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Special Article

The True Ponte Osteotomy: By the One Who Developed It

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Abstract

Study Design: Technique and applications.
Objectives: To define the anatomy, biomechanics, indications, and surgical technique of the true Ponte osteotomy.
Summary of Background Data: The Ponte osteotomy, originally developed for thoracic kyphosis, was the first one to obtain posterior shortening of the thoracic spine, maintaining the anterior column load-sharing capacity. It has become a widely applied technique in various types of spine deformities and a frequent topic of presentations at meetings and in scientific articles. Several of them offer unquestionable evidence of an incorrect execution, with consequently distorted outcomes and erroneous conclusions. A clearing up became essential.
Methods: Our original experience is based on a series of 240 patients with thoracic hyperkyphosis operated in the years 1969-2015, at first with a standard posterior Harrington technique and then by using the Ponte osteotomy with different instrumentations. A series of 78 of them, operated in the years 1987-1997, who had Ponte osteotomies at every level, is presented.
Results: The average preoperative kyphosis has been corrected from 80° (range 61°-102°) to 31° (range 15°-50°) by a substantial posterior shortening.
Conclusions: A number of publications use the term *Ponte osteotomy* loosely for by far incomplete resections and mixing it up with Smith-Petersen's osteotomy. The true Ponte osteotomy is capable of producing marked flexibility in extension, flexion and rotation, justifying its wide use in thoracic deformities, mainly in scoliosis. An exact performance of the osteotomy with adequate bony resections, including the laminae, is an absolute condition to take full advantage of its properties.
Level of Evidence: Level IV, therapeutic study.

Keywords: Ponte osteotomy; Smith-Petersen osteotomy; Thoracic kyphosis; Posterior column shortening; Flexibility; Scoliosis; Kyphoscoliosis; Ankylosing spondylitis

Introduction

The lead author's aim in the years 1984-1987, to correct long-segment thoracic kyphosis by a shortening of the posterior column in a single posterior stage, resulted in the development of this osteotomy. All other techniques in use obtained correction mainly or only by lengthening the anterior column. Since then, the Ponte osteotomy has become a widely applied technique in various types of spine deformities and a frequent topic of presentations at meetings and in scientific articles. Several of them offer unquestionable evidence of a wrong technique and consequently distorted outcomes and erroneous conclusions [1,2]. Another fact that needs to be cleared up is a frequent confusion with Smith-Petersen's osteotomy, mistakenly used interchangeably [1,3,4]. The notable differences between the two osteotomies are in the type and amount of resections, in the different anatomy of the regions they were originally developed for, that is lumbar versus thoracic and also in the grading in Schwab's Osteotomy Classification—Grade 1 for Smith-Petersen osteotomy and Grade 2 for Ponte osteotomy [5].

Smith-Petersen's osteotomy was described in 1945 for the correction of a flat lumbar spine from ankylosing spondylitis. The only time it was performed at thoracic levels gave "no objective evidence of improvement" [6]. This osteotomy consists in a narrow resection of lumbar

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facet joints and in a detachment of ligamentum flavum from the inferior margin of the lamina and inferior articular process (Fig. 1). There are no resections of the laminae. If used to obtain flexibility in thoracic kyphosis, correction is obtained by a wide opening of anterior disc spaces and a lengthening of the anterior column.

The Ponte osteotomy, developed in 1987, consists in a wide resection of thoracic facet joints as well as of laminae and in a complete removal of the ligamentum flavum (Fig. 2). Thoracic kyphosis, the original indication, is corrected by a substantial shortening of the posterior column, obtained by closing the gaps of osteotomies, preferably through segmentally applied and apically directed compression forces. The absence of anterior column lengthening due to major openings of anterior disc spaces preserves the immediate and long-term load sharing capacity and the stability of correction.

Correction of thoracic hyperkyphosis can be achieved by direct or indirect modes. A direct mode corrects by acting primarily on the involved structure, in this case mainly bone. An indirect mode corrects by acting primarily on uninvolved or less involved structures, which are ligaments and discs. Since rigid kyphosis is mainly a bony deformity, a direct mode of correction through bony shortening of the posterior spine seems more logical. Moreover, shortening the convexity of a spinal deformity provides greater safety than lengthening the concavity. Surgical techniques obtain correction by combining anterior lengthening and posterior shortening of the spine. Each technique, however, primarily lengthens the anterior spine or primarily shortens the posterior spine. It is important to note that in thoracic hyperkyphosis there is an increased length of the spinal canal, with the dural sac and the spinal cord taking a shorter and straighter route [7]. In severe cases, an anterior displacement of both the dural sac and cord can be present, with

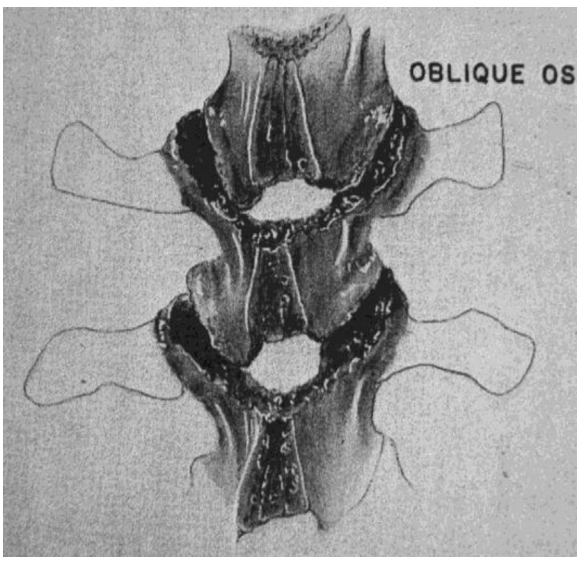

Fig. 1. Smith-Petersen's osteotomy. The original drawing.

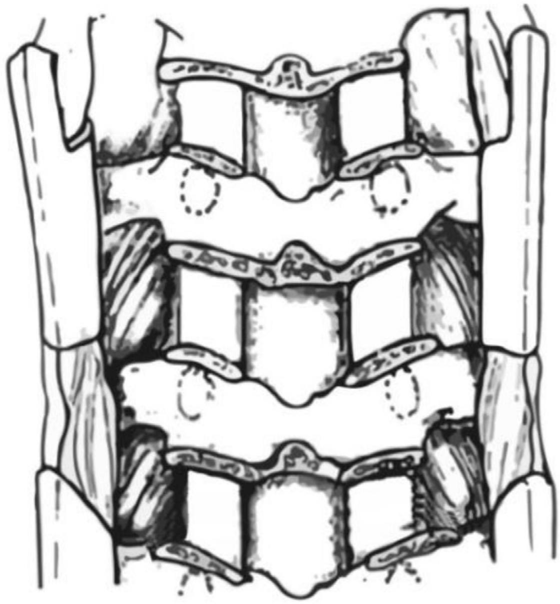

Fig. 2. Ponte osteotomy.

reduction or even obliteration of the anterior epidural and subarachnoid spaces. A consequent widening of the posterior epidural space will result.

Surgical treatment of thoracic kyphosis began with the standard posterior technique described by Harrington, consisting in two parallel compression rods and fusion. Correction was almost entirely obtained by lengthening of the anterior column. Marked losses of correction and a large number of implant failures induced surgeons to abandon this method [8]. The combined anterior/posterior technique, consisting in anterior discectomies, followed by an instrumented posterior fusion, became the treatment of choice [9]. Correction was obtained in two stages and by a marked lengthening of the anterior column. Intercorporal cages or other structural devices were needed to restore the anterior column support. Considering that hyperkyphosis is not only an anterior shortening but also a marked lengthening of the posterior column, it became evident that a substantial posterior shortening with preservation of the anterior column length and its load-sharing capacity would be an appropriate and stable form of correction. On this basis, the Ponte osteotomy has been developed. Anterior lengthening at midthoracic levels, where one single anterior longitudinal artery supplies the anterior two thirds of the spinal cord [10], also represents a high neurologic risk (see below).

Biomechanics

To fully understand the rationale of posterior column shortening by segmental Ponte osteotomies, one has to define the motion of the spinal column in extension. Any motion of an object in a plane can be explained by knowing

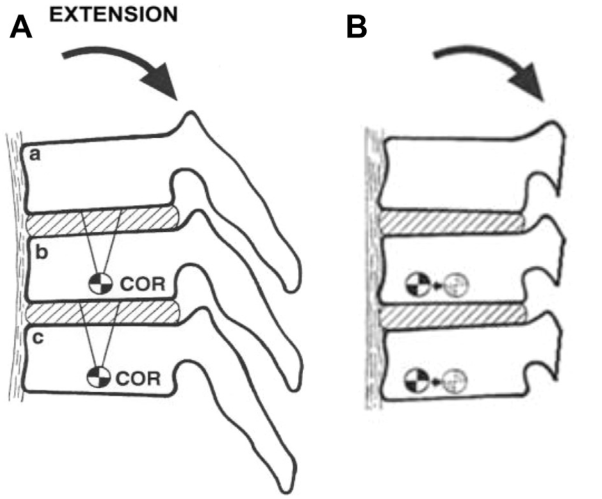

Fig. 3. (A) The center of rotation (COR) or instantaneous axis of rotation (IAR) for the movement of extension of the thoracic spine. (B) Anterior migration of the IAR in the correction of kyphosis with Ponte osteotomies, resulting in a long moment arm for posterior corrective forces.

or locating the center of rotation (COR). The COR, also defined as the instantaneous axis of rotation (IAR), is a convenient and concise biomechanical concept for documenting the kinematic behavior of a body in a planar motion. An experimental in vitro study by Panjabi [11], utilizing fresh cadaveric human spines, determined the COR/IAR of motion segments of the thoracic spine. Its location for the movement of extension is in the vertebral body below and not in the disc space as frequently thought (Fig. 3A). Because thoracic hyperkyphosis is a uniplanar deformity with correction being comparable to a movement of extension, Panjabi's study can in vivo be applied to locate the correction-induced change of position of the IARs on lateral radiographs before and after surgery.

The IAR also represents the axis of segmental correction of a kyphosis in the sagittal plane. By knowing the location of the IAR, the length of the moment arm for posterior corrective forces can be determined and consequently the amount of the biomechanical advantage. If a structure is changed or compromised, the IAR migrates to the most dense or stiffest part of the structure [12]. This concept also applies to the spine. Treatment techniques can therefore be analyzed with respect to their influence on the IAR.

The lead author determined the location of the IAR in 15 of his cases of thoracic kyphosis operated by the standard posterior Harrington technique plus Smith-Petersen–type narrow facet joint resections and in 15 other cases by his osteotomy at every segmental level. Lateral radiographs, taken immediately before and after surgical correction, were used. The levels examined were the five apical thoracic vertebrae and the four apical motion segments representing the most significant portion of the deformity. In the standard posterior technique plus narrow facet joint resections, the IARs, clustered in small ellipses, did migrate posteriorly, causing a short moment arm for posterior corrective forces. The technique using Ponte osteotomies instead produced an anterior migration of the IARs toward the intact anterior spine (Fig. 3B). This results in a long moment arm and a positive biomechanical advantage for posterior corrective forces [13]. The anterior longitudinal ligament and anterior discs are acting as a tension band. Their integrity is therefore an absolute requisite. Posterior joints are pivotal. Their complete resection is essential. Resecting the laminae induces the biomechanical advantage in extension for posterior corrective forces.

Surgical technique

As already stated, the osteotomy was developed to correct thoracic hyperkyphosis by a substantial shortening of the posterior column. This was obtained by first creating and then closing wide posterior intersegmental gaps [14,15]. The high destabilizing power of the osteotomy determined its successful application in scoliosis in the years to follow.

A posterior midline approach and subperiosteal exposure is performed in the usual fashion, encompassing the deformity. The subperiosteal exposure should include one vertebra above and one below the fusion levels previously determined. The ligamentous structures connecting the cranial and caudal end vertebrae to be instrumented with the adjacent segments should be protected and spared. Spinous processes are resected at their base to allow better visualization of the bony parts to be removed (Fig. 4A). An angled double-action rongeur and/or a Kerrison is used to perform the bony resections. Complete facetectomies and wide inferior and superior laminectomies are performed at every intersegmental level of the entire fusion area, obtaining gaps of 5 to 8 mm, depending on the magnitude of the deformity and the size of the patient. A generous resection of facet joints and laminae, in severe deformities as far as the pedicles, is an essential step of the osteotomy and the technique. By not doing so, bony remnants will act as hinges during the phase of compression and alter the mechanics of correction. The ligamentum flavum is removed entirely at all levels. The gaps extend uniformly over the entire width of the posterior spine. A straight nerve root retractor of 4-5 mm width, held vertically and horizontally, is used to assess that the resections are completed thoroughly in width and in depth. The borders of the bony resections should be even, paying attention to remove any residual bony spikes. This will later permit the closure of the gaps at thoracic levels. At apical levels of severe and stiff deformities, the osteotomy should extend from pedicle to pedicle (Fig. 4B).

A marked segmental flexibility in all three planes, primarily in extension, has been established over the entire curve and will be used for the correction. Manual pressure on the apical vertebrae of a kyphosis can already induce a momentary "spring-loaded" reduction. The instrumentation

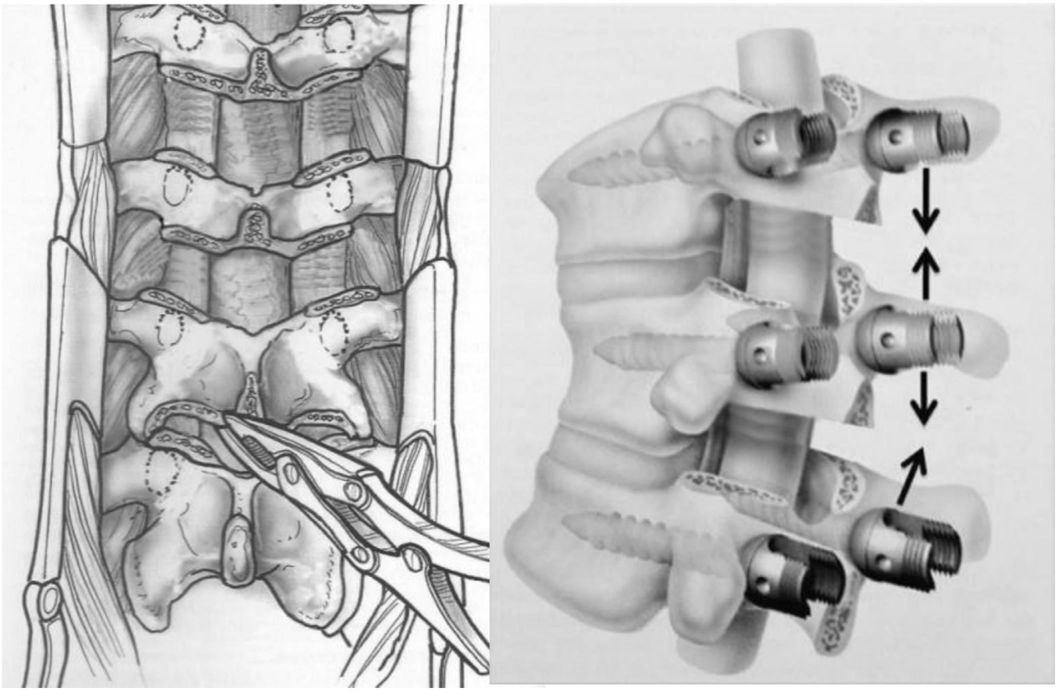

Fig. 4. (A) Ponte osteotomy. (B) Ponte osteotomy from pedicle to pedicle.

of choice can now be applied to obtain correction and its maintenance. A fully segmental instrumentation has a direct control of every single gap resulting from the osteotomies, permitting their closure [14,15]. Closure of the gaps should be gradual, beginning at the apex and proceeding toward the ends of the deformity. A direct contact of the opposite laminar borders can be obtained through segmentally applied compression forces. In our experience, this occurs better with semirigid rod constructs than with stiff rods acting by cantilever. The correction should be evenly distributed over the entire curve. This requires greater forces where the deformity is the most rigid, usually the apex, and lesser forces on the less rigid upper and lower part of the deformity. A routine intraoperative lateral radiograph has been useful to assess the magnitude of correction and determine the segmental levels requiring adjustments in order to obtain its harmonious distribution.

Personal experience

The first series of cases having surgical treatment of long-segment thoracic hyperkyphosis consists of 146 patients, all skeletally mature, 142 Scheuermann and 4 from postmenopausal osteoporosis, operated between 1969 and 1997 and with follow-up from 2 to 16 years. All the deformities were rigid on forced hyperextension with an average vertebral wedging of 15° (range 7°-25°). The mean age at surgery for the entire series was 26 years 7 months (range 15-56 years). Sixty-two more patients with thoracic kyphosis, operated in the years 1969-1982, are not included in the above series. Twenty-nine had a minor degree of scoliosis (15°-20°), which at that time was considered sufficient to exclude them from the series. The other 33 had different etiologies such as congenital, neurofibromatosis, tubercular, postlaminectomy, posttraumatic, and Morquio [16]. Correction in all 146 patients was obtained by two symmetrical semirigid rod-hook compression systems. In the very first 19 patients (1969-1970), hooks were around the transverse processes, with only the two most caudal ones under the laminae [16]. The subsequent 127 patients had two laminar hooks at every segmental level, supralaminar above the apex and infralaminar below the apex. Hooks with narrow blades (5 mm) have been used to prevent their overlapping inside the canal at upper thoracic levels and in small patients. Small notches in the laminae have been used to place the hooks to permit the complete closure of the gaps. The presence of 22-26 laminar hooks per case does not imply a greater risk due to the invasion of the vertebral canal. Besides, a widening of the posterior epidural space, induced by an anterior displacement of the spinal cord, is frequently present in severe kyphosis. More sites of canal invasion do not mean a greater invasion of canal sites. More than 3000 laminar hooks in 128 patients with kyphosis did not cause any neurologic injury.

In the first 68 patients (1969-1987), the standard posterior Harrington technique was used [16-18]. Smith-Petersen type narrow resections of facet joints were added to gain flexibility. Correction by the compression constructs did cause marked anterior opening of disc spaces in all cases. A postoperative Risser Localizer cast was applied for

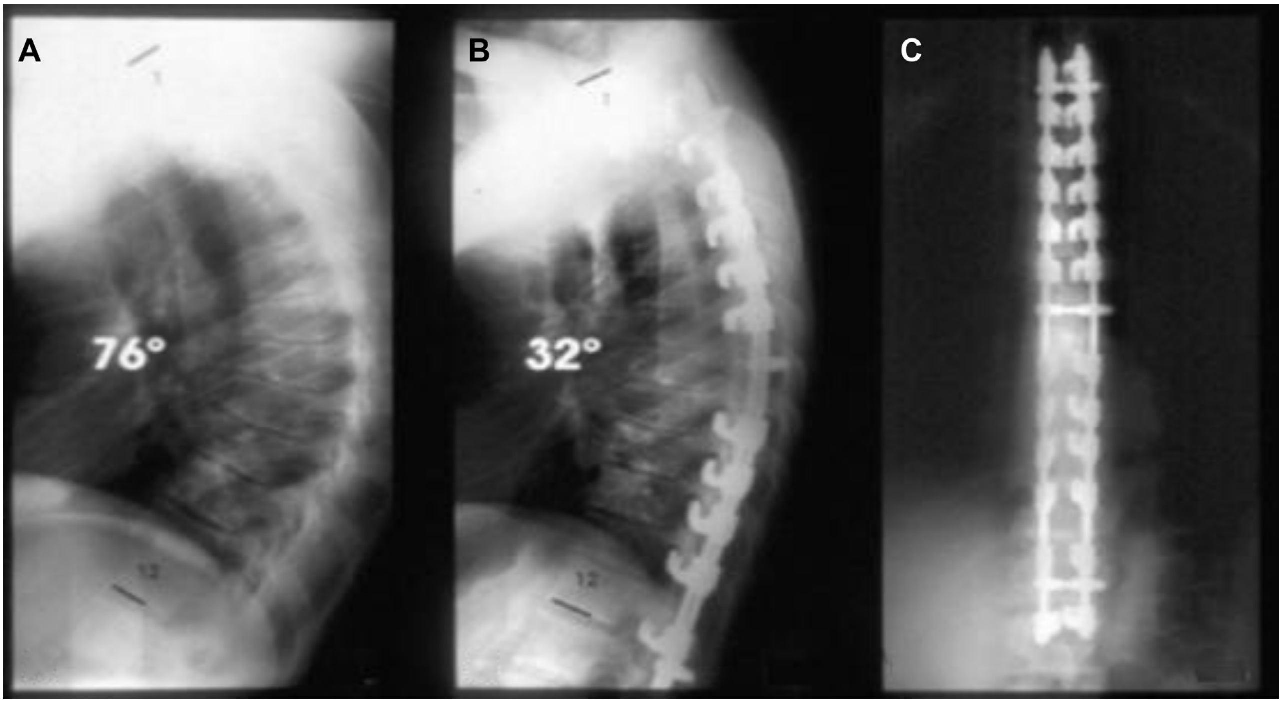

Fig. 5. A 29-year-old male patient with Scheuermann kyphosis. (A) Preoperative standing lateral radiograph showing a 76° kyphosis. Surgery consisted of 12 levels of Ponte osteotomy, instrumentation, and fusion from T1 to L1 with 24 laminar hooks and a 4.8-mm semirigid rod compression construct. (B) Standing lateral radiograph 32 months after surgery showing a correction to 32°. (C) Standing AP radiograph showing the fully segmental construct, extending from T1 to L1 (No long radiographs then). AP, anteroposterior.

4 months, followed by a second-stage augmentation fusion, performed to obtain a thicker fusion mass and reduce loss of correction. In 10 cases with particularly wide anterior disc openings, an anterior fusion was performed as a second stage. The average initial curve was 78.1° (range 63°-140°). The average curve at follow-up was 44.6°, with an average loss of correction of 8.5°.

The following 78 patients operated in the years 1987-1997 had Ponte osteotomies at every level and an all segmental laminar hook semirigid rod compression system (Fig. 5). Four patients had hyperkyphosis from postmenopausal osteoporosis. The second-stage augmentation fusion and the postoperative Risser cast had been discontinued. The average preoperative kyphosis corrected from 80° (range 61°-102°) to 31° (range 15°-50°) with a substantial posterior shortening. The average improvement was 49 degrees, obtained only by compression forces and without any cantilever. At a mean follow-up of 40 months, the average curve measured 34° (range 22°-54°) with an average loss of correction of 3°. Thoracic kyphosis has always been measured in its real extent, with the upper limits usually being T1 or T2. The amount of posterior shortening of the spine, determined in a few of our cases by measuring the excess in length of compression rods between before and after correction ranged from 3.5 to 6 cm. There were no cases of pseudoarthrosis or implant failures. Pain reduced from the original 85% to 16%. The gain in height ranged from 6 to 11 cm. Patient satisfaction regarding correction was 98%, as determined by anonymously completed patient questionnaires.

Preoperative compensatory increase of lumbar lordosis was never structural. Surgical correction of the kyphosis, even to optimal physiological values, induced in all cases a spontaneous return to a proportional lumbar lordosis with a normal standing sagittal spinal alignment. Lower fusion levels were mainly L1 or L2 with only two cases of L3. Five cases in our series of 78 patients had an increased pelvic incidence, but no sagittal spinal malalignment. An interesting observation in these cases was that even a correction of kyphosis to optimal physiological ranges did not prevent a normal postoperative sagittal spinal balance. The presence of an increased pelvic incidence, with normal sagittal alignment, did never limit surgical correction if there were three or more mobile lumbar discs.

A subsequent series of 34 patients of thoracic kyphosis, operated from 1999 to 2015, has been treated by all-segmental Ponte osteotomies, pedicle screw instrumentation, pre-bent 7- or 5.5-mm rods and correction by cantilever action, followed by segmental compression of the screws. There were seven cases of junctional kyphosis, three proximal and four distal. Five of them needed reoperation, four were distal and one proximal. The much higher incidence of junctional kyphosis, compared to our laminar hook semirigid rod series, is in our opinion due to the huge load concentration on the more mobile ends of the deformity, exerted by the cantilever action with

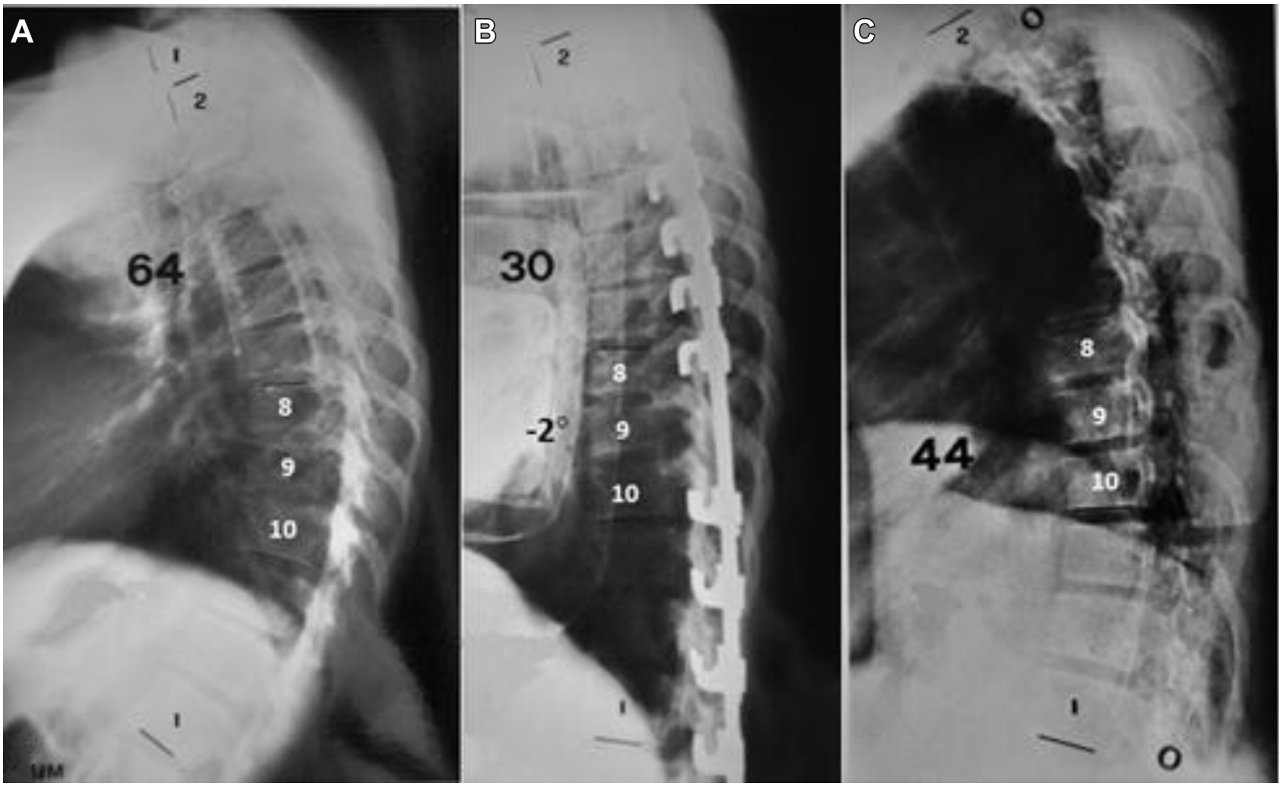

Fig. 6. Example of a postoperative neurologic complication on a likely vascular basis. An apical overcorrection with a T8—T10 lordosis of 2 degrees causing a medullary ischemia was the most likely reason inducing a paraparesis at level T8. Complete recovery occurred after immediate implant removal. (A) Standing lateral preoperative radiograph. (B) Postoperative lateral radiograph showing a segmental lordosis at T8—T10. (C) Standing lateral radiograph 8 days after surgery showing the correction in a Risser localizer cast.

high-stiffness rods. The greater the cantilever force needed to overcome the resistance, the higher the risk of junctional kyphosis.

Complications

In the series of 78 patients treated with Ponte osteotomies and semirigid constructs, there were 4 cases of proximal junctional kyphosis, which never exceeded 15° (range 8°-15°). In all these cases the upper instrumented vertebra had been T3 instead of T1, as would have been the correct choice. There was one patient with distal junctional kyphosis of 12° due to an excessive correction of the deformity (from 65°-15°). There were two cases of temporary, late-onset paraparesis, one and four hours after awakening from surgery, both with a neurologic level of T8. Prompt and complete recovery occurred in both patients following implant removal within one hour. The standard protocol of taking a postcorrection intraoperative radiograph and making the necessary adjustments had not been followed. A short-segment lordosis of the three apical thoracic vertebrae was only recognized on the postoperative radiograph (Fig. 6). This was the case in both patients and is thought to have caused the complication on a vascular basis.

As demonstrated by Dommisse in his anatomical study of the vascular patterns of the human spinal cord [10], there is a zone of critical blood supply to the anterior spinal cord at midthoracic levels, which can vary between T4 and T9. Only one single anterior longitudinal artery supplies the anterior two-thirds of the spinal cord. A longitudinal traction on this single artery can cause medullary ischemia. The greater incidence of neurologic complications from surgical correction of thoracic kyphosis, present in all morbidity reports, seems mainly due to the above vascular reason.

In our series operated with pedicle screws, there was a high incidence of junctional kyphosis, 7 cases of 34, with 5 of them needing reoperation. In our opinion, this is due to the huge three-point load concentration exerted by the cantilever action for correction.

Discussion

The true Ponte osteotomy is capable of producing marked flexibility in deformities of the thoracic spine. The considerable amount of flexibility in extension, flexion, and rotation justifies its wide use in thoracic deformities, permitting corrective maneuvers to become more effective and achieving better results [19-21]. An exact performance of the osteotomy with adequate bony resections, including

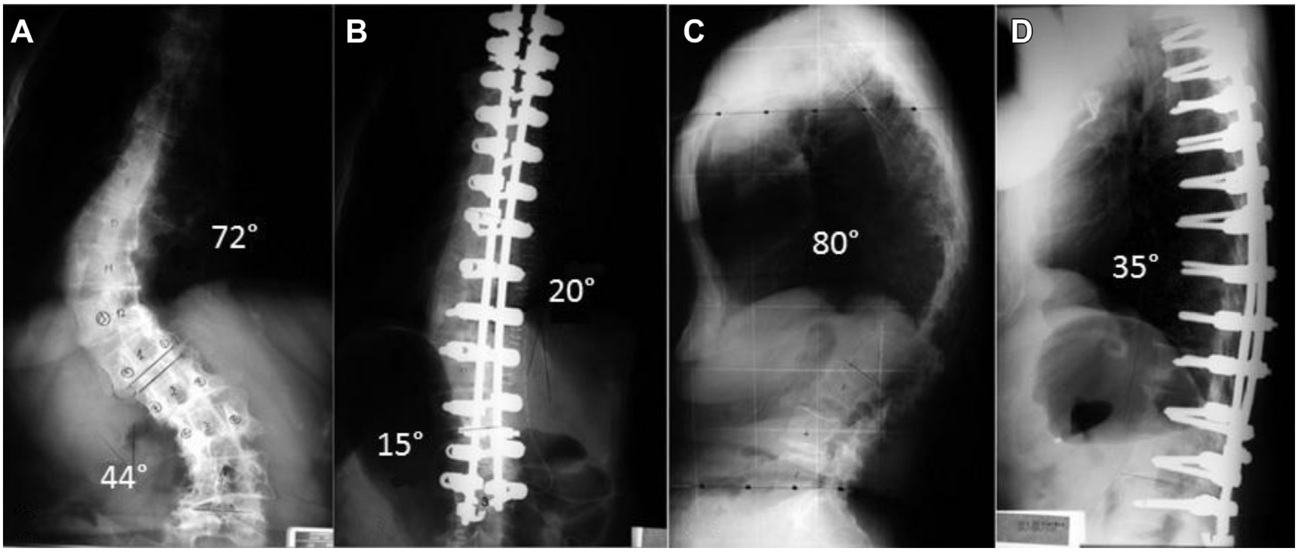

Fig. 7. A 69-year-old female patient. Severe postmenopausal kyphoscoliosis with marked worsening over the last years. Correction consisted in 12 levels of asymmetric Ponte osteotomy and an all-segmental construct with 26 pedicle screws from T2 to L3 in moderately porotic bone. (A) Preoperative standing AP radiograph. (B) Standing AP radiograph 24 months after surgery. (C) Preoperative standing lateral radiograph. (D) Standing lateral radiograph 24 months after surgery. AP, anteroposterior.

the laminae, is an absolute condition to take full advantage of its properties (Figs. 7-10).

The original aim of the osteotomy was to correct thoracic hyperkyphosis by substantial shortening of the posterior column without anterior lengthening, preserving the immediate and long-term load-sharing capacity of the anterior column. Harmonious corrections, intending a uniform distribution of correction over each segment of the curve, have been achieved by adequately graduating the corrective compression forces. An intraoperative post-correction lateral radiograph is needed to assess it. A narrowing of posterior disc spaces over the entire curve was a frequent finding. Posterior disc protrusions at apical levels were present in a few cases. Posterior disc herniation did never occur. With correctly performed osteotomies, anterior disc openings were minimal or absent, or a deceptive appearance because of the posterior narrowing. This also means no or only minimal loss of correction. The opposite did occur in the first group of patients operated with the standard Harrington technique plus Smith-Petersen–type narrow facet resections, where marked opening of anterior disc spaces and major losses of correction were the norm.

Ponte osteotomy and Smith-Petersen osteotomy, frequently and mistakenly used interchangeably creating confusion, are anatomically and biomechanically very different types of bony resections. Thoracic hyperkyphosis

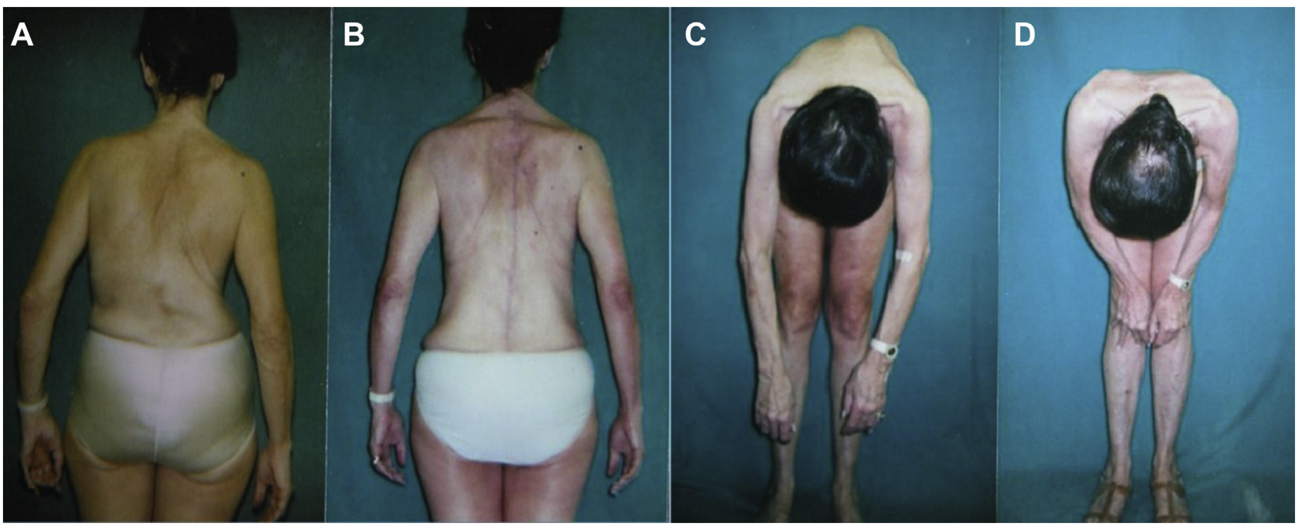

Fig. 8. Same patient. Clinical result: A and B showing a 7.5 cm increase in height, and C and D showing a marked reduction of the rib-hump. No thoracoplasty and no anterior surgery had been performed.

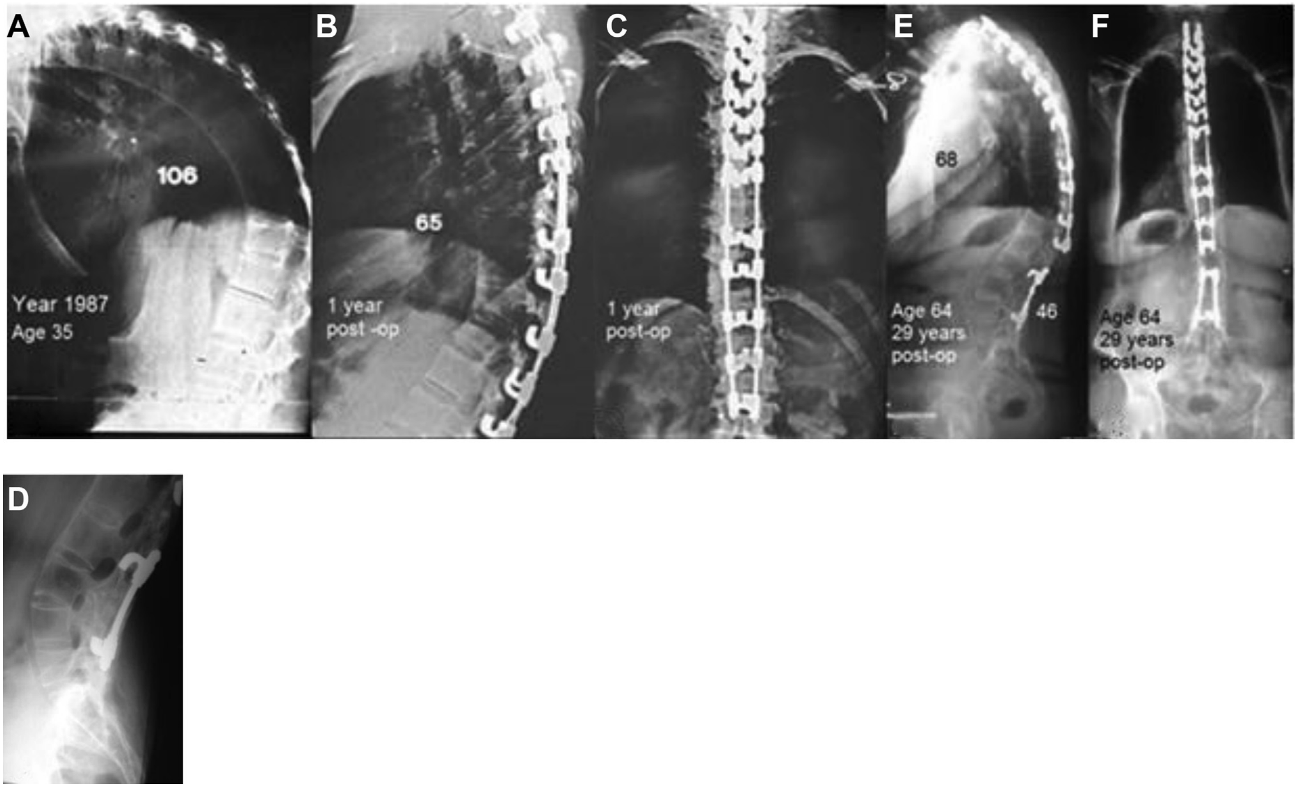

Fig. 9. A 35-year-old female patient. Hyperkyphosis from ankylosing spondylitis developing in 3 years. Inability to look straight ahead, rapid progression, major functional restrictions, interference with having sexual intercourse, were the indications for surgery. Extreme rigidity of the deformity, ossification of ligaments, marked softness and heavy bleeding of the vertebral bone were present at surgery. Twelve levels of Ponte osteotomy and a 24 laminar hook compression system obtained correction of the primary thoracic deformity by bending the ossified anterior longitudinal ligament. (A) Year 1987. Preoperative standing lateral radiograph. No long radiographs then. (B) One-year postoperative standing lateral radiograph. (C) One-year postoperative standing AP radiograph. (D) A two-level lumbar Smith-Petersen osteotomy L2—L3 and L3—L4 had been performed 14 months after the thoracic procedure, with removal of the 2 laminar hooks on L1 (no way to connect the two types of instrumentation, no long radiographs then). (E) Age 64. A 29-year follow-up standing lateral radiograph showing maintenance of correction. This in spite of the marked progressiveness of kyphosis in this pathology. (F) A 29-year postoperative standing AP radiograph. AP, anteroposterior.

is where the Ponte osteotomy, correctly performed, also provides an important biomechanical advantage [13], consisting in a lengthened moment arm for posterior corrective forces, with the anterior longitudinal ligament acting as a tension band (see the Biomechanics section). A much lesser force is needed to obtain the same bending moment and correction, with a smaller load on the bone/metal interface.

The results of our vast series of 240 surgically treated kyphoses indicate the following. Semirigid rod laminar hook constructs, correcting only by compression forces obtain excellent and stable results and do not cause junctional kyphosis, unless the area of the instrumentation is wrong. High-stiffness rods, correcting by a powerful three-point cantilever action, are cause of frequent junctional kyphosis also with correct areas of fusion.

Key points

- There are a number of publications using the term *Ponte osteotomy* loosely for by far incomplete resections, a real misnomer. Their results and conclusions are of no value for the osteotomy. At the most, they could be called partial or incomplete Ponte osteotomies.
- The properties of the true Ponte osteotomy are (1) a high destabilizing power for thoracic deformities, providing flexibility in flexion, extension, and rotation to maximize coronal, sagittal, and rotational corrections and (2) a biomechanical advantage for posterior corrective forces in kyphosis and kyphoscoliosis.
- An exact performance of the osteotomy, including an adequate resection of laminae, is an absolute requirement. At apical levels of severe and rigid deformities, it might be necessary to extend the osteotomy from pedicle to pedicle.
- A distinctive property of the osteotomy is the correction of long-segment thoracic hyperkyphosis by substantial shortening of the posterior column. There is no anterior lengthening with major openings of anterior disc spaces. The preserved anterior load-sharing capacity prevents noteworthy losses of correction.

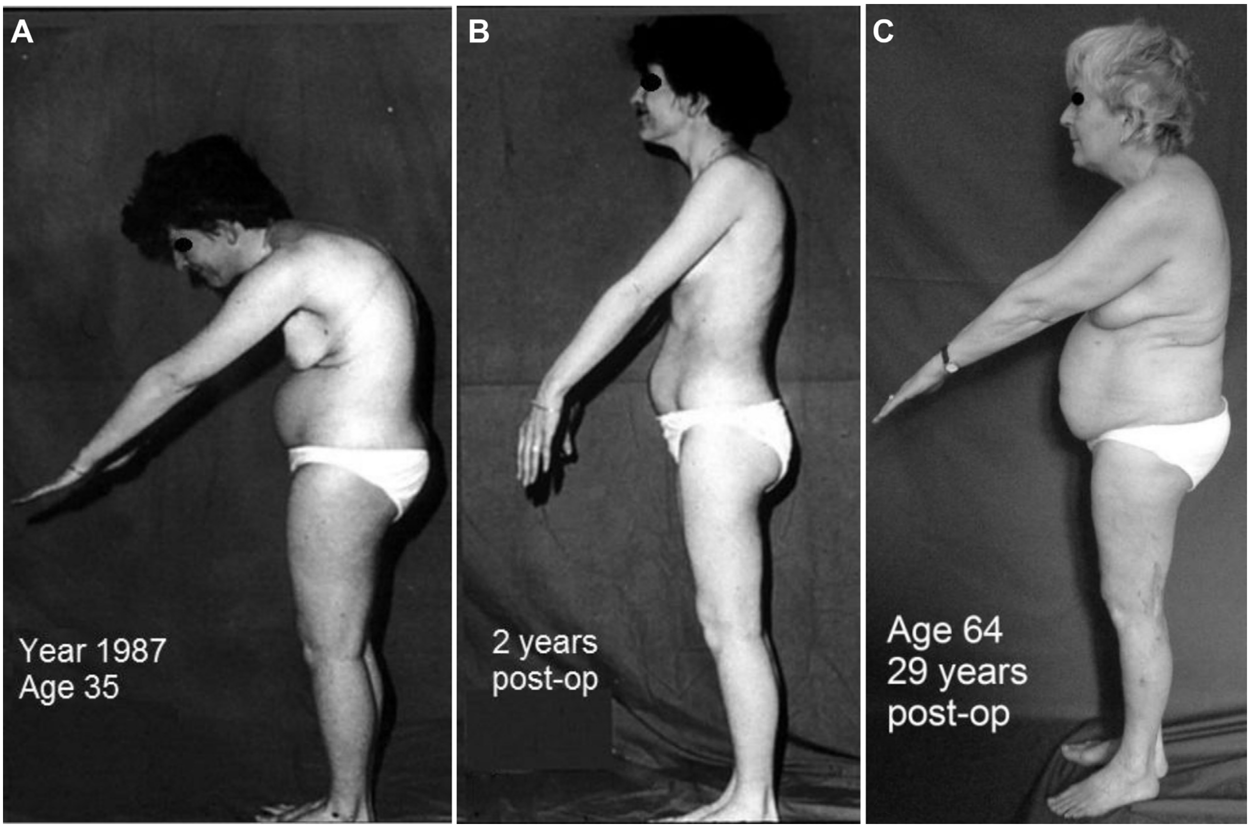

Fig. 10. Same patient. Clinical result. (A) Before surgery, (B) 1 year after surgery, (C) 29 years after surgery. The patient is conducting a normal life and is still active as a teacher, with complete absence of back pain.

- There are no reasons to limit the amount of correction of thoracic kyphosis. Optimal physiological levels have been obtained with a spontaneous return to a proportional lumbar lordosis. A normal standing sagittal alignment was present and maintained at long-term follow-up in all our cases operated with semi-rigid rod constructs.
- Kyphosis and kyphoscoliosis benefit from the considerable biomechanical advantage consisting in a lengthened moment arm for posterior corrective forces. Anterior release is contraindicated (see the Biomechanics section).
- An asymmetric osteotomy, wider on the convexity, is essential in kyphoscoliosis and indicated in severe scoliosis.
- Anterior column mobility is not an absolute need. The biomechanical increased capability of posterior corrective forces to overcome stiffness extends the indications to kyphosis from ankylosing spondylitis. Correction is obtained by bending the ossified anterior longitudinal ligament.
- A wide use in scoliosis surgery is fully justified by the substantial increase of flexibility the osteotomy does provide, maximizing coronal, sagittal, and rotational corrections.

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