for writing and computer](image1.png)

**Stage III: What to do: Example exercises**

The gymnastic exercises are the basis of physiotherapy. They must be simple in order to be repeated every day at home. The exercises are symmetrical, mainly made in the supine position; indeed, the radiological scoliotic angle is higher in the standing position than in the lying down position.

Standing the “grand porter” consists of walking on tiptoes with a sandbag on the head. The child tries to stretch the spine along the axis while controlling the balance by looking at the feedback mirror. (figure 2)

![Fig. 2. “grand porter”](image2.png)

The art of the therapist is to adapt exercises by changing various parameters such as pace, intensity, duration...

**Stage IV: What not to do and why?**

Much more important and rarely described are exercises and postures to avoid in scoliosis.

1. The function plan is the sagittal spine. In this plane the extreme magnitudes should be avoided. By extension the flat back is accentuated, and by flexion, the disc pressure is increased. Furthermore, especially beyond a 25° degree rotation, the apical vertebra tends to further increase the existing rotation due to paraspinal muscles lever arm and the position of the Instantaneous Centre of Rotation. (figure 3)

![Fig. 3. Increasing rotation during trunk flexion for a scoliosis of more than 25°](image3.png)
2. The profound inhalation favours the rotation of the apical vertebra, therefore, avoid shortness of breath.

3. The modelling of the rib hump in the sagittal plane favours the flat back. For a true derotation in the prone position, place a cushion under the opposite anterior chondrocostal prominence and press the inner slope of the rib hump. (figure 4)

4. Strengthening the muscles body building type is useless, we must work on endurance.

**Stage V: Sport and physiotherapy**

Many physiotherapists ask their patients to stop practicing sport. Lyon method allows the pursuit of sport in so far as contraindications of step 4 are met. So it’s more how to practice the sport rather than the sport itself that matters. Our best results are obtained in Lyon brace in the group of children who perform more than 5 hours of sport a week. The best sports for scoliosis are combat sports; the worst, rock climbing, as it promotes too much the extension of the spine. We must adapt the sport at the age of the child. Before puberty, sports of balance and coordination are preferred. Swimming is excellent during the pubertal growth phase. After 15 years the axial impact sports promote calcium fixation to the bone and improve bone mass.

**Physiotherapy and Lyon bracing management**

When scoliosis is evolving, i.e., moves from a chaotic phase to a linear phase, the Lyon method combines physiotherapy and the Lyon brace. The Lyon brace is always preceded by a plaster cast that allows a real lengthening of the concavity beyond the simple mobilization (de Mauroy 2011). Physiotherapy is greatly facilitated by the plaster cast, just ask the children to grow up self-dodging support. This is a true three-dimensional correction because the pelvis is fully stabilized. (figure 5)

Fig. 5. Auto-3D correction of scoliosis with Lyon plaster cast

During the plaster cast or total time (one to four months), physiotherapy is intensified with at least two sessions a week supervised by the physiotherapist. The work plan includes:
- Breath control with use of expiratory reserve volume
- 3D mobilization of the spine
- Mobilization of the ilio-lumbar angle (lumbar scoliosis)
- Therapeutic patient education (food control, skin care ...)
- Sitting position check

The advantage of the plaster cast or total time for scoliosis under 30 degrees is that the brace is worn only during the night. Physical therapy will continue at least once a week.

When scoliosis exceeds 30°, the brace must be worn during part of the day. The physiotherapist will perform physical therapy with or without brace. (figure 6)
Fig. 6. Group physiotherapy in Lyon brace

Psychologically group physiotherapy is better.

Unfortunately, the Lyon method physiotherapy for scoliosis is not a universal standard protocol but has to adapt to each child and develop during growth. It is therefore very difficult to quantify results in terms of angular correction for scoliosis, but it is essential when the Lyon brace is prescribed.

References

The brace wearing time can be increased if the reducibility is less than 50%. When the patient is seen six months after the full time wearing, it is possible to appreciate scoliotic elasticity (difference between in-brace angulation and Cobb angle without a brace at 6 months). When the elasticity is less than 10°, the protocol provides a decreasing of the wearing time of further 4 hours during the day. When the elasticity is greater than 10°, the same protocol is maintained or exceptionally the wearing time is increased. We proceed in the same way to the next check until the last step which is the night time wearing.

<table>
<thead>
<tr>
<th>Cobb °</th>
<th>Total time</th>
<th>Partial time at end of growth</th>
<th>Progressive weaning 4 hours less every 6 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>20° - 29°</td>
<td>1 year</td>
<td>16h/24</td>
<td>12h/24 6 months 8h°24 (night) 6 months</td>
</tr>
<tr>
<td>30° - 39°</td>
<td>18 months</td>
<td>20h/24</td>
<td>6h/24 6 months 12h/24 6 months 8h°24 (night) 6 months</td>
</tr>
<tr>
<td>&gt; 40°</td>
<td>2 years</td>
<td>23h/24</td>
<td>20h/24 6 months 16h/24 6 months 12h/24 6 months 8h°24 (night) 6 months</td>
</tr>
</tbody>
</table>

Weaning management based on Cobb angle

The management is intended with a stable angulation at each control.

**Special cases:**
- **If the angulation is less than 10°** it is proposed 6 months test without brace before making a new brace.
- **If the angulation progresses by more than 5° between 2 controls:**
  1. Strict verification of compliance (additional psychological support)
  2. Verification of the brace
  3. Supplements Calcium and Vit. D (no vegetarian)
  4. Verification of physiotherapy
  5. Increase the wearing time of the orthosis (+ 2 hours during the day)

**Practice of sport**
The weaning is authorised without any time limitation for the practice of sport. Generally, we advise the sports favouring the tonification of the muscular ligamentar paravertebral structure during puberty growth: such as swimming, climbing. From the first period and when the body is fully developed. When the body is fully developed, we advise high impact sports such as running, dance, to favour the fixation of the calcium on the bone and the constitution of an important bony mass.

In a specific way when the ribs are asymmetric we recommend to avoid deep and quick inhalation which favours the vertebral rotation and therefore the breathlessness during the practice of sports.

For lumbar curves, we advise, as well, against the quick flexions of the trunk forward or the position extending with an anterior flexion of the trunk.

<table>
<thead>
<tr>
<th>Age (girls)</th>
<th>Physiology</th>
<th>Activity (example)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 7 years</td>
<td>Before myelinization and lateralization</td>
<td>higher activities of walking &amp; cycling balance</td>
</tr>
<tr>
<td>7-11 years</td>
<td>Before Tensegrity</td>
<td>ball games (boys) and dance (girls) strength</td>
</tr>
<tr>
<td>11-15 years</td>
<td>Before end of growth</td>
<td>combat sports, swimming, climbing adjustment of paravertebral tensions</td>
</tr>
<tr>
<td>15-21 years</td>
<td>Before complete bone mass</td>
<td>Jogging &amp; running axial impact and spiral chains</td>
</tr>
<tr>
<td>21-40 years</td>
<td>Before sarcopenia &amp; osteopenia (Tensegrity)</td>
<td>Fitness</td>
</tr>
<tr>
<td>40 to retirement</td>
<td>Before extra pyramidal weakness (postural system)</td>
<td>Nordic walking</td>
</tr>
</tbody>
</table>

**SPORT ACTIVITY IN RELATION TO AGE**

**Body cares**
Perfumes and chemical colourings have to be avoided and use a neutral soap or alcohol is better. The undershirt under the brace is in cotton long enough to cover the pelvis and if possible seamless, like a T shirt. In France, 8 under shirts like the one described are delivered with the brace.

**Alimentation**
The straightening up of a scoliosis can modify the oesophagus gastric passing through the diaphragm. The inflation of the stomach has to be reduced by spreading meals throughout, and avoiding all fizzy drinks.
Sitting position
We have to dissociate the « listening » sitting position: feet forward, ischion behind the bottom, and back against the dorsal support, from the “writing” sitting position: feet backwards, ischion in front of the bottom, brace against the anterior edge of the counter, the two forearms lying on the desk.

At night
The mattress has to be thick, a little pillow stabilizing the cervical spine. If the patient complains of a superior member dysaesthesia, we have to use a second pillow to move aside the arm in abduction.

14. Results & discussion

Methods

Study design
This is a prospective controlled cohort observational study based on ongoing database (from 1998) including 544 patients with AIS treated thanks to the ARTbrace from May 2013 to November 2015. A historical retrospective case series of 100 consecutive scoliosis treated with the old Lyon brace management was used for comparative purposes. These are the last 100 patients treated before May 2013 only primary curves were selected, lumbar curves Lenke 5 are excluded as they are treated with the short GTB brace.

Protocol
Brace checking is performed 3-4 days after brace delivery with ultra-low dose EOS system.

Statistical Analysis
The statistical analysis has been conducted with SPSS v20. For all variables, normality of data was ascertained by the Kolmogorov-Smirnov’s test. All analyses were performed according to the intention-to-treat principle. All tests were two-sided, with significance set at p < 0.05. Results are presented as mean ± standard deviation (SD).

To measure the effectiveness of a brace two main factors can be involved:
1. The immediate in-brace reduction depending how to get the three-dimensional correction and its reproducibility;
2. The patient’s adherence (compliance) which depends on aesthetics and tolerance.

In-brace Correction for the 141 first patients with SRS criteria
All 141 patients was reviewed at the control: no drop out
The mean age was 12.92 years (SD=1.39, range: 10–15). 125 patients are female (88.7 %)

<table>
<thead>
<tr>
<th>n</th>
<th>Cobb init</th>
<th>In-brace</th>
<th>% correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorac (98)</td>
<td>30.33° ± 4.6</td>
<td>10.04° ± 7.2</td>
<td>67.7% ± 21.2</td>
</tr>
<tr>
<td>Lumbar (75)</td>
<td>28.61° ± 4.1</td>
<td>6.36° ± 6.5</td>
<td>78.8% ± 21.3</td>
</tr>
<tr>
<td>Total (141)</td>
<td>29.62° ± 4.6</td>
<td>8.45° ± 7.1</td>
<td>72.5% ± 21.9</td>
</tr>
</tbody>
</table>
A Spearman’s rank-order correlation was run to determine the relationship between initial thoracic angulation and in-brace correction (Percent). There was a strong, positive correlation between initial and in-brace correction, which was statistically significant ($r = -0.339$, $p = 0.001$).

There was also a strong, positive correlation between initial and in-brace correction for lumbar curves, which was statistically significant ($r = -0.296$, $p = 0.001$).

For the BrAIST study, average in-brace correction was 33% (n=152, range: -48 to 100%)

Sagittal Correction

The radiological follow-up of old Lyon braces was performed without lateral X-ray and therefore it is not possible to make a statistical comparison. But thanks to the use of the micro dose EOS system a systematic sagittal analysis was possible for the main group of patients (ARTbrace).

In a previous study, we showed that the average thoracic kyphosis angle with the upper limit T4 was 37°. For this study, we set the cut off at 30° for hypokyphosis or flat back.

The results are the subject of a separate presentation we can summarise in the following table.

<table>
<thead>
<tr>
<th>T4-T12&lt;30°</th>
<th>Cobb init</th>
<th>In-brace</th>
<th>1 year</th>
</tr>
</thead>
<tbody>
<tr>
<td>73/148 (49.4%)</td>
<td>19.6° ± 6.8</td>
<td>28.45° ± 5.8</td>
<td>27.15 ± 5.4</td>
</tr>
</tbody>
</table>

The in-brace improvement is 9° (rate 50 %) and very significant ($p = 0.000$), and without brace at the last 1 year follow up, the improvement rate is 46 % ($p = 0.000$). There was no statistical difference between the in-brace group and 1 year after when not wearing a brace ($p = 0.289$). The in-brace improvement is therefore maintained at the 1 year follow up when the brace is off.

38 % of patients showed an improvement of 10° or more, 36 % of patients showed an improvement between 5° and 9°, 26 % of cases with stability, no back flat worsened.

Progressive Improvement in 1 year

Cosmetic Results at 1 year

The aesthetic results were evaluated at 1 year, comparing them with those obtained by the former Lyon protocol. The improvement in ARTbrace is statistically significant. They were evaluated at T0 (initial) and T2 (1 year monitoring) for the rib hump and ATR (angle of trunk rotation)

FINAL Results 2 years after Weaning for the first 111 patients with SRS-SOSORT criteria

The dropout rate calculated for the first 125 patients is 14%.

Description of the population

111 (92 women and 19 men) AIS (Adolescent Idiopathic Scoliosis) meeting the inclusion criteria were treated from 29/04/2013 to 02/09/2015. There were 49 primary thoracic curves, 25 double major curves and 37 thoraco-lumbar curves. This is a consecutive series extracted from a prospective database started in 1998. The average age at the start of treatment is 13 years and 5 months ($± 1$ year). At the time of the study 1125 patients had been treated with the ART-brace. As the lumbar curves continue to be treated by a short brace, it is mainly thoracic, thoraco-lumbar and double major curves.

Statistical analysis

The patients were divided into 2 groups according to the anatomo-radiological location of the curvature: group A = 74 thoracic curvatures and group B 62 lumbar and thoraco-lumbar curvatures. The clinical and radiological parameters were studied throughout the treatment: 1. Initial; 2. in-brace; 3. Six months after placement of the brace (Rx without brace) 4. Removal of the brace; 5. 6 months after weaning; 6. 2 years after weaning.

Standard statistical methods were used for descriptive statistics. Normally distributed continuous variables were analysed using a t-test based on an independent sample. Angular changes in Cobb’s angle were evaluated using unidirectional analysis of variance for repeated measurements.

Demography

111 patients with 136 curvatures divided into 74 thoracic curvatures and 62 primary thoraco-lumbar and lumbar curvatures. 25 patients had double major curves. The mean age at the start of treatment was 13.5 ($± 1.35$).

The initial mean angulation was: 29.9 ° ($± 8.05$) (20 ° to 48 °)

The average in-brace angulation was: 8.83 ° ($± 9.24$)  
Mean angulation at 6 months without brace was: 17.3 ° ($± 10.7$)  
Mean angulation at weaning was: 18.5 ° ($± 11.8$)  
Mean angulation 6 months after weaning was: 19.5 ° ($± 11.5$)

Mean angulation two years after weaning was: 19.1 ° ($± 11.5$)  
The average percentage of in-brace correction was 73%, the final average correction two years after weaning was 36%.

95% of the curves are improved by more than 5 °, 5% are stable, no curve is worsened.

<table>
<thead>
<tr>
<th>Cobb Init</th>
<th>In-brace</th>
<th>Weaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>29.9° ± 8.0</td>
<td>8.83° ± 9.24 (73% ± 24.6)</td>
<td>18.5° ± 11.8 (33.0% ± 23.6)</td>
</tr>
</tbody>
</table>

For Group A (n = 74), the mean initial angulation was 29.88 ° ($± 9.12$). The in-brace angulation was 11.05 ° ($± 9.07$) (63% correction). Angulation at 6 months without brace was 19.74 ($± 10.49$). The angulation at weaning was 20.81 ($± 11.58$).
Angulation 6 months after weaning was: 21.76 (± 11.93). Angulation 2 years after weaning was 22.03 ± 11.45, (final correction 34%).

For Group B (n = 62), the mean initial angulation was 27.26 ° (± 6.92). The in-brace angulation was 6.03 ° (± 8.42) (78% correction). Angulation at 6 months without brace was 14.13 (± 9.70). The angulation at weaning was 15.73 (± 10.05). Angulation 6 months after weaning was: 16.56 (± 9.86). Angulation 2 years after weaning was 15.85 ° (± 9.75), (final correction 42%)

A Pearson correlation coefficient was calculated to evaluate the relationship between Cobb angulation at 6 months and Cobb angulation 2 years after weaning. There was an excellent positive correlation between the two variables: r = 0.907, n = 74 p <0.001, for the thoracic curves and r = 0.900, n = 62 p <0.001 for the lumbar curves.

A Pearson correlation coefficient was calculated to evaluate the relationship between in-brace correction and Cobb angulation 2 years after weaning. There was a good positive correlation between the two variables, r = 0.866, n = 74, p <0.001 for thoracic curves and r = 0.742, n = 62 p <0.001 for lumbar curves.

Cohort Results
Comparison <30 °and ≥30 ° for all curves
34 patients had a curve greater than or equal to 30 ° or 25 thoracic curvatures and 20 lumbar curves. For the group of 71 patients with angulation between 20 and 30 ° we note 43 thoracic curves and 40 lumbar curves. 6 patients with a curve greater than 40 ° were not included. The results are shown in Table 1.

<table>
<thead>
<tr>
<th>&lt;30°</th>
<th>Mean</th>
<th>SD</th>
<th>≥30°</th>
<th>Mean</th>
<th>SD</th>
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<td>5,26</td>
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<tr>
<td>T 6 months</td>
<td>14,19</td>
<td>6,32</td>
<td>23,84</td>
<td>7,45</td>
<td></td>
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<tr>
<td>T Weaning</td>
<td>14,19</td>
<td>6,89</td>
<td>26,60</td>
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<tr>
<td>T W + 6m</td>
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<td>6,38</td>
<td>27,56</td>
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<td>27,72</td>
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<td></td>
</tr>
<tr>
<td>L init</td>
<td>23,15</td>
<td>2,89</td>
<td>33,85</td>
<td>5,04</td>
<td></td>
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<tr>
<td>L in brace</td>
<td>3,15</td>
<td>6,98</td>
<td>10,15</td>
<td>7,84</td>
<td></td>
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<tr>
<td>L 6 months</td>
<td>10,40</td>
<td>7,61</td>
<td>19,45</td>
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<td></td>
</tr>
<tr>
<td>L Weaning</td>
<td>12,28</td>
<td>7,53</td>
<td>20,15</td>
<td>9,82</td>
<td></td>
</tr>
<tr>
<td>L W + 6m</td>
<td>13,03</td>
<td>6,91</td>
<td>21,10</td>
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<td></td>
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<tr>
<td>L W + 2y</td>
<td>12,25</td>
<td>7,50</td>
<td>20,75</td>
<td>2,00</td>
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Table 1: Evolution of the results according to the initial angulation for a cut off of 30 °

DISCUSSION
The ARTbrace is currently the most effective brace (70% average in-brace correction) in respect of the frontal plane. This work confirms that there is a strong correlation between the in-brace reduction and the final result of nearly 90% for thoracic and lumbar curvatures. The remaining 10% are probably related to compliance. The average in-brace correction could be compared [10]: Rigo System Chêneau 48% [11]; Scoliologic Lightweight 51% [12]; old Lyon brace 38.7% [8]; TriaC 22% [13]; Osaka Medical College (OMC) 46.8% [14]; and the Boston 50% [15]

The improvement of almost 40% of the in-brace correction compared to the most recent braces is explained by the new biomechanical concepts of the ARTbrace: 1. It is no longer a flat geometry, but of a geometry of solids. The brace performs a kind of Bobsleigh track in the opposite direction of the scoliosis torso column. There is no more press hold, but a soft contact that will vary with the different...
positions during the day. This is a dynamic brace; 2. Specific digital correction with superposition of 3 blocks. The asymmetry is not the consequence of a complex classification, but the result of 3 successive scanners, the first in translation along the vertical axis, the second in lumbar shift and physiological lordosis, the third in bending and thoracic kyphosis. The very precise protocol ensures the reproducibility of the measurements; 3. Untwisting is achieved by coupled motions in the frontal plane and in the sagittal plane. Detorsion is geometric and mechanical; 4. The correcting moment combines an action in the transversal plane by tightening at the level of the chondro-costal awnings using a rack closure and a translation along the vertical axis that can be compared to that of the a lever corkscrew with lowering of initially raised shoulders as the detorsion of the spine is progressing; 5. The very high rigidity of the Europlex'O, however, requires a high 1mm precision of CAD/CAM digitizer technology and professional software. [16]. The importance of immediate in-brace reduction also explains the prognosis of the final result only 6 months after fitting the brace, which may encourage the child’s compliance. The other parameters with improved curves in the sagittal plane and in the horizontal plane have already been presented [5,9].

The goals of non-surgical orthopaedic treatment can be expanded. It is no longer only a question of avoiding surgery with a lower than 50° angulation, nor even of stabilizing the scoliosis during the period of growth, but of getting a final gain of approximately 30% at the end of treatment. This treatment has the advantage of promoting teamwork with the doctor who performs the digital cast and the orthopaedic technician who will make the final brace.

Correlations
There is a negative correlation between initial angulation and end treatment percent correction, r=-0.414, n=43, p=0.001 for thoracic curves and less r=-0.292, n=53, p=0.034 for lumbar curves.
There is a strong positive correlation between in-brace correction rate and end treatment correction rate, r=0.684, n=43, p=0.000 for thoracic curves and r=0.596, n=53, p=0.000 for lumbar curves.
In our experience, the weaning results are very close to those 2 years after weaning and can be considered as significant. Patients are a little older (14.4 vs 13.4) and with lower initial angulation than in the general statistics (26.84 vs 29.61). The in-brace reduction is greater (79.4% vs 69.4%) which explains the outstanding weaning correction rate (50% vs 25% for the old Lyon brace)

CONCLUSION
For the same indications and with the same management principles, we can confirm that:
1. The early treatment with low angle,
2. The quality of immediate in-brace correction is fundamental to a successful outcome.

Discussion
Castro, studying a prospective cohort of 41 AIS, concludes that the brace treatment is not recommended with patients whose correction is less than 0.20 in TLSO.
Appelgreen, in an article detailing measurement of the Cobb angle from the end vertebra in 121 AIS, concludes that an average in-brace correction of 0.30 gives hope a correction at the end of treatment.
Landauer, studying the predictive criteria of conservative treatment results in the first 6 months of treatment, wrote that compliant patients who have a high initial correction greater than 0.40 can expect a final reduction of about 7° and bad compliance is always associated with curve progression.
Wong, comparing the results of the electronic mould of 20 patients versus the traditional plaster moulding of 20 other patients, noted an improvement in the in-brace reduction from 0.32 to 0.42 in support of CAD/CAM moulding.
Bullmann, presenting the prospective results of 52 patients treated with the Chêneau-Toulouse-Münster brace with curves between 25° and 40°, estimated the in-brace correction at 0.43. There was a positive correlation between flexibility and Cobb angle correction during brace treatment and a negative correlation between Cobb angle correction during brace treatment and curve progression. In the sagittal plane, the correction obtained in the flat back is unique today. Indeed, most authors consider that the correction in the frontal plane is related to axial stretching accentuating the flat back. With the ARTbrace there is certainly an extension, but the main part of the correction is made by unscrewing or untwisting the spine with translation of the vertebral bodies near the midline.
15. Conclusion

After more than two years using the ARTbrace, we can summarise some improvements (in alphabetical order):

- **4D action**: hypercorrection action in the frontal and horizontal planes during breathing and motion.
- **Aesthetics**: the brace is transparent, almost invisible under clothing. However, the asymmetrical ARTbrace is less aesthetic than the symmetrical Sforzesco brace.
- **Economy**: no more plaster casts, no more hospitalisation, and the life-span of the brace is greater than that of the plaster cast.
- **Efficiency**: the brace is adjustable in the frontal plane; an additional correction by internal pad is easy.
- **Hygiene**: a daily 15 minute shower is possible.
- **Insulation**: the Europlex'O is more insulating than the glass and there is no need for perforation.
- **Lightness**: it is the end of 5-7 kg plaster casts, and the ARTbrace is 25% lighter than the historical Lyon brace.
- **Originality**: this is the first untwisting brace of the whole spine in three planes of space.
- **Simplicity**: anyone can make a frontal bending with lordosis or kyphosis; no major correction of the positive mould is necessary, like the Chêneau brace.
- **Tolerance**: Europlex'O is biologically well tolerated.
- **Universality**: it is possible to correct hyperkyphosis like hypokyphosis.

These short-term results can not predict the final outcome, but during the last 50 years, the immediate in-brace reducibility of scoliosis remained around 0.50 and progress focused on aesthetics and tolerance. Thanks to advances in computer graphic technology this correction exceeds for the first time 0.70 with the ARTbrace.

This correction requires no more significant alteration of the positive mould, but the superposition of three segmental CAD/CAM in a simple and strictly defined posture.

Improving the flat back in the sagittal plane has never been described with scoliosis braces used to date.

Lyon brace management and protocol are not modified by the use of the ARTbrace and a priori the final results of the treatment cannot be worse than the historic Lyon brace.

While the ARTbrace could be defined as a modified or “new” Lyon brace, the new concepts and first results prove that it can completely replace the casting and old Lyon brace process; it really deserves to be recognised, as its unique design has surpassed its predecessor and former protocol.

Further results will be inserted progressively in this book:
The best BRACE does not exist, but the best in-brace correction does

Annex 1: Comparative tables of different materials

<table>
<thead>
<tr>
<th></th>
<th>Soft</th>
<th>Polyethylene</th>
<th>Europlex'O</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frontal</td>
<td>38%</td>
<td>43%</td>
<td>70%</td>
<td>In-brace</td>
</tr>
<tr>
<td>Sagittal</td>
<td>No publication</td>
<td>-3°</td>
<td>+8°</td>
<td>Flat back</td>
</tr>
<tr>
<td>Rotation (apical)</td>
<td>?</td>
<td>+++</td>
<td>+++</td>
<td></td>
</tr>
<tr>
<td>Torsion (Global)</td>
<td>?</td>
<td>++</td>
<td>+++</td>
<td>Need high rigid upper point</td>
</tr>
<tr>
<td>Axial Elongation</td>
<td>0</td>
<td>++</td>
<td>+++</td>
<td>1.8 cm</td>
</tr>
<tr>
<td>Contact</td>
<td>Strap</td>
<td>Pads</td>
<td>Soft</td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>0</td>
<td>++</td>
<td>+++</td>
<td>(cost)</td>
</tr>
<tr>
<td>Efficacy</td>
<td>+</td>
<td>+++</td>
<td>+++</td>
<td></td>
</tr>
<tr>
<td>Efficacy</td>
<td>+</td>
<td>+++</td>
<td>+++</td>
<td></td>
</tr>
<tr>
<td>Tolerance</td>
<td>++++</td>
<td>+++</td>
<td>+++</td>
<td>Initial full time</td>
</tr>
<tr>
<td>Invasive +</td>
<td>+</td>
<td>+++</td>
<td>+++</td>
<td>Soft contact</td>
</tr>
<tr>
<td>Versatility</td>
<td>++++</td>
<td>+</td>
<td>+++</td>
<td>Plan B night overcorrecting</td>
</tr>
<tr>
<td>Easiness</td>
<td>++++</td>
<td>++</td>
<td>+++</td>
<td>Full 3D instantaneous</td>
</tr>
<tr>
<td>Repeatability</td>
<td>+</td>
<td>++</td>
<td>+++</td>
<td>3 regional moulading</td>
</tr>
<tr>
<td>Precision</td>
<td>++</td>
<td>++</td>
<td>+++</td>
<td>High Rigid</td>
</tr>
<tr>
<td>Adaptation time</td>
<td>1 hour + physio</td>
<td>3 weeks</td>
<td>3 days</td>
<td>Initial full time</td>
</tr>
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### Acronyms and abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>2D</td>
<td>Two Dimensions usually Frontal &amp; Sagittal planes</td>
</tr>
<tr>
<td>3D</td>
<td>Three Dimensions = 2D + Horizontal plane (rotation)</td>
</tr>
<tr>
<td>4D</td>
<td>The Fourth Dimension could be the Time, but usually used to describe the biomechanical changes of the brace during movement and breathing.</td>
</tr>
<tr>
<td>AIS</td>
<td>Adolescent Idiopathic Scoliosis</td>
</tr>
<tr>
<td>ART</td>
<td>Asymmetrical Rigid Torsion (detorsion)</td>
</tr>
<tr>
<td>ATR</td>
<td>Angle of trunk Rotation (Bunnel Scoliometer)</td>
</tr>
<tr>
<td>BrAIST</td>
<td>Bracing Scoliosis in Adolescent idiopathic Scoliosis Tal</td>
</tr>
<tr>
<td>CAD/CAM</td>
<td>Computer-Aided Design/Computer-Aided Manufacturing</td>
</tr>
<tr>
<td>CPO</td>
<td>Certified for Prosthetics and Orthotics</td>
</tr>
<tr>
<td>EDF</td>
<td>Elongation, Derotation, Flexion used for a plaster cast in Cotrel’s frame</td>
</tr>
<tr>
<td>EOS</td>
<td>Radiological device using ultra low dose irradiation</td>
</tr>
<tr>
<td>PMMA</td>
<td>Polymethylmetacrylate (plexidur)</td>
</tr>
<tr>
<td>TLSO</td>
<td>Thoraco Lumbo Sacral Orthesis</td>
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</table>
ARTbrace indexed References

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