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Managing Incomplete and Complete Thoracolumbar Burst Fractures (AO Spine A3 and A4). Results from a Prospective Single-Center Study Comparing Posterior Percutaneous Instrumentation plus Mini-Open Anterolateral Fusion versus Single-Stage Posterior Instrumented Fusion

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Title: Managing incomplete and complete thoraco-lumbar burst fractures (AO Spine A3 and A4). Results from a prospective single center study comparing posterior percutaneous instrumentation plus mini-open antero-lateral fusion versus single stage posterior instrumented fusion.

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Short Title: Managing thoracolumbar fractures with a two-stages MIS strategy

Keywords: thoracolumbar fracture, burst fracture, anterolateral fusion, corpectomy, titanium cage, rib graft, pseudarthrosis, minimally invasive surgery (MIS).

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Title Managing incomplete and complete thoraco-lumbar burst fractures (AO Spine A3 and A4). Results from a prospective single center study comparing posterior percutaneous instrumentation plus mini-open antero-lateral fusion versus single stage posterior instrumented fusion.

ABSTRACT

Object

Treatment strategy for thoraco-lumbar burst fractures is still debated. The aim of this study is to evaluate clinical and radiological outcomes of a two-stage strategy with immediate posterior percutaneous instrumentation and delayed antero-lateral fusion (Group A) versus a single stage open posterior instrumented fusion (Group B).

Patients and methods

Demographics, clinical and surgical data of patients operated for AO Spine A3 and A4 fractures were prospectively collected. Vertebral height and deformity were evaluated prior and after surgery. VAS for back pain, ODI and SF-12 for quality of life assessment were collected during follow up.

Results

Among the 110 patients enrolled, 66 were allocated to Group A and 44 to Group B; most common fractured level was T12 (34%). Postoperative complications resulted higher in Group B, especially wound infection rate (18% vs 3%), and pseudo-meningocele (14% vs 0%). The two-stage approach allowed an average long-term gain of 15.8° at the local kyphosis of fractured vertebra and 5.8° at the regional level (Cobb Angle), vs 15,4° and 5,5° of Group B. At 2-year follow-up, both Groups demonstrated significant functional improvements, however VAS and ODI metrics appeared more favorable for Group A patients ($p<0.0001$ vs $p<0.003$). Complete fusion rate was obtained in 100% of Group A vs 65% of Group B.

Conclusion

Our study indicates that percutaneous instrumentation and anterior fusion or expandable cage lead to excellent long-term clinical and radiological outcomes with lower complication rate and higher fusion rate than open posterior approaches.

Keywords: thoracolumbar fracture; anterolateral fusion; corpectomy; titanium cage; pseudarthrosis; minimally invasive surgery (MIS); early recovery after surgery.

INTRODUCTION

Reconstructing the anterior column in thoraco-lumbar burst fractures is nowadays considered essential to restore/maintain sagittal and coronal alignment, achieve satisfactory fusion and prevent failure of posterior implants [1]. It is well known that posterior instrumentation alone might be subject to failure of the anterior column, as per the three-column concept of thoraco-lumbar spinal fractures initially devised by Francis Denis, hence bearing an intrinsic risk of progressive postoperative kyphosis. The combination of posterior and anterior approaches has therefore been proposed as a more effective strategy to tackle the loss of correction in the long term [2].

This said, the best management of such fractures is still a matter of debate, while we lack a shared, universal consensus, the surgical strategy is tailored to the individual patient's characteristics and surgeon's preference[3,4]. Arguments in favor of open posterior decompression and fixation include the easy and well standardized approach with direct decompression of the spinal cord and conus medullaris, the rapid reduction of these fractures, and the reasonable correction of the thoraco-lumbar alignment. Posterior approaches also spare the operating team and patients from the operative morbidity of anterior approaches, given their burden of potentially severe pulmonary and vascular complications[5, 6]. In fact, the presence of diaphragm, pleura and peritoneum in close proximity to this spine represents a specific operative challenge for any anterior surgical access[7]. Nonetheless the main criticism for open approaches is that they damage the posterior column, which is otherwise usually spared from traumatic mechanisms leading to A3 and A4 fractures.

During the last decades, the development of less invasive extra-pleural and retroperitoneal approaches[8] has minimized risks of open anterior approaches, while providing excellent exposure for good decompression and antero-lateral anatomical reconstruction[9, 10]. Although the development of expandable cages to support the anterior column offered remarkable biomechanical advantages, it has not eliminated the need for lateral and in many instances also posterior screw fixation[11]. Hopefully new strategies spurred from the implementation of combined approaches leveraging on the holistic concepts of minimally invasive surgery (MIS), as such immediate percutaneous posterior screw fixation to immobilize the thoraco-lumbar junction, followed by a delayed mini open anterior approach to reconstruct the anterior column, became the philosophy of choice in our Institution. In theory, this strategy would offer a series of advantages from both clinical and biomechanical perspectives, those include: a reduced morbidity rate compared to more invasive open approaches, an increased

chance to avoid kyphotic deformities, a potentially faster fusion process, etc.

This study was meant to ascertain the theoretical advantages of the abovementioned 360° spinal fixation strategy in managing single level thoraco-lumbar burst fractures compared to open posterior instrumented fusion. With the aim to contribute to the current literature on burst fracture, our objectives were to evaluate the perioperative complication rate, and to assess the radiological and functional outcomes of patients enrolled in this prospective comparative study.

PATIENTS AND METHODS

Design of the study

This is a single-center prospective study conducted between January 2007 and December 2016 on a series of 110 patients treated for unstable thoraco-lumbar burst fractures (AO Spine A3 and A4). A Thoraco-Lumbar Injury Classification and Severity System (TLICS)[12] score $\geq$ 5, and an American Spinal Injury Association Impairment Scale (AIS) E or D represented the most important inclusion criteria; fractures' instability and the need for anterior treatment were also assessed with the Load Sharing Score (LSS)[13], with all candidates considered for inclusion scoring ≥ 7.

Exclusion criteria were as follows: AIS A, B or C, multilevel vertebral fractures, an history of instrumented spine surgery. Child bearing women and patients below 18 years were also not included. Smoking status, as well as presence of comorbidities such as diabetes, obesity, blood hypertension, and cardiovascular pathologies did not represent a contraindication to the enrollment in this study; however they were duly recorded and considered in the post-hoc analysis. At time of consenting for surgical management, patients were given the chance to opt for either a two-stage strategy with immediate posterior percutaneous instrumentation and delayed antero-lateral fusion (Group A), or a single stage open posterior instrumented fusion (Group B).

Clinical evaluation

Impairment scale calculations were performed by using an electronic version (www.isncscialgorithm.com) of the ASIA International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI). Patients were followed up clinically at 3, 6, 12 and 24 months; Data regarding Visual Analogue Scale (VAS) for back pain, Oswestry Disability Index (ODI) and quality of life assessed by the 12-Item Short Form Health Survey (SF-12), exploring the physical component score (PCS) and mental component score (MCS),

were collected for all patients at 24 months postoperatively follow-up (FU), and duly registered in their case report form (CRF).

Presence of comorbidities and details from previous medical history were recorded at time of clerking patients: prevalence of diabetes (type I and II) and blood hypertension were recorded as dichotomy variables, whereas obesity in terms of body mass index (BMI) was calculated as a continuous variable. Average for Group A and B was calculated at time of post-hoc analysis and correlated to postoperative outcomes.

Radiological evaluation

Radiological evaluation was conducted by 2 independents radiologists using standing x-rays in antero-posterior (AP) and lateral (LL) views, as well as sagittal and coronal CT scans with bone window .

Two aspects were included in the analysis: 1) the vertebral height and deformity of the spine before and after surgery, and 2) the long-term implant integration and bony fusion. For the purposes of this study the images were analyzed at the following time points: preoperatively, postoperatively after the MIS instrumentation, postoperatively after the anterolateral fusion and finally at 2-year follow up.

The first aspect, spinal alignment, was thoroughly assessed on sagittal CT scan images and on standing LL x-rays; to this extent, three pre-and postoperative parameters were considered [**Figure 1**]:

- 1) the kyphotic deformation of the fractured vertebra was assessed by calculating the angle between the upper plate and the lower plate (Angle 1).
- 2) the Cobb angle was assessed by calculating the regional kyphosis angle between the upper plate of the overlying vertebra and the lower plate of the vertebra underlying the fracture (Angle 2).
- 3) the Gardner's angle was assessed by calculating the kyphosis angle formed between the upper plate of the vertebra above the fracture and the lower plate of the fractured vertebra (Angle 3).

The second aspect, bone fusion, was assessed on coronal and sagittal CT scan with bone windows, and defined as complete and incomplete depending on the presence or absence of bony bridges between the cage and the superior/inferior vertebral body as well as through the cage for Group A, and the presence of postero-lateral fusion for Group B.

Surgical strategies

Group A underwent immediate posterior percutaneous instrumentation extended two levels above and below the fracture in an emergency setting **[Figure 2].** Screw insertion (ES2 Spinal system©; Stryker) was performed under radiological guidance with AP and LL views obtained by C-arm fluoroscopy on a radiolucent operating table, a focal decompression was obtained if needed (i.e. AIS D on admission) through a short midline incision as per standard MIS practice. In this Group a delayed second stage intervention was planned (2 and 3 weeks later) on an elective list during daytime hours, this consisted in a mini-open antero-lateral approach with selective corpectomy of the fractured vertebral body and interbody fusion by either a titanium mesh (Pyramesh®; Medtronic) or an expandable cage (V-lift©; Stryker) [**Figure 3**]. In either case, the implant was filled with bone resulting from the corpectomy and when available the split rib used as a strut graft. Between the first and second stage additional investigations were carried out, and specifically standing x-rays and CT scan with bone window. Group B patients underwent an open posterior instrumented fusion in an emergency setting. In this Group pedicle screws and roads (XIA Spinal system© Stryker) were inserted two levels above and below the fracture using anatomical landmarks with radiological verification; furthermore, a postero-lateral grafting was always carried out by using either bone fragments resulting from any laminectomy or allogeneic grafts from bone bank.

Statistical analysis

The statistical analysis included a descriptive comparison of preoperative and postoperative variables by using the t-test for continuous data (i.e. pre and post-op VAS, angle measurements), whereas z-score and OR were calculated to correlate the presence of preoperative comorbidities (smoking, diabetes, and BMI>30) with the primary postoperative outcome: osseointegration. Two-sided significance level was defined as p.05. Data analysis was performed using GraphPad Prism version 6.00 for Windows (GraphPad Software, La Jolla, California, USA, www.graphpad.com);

Ethics

This study was conducted according to the Ethical Principles for Medical Research Involving Human subjects stated in the 2004 and its further revision made in 2008 and 2013 of the Declaration of Helsinki. To be eligible for the study, patients were asked to sign an informed consent form previously approved by the Institutional Research Board. To report our results, we followed the recommendations of the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement for observational studies [14].The study was

approved by the IRB the French National Neurosurgery society (Reference n°: IRB-00011687).

RESULTS

Patients demographic and radiological pre-operative features

Hundred-ten patients (52 women and 58 men, mean age 41±15 years) were included in this study, 66 were allocated to Group A and 44 to Group B. In Group A, the most common fracture level was T12 (34.8%), with a prevalence of A4 complete burst fractures (66.6%) over A3 incomplete burst fractures. In Group B, the most common fracture level was still T12 (40.9%), with a strong prevalence of A4 complete burst fractures (68.2%). In both group of patients, the median scores for TLICS and LSS were 6 ± 1 and 8 ± 1, respectively [**Table 1**]. Overall, 87% of patients were AIS E on admission. In Group A, during mini-open antero-lateral approach, 7 patients (11%) underwent insertion of titanium mesh, while all the other patients (n=59) had expandable cages (89%). Median operating time resulted to be 105±18 minutes and 145±25 minutes for the percutaneous fixation and mini-open lateral approaches respectively, whereas in Group B operating time was 175±35 minutes. Average blood loss was significantly different in the two Groups: in Group A, it was negligible for both the posterior percutaneous approach and the antero-lateral one (180 ml; range: 110 to 390 ml); whereas perioperative blood loss in Group B was much higher (650 ml; range 550 to 1100 ml).

Clinical and radiological data postoperatively

Median postoperative hospital stay for Group A was of 4±1 days and of 6±2 for the first and second stage surgery, respectively: whereas patients in Group B had a median length of stay of 11±3 days. No perioperative neurological complications or implants malposition needing surgical revision were recorded in either group. Postoperative complications in Group A included: superficial wound infection in 2 cases (3%), symptomatic hemothorax in 2 cases (3%), and pneumothorax in 5 cases (7.5%) requiring a 3-day course of drainage via chest tube. All those complications were managed conservatively with no need for revision surgery. Infection rate in Group B resulted to be 18%, hence much higher than in patients treated with the 2-stage strategy, furthermore Group B patients had a 14% incidence of clinically significant pseudo-meningocele requiring surgical revision.

At the 2 years follow up all patients in Group A had a minimal ODI score (0 to 20%) and significant improvement in VAS score (1±0,8 versus 8.6±0,8 preoperatively, $p<0,0001$), their

average SF-12 PCS score was of 57.9% ± 6.1% and SF-12 MCS score was of 62.5% ± 10.5%. On the other hand, patients in Group B also achieved a minimal ODI score (0 to 20%), although they showed a lesser improvement of VAS score (4.5±1 versus 9±0.5, p<0,003), their average SF-12 PCS score was of 53.4% ± 5.2% and SF-12 MCS score was of 50.2% ± 9.2% [**Figure 4**].

Our study demonstrated a statistically significant difference for all the 3 radiological parameters assessed pre- and postoperatively [**Table 2**]. In Group A, Angle 1 (kyphotic deformation of the fractured vertebra) resulted in an average difference of 15,8° CI 95% [8,8; 20,7] p < 0,0001; Angle 2 (Cobb angle) an average difference of 5,8° IC 95% [0,6; 10,1] p = 0,002; and Angle 3 (Gardner's Angle) an average difference of 7,1° 95% CI [3,5; 10,7] p = 0,0005; On the other hand, in Group B, Angle 1 resulted in an average difference of 15,4° CI 95% [8; 19,9] p < 0,0001; Angle 2 an average difference of 5,5° CI 95% [1,1; 9,2] p = 0,003; and Angle 3 an average difference of 6,5° CI 95% [3,1; 11,6] p = 0,0003. No statistically significant differences were recorded between the two groups regarding all the pre and postoperative radiological parameters evaluated. Of note, the correction loss over time of the injured vertebra was minimal, and additional statistical analysis failed to demonstrate any significance with regards to these time points.

Remarkable bony integration within the mesh/cage and across the level of fracture was achieved in 100% of the cases in Group A; bone fusion was instead achieved in only 65% of the Group B patients. Given the superior fusion rate and quality, a choice of posterior instrumentation removal was systematically offered to all patients in Group A, however only 80% of them opted for implant removal. Younger patients complaining of local discomfort or reporting a limitation of flexion/extension spine movements mostly took this choice. The same option was offered to all patients in Group B although none of them requested removal of the instrumentation, even in those cases where complete fusion was confirmed on long-term FU. The reason for this decision was unanimously the aversion for additional surgical interventions, which justifies their initial option for posterior surgery alone.

Descriptive analysis revealed that a homogeneous distribution of comorbidities across the two groups with the exception of a higher prevalence of individuals with diabetes (p = 0,0088) and blood hypertension (p = 0,01108) in Group B [**Table 3**]. Post-hoc analysis confirmed that smoking (OR 4.09, CI 95% 1.02, 16.4) and BMI >30 (OR 2.48 CI 95% 0.45, 13.51) represented a risk factor for lack of osteointegration in Group B. No other relevant correlation was found between preoperative comorbidities and postoperative outcome.

DISCUSSION

The present study evaluated the perioperative complication rate and assessed radiological and functional outcomes of patients admitted with incomplete and complete thoraco-lumbar burst fracture treated with two different surgical strategies. The statistical analysis carried out to compare the 360° MIS instrumented fusion of Group A with the open posterior instrumented fusion of Group B revealed that the two-stage strategy delivers its theoretical advantages.

In fact, Group A patients appeared to have comparable length of stay, with lower postoperative complications, better functional recovery and higher fusion rate at 2 years follow up. In the present study the 360° strategy led also to a satisfactory correction of spinal alignment which was maintained very nicely at long-term follow up. Of note, our study also contributed to shed light on the clinical implications of kyphotic correction, which is still a matter of debate because earlier studies failed to find a clear correlation between the postoperative degree of kyphosis and the long-term degree of pain or disability[6, 15]. Although for scientific and organizational reasons open posterior instrumented fusion remains a well standardized and universally accepted practice, the radiological and clinical results achieved in Group A justify the growing interest toward MIS multi-staged strategies, such as that proposed in our Institution.

Stabilization of Posterior and Middle Columns

Over the years, pedicle screw fixation for the treatment of thoraco-lumbar burst fractures became a popular strategy overcoming the limitations of laminar hooks and allowing for a good rigid fixation[16]. The advantages of posterior instrumentation also include the immediate decompression of spinal canal, the identification of intracanalar fragments, which might be facilitated by use of intraoperative ultrasound, and a consideration for ligamentotaxis[17]. However, it should be noted that the differences between long and short posterior instrumentation are not so obvious, especially when using mono-axial screws. Recently, Dobran et al[19] compared long and short instrumentation for fractures at the thoraco-lumbar junction and reported similar results regarding both correction of kyphosis and the maintenance of sagittal alignment. Shorter constructs however have the advantage of reduced operative time as well as risk of screw malposition and related neurological complications, and obviously preserve two extra segments of vertebral motion. Longer posterior instrumentation, on the other hand, ensures a better distribution of biomechanical stress across the thoraco-lumbar junction and reduces the risk of pull out. Unfortunately, those

biomechanical needs are relevant only in the first year following the traumatic event, in fact, once spine fusion is achieved, long constructs put a toll in terms of spine stiffness and patient compliance. In our experience the advantages of performing a long posterior instrumentation combined with mini open anterior approach, even beyond the consolidation process, are highest in patients with obesity, osteoporosis, and significant vertebral splitting with major loss of height of the vertebral body.

Stabilization of Anterior column

A reconstruction of the anterior column is indicated in thoraco-lumbar fractures caused by compression mechanisms with burst of the vertebral body. Our series confirms that a selective rather than a total corpectomy helps maintaining a relatively short average operative time but also allow achieving a satisfactory biomechanical stability[20]. Furthermore, our study bring additional evidence that the preservation of the endogenous blood supply by a selective corpectomy promotes faster healing and better fusion[21].

The use of mesh or expandable titanium cages allows avoiding the need for autologous graft from distant donor sites, as well as the use of bone from tissue banks, hence increasing the overall safety of the approach and reducing costs. In our series, the choice between mesh and expandable cage was systematically made according to the extent of the performed corpectomy. Depending on the characteristic of the fracture, the selective corpectomy entailed either a 1-disc level fusion (such as A3 fractures where one endplate of the affected vertebral body was preserved) or a 2-disc levels fusion (in all other A4 fractures where the mesh/cage was bridging the inferior endplate of the vertebra above and the superior endplate of the vertebra below the fractured one). These implants offer the advantage of an immediate mechanical strength and have good resistance to pullout [22]. In addition, the cancellous bone obtained at time of the corpectomy and filled into the cage/mesh provides a greater amount of cells and osteogenic factors that the tri-cortical bone obtained from iliac crest[1]. Whenever a rib was excised to approach the fractured vertebra, we always applied it as strut graft on either side of the cage to enhance the bone fusion. Our guiding belief was that all those aspects of our surgical strategy played an important role in preventing the risk of pseudarthrosis. Of note, in our study we did not explored the use of heterologous substitute (i.e. BMP), hence an educated inference can be made regarding the biomechanical advantages of our 360° construct without any confounding factor caused by the use of biologics.

Surgical Timing

The advantages of our strategy include the possibility to intervene as early as possible and

provide a MIS stabilization of the fracture, while carefully planning for the reconstruction of the anterior column in a delayed elective surgical session. The second stage allows for a direct visualization of the spinal canal enhancing the chance of good decompression which is certainly superior to the one obtained from a posterior approaches alone [23]. The choice of performing a percutaneous approach without laminar decompression is based on the nature of burst fractures: essentially, the mechanism of injury involves the anterior elements while posterior ones might be initially spared, hence to our eyes preserving the posterior ligamentous complex and paraspinal muscles represent whenever feasible a more biomechanically-sound choice. In fact, while the patients included in this series were all presenting with AIS E, it should be noted that in those presenting with AIS D, C and B at baseline we tend to adopt the same surgical strategy with only a small variation which consists in supplementing the initial percutaneous screw insertion with a midline incision and selective laminectomy to decompress the spinal canal and relieve the pressure from the neural elements.

Paradoxically, despite Group A patients underwent multiple procedures, their treatment was tailored to the biomechanical needs of AO Spine A3 and A4 fractures. On the other hand, we can argue that privileging the technically easier open posterior instrumented fusion may lead to the risk of an overtreatment with time-consuming muscle dissection and extension of the construct up to 3 levels above and below the fractured vertebra.

Bony integration

Long-term bony integration following any type of spinal fixation is greatly dependent on a good primary stability at the time of initial surgery and subsequent creation of sustained structural and functional bridging between the surrounding living bone and the surface of the load-bearing implant[43]. Although failure to achieve bony integration does not preclude a good clinical outcome (hence the concept of short non fusion surgery for thoracolumbar fractures), it increases the risk of dissatisfaction with treatment[42]. For this reasons surgeons and scientists have focused so much attention over the last decades to achieve rapid bio-integration and long-lasting bone fusion. Successful bony integration (which might be as low as 40% in some series) requires a series of events including initial inflammation, bone formation, and remodeling which could be impaired in patients with diabetes, high BMI and smoking habitus[43,44]. While our cohort appeared to be homogeneous in terms of baseline comorbidities, Group A patients were younger than Group B, who showed instead higher prevalence of diabetes and blood hypertension. Our statistical analysis, though, revealed that the only

factors affecting the chance of achieving bony integration were smoking and BMI >30. On one hand, we may suggest that they contributed to the lower rate of osseointegration noted in Group B compared to Group A; on the other hand, we may also argue that in Group A the anterior and posterior stabilization contributed to offset the impact of those risk factors, justifying why bony integration was achieved at follow up in all patients. A preliminary conclusion that can be drawn from our series is therefore that the combined approach could potentially yield better results in patients more at risk of pseudo-arthrosis due to their baseline comorbidities. This hypothesis might serve as a valuable research question for further studies.

Technical evolution of MIS approaches

In the last few years several reports have shown very good outcomes using the mini-open antero-lateral approach combined with posterior fixation for burst and compression fractures[4, 24-30]. This less invasive approach allows for satisfactory exposure with limited risks; however other techniques have also been developed to further minimize exposure-related morbidity, they include the antero-lateral video-laparoscopic/-thoracoscopic approach as well as the extreme lateral approach (XLIF), which is mostly used in degenerative lumbar surgery[31-33]. These approaches to the anterior thoraco-lumbar spine are known to result in shorter hospital stays, shorter convalescence time and better cosmetic results compared to open approaches[34-36], nevertheless their longer learning curve justifies the paucity of reports/series available to date.

It is known that anterior column reconstruction through a posterior approach with uni- or bilateral transpedicular corpectomy offers a limited operative corridor, resulting in a poorer visualization of the vertebral body compared to an antero-lateral approach, and an increased risk of subsequent loss of correction[10]. This explains why the long-term results obtained through posterior vertebrectomies are less favorable when compared to antero-lateral ones[4, 7, 37]. Additionally, the mini-open access used in our series has several advantages: 1) it avoids unwanted and dangerous retraction of retroperitoneal vessels, 2) it does not require dissection of the sympathetic plexus, 3) it does not entail unnecessary manipulation of abdominal viscera, 4) it limits muscle dissection, 5) it reduces manipulation of nerve structures and increases the operative working area needed to fully excise the vertebral body and adjacent discs[9].

Complications

Our series contributes to the discussion on early recovery after surgery by highlighting that a 360° strategy can combine the advantages of percutaneous screw fixation and mini-open

antero-lateral approach. On paper this choice does not come without drawbacks: patients with dual approaches are more likely to have infectious complications, scarring issues, breathing problem, and blood loss [4, 29, 38, 39]. However, while known complications for any antero-lateral approach include dural tear, intercostal neuralgia, spleen hemorrhage, paraspinal abscesses, cage subsidence, and chest infection[13, 25], none of them occurred in our series of mini-open anterior approaches. On the contrary, the higher incidence of infection complications in Group B might be attributed to the intrinsic risk associated to open surgery performed during night-time, which is a known contributing factor to intra- and postoperative complications. Additionally, no anesthetic complications occurred during this study: this aspect is particularly important because Group A patients had two general anesthesia ± one in case of screws removal, Group B patients has a 14% incidence of redo surgery to address wound dehiscence due to persistent pseudo-meningocele. Furthermore, the rate of thromboembolism in our series was also remarkably low, perhaps because of our established protocol which is particularly relevant in patients with spinal cord injuries [40, 41], and the faster mobilization after treatment.

Limitations of the study

The main limitation of our study is its non-randomized design, nonetheless the two-stage strategy with 360° approach to burst fractures became our philosophy hence the lack of equipoise to accept this type of methodology for patient's selection. In drafting the research protocol we have been guided by our good clinical practice principles of having an honest and sensitive discussion with patients about their clinical condition, their management options and expected clinical course, which eventually led to an informed and deliberate consent, ensuring adhesion of our study to the highest ethical standards. While the strict inclusion criteria enhanced internal validity, they made hard to possibly extend our discussion to other patients or fracture categories (such as pathologic fractures, pediatric population, etc.), as such together with the randomization issue they somehow limit the external validity of our study.

CONCLUSION

Our 360° strategy led to higher fusion rates, providing good long-term clinical and radiological outcomes in patients with thoraco-lumbar incomplete and complete burst fractures comparing to single stage open posterior instrumented fusion. Beside correcting the post-traumatic angular deformation and leading to a longstanding biomechanical stability, this combined less invasive strategy paves the way for safe removal of the posterior screws and

release of two segments of vertebral movements once the osteosynthesis process has terminated; hence offering potential advantages to younger patients.

Disclosure of interest: the authors report no conflict of interest concerning the material or methods used in this study or the findings specified in this paper.

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Figure 1. L2 fracture before and at the end of the treatment with the different angle measurements. Felted line: Angle 1 of kyphotic deformation of the fractured vertebra Dotted line: Cobb Angle 2; Full line: Gardner Angle 3.

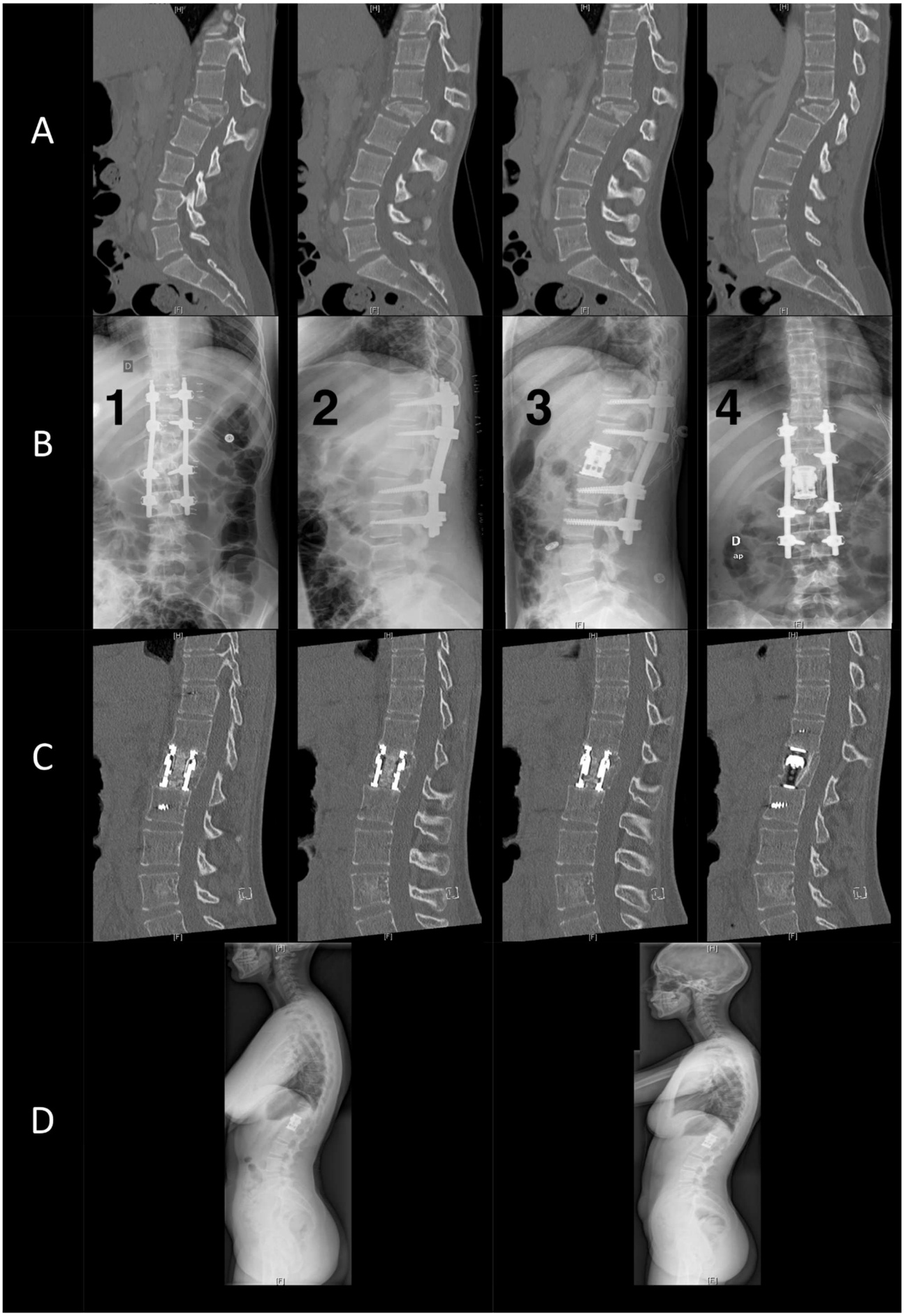
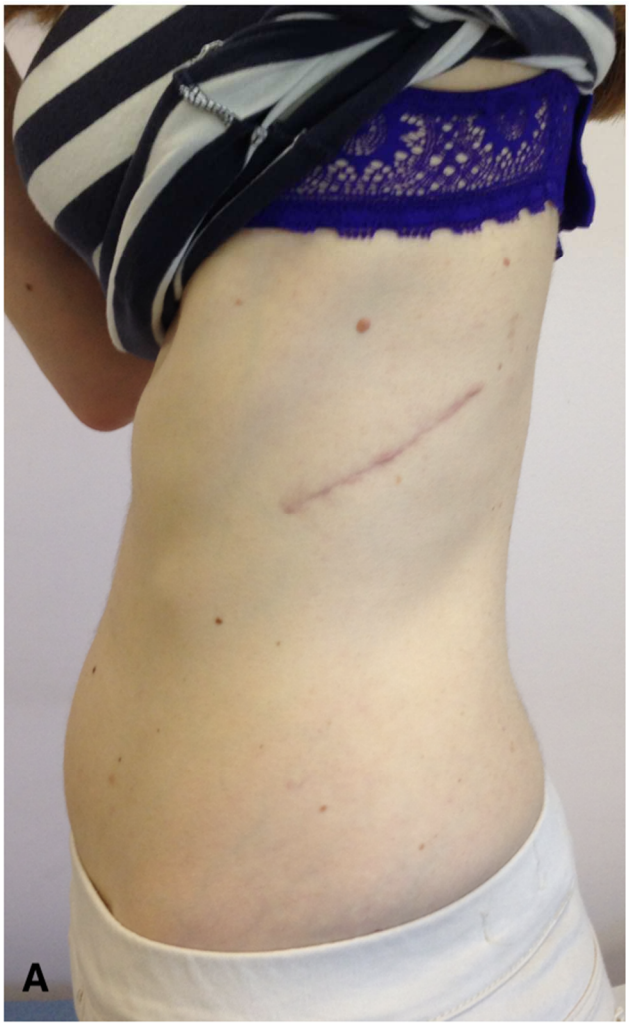

A
B
1
2
3
4
C
D

Figure 2. Example of a 3-stage sequential treatment of a post traumatic L1 A4 (AoSpine) fracture in a 25-year-old woman. Images A: sagittal bone CT showing the fracture. Images B: after posterior MIS osteosynthesis (first 2 images) and after previous arthrodesis treatment (last 2 images). C: Sagittal bone scan at 1 year showing absence of pseudarthrosis with complete ossification. D: Sagittal Tele-column after removal of posterior MIS instrumentation after 1 and 2 years showing good stability with a correct sagittal balance without local sagging.



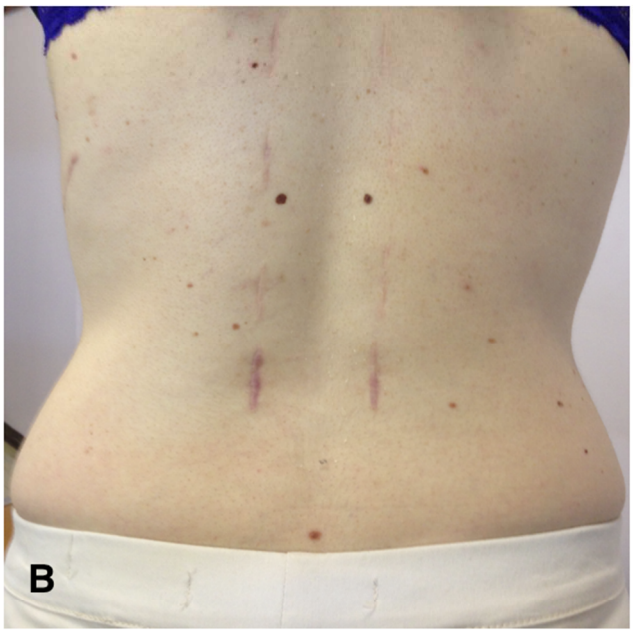


Figure 3. Pictures showing anterior and posterior scars 6 months after surgery.

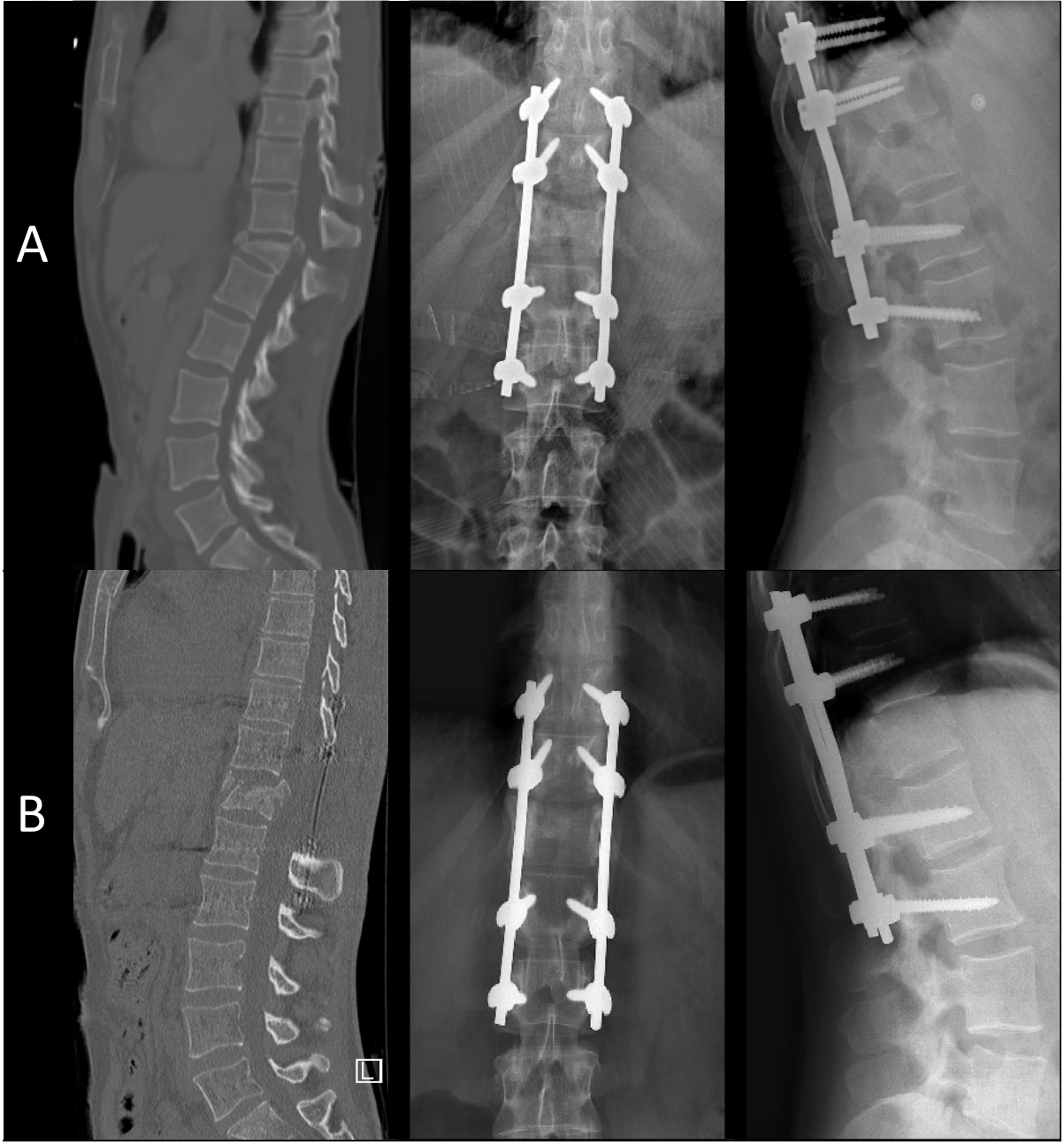


Figure 4 A-B: A) Preoperative sagittal CT scan (left side) showing the fracture, and early postoperative (middle and right side) x-ray check demonstrating a good correction. B) 2 years postoperative sagittal CT scan (left side) and postoperative x-ray check (middle and right side) demonstrating the absence of bony consolidation as well as a slight loss of correction.

		N / %	
		Group A	**Group B**
Women		32 / 48.5%	20 / 45.5%
Man		34 / 51.5%	24 / 54.5%
median age		42.2±11.3	51.1±14.3
median TLICS		6 ± 1	6 ± 1
median LSS		8 ± 1	8 ± 1
Level	T11	9 / 13,6%	4 / 9,1%
	T12	23 / 34,9 %	18 / 40,9%
	L1	19 / 28,8 %	16 / 36,4%
	L2	15 / 22,7 %	6 / 13,6%
Type	A3	22 / 33,3 %	14 / 31,8%
	A4	44 / 66,7%	30 / 68,2%

Table 1: *Characteristic of the population, level and type of fracture*

Thoraco-lumbar angles		**Pre-op values at time 0**	**Early Post-op values**		**Post-op values at 2 years**	**Δ time 0-2 years**	***P value***
			Posterior MIS	Anterior ALF			
Group A Angles	1: local kyphotic deformation of the fractured vertebra	20,2°	5,9°	4,0°	4,4°	15,8°	$p <$ 0,0001
	2: Cobb regional	14,5°	9,8°	9,1°	8,7°	5,8°	$p =$ 0,002
	3: Gardner	16,6°	10,8°	9,2°	9,5°	7,1°	$p =$ 0,0005
Group B Angles	1: local kyphotic deformation of the fractured vertebra	19,3°	-	-	3,9	15,4°	$p <$ 0,0001
	2: Cobb regional	14°	-	-	8,5°	5,5°	$p =$ 0,003
	3: Gardner	16,1°	-	-	9,6°	6,5°	$p =$ 0,0003
Difference between the 2 groups					*NS*		

Table2. Patient series: pre and post-operative radiological angles/correction measurements (Δ: gradient, MIS: minimally invasive surgery; ALF: antero-lateral fusion, NS: not significant).

	Group A	Group B	Z score (P value)
Patients	66	44	-
Smokers	14 (21%)	13 (29%)	0.9949 (0.32218)
Diabetes (Type I and II)	12 (18%)	18 (41%)	**-2.622 (0.0088)**
BMI > 30	13 (19%)	10 (22%)	-0.3829 (0.70394)
Blood hypertension	9 (14%)	15 (34%)	**-2.5447 (0.01108)**
Cardiovascular pathologies	2 (3%)	5 (11%)	-1.7541 (0.08012)
Osseointegration	66 (100%)	29 (65%)	**5.1042 (0.0001)**

Table 3. *Prevalence of comorbidities in Groups A and B (significant differences in bold)*