Chapter

Bracing Adult Scoliosis: From Immobilization to Correction of Adult Scoliosis

Jean Claude de Mauroy, Fabio Gagliano, Rosario Gagliano and Piera Lusenti

Abstract

Unlike adolescent idiopathic scoliosis, bracing was used in adults less and was used more as a way of reducing pain. There is little publication of adult scoliosis series in the literature. The use of very high-rigidity and high-precision CAD/CAM technologies currently makes it possible to create corrective braces for the adult. The digital CAD/CAM cast in three blocks allows for precise correction at the pelvic, lumbar, and thoracic levels. This chapter presents the results of a series of 62 consecutive adult scoliotic patients treated with a corrective asymmetric detorsion brace of very high rigidity made in 2014–2016. Tolerance and angular correction results will be compared to those of 158 patients treated with the former bivalve polyethylene overlapping immobilization brace mainly used for lumbar scoliosis. The new Lyon adult ARTbrace is a detorsion brace adapted to all the curvatures which controls the sagittal plane. Despite a resistance four times greater than that of polyethylene of the same thickness, the tolerance of the Europlex'O is excellent as it is a "shock absorber," and the anterior opening facilitates the use for very old people. Consequently, the aim of this chapter is to consider if it is possible to envisage for some patients an alternative to surgery, thanks to the new technologies of bracing.

Keywords: adult scoliosis, bracing, de novo scoliosis, camptocormia, Lyon method, nonsurgical, PSSE, ARTbrace

1. Introduction

1.1 Adult scoliosis instability

1.1.1 Bracing history

Lyon has always had a great tradition of orthopedic, and Charles Gabriel Pravaz was not only the inventor of the syringe, but he also created in Lyon a great orthopedic institute to treat scoliosis 200 years ago. The first Lyon brace, which was made of leather and steel, was created by Stagnara 70 years ago. It undergone a first change with the replacement of leather by polymethacrylate. This brace was used in adults in addition to surgery while waiting for the graft fusion, at a time when osteosynthesis did not have the current quality. In 2013, the use of adult ARTbrace in Europlex'O in polyamide and asymmetry allowed to avoid the plaster cast which

has always been the characteristic of the Lyon management. The use of polyamide and digital allows treatment of thoracic and double major curves.

1.1.2 Frequency of adult scoliosis

Vanderpool et al. [1] shows that the frequency of scoliosis in adults increases steadily with age, from 6% of scoliosis after the patient reaches 40 years until it reaches 10% of the population at age 65. The sex ratio was 2 females to 1 male. It is women who have the most painful instabilities and imbalances. Their bone mass is lower than that of men with a vertebral fracture threshold at age 65. Pregnancy and menopause could be also aggravating factors [2].

1.1.3 Adult patients are different

Akbarnia et al. [3] described the key features as curve stiffness, degeneration of the discs, osteoporosis, spinal imbalance both coronal and sagittal, rotary subluxation, spinal stenosis, and higher rate of complications (pulmonary, etc.). The esthetic aspect is not negligible, and even surgery performed during adolescence does not solve everything. Edgar and Mehta [4] has shown that self-image representation and social life is different after surgery in adolescence. 82% of adult scoliosis without surgery was married compared to 60% of scoliosis operated in adolescence. O'Brien [5] analyzes the consequences of scoliosis in adulthood. He noted that for adult scoliosis abnormal physical appearance and diminished self-esteem may always be present, but breathing limitations, inability to function, and other quality of life issues generally become the driving forces for clinical examination, diagnosis, and treatment.

1.1.4 Complications of surgical treatment vs. non-operative

The complications were analyzed by many authors. For Baron and Albert [6] the incidence of medical complications ranges between 40 and 86%. Local complications include infection, pseudarthrosis or failure of instrumentation, and neurological and adjacent-level degeneration or instability. Common medical complications include pneumonia, atelectasis, ileus, delirium, and cerebrovascular incidents. Smith et al. [7] studied the incidence of complications according to age. His conclusions were the following: the oldest age group (65–85 years) has nearly four times the number of minor complications and nearly five times the number of major complications when compared with the youngest age group (25–44 years). As invasive surgical therapy needs a perfect understanding of risk/benefit, Ogilvie [8] suggests that the decision to proceed with surgical treatment even if justified in many cases must be based on a thorough understanding of the anticipated benefits from surgical treatment and the risk of serious complications. These potential complications lead to multiple surgeries with results that can be less desirable than the original condition. The results of conservative orthopedic treatment are more difficult to assess. Kluba et al. [9] compares surgical and conservative treatment for degenerative lumbar scoliosis. He finds a significantly higher rate of spinal stenosis and degenerative spondylolisthesis in the group of patients with surgery. However no significant difference was evident between the two groups in terms of lumbar back pain after 4 years, respectively.

Everett and Patel [10] conducted a systematic review of non-operative treatment. There is indeterminate, level III/IV evidence on the effectiveness of any conservative option; level IV evidence on the role of physical therapy, chiropractic care, and bracing; and level III evidence for injections in the conservative treatment of adult deformity. The use of rigid or hard bracing in adult scoliosis is generally not recommended. This is due to the risk of muscle weakening effects from hard bracing and the fact that

this could accelerate the degenerative process in some cases. Chuah et al. [11] notes that bracing may sometimes help the symptoms, but it has no effect on curve progression.

Pain is not synonymous with deformity progression. Some stable scoliosis patient report pain, and others evolve without pain. It will be necessary to try to make the difference between the "physical" pain and the "emotional" suffering when the patient does not support his deformation anymore.

1.2 Anatomo-pathological classification of painful instabilities

a. Thoracolumbar pain often corresponds to minor joint instability.

b. The pain of convexity is of muscular origin.

c. The pain of the concavity is posterior: facet syndrome.

d. The lumbosacral pain is of ligament origin.

These pains respond perfectly to physiotherapy.

When scoliosis progresses, it is either (1) the evolution in adulthood of an adolescent idiopathic scoliosis, (2) a de novo scoliosis usually of discal origin, or (3) a camptocormia of muscular origin. In all cases, there may be a disc disease with sometimes rotatory dislocation, postural impairment with imbalance, extrapyramidal muscle involvement, and bone involvement (osteoporosis). In these progressive cases of instability, bracing or surgery may be necessary.

1.3 Classification of painful instabilities according to age

a. From 20 to 30 years old, the main problem is the anatomical pain.

b. From 30 to 50 years old, the main problem is the discal decompensation.

c. After 50 years old, there are two main problems: degenerative scoliosis very rigid with arthrosis and camptocormia reducible with paravertebral muscular atrophy.

1.4 Natural history of idiopathic scoliosis from adolescent to adulthood

Early works on scoliosis progression in adulthood were pessimistic [12], but at this time, idiopathic scoliosis, especially rachitic infantile, is mixed with neurological poliomyelitis that no longer exists.

In 2003 Weinstein published the spontaneous evolution of 117 idiopathic scolioses over more than 50 years [13]. Thoracic curves of more than 50 degrees at skeletal maturity progressed with an average of 29.4 degrees. Thoracolumbar curves between 50 and 75 degrees increased with an average of 22.3 degrees. Lumbar curves had the most progression, especially when the L5 vertebra was not well seated and when the apical rotation was greater than 33%. He does not observe a functional respiratory or painful repercussion below 70°. This angulation could be currently the functional surgical Cobb limit. Pregnancy does not change the progression of scoliosis in adulthood, except in cases of twin pregnancy.

1.5 The two distinct entities

In 2007 Marty-Poumarat [14] describes two specific adult scoliosis entities: adolescent scoliosis in adult (ASA) and degenerative de novo scoliosis (DDS).

Group A (ASA) = adult progression of AIS > 40° with first dislocation at 45 years. The progression can be sometimes regular, sometimes chaotic.

Group B (DDS) = de novo scoliosis with low Cobb after 50°, first dislocation at 52 years after menopause. DDS is more progressive than AIS. Because DDS is a result of degenerative disc instability, it is almost always progressive. Lumbar and thoracolumbar are the most progressive degenerative curves. Duval-Beaupere and Dubousset [15] have first described the mechanism of rotatory subluxation. Following their work, many authors have insisted on the importance of the lumbo-pelvic parameters [16–18].

1.6 Risk factors for instability

The radiological risk factors for instability are (1) rotatory dislocation with lateral olisthesis (**Figure 1**), (2) L3–L4 inclination, (3) hypolordosis, and (4) increased thoracolumbar kyphosis [19–20].

1.7 Indications of bracing

The physical activity and fracture rate of adult scoliosis is identical to that of the general population, except for operated patients who have less physical activity [21]. Unlike adolescence, when bracing is systematic when scoliosis progresses, the corrective bracing indication in adults is less related to Cobb angulation but more to the instability which results in pain, abnormal angular evolution, or imbalances (**Figure 2**).

From a database started in 1998, we selected all adult scoliosis in which conservative orthopedic treatment has been proposed to, even if the treatment had not been achieved by the patient. Scoliosis treated during adolescence and monitored in adulthood were excluded [22]. In this case series study, we analyzed 779 patients referred for nonsurgical treatment, and we correlated three parameters: the etiology, age, and Cobb angulation (**Table 1**).

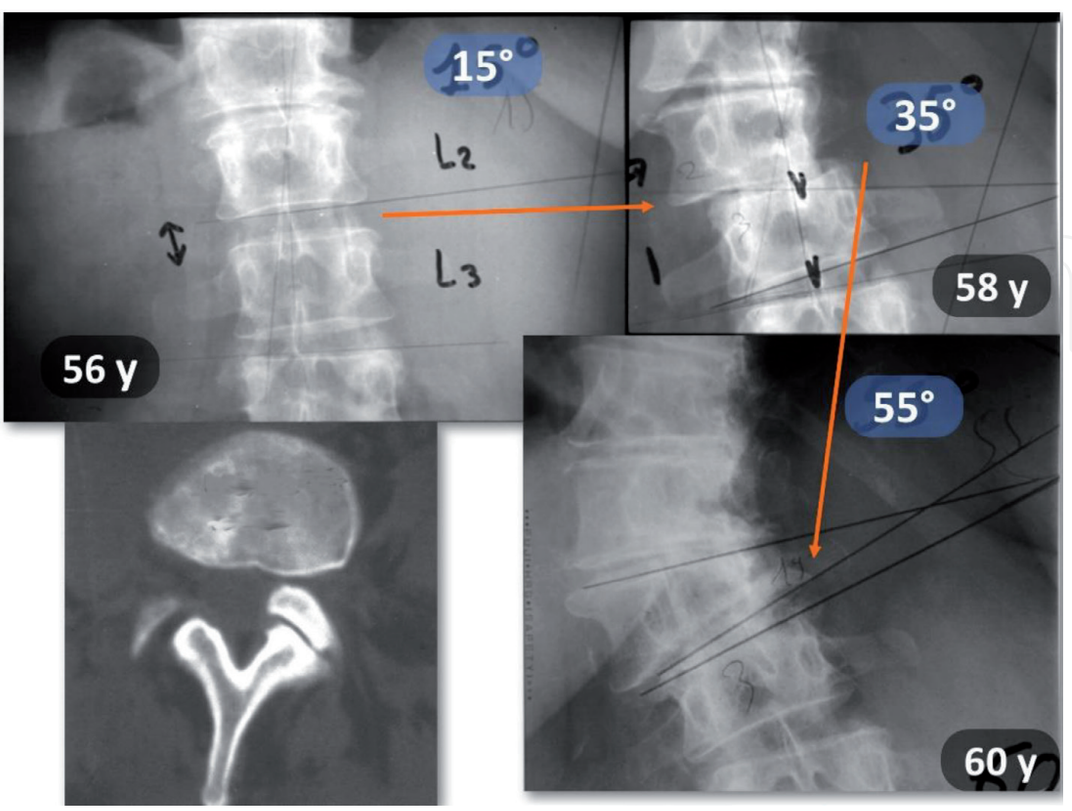

Figure 1.
De novo scoliosis with constitution of a rotatory dislocation in 2 years, then scoliosis worsening by osteoporotic cuneiformization.

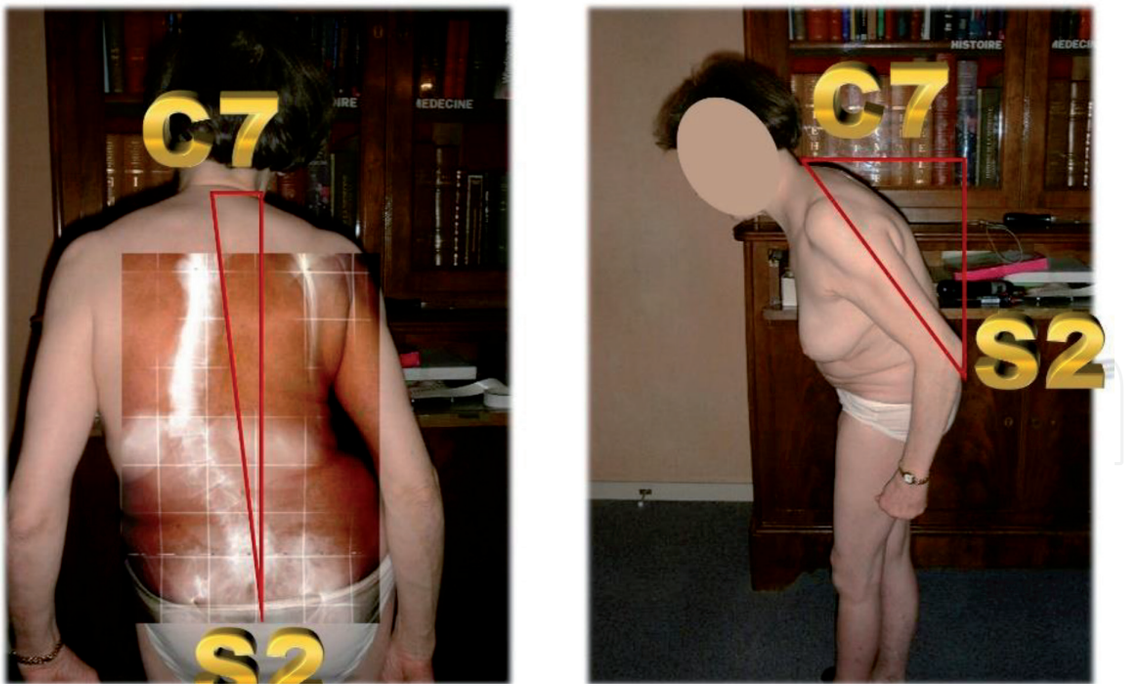

Figure 2.
Clinical imbalances in the frontal and the sagittal planes.

Indications ARTbrace adult (n = 779)	Rate %	Mean age	Mean angulation
Rotatory dislocation (n = 361)	46.5%	59.73 y ± 13.50	39.08° ± 16.56
Segmental instability (n = 150)	19%	46.03 y ± 15.49	25.29° ± 12.29
Instability post-surgery (n = 86)	11%	53.09 y ± 12.91	40.49° ± 15.38
Camptocormia (n = 68)	9%	69.78 y ± 12.19	38.09° ± 14.23
Kyphosis (thoracolumbar) (n = 62)	8%	60.73 y ± 15.51	43.34° ± 21.48
Disabling pain (n = 33)	4%	48.36 y ± 13.73	36.45° ± 21.48
Spondylolisthesis and spinal stenosis (n = 19)	2.5%		

Table 1.
Main indications for adult scoliosis bracing with frequency classification.

The rate of dropout patients not wearing the brace is 17% which is not excessive, especially since the plaster cast at that time was made before the brace discouraged patients.

A tentative classification according to etiology, age, and angulation is proposed (**Figure 3**).

More than half of the indications concern the rotational dislocation, which is the specific complication of adult scoliosis. The rotary dislocation is visible on the CT scan with subluxation and joint narrowing on the sliding side and widening of the articular space on the opposite side.

One-fourth of the indications concern disc instability, which can be considered as the early stage of rotational dislocation.

The other etiologies are less frequent: lumbar-pelvic-femoral kyphosis, secondary instability under arthrodesis, root pain, and rarely spinal stenosis which requires neurosurgery. Camptocormia is linked to weakness of the deep posterior musculature [23]. The patient increases kyphosis gradually to tighten his weak paravertebral muscles. There is often an extrapyramidal context of Parkinson's

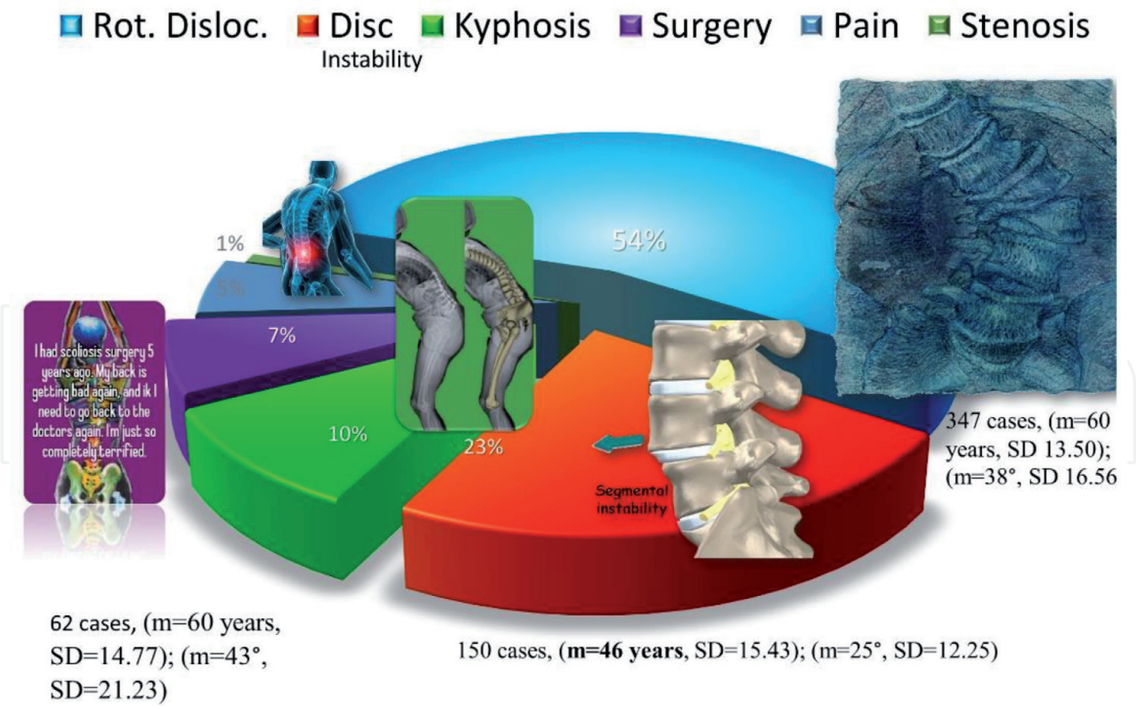

Figure 3.
Indications of nonsurgical treatment by etiology (n = 739).

disease [23]. MRI cross sections highlight the fatty degeneration. Some authors have mentioned paravertebral myopathy [24].

According to age, there is no Cobb angle difference between patients aged 39 and 80 years old, even if we notice a slight worsening between patients aged 80 and 90 years old. It can be concluded that after 40 years, for the same angulation, the risk of decompensation does not depend on age [22].

If we examine in more detail the distribution of patients according to Cobb angle, we find that Cobb angle is not a discriminating factor like aging.

1.8 Eligibility test

One of the bracing eligibility tests especially for camptocormia is self-correction by using the hands on the thighs, even if this self-correction does not last long in time. The second test of reducibility is carried out in supine position. The occipital patient must rely on the plane of the examination table. The placement of the ARTbrace is performed by the patient who stabilizes the brace at the pelvic level then unrolls the spine using the rigidity of the posterior bar and finally blocks the upper part. As for children, the "mayonnaise tube" effect of the two lateral hemi-valves completes the correction in the sagittal plane.

2. Methodology and results

2.1 Evolution of management

Adult scoliosis bracing is performed only in technically equipped medical clinics. Hospitalization is not essential because the use of the brace must be integrated into the patient's environment. On the other hand, physiotherapy scoliosis-specific exercises (PSSE) is mandatory.

The brace wearing time protocol is a total time of 24 hours a day during 3 weeks with a plaster cast (or digital cast) to adjust the length of the ligaments with plastic

Management	Wearing time	Particularity	Follow-up examination
First 3 weeks	Total time 24/24	Only 10′ for shower, no work interruption	At the end of total time without X-ray
First 6 months	4 hours/24	Systematically for 2 hours after physical activity	At 6 months with X-ray
6 m to 2 years	On demand and 2 hours after sport	In case of pain, in prevention before major efforts	At 2 years with X-ray
After 2 years	No specific indication	Brace is kept for safety	AT 5 years with X-ray, then every 5 years

Table 2.
Adult bracing management (Lyon ARTbrace).

deformation and, then, at least 4 hours per day for a minimum of 6 months, including systematically for 2 hours after the practice of sports activity (**Table 2**).

Wearing the brace for a "total time" allows the patient to relearn all the gestures of daily living in a good posture, for example, the sitting writing posture with feet behind the chair and buttocks in front of the seat. The lower part of the chest touches the anterior edge of the table, and the forearms rest on the desktop.

The digital cast is made in three blocks according to the deviations as in the teenager, but in deep inspiration. In many cases, only a scan in maximum corrective posture perfectly balanced is performed. The corrective posture is derived from Schroth. The sagittal plane and the frontal plane are simultaneously corrected, ensuring the overall balance of the spine. The spine is placed in maximum extension to promote lumbar lordosis and reduce thoracic hyperkyphosis. The convex hand is placed on the vertical support, the concave hand is placed on the head, and the operator supports the patient's elbow (**Figure 4**).

The thickness of Europlex'O used in adults is 3 mm. The digital cast is made in blocks according to the deviations as in the teenager, but in deep inspiration. The advantages are manifold: (1) The patient can maintain the maximum corrected position for a few seconds while standing; (2) breathing is controlled, and the patient can be asked to perform maximum inspiration; and (3) the accuracy of the eight structure sensors is less than 1 mm. The 3 mm Europlex'O with very high rigidity can be used instead of polyethylene. It is possible to work bare skin, but the thin optical vest in jersey allows the use of landmarks for the superposition of the

Figure 4.
Digital cast with simultaneous correction in the frontal and in the sagittal planes.

three blocks. The processing with a specific software allows the creation of a positive which will be milled by a digital milling machine. The CPO has all the tools to rework on the captured shapes. After a period of 3 weeks of "total time," the brace is worn for a minimum of 4 hours/24 for 6 months, then on demand.

2.2 Aims of rigid bracing

2.2.1 Instability pain management

Instability pain management is obtained by:

- A skin contact of the brace like a massage.
- A discharge of the lumbar discs and vertebral body by the "composite beam effect." The discharge of 30% is provided by the waist grip in the frontal plane, while the sagittal plane is free to prevent an excessive abdominal pressure.
- A rebalancing spine in the frontal and sagittal plane.
- A limitation of extreme postures.

2.2.2 Muscle strengthening

The rigid brace is an active brace. The patient spontaneously tends to contract the paravertebral musculature in the sense of self-active axial elongation. Associated physiotherapy is however essential.

2.2.3 Esthetics

The brace can reshape the waist. It can also symmetrize the body for the largest scoliotic curves by the adjunction of a foam cushion in the concavity.

2.2.4 Saving spine: development of compensations

The lock automatically performed by the brace facilitates motion and strengthens the musculature of the lower limbs. There is also a better mobility of shoulder girdle because of the stabilization of shoulder blades in a more physiological position.

2.3 Lyon method of physiotherapy for adult scoliosis

The wearing of a rigid brace is obligatorily supplemented by physiotherapy scoliosis-specific exercises. The ideal is to act when the spine begins to disrupt or becomes painful, indicating instability. The therapeutic progression is usual:

2.3.1 Aims

- Analgesia.
- Preventing muscle atrophy lumbo-abdominal strengthening in isometric and improving paravertebral deep muscles (**Figure 5**).
- Promoting more flexible self-active axial elongation (**Figure 6**).

Figure 5.
Isometric strengthening of the deep front line with correction of thoracolumbar kyphosis.

Figure 6.
Self-active axial elongation in closed kinetic chain (hands/espalier).

- Correcting 3D spine balance: in the frontal plane, rebalance of the occipital axis; in the sagittal plane, restoration of sagittal lumbar and pelvic curvatures (pelvic anteversion and lumbar lordosis (strengthening of the iliopsoas)); and in the horizontal plane, dissociation of pelvic and shoulder girdles.

- Developing compensation at the lower and upper limbs: relaxation under pelvic extension (hamstring stretching) (**Figure 7**).

- Stimulating the mechanisms of postural correction with reharmonization of the paravertebral tensions (muscular chains) (**Figure 8**).

The main differences between adolescent and adult scoliosis are demonstrated in **Table 3**.

Figure 7.
Posture of stretching posterior chains of the lower limbs.

Figure 8.
Reharmonization of paravertebral tensions with mirror control.

2.3.2 Lyon method during the total time

First week. Physiotherapy is for analgesic purposes and is performed in the supine position by soft traction and a muscular work with irradiation of the short external rotators. Breathing is controlled because of the limitation of the abdominal expansion. The thoracic breathing is facilitated by the mobilization of the intercostal muscles.

Second week. The iliolumbar angle is mobilized to adjust tension at the iliolumbar level. The hump can be modeled with progressive closure of the ratcheting buckle. Physiotherapy is performed in sitting position.

Third week. Physiotherapy is more global, more general, more tonic, and stronger. The lever arm of shoulder and pelvic girdles is used. The sessions are made in standing position.

Physiology and biomechanics	Adolescent	Adult
No specific pain in adolescents. Painful instability in adults	No pain relief techniques	Pain relief techniques, massage, and others
Flat back in the teenager. Loss of lordosis and hyperkyphosis in adults	Restoration of physiological sagittal curves (arms projected forward)	Physiotherapy in lumbar lordosis (hands crossed in the back)
The brace aims to stiffen the spine (rust the spring). Spine mobilization in adults can lead to curve progression	Spine mobilization during cast and brace in all the amplitudes	No spine mobilization beyond the corrected posture
Strengthening muscle fibers (adult sarcopenia)	Reinforcement of the reticulospinal system (aerobic)	Reinforcement of voluntary musculature in anaerobic metabolism.
Translation along the vertical axis	Active axial self-elongation in standing position (grand porter) Open kinetic chain	Active axial self-elongation trunk bent at 90°, hands resting on the espalier. Closed kinetic chain
Lumbo-pelvic region	Opening the iliolumbar angle	Anterior lumbo-pelvic strengthening (iliopsoas, abdo, quad)
Lower limbs	No specific stretching. Global training without excessive resistance	Stretching of the posterior chain at the level of the lower limbs
One-third of the thorax volume develops after the end of the stature growth	Resistance breathing exercises (inflating a balloon)	Breathing exercises in forced expiration

Table 3.
Main differences between adolescent and adult scoliosis Lyon method physiotherapy.

2.3.3 Physiotherapy during partial time bracing

We first determine the sagittal direction of muscular work, usually lordosis for lumbar and thoracolumbar scoliosis. For each session there is a progression from supine to sitting and standing position.

2.3.3.1 Examples of basic exercises

Rib hump erasing. Having refocused the spine from the vertical in the sagittal plane and in the frontal plane, the patient is asked to lengthen from the brace at the rib hump level. The movement is controlled manually. The trapezius muscle is relaxed.

Sagittal tensioning girdles. The aim is to relax the posterior chain muscles while avoiding cervical lordosis. The exercise is made with control of inspiration breathing.

Self-axial lengthening. The patient straightens his head, his hands resting on the anterosuperior part of the brace. It can be done in a sitting position using a proprioceptive system. When the head is at the correct high position, a sound and a light stimulate the patient. If the spine is close to a wall, a cushion at the cervical level must be stabilized by the patient. This exercise can be completed with the upper limb extension.

Posture memorization. Exercise can be more complete with the work of the lower limbs. The starting position is knees bent for self-axial elongation of the spine; the upper limbs are fixed on the espalier. The patient is asked to stand up to a position of global extension. This exercise improves the quadricep muscle that will be key to saving the spine.

Strengthening of weak muscles: quadriceps and abdominals. The exercise will be started in a supine position. The pelvis is locked in the brace posture. This work is associated with an isometric tension of the posterior chain and expiration. This exercise is completed by a stabilization of the shoulder girdle with a stick and control of the rotation of the hip by a ball between the knees. The solicitation is obtained by an oblique manual push on the side of the patient. By gradually lowering the legs, it also seeks the rectus femoris. The anterior chain has been stretched, and it is in this posture of extension that strengthening is performed with isometric contract-relax muscular work.

Stretching strong muscles: hamstrings and short external rotators. It starts at the lumbosacral junction with pelvic-femoral, tricep, and hamstring stretch in lumbar lock controlled by the brace. It also stretches the psoas and rectus femoris. We can stimulate muscular work by manual push on the pelvis. The buttocks and the latissimus dorsi are solicited in the prone position, emphasizing the control of the cervical lordosis. When sitting, it stretches the anterior chain by adjusting the hip. Stretching can also be controlled at home on a stair. The exercise at the bar also allows global stretching.

Proprioceptive rehabilitation. On a Klein Vogelbach ball, it transfers the body weight in all plans, with emphasis on relaxation of tone and breathing control. The muscle tonicity is improved by changes in posture, standing, and lying and by the addition of loads. The global proprioceptive work prepares the patient for the definitive weaning of the brace.

2.3.4 Advice

In case of major disc degeneration, physiotherapy will be conducted in physiological lordosis, rather than in a standing position.

In case of major facet joint degeneration, physiotherapy will be conducted in physiological lordosis in prone position, legs bent or in a sitting position.

In case of leg length discrepancy, the feet imbalances adjustment with a shoe lift of 5 mm if it improves both pelvic and spine alignment.

In the sagittal plane, one can use small high heel stubs from 3 to 5 cm to reduce a lumbar kyphosis.

The food control helps to reduce overweight.

The postural control concerns mainly the workstation.

The regular practice of physical activity outside is essential. It is necessary to insist on the strict brace wearing during 2 hours after the sports activity.

2.3.5 Difficulties

Excessive mobilization of passive structures may lead to a progression of scoliosis, so the hyper flexibility is avoided and a position closest to that of the brace is better.

High thoracic breathing is less efficient than the usual abdominal breathing, and we must insist on improving the vital capacity for thoracic or double major curves. If lumbar scoliosis is treated, the risk of an increase of scoliosis during inspiration is low; however, breathlessness is to be avoided.

As the brace can be asymmetrical in the direction of the rebalancing of the spine, it will, however, always ensure the balance of the shoulder girdle.

2.3.6 Practice of sport

When the body is fully developed, we advise high-impact sports such as running and dance, to favor the fixation of the calcium on the bone and the constitution of an important bony mass.

In a specific way when ribs are asymmetric, we recommend avoiding deep and quick inhalation which favors 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.

During the period of maximal tensegrity up to 40 years, all sports can be performed at a high level as long as the spine is straight.

After 40 years, decreased intervertebral disc height and sarcopenia reduce the body's performance.

After 65 years, osteoarthritis is predominant. Swimming avoids overloading the lower limbs and helps maintain lumbar lordosis (**Table 4**).

2.4 Results

2.4.1 Bivalve polyethylene short brace with lateral overlap for lumbar scoliosis

Immobilization braces made of polyethylene have been used for more than 50 years in case of mechanical pain. They complement classical physiotherapy by reducing load by 30% at the lumbar spine. We specifically studied the 158 patients with 5-year follow-up from our prospective database [25].

The principle of bracing is completely different from that of adolescent scoliosis. Indeed, we try to:

1. Decompress the discs with the "sandglass effect" lifting the trunk under the ribs and transferring the load on the pelvis.

2. Rebalance the spine in both the frontal plane and in the sagittal planes, mostly by recreating lumbar lordosis.

3. Relieve pain by the analgesic effect of rigid low back brace.

A specific frame is used to stabilize the patient in the most corrective posture in the frontal and the sagittal plane.

For those patients who had a progressive scoliosis, Cobb angle is stabilized or improved by more than 5° in 80% of cases, and only 20% of scoliosis remain candidates for surgery [25].

The frontal and horizontal clinical parameters are improved, but not the sagittal parameters with the forward trunk projection (**Figure 9**).

The sternoclavicular support is poorly tolerated, and due to reduced dexterity in the older person, lateral closure is a handicap for elderly patients, even if adaptations are possible, that is why we currently use the 3 mm Europlex'O.

Age (girls)	Physiology	Activity (example)
15–21 years	Before complete bone mass	Jogging and running Axial impact and spiral chains
21–40 years	Before sarcopenia and osteopenia (tensegrity)	Fitness, sports reinforcing spiral chains
40 to retirement	Before extrapyramidal weakness (postural system)	Nordic walking, cycling
Retirement	Osteoarthritis, Pisa syndrome	Swimming

Table 4.
Sports activity according to the age.

2.4.2 Nonsurgical orthopedic treatment of 62 adult vertebral deviations treated with adult ARTbrace

Instability in adulthood is frequent, and surgery is the most frequently offered solution despite the high rate of complications, as there was no alternative to date for thoracic and thoracolumbar curves. Only overlapped bivalve polyethylene braces were used for lumbar scoliosis with good frontal stabilization but no control in the sagittal plane (**Figure 9**). The ARTbrace in Europlex'O which allows an average reduction of 70% for the children has been used since 2015 in the adult for all the deviations.

The results of a consecutive series of 62 patients (6.2% of all ARTbrace patients) were treated between 2015 and 2016, as an alternative to surgery.

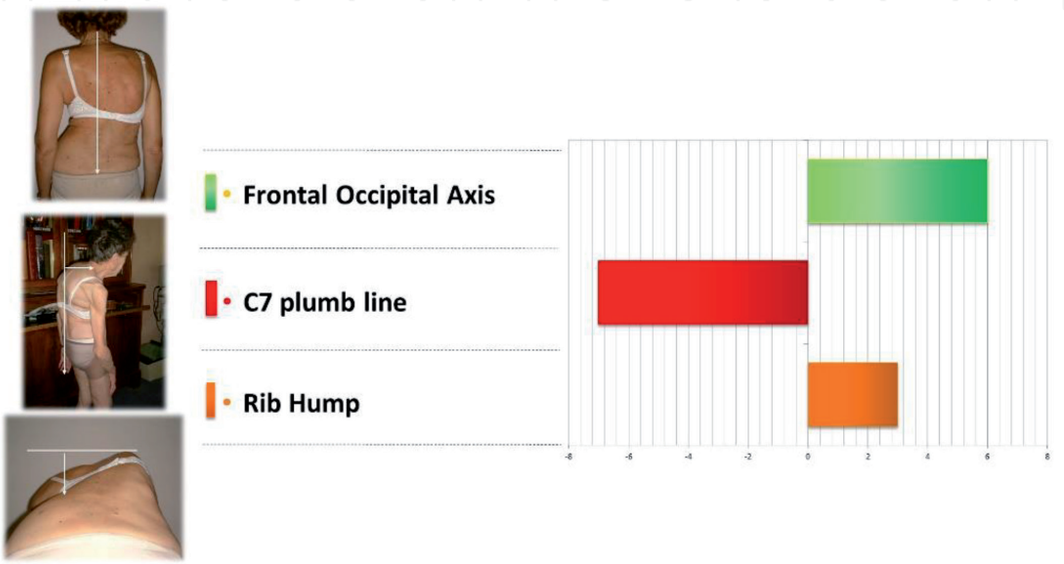

Figure 9.
Insufficient correction in the sagittal plane.

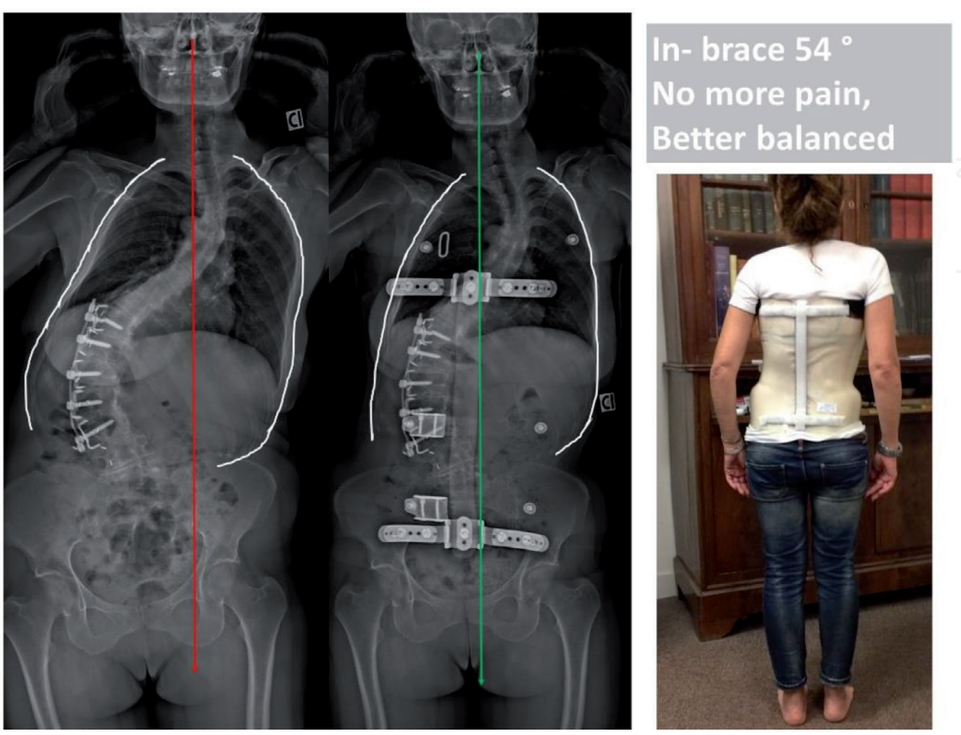

Figure 10.
Reduction in the frontal plane after decompensation upon arthrodesis.

Nine patients (15%) which constitute the dropout were not seen at 6 months, which is very little considering the general condition and age of patients. The percentage of dropouts is identical to the previous series of lumbar curves treatments.

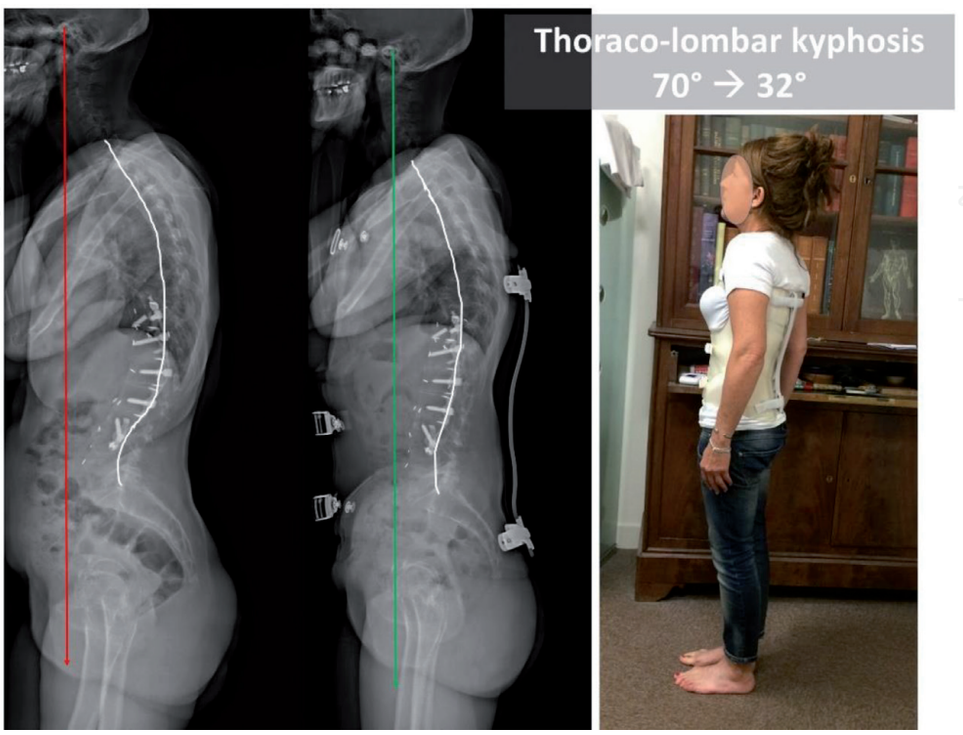

Figure 11.
Correction of kyphosis in the sagittal plane.

Figure 12.
EOS 3D confirms thoracolumbar spine detorsion in ARTbrace.

Despite the very high rigidity, Europlex'O which needs a precision of 1 mm is therefore as well tolerated as polyethylene.

In the frontal plane, the average in-brace reduction is 27%, slightly higher for lumbar and thoracolumbar curvatures. The reduction to 2 years without brace is 15%, and especially the symptomatology of instability disappears. It is now possible to stabilize all thoracolumbar, thoracic, and double major scoliosis (**Figure 10**).

In the sagittal plane, the average in-brace reduction is 32% and at 2 years without brace of 25% (**Figure 11**).

In the horizontal plane, some characteristic case study with EOS 3D confirms that adult ARTbrace is indeed, as in the child, a detorsion brace. Adult ARTbrace is the only brace to correct kyphosis and thus compensate for the insufficiency of polyethylene whose sternoclavicular support was not tolerated (**Figure 12**).

3. Discussion

Adult deformity is a major demographic health issue in the geriatric population. Surgeons are often very conservative in the treatment of adult scoliosis because of the complication rates associated with the surgeries and the marginal bone quality endemic to this population. Medical complications are a major concern in adult spinal deformity surgery [26]. The incidence ranges between 40% and 86%, but there is indeterminate level III/IV evidence on the effectiveness of any usual conservative care option. There is currently a lack of consensus on the most efficacious conservative treatments for adult deformity.

Very few results have been published concerning scoliosis adult bracing. Most of them only concern low back pain [27, 28]. Pain is the usual reason of medical consultation. Pain means instability when combined with the following clinical signs:

- Frontal and sagittal Imbalance. The lumbar kyphoscoliosis is due to pelvic retroversion. The hips are extended under a retroverted pelvis, femurs were oriented downward and forward, and knees and ankles compensate with flexion deformity. Pelvic retroversion is limited by osteoarthritis of the hip, flexion deformity of the knee is poorly tolerated, and the patient will use a walking stick to walk. The thorax can enter in conflict with the pelvis at the concavity level pushing the viscera down. The patient suffers from breathing difficulty; digestive disorders are common and promote abdominal hypertension and sphincter disorders. The loss of lumbar lordosis has multiple causes: a decrease in the anterior height of the disc, hypertrophy of the facet joints and spinous process increasing the posterior height, and loss of extensors muscle strength [29].

- In the horizontal plane, there is a rotation of the shoulder girdle as if the patient looks on the concave side of thoracic scoliosis. The pelvis is drawn by lumbar scoliosis. The convex hemi-pelvis moves back, and the hip is placed in internal rotation, while the concave hemi-pelvis moves forward, and the hip is placed in external rotation.

On each occasion when examining a patient at least every 5 years, verification X-ray is necessary in order to define a progression while being aware that in many cases the progression is chaotic.

- The most characteristic sign of decompensating is the disc height loss that can sometimes exceed 10 mm. The disc corruption results in loss of physiological lordosis and ligament instability by hypermobility.

- The losses of the gluteal muscles are very distinct when we make the plaster cast. It explains in part the pelvic retroversion; the spine tends to relocate along the line of gravity.

Muscular atrophy is a common criticism for rigid braces. In fact, the conservative orthopedic treatment does not suffer approximation. Its teamwork incorporates a specific physical therapy, the continuation of normal activity, and the practice of regular physical activity. No patient is wearing the brace for pleasure. The risk of overtreatment is zero.

Usually the total time bracing relieves pain, and the partial time bracing extends the improvement obtained. When the patient is not relieved, we can discuss the surgery with better arguments. The nonsurgical treatment treats the cause of lumbar instability mainly by discharging the pressure in the disc and stabilizing the lumbar area in lordosis to restore the tensegrity of the spine.

The esthetic improvement of the rib hump and asymmetrical waist is logical; the orthopedic brace is the best way to remodel a trunk. The cosmetic result continues 5 years after starting the treatment, with improvement of the rib hump measured with the plumb line and the Bunnel angle of trunk rotation (**Figure 9**).

The nonsurgical treatment can fit into a therapeutic progression. The indications may be progressive: observation, physiotherapy, medicine, conservative orthopedic Treatment, and surgery.

The good surgical indications concern the degenerative scoliosis not relieved by bracing, or relieved by total time, but insufficiently by partial time and especially if there is a spinal stenosis. It can also be used to complete surgery if remaining instability.

The Greek study [30] associating Schroth and Chêneau brace shows that patients have great difficulty to follow the protocol. For the quarter of patients following the protocol, the results are correct on pain and posture, but in 39% of patients, Cobb angle continues to increase.

Josette Bettany [31] confirms that for adult scoliosis, there are only a few studies on the effectiveness of PSSEs and a conclusion cannot yet be drawn. Recently a RCT proves the effectiveness of a motor and cognitive rehabilitation [32].

3.1 Differences between adult and non-adult bracing

The motivation of the patient is fundamental. The brace should be designed as a tool to facilitate physiotherapy.

The use of an instantaneous and accurate CAD/CAM is better because the adult patient can only maintain the corrected position for a few seconds.

The scan is made in deep inspiration to not limit the vital capacity.

The management is 4 hours a day including systematically for 2 hours after any physical activity. Physiotherapy is even more important than during adolescence [33].

4. Conclusion

The frequency of adult scoliosis makes it a public health problem. The new digital technologies have changed the adult scoliosis bracing, and conservative care in general may be a helpful option for adult deformity, but evidence for this decision was lacking. Lyon nonsurgical treatment is effective and offers new perspectives to adult scoliosis bracing. Not only does the brace relieve pain and support the spine, but for the first time, it corrects deviations in the frontal, sagittal, and horizontal planes. Immobilization braces in polyethylene allow a treatment of the cause of pain

without side effects. Worn a few hours in the day, they complement physiotherapy. The first results confirm the excellent tolerance of Europlex'O adult ARTbrace with its ease of implementation and corrections unmatched to date in adults. These corrections make it possible to restore stability of the deviations without surgery. Adult scoliosis bracing as an alternative to surgery could be possible. Initially reserved for the most severe cases, this management deserves to be more widely used for adult scoliosis. The increasing number of CPO using the most modern CAD/CAM technologies should facilitate research in the field of very high rigidity.

Acknowledgements

Thanks to my daughter Agnès Thornton de Mauroy, for proofreading in English.

Acronyms and abbreviations

ARTbrace	asymmetrical rigid torsion brace
ASA	adolescent scoliosis in adult
CAD/CAM	computer-aided design/computer-aided manufacturing
CPO	certified prosthetist/orthotist
CT scan	computed tomography scan
DDS	degenerative de novo scoliosis
EOS	low-dose X-ray imaging
MRI	magnetic resonance imaging
PSSE	physiotherapy scoliosis-specific exercises
RCT	randomized controlled trial

Author details

Jean Claude de Mauroy[1*], Fabio Gagliano[1], Rosario Gagliano[2] and Piera Lusenti[3]

1 Clinique du Parc, Lyon, France

2 ROGA, Enna, Italy

3 Poliambulatorio Baia del Re, Piacenza, Italy

*Address all correspondence to: demauroy@aol.com

References

[1] Vanderpool DW, James JI, Wynne-Davies R. Scoliosis in the elderly. Journal of Bone and Joint Surgery. 1969;**51**:446-455

[2] Schroeder JE, Dettori JR, Ecker E, Kaplan L. Does pregnancy increase curve progression in women with scoliosis treated without surgery? Evidence-Based Spine-Care Journal. 2011;**2**(3):43-50

[3] Akbarnia BA, Ogilvie JW, Hammerberg KW. Debate: Degenerative scoliosis: To operate or not to operate. Spine. 2006;**31**:S195-S201

[4] Edgar MA, Mehta MH. Long term follow-up of fused and unfused idiopathic scoliosis. Journal of Bone and Joint Surgery. 1988;**70-B**:712-716

[5] O'Brien J. Living with scoliosis: An adult perspective. Scoliosis. 2010;**5**:O43

[6] Baron EM, Albert TJ. Medical complications of surgical treatment of adult spinal deformity and how to avoid them. Spine. 2006;**31**:S106-S118

[7] Smith JS, Shaffrey CI, Glassman SD, Berven SH, Schwab FJ, Hamill CL, et al. Risk-benefit assessment of surgery for adult scoliosis. An analysis based on patient age. Spine. 2010;**36**:817-824

[8] Ogilvie JW. Adult scoliosis: Evaluation and nonsurgical treatment. Instructional Course Lectures. 1992;**41**:251-255

[9] Kluba T, Dikmenli G, Dietz K, Giehl JP, Niemeyer T. Comparison of surgical and conservative treatment for degenerative lumbar scoliosis. Archives of Orthopaedic and Trauma Surgery. 2009;**129**(1):1-5

[10] Everett CR, Patel RK. A systematic literature review of nonsurgical treatment in adult scoliosis. Spine. 2007;**32**:S130-S134

[11] Chuah SL, Kareem BA, Selvakumar K, Borhan TA, Harwant S. The natural history of scoliosis: Curve progression of untreated curves of different etiology, with early (mean 2 year) follow-up in surgically treated curves. The Medical Journal of Malaysia. 2001;**56**(suppl C):37-40

[12] Weinstein SL, Zavala DC, Ponsetti I. Idiopathic scoliosis; long-term follow-up and prognosis in untreated patients. Journal of Bone and Joint Surgery. 1983;**63A**:702-712

[13] Weinstein SL, Dolan LA, Spratt KF, Peterson KK, Spoonamore MJ, Ponseti IV. Health and function of patients with untreated idiopathic scoliosis: A 50-year natural history study. Journal of the American Medical Association. 2003;**289**(5):559-567

[14] Marty-Poumarat C, Scattin L, Marpeau M, Garreau de Loubresse C, Aegerter P. Natural history of progressive adult scoliosis. Spine (Phila Pa 1976). 2007;**32**(11):1227-1234. discussion 1235

[15] Duval-Beaupere G, Dubousset J. La dislocation rotatoire progressive du rachis. Processus mécanique commun aux cypho-scolioses évolutives génératrices de troubles neurologiques. A propos de 16 observations. Revue de Chirurgie Orthopédique. 1972;**58**:323-334

[16] Hong JY, Suh SW, Modi HN, Hur CY, Yang JH, Song HR. Correlation of pelvic orientation with adult scoliosis. Journal of Spinal Disorders & Techniques. Oct 2010;**23**(7):461-466

[17] Murata Y, Takahashi K, Hanaoka E, Utsumi T, Yamagata M, Moriya H. Changes in scoliotic curvature and lordotic angle during the early phase of degenerative lumbar scoliosis. Spine. 2002;**27**(20):2268-2273

[18] Ploumis A, Liu H, Mehbod AA, Transfeldt EE, Winter RB. A correlation of radiographic and functional measurements in adult degenerative scoliosis. Spine. 2009;**34**(15):1581-1584

[19] Schwab FJ, Smith VA, Biserni M, Gamez L, Farcy JP, Pagala M. Adult scoliosis: A quantitative radiographic and clinical analysis. Spine (Phila Pa 1976). 2002;**27**(4):387-392

[20] Naresh-Babu J, Viswanadha AK, Ito M, Park JB. What should an ideal adult spinal deformity classification system consist of?: Review of the factors affecting outcomes of adult spinal deformity management. Asian Spine Journal. 2019;**13**(4):694-703

[21] Diarbakerli E, Grauers A, Danielsson A, Gerdhem P. Adults with idiopathic scoliosis diagnosed at youth experience similar physical activity and fracture rate as controls. Spine (Phila Pa 1976). 1 Apr 2017;**42**(7):E404-E410

[22] de Mauroy JC, Lecante C, Barral F, Pourret S. Bracing in adult with scoliosis: Experience in diagnosis and classification from a 15-year prospective study of 739 patients. Scoliosis and Spinal Disorders. 2016;**11**(Suppl 2):29

[23] Schulz-Schaeffer WJ. Camptocormia in Parkinson's disease: A muscle disease due to dysregulated proprioceptive polysynaptic reflex arch. Frontiers in Aging Neuroscience. 2016;**8**:128

[24] Lenoir T, Guedj N, Boulu P, Guigui P, Benoist M. Camptocormia: The bent spine syndrome, an update. European Spine Journal. 2010;**19**(8):1229-1237. DOI: 10.1007/s00586-010-1370-5

[25] de Mauroy JC, Lecante C, Barral F, Pourret S. Prospective study of 158 adult scoliosis treated by a bivalve polyethylene overlapping brace and reviewed at least 5 years after brace fitting. Scoliosis and Spinal Disorders. 2016;**11**(Suppl 2):28

[26] Smith JS, Shaffrey CI, Glassman SD, Berven SH, Schwab FJ, Hamill CL, et al. Spinal deformity study group. Risk-benefit assessment of surgery for adult scoliosis: An analysis based on patient age. Spine (Phila Pa 1976). 2011;**36**(10):817-824

[27] Weiss HR, Dallmayer R, Stephan C. First results of pain treatment in scoliosis patients using a sagittal realignment brace. Studies in Health Technology and Informatics. 2006;**123**:582-585

[28] Gallo D. Case reports: Orthotic treatment of adult scoliosis patients with chronic back pain. Scoliosis. 2014;**9**:18. DOI: 10.1186/1748-7161-9-18

[29] York PJ, Kim HJ. Degenerative Scoliosis. Current Reviews in Musculoskeletal Medicine. 2017;**10**(4):547-558

[30] Papadopoulos D. Adult scoliosis treatment combining brace and exercises. Scoliosis. 2013;**8**(Suppl 2):O8. DOI: 10.1186/1748-7161-8-S2-O8

[31] Bettany-Saltikov J, Turnbull D, Ng SY, Webb R. Management of spinal deformities and evidence of treatment effectiveness. The Open Orthopaedics Journal. 2017;**11**(Suppl-9, M6):1521-1547

[32] Monticone M, Ambrosini E, Cazzaniga D, Rocca B, Motta L, Cerri C, et al. Adults with idiopathic scoliosis improve disability after motor and cognitive rehabilitation: Results of a randomised controlled trial. European Spine Journal. Oct 2016;**25**(10):3120-3129. Epub 2016 Mar 25

[33] de Mauroy JC, Vallèse P, Lalain JJ. Lyon conservative treatment of adult scoliosis. Minerva Ortopedica e Traumatologica. 2011;**62**(5):385-396