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Minimally invasive fixation techniques for thoracolumbar fractures: comparison between percutaneous pedicle screw with intermediate screw (PPSIS) and percutaneous pedicle screw with kyphoplasty (PPSK)

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Abstract

Purpose To assess and compare the efficacy of two minimally invasive techniques (percutaneous pedicle screw with intermediate screw vs. percutaneous pedicle screw with kyphoplasty) for spinal fracture fixation by comparing the segmental kyphosis and vertebral kyphosis angles after trauma before surgery, after surgery, and at 4-month and 12-month follow-up.

Methods Data from 49 patients without neurological deficit treated by either percutaneous pedicle screw with intermediate screw or percutaneous pedicle screw with kyphoplasty were retrospectively analysed. The segmental kyphosis and vertebral kyphosis angles over time were calculated and correlated with the type of procedure, AO classification, lumbar or thoracic site and the age and sex of the patients.

Results After surgery, both techniques were found to be efficacious means of bringing about a significant correction of the segmental kyphosis angle ($p = 0.002$) and a just significant correction of the vertebral kyphosis angle ($p = 0.06$), although less effectively in thoracic fractures ($p = 0.004$). At follow-up, the vertebral kyphosis angle was stable in both groups, while there was a significant loss of segmental kyphosis angle stability in the percutaneous pedicle screw with kyphoplasty group at 1 year ($p = 0.004$); fractured thoracic vertebrae maintained a greater vertebral kyphosis angle ($p = 0.06$) and segmental kyphosis angle ($p < 0.001$), than the lumbar.

Conclusion At 1 year after surgery, the use of intermediate screws in fractured vertebrae seemed to maintain a more efficacious correction with respect to kyphoplasty, although thoracic fracture sites appear to be associated with greater post-traumatic segmental kyphosis and lesser stability in the long term after both percutaneous surgical techniques.

Keywords Thoracolumbar fractures · Minimally invasive fixation · Percutaneous screws · Intermediate screw · Kyphoplasty · Vertebral kyphosis · Segmental kyphosis

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Introduction

Despite their frequency, the management of thoracolumbar fractures varies widely and is still disputed [1]. Surgical management of thoracolumbar fractures is the consensus for patients with progressive neurological loss, unstable fractures or polytrauma, who require fixation for earlier and easier rehabilitation. Nevertheless, a universally accepted algorithm to decide the appropriate surgical technique is still lacking [2], and conservative or surgical management of thoracolumbar fracture remains controversial in patients without neurological deficit [3, 4].

In recent years, minimally invasive surgical techniques for stabilising such fractures have been growing in popularity [2, 5, 6]. In particular, kyphoplasty and other direct methods of reduction and augmentation of the vertebral body, and percutaneous pedicle screw fixation are used alone or in combination [7–9] to improve the clinical conditions of the patient in the short term, and to prevent the occurrence of secondary complications in the future due to the spine shifting on the sagittal plane. Recently the use of screws at the level of the fractured, the so-called intermediate screw, first proposed by Dick et al. [10], has been popularised to keep the instrumentation short without the use of anterior support [11, 12].

The availability of minimally invasive surgical techniques for the treatment of these fractures has made it possible to extend the indication to surgery also to fractures that are traditionally treated conservatively (such as A1 of the AOSpine classification) in patients who require an early functional recovery after trauma.

However, it is still unclear what the real indications of these approaches are in the treatment of traumatic fractures, and whether or not they are associated with different clinical outcomes or stability in the long term. Hence we set out to conduct a retrospective analysis of a series of patients with traumatic vertebral fractures without myelopathy who underwent minimally invasive fixation surgery.

Therefore, the purpose of this study was to assess and compare the efficacy of two minimally invasive surgical techniques (percutaneous pedicle screw with intermediate screw, PPSIS, and percutaneous pedicle screw with kyphoplasty, PPSK) for spinal fracture fixation on the sagittal plane by comparing the segmental kyphosis (SK) and vertebral kyphosis (VK) angles after trauma before surgery (T0), immediately after surgery (T1), and at 4-month (T2) and 12-month (T3) follow-up.

Materials and methods

A retrospective analysis of data pertaining to patients who underwent minimally invasive vertebral fixation surgery in our Trauma Surgery Unit between January 2005 and March 2015 was performed. For inclusion, records had to include details of a complete follow-up—including adequate radiographic images—of at least 4 months and 1 year from surgery.

Patients of both sexes were included on the basis of the following criteria: age between 30 and 65 years, acute single fracture to the thoracic (T) or lumbar (L) vertebrae without neurological deficit, treated by minimally invasive percutaneous pedicle screw fixation with intermediate screw (PPIS) in the fractured vertebrae (Fig. 1) or kyphoplasty of the fractured vertebrae (PPSK) (Fig. 2). Patients with pathological

and/or osteoporotic fractures and/or inadequate follow-up were excluded.

Patients were clinically and radiographically examined at baseline (T0), after surgery (within 2 days) (T1), 4 months after surgery $\pm$ 1 month (T2) and 1 year after surgery $\pm$ 1 month (T3). Lesions were classified according to the most recent AOSpine thoracolumbar classification system [12] using X-rays (RX), the computed tomography (CT) and magnetic resonance imaging (MRI) available at baseline. The number of pedicle screws percutaneously fixed in each patient was also calculated.

In order to evaluate the efficacy of the treatment in terms of stabilisation of the spinal column on the sagittal plane, we considered variations in the segmental kyphosis (SK) and vertebral kyphosis (VK) angles at T0, T1, T2 and T3, calculated according to the method proposed by Cobb on radiographs obtained with the patient in a supine position.

The data pertaining to 49 patients were considered suitable for evaluating the efficacy of the minimally invasive vertebral fixation strategies. Fractures were thoracolumbar (between vertebrae T9 and L4) and classified on the basis of the most recent AOSpine system [13]. Of the sample considered, 16 cases of type A1 fractures, 7 of type A2, 8 of type A3, 2 type A4 and 16 of type B2 were observed. Hence, ten patients (10%) were classified as A3/A4 group, 16 (33%) as B2 group and the remaining 23 patients (47%) as A1/A2 group.

Statistical analysis

Qualitative variables were described as absolute values and percentages, while quantitative variables are reported and mean $\pm$ SD across the entire population and the various subgroups identified.

The distribution of the qualitative variables between the two groups defined on the basis of treatment (PPSIS and PPSK) was evaluated by univariate analysis by means of Fisher's exact test. This test is used to verify the hypotheses that the frequency of the variables under investigation, namely sex (M and F), age range (< or > 50 years), lesion site (L vs. T) of the two groups defined on the basis of the treatment received (PPSIS or PPSK) was compatible with the null hypothesis (H_0) that the populations of origin of the two treatment groups were characterised by the same dichotomous subdivision, and that any differences between their datasets were due to chance rather than design.

Student's t test was used to evaluate whether the mean of two quantitative variables such as VK and SK differ between the groups defined according to the type of treatment received or based on patient characteristics and fractures.

Multilevel modelling for longitudinal data was used to conduct a comparative analysis of the variations in SK and VK angles from T0 to T1 and from T1 to T2 and T3 in

Fig. 1 Pedicle screw technique with intermediate screw (PPIS). **a**, **b** Pre-operative radiographs; **c**, **d** post-operative radiographs

treatment groups, and to analyse the role of the clinical factors and lesion characteristics investigated, and the effect of treatment received. In this case, two levels were considered, namely time (T0 vs. T1, and T1 vs. T2 and T3) and patient characteristics, respectively.

A significance level of 5% was set for all statistical tests, that is, statistical significance was ascribed to any difference below a probability of 0.05.

All statistical analysis was performed using STATA software.

Ethics

This study was approved by the local ethics committee. Written informed consent to participate and to share data anonymously was obtained from all participants, in accordance with the 1964 Helsinki declaration and its later amendments.

Results

Patients were then subdivided into two groups, based on the type of minimally invasive treatment received; accordingly there were 23 patients in the PPSIS group and 26 in the PPSK group.

The number of screws positioned in the PPSIS group was 147, a mean of 6.4 screws per patient (range 4–10), and 120 were positioned in the PPSK group, a mean of 4.6 screws per patient (range 4–8).

Fig. 2 Pedicle screw technique with kyphoplasty (PPSK). **a**, **b** Pre-operative radiographs; **c**, **d** post-operative radiographs
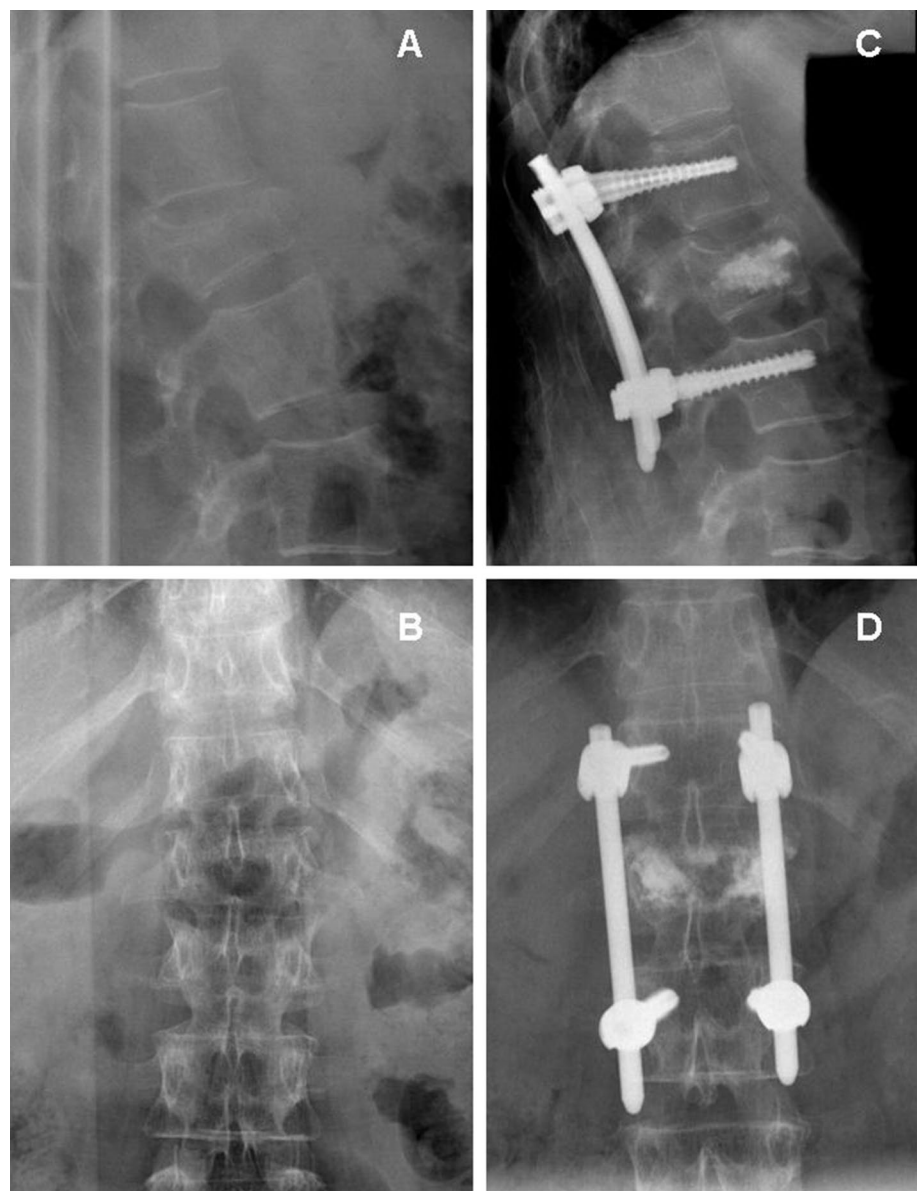
Table 1 shows the distribution of the patient characteristics at T0 across the entire sample and by the type of treatment received. The two treatment groups were homogeneous in terms of the distribution of patient characteristics, and there was no statistically significant difference between them in any of the variables considered.

The SK and VK angles were measured for each fracture at T0 (Table 2). The pre-operative SK and VK angles were comparable between populations, and application of the t test to baseline values revealed no statistically significant difference between the two treatment groups. Similarly, analysis of the baseline SK and VK angles with the patients subdivided according to their patient characteristics and fracture type revealed no statistically significant difference among subgroups, as shown in Table 3. However, it should

be noted that there was a relatively large (although non-significant) difference in SK angle between patients divided by fracture type, which exceeded 5° in the thoracic PPSIS subgroup ($p = 0.06$) and over 4° in those who received PPSK for thoracic fractures.

In order to evaluate the respective efficacy of the two treatments, variations in the SK and VK angles from T0 (before surgery) to T1 (immediately after surgery) were calculated (Tables 4, 5). Analysis of the variation in SK (Table 4) by treatment showed that both reduced the SK angle to a similar extent. However, there was a slightly greater mean reduction in SK angle in the PPSK group ($- 5.67° \pm 5.17°$) with respect to the PPSIS group ($- 3.76° \pm 6.37°$). Multilevel modelling of SK angles showed a large statistically significant difference ($p = 0.002$) in the time variable (T1 vs. T0),

Table 1 Population characteristics at time T0

	Total (n = 49)		PPSIS (n = 23)		PPSK (n = 26)		p value
	n	(%)	n	(%)	n	(%)	
Sex							
M	32	(65.31)	18	(78.26)	14	(53.85)	0.073
F	17	(34.69)	5	(21.74)	12	(46.15)	
Age (years)							
Mean ± SD	47 ± 12.10		45.43 ± 11.26		48.73 ± 12.81		
Range [min–max]	[31–64]		[35–62]		[31–64]		
Age classes (years)							
≤ 50	28	(57.14)	14	(60.87)	14	(53.85)	0.620
> 50	21	(42.86)	9	(39.13)	12	(46.15)	
Vertebra							
Lumbar (L)	35	(71.4)	16	(69.57)	19	(73.08)	0.786*
L1	24	(48.98)	9	(39.13)	15	(57.69)	
L2 + L3 + L4	11	(22.45)	7	(30.43)	4	(15.38)	
Thoracic (T)	14	(28.57)	7	(30.43)	7	(26.92)	
AOSpine TLCS							
A3/A4	10	(20.41)	5	(21.74)	5	(19.23)	0.946 (2 gdl^)
B2	16	(32.65)	7	(30.43)	9	(34.62)	
A1/A2	23	(46.94)	11	(47.83)	12	(46.15)	

*T versus L ^ gdl = degrees of freedom

Table 2 Descriptive statistics of values at time T0 for the angle of segmental kyphosis (SK) and vertebral kyphosis (VK)

	Total (n = 49)	PPSIS (n = 23)	PPSK (n = 26)	p value
Segmental kyphosis (SK°)				
Mean ± SD	13.66 ± 6.30	12.81 ± 6.41	14.41 ± 6.22	0.379
Vertebral kyphosis (VK°)				
Mean ± SD	14.08 ± 7.33	13.81 ± 7.20	14.31 ± 7.58	0.814

while the treatment variable (PPSIS vs. PPSK) showed no apparent influence of this factor on the variation in SK angle. Similar effects were also seen when gender, age and AO class were introduced into the model as confounding factors.

Multilevel modelling comprising the lesion site (thoracic vs. lumbar), however, showed that this was a statistically significant variable, with an SK angle > 3.9° in the T group with respect to the L group. Nevertheless, the treatment/site interaction was not found to be statistically significant, implying that the treatment received had no great influence on the difference in SK angle.

As shown in Table 5, multilevel modelling of the VK angle yielded similar results. The significance of the effect of the lesion site on the VK angle at T1 was 0.06—just above the significance threshold considered. Among those who received PPSIS, the patients in the AO type A3/A4 subgroup showed the greatest mean reduction in VK angle

(> 9°), while the patients > 50 years of age or with an AO fracture type B displayed the least favourable outcomes (< 2°). The PPSK subgroups, on the other hand, exhibited a more homogeneous variation between baseline and post-treatment VK angles.

Analysis of patients subdivided by clinical and lesion characteristics at T0 (Table 4) revealed no statistically significant differences in the mean SK angle at T1 in any of the treatment subgroups, irrespective of the baseline value. A similar trend was exhibited in the analysis on the basis of the VK angle at T1 (Table 5). Across the entire sample, the VK angle was 7.12° ± 4.78° on average; similar values were exhibited by both treatment groups which was on average greater than 6°. In the group that received PPSIS, the smallest pre-post-treatment variation was found in B-type fractures, whereas the largest pre-post-treatment variation was found in AO class A3/A4. The same result was also evident in patients who received PPSK.

A comparison of the treatment stability (PPSIS vs. PPSK) was performed on the basis of the SK and VK angle measurements taken at follow-ups T2 and T3, which were compared with those taken immediately after surgery at T1. As clearly shown in Figs. 3 and 4, there were considerable differences between the two trends. In particular, the SK angle (Fig. 3) showed a very different behaviour over time, depending on the treatment received. Specifically, the mean SK angle remained under 9° in patients treated via PPSIS, even a year after treatment, while in the PPSK group

Table 3 Mean value± SD of SK and VK at baseline for patients subgroup

	Segmental kyphosis SK		Vertebral kyphosis VK	
	PPSIS (n = 23)	PPSK (n = 26)	PPSIS (n = 23)	PPSK (n = 26)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Sex				
M	13.55 ± 6.63	13.89 ± 6.47	13.95 ± 7.25	13.89 ± 7.89
F	10.15 ± 5.31	15.03 ± 6.14	13.32 ± 7.82	14.82 ± 7.51
Age classes (years)				
≤ 50	12.91 ± 5.63	14.59 ± 7.23	16.52 ± 5.16	14.83 ± 6.46
> 50	12.64 ± 7.85	14.21 ± 5.10	9.60 ± 8.15	13.71 ± 8.96
Vertebra				
Lumbar (L)	11.17 ± 6.92	13.24 ± 5.68	12.53 ± 7.14	13.83 ± 6.16
Thoracic (T)	16.56 ± 2.74	17.60 ± 6.94	16.76 ± 6.93	15.61 ± 11.09
AOSpine TLCS				
A3/A4	15.49 ± 5.93	13.09 ± 6.89	16.36 ± 3.54	15.01 ± 6.54
B2	9.50 ± 6.28	13.23 ± 6.14	14.15 ± 9.63	14.63 ± 6.61
A1/A2	13.70 ± 6.38	15.83 ± 6.26	12.44 ± 6.93	13.79 ± 8.50

Table 4 Segmental kyphosis (SK) over time (T0, T1, T2 e T3) in function of the treatment received

Segmental kyphosis	PPSIS				PPSK			
	T0	T1	T2	T3	T0	T1	T2	T3
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Total	12.81 ± 6.41	8.82 ± 8.02	8.77 ± 6.17	8.97 ± 5.80	14,41 ± 6.22	8.91 ± 6.71	9.93 ± 7.10	11.89 ± 8.95
Sex								
M	13.55 ± 6.63	9.08 ± 9.08	9.18 ± 6.43	9.21 ± 6.36	13.89 ± 6.47	10.10 ± 7.00	12.12 ± 7.44	13.55 ± 8.58
F	10.15 ± 5.31	8.00 ± 3.34	7.03 ± 5.33	8.1 ± 3.40	15.03 ± 6.14	7.63 ± 6.44	7.57 ± 6.16	9.92 ± 9.39
Age classes (years)								
≤ 50	12.91 ± 5.63	7.59 ± 4.30	8.78 ± 5.76	10.81 ± 5.68	14.59 ± 7.23	8.83 ± 6.71	10.63 ± 7.92	11.01 ± 8.53
> 50	12.64 ± 7.85	10.83 ± 12.03	8.75 ± 7.04	6.65 ± 5.27	14.21 ± 5.10	9.00 ± 7.01	9.04 ± 6.16	13.11 ± 9.84
Vertebra								
Lumbar (L)	11.17 ± 6.92	7.94 ± 9.13	6.69 ± 5.72	5.49 ± 3.29	13.24 ± 5.68	8.17 ± 6.93	8.08 ± 5.85	8.21 ± 7.12
Thoracic (T)	16.56 ± 2.74	11.02 ± 3.96	13.98 ± 3.89	14.94 ± 3.91	17.60 ± 6.94	10.82 ± 6.20	15.81 ± 8.04	20.81 ± 6.36
AOSpine TLCS								
A3/A4	15.49 ± 5.93	6.45 ± 6.70	7.62 ± 4.95	8.22 ± 6.52	13.09 ± 6.89	7.62 ± 8.69	10.61 ± 6.72	8.51 ± 6.34
B2	9.50 ± 6.28	7.19 ± 3.13	8.41 ± 3.75	10.11 ± 4.32	13.23 ± 6.14	7.26 ± 4.08	6.42 ± 4.49	8.24 ± 6.72
A1/A2	13.70 ± 6.38	10.99 ± 10.36	9.45 ± 7.71	8.76 ± 6.62	15.83 ± 6.26	10.58 ± 7.73	12.50 ± 8.26	16.07 ± 10.05

it tended to increase, even at T2, reaching almost 12° 1 year after surgery. Regarding the VK angle (Fig. 4), at 1 year after surgery, both treatment groups showed similar levels across the entire sample, with an increase in follow-up VK angles of 2° with respect to those measured immediately after surgery; at T2, the mean difference between PPSK and PPSIS groups was roughly 1.5°, favouring the latter.

Indeed, multilevel modelling of the differences in SK angle at T2 and T3 with respect to T1 showed statistically non-significant differences in the PPSIS, indicating that the SK angles achieved after surgery remained largely stable over time, at least for 1 year of follow-up. In the PPSK group on the other hand, although the variation in SK angle between T1 and T2 was not significant, there was an increase of almost 3° between T1 and T3 ($p = 0.004$). As regards analogous multilevel modelling of the VK angle, this showed that it remained largely stable between T1 and T2 and T3 in both groups, i.e. there was no significant difference between PPSIS and PPSK in terms of variation in VK angle.

As shown in Table 4, there were several differences in SK angle at T2 and T3 with respect to T1 based on the lesion

Table 5 Vertebral kyphosis (VK) over time (T0, T1, T2 e T3) in function of the treatment received

Vertebral kyphosis	PPSIS				PPSK			
	T0	T1	T2	T3	T0	T1	T2	T3
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Total	13.81 ± 7.20	7.01 ± 3.89	7.33 ± 4.59	8.78 ± 5.04	14.31 ± 7.58	7.21 ± 4.50	8.78 ± 5.36	8.64 ± 5.61
Sex								
M	13.95 ± 7.25	6.46 ± 2.70	7.23 ± 5.02	8.96 ± 5.30	13.89 ± 7.89	8.23 ± 6.63	9.38 ± 6.21	10.49 ± 6.54
F	13.32 ± 7.82	8.77 ± 6.59	7.78 ± 2.38	7.51 ± 4.38	14.82 ± 7.51	6.11 ± 3.91	8.12 ± 4.43	6.45 ± 3.36
Age classes (years)								
≤ 50	16.52 ± 5.16	8.18 ± 3.85	9.48 ± 3.73	10.33 ± 5.46	14.83 ± 6.46	6.44 ± 4.07	9.18 ± 4.85	8.08 ± 5.22
> 50	9.60 ± 8.15	5.11 ± 3.35	9.47 ± 4.17	6.34 ± 3.50	13.71 ± 8.96	8.05 ± 6.80	8.27 ± 6.14	9.42 ± 6.31
Vertebra								
Lumbar (L)	12.53 ± 7.14	6.32 ± 3.34	6.51 ± 4.67	7.17 ± 4.04	13.83 ± 6.16	6.45 ± 3.54	7.17 ± 4.14	7.16 ± 4.17
Thoracic (T)	16.76 ± 6.93	8.73 ± 4.95	9.40 ± 4.01	11.20 ± 5.87	15.61 ± 11.09	9.17 ± 8.89	13.88 ± 5.90	12.23 ± 7.29
AOSpine TLCS								
A3/A4	16.36 ± 3.54	6.47 ± 1.85	8.75 ± 4.65	8.77 ± 1.34	15.01 ± 6.54	4.36 ± 1.37	5.46 ± 3.66	6.33 ± 4.83
B2	14.15 ± 9.63	7.62 ± 6.45	5.7 ± 3.85	9.60 ± 8.30	14.63 ± 6.61	6.75 ± 3.89	8.46 ± 4.93	7.76 ± 3.85
A1/A2	12.44 ± 6.93	6.91 ± 2.94	7.43 ± 5.03	8.07 ± 4.57	13.79 ± 8.50	8.51 ± 7.03	10.55 ± 5.91	10.32 ± 6.80
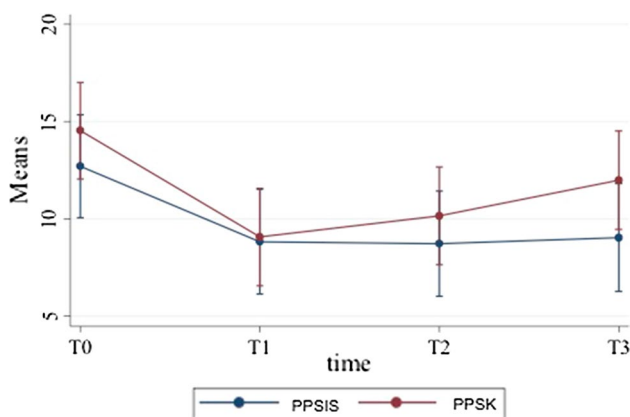
Fig. 3 Trend in mean SK ± SD over time in function of the treatment received
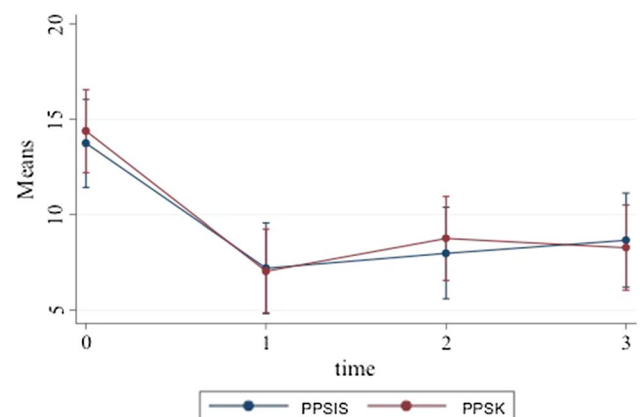
Fig. 4 Trend in mean VK ± SD over time in function of the treatment received

types and patient characteristics. In particular, kyphosis of this angle was more evident in males and patients over 50 years of age, and especially in thoracic lesions and those of AO type A1/A2. It is important to note, however, that 1 year after surgery, both treatment groups presented very similar values for the SK angle, albeit not greater than that measured at baseline (T0).

In contrast, the variations in VK angle (Table 5) were largely homogeneous among the various PPSIS subgroups, while in the PPSK, the thoracic vertebrae displayed greater VK angles, even at T2.

Separate multilevel modelling of SK and VK outcomes comprising all time periods (baseline = reference class), the treatment received (PPSIS = reference treatment) and the variation in vertebral site (L = reference class) revealed that the thoracic vertebrae retain a greater VK angle (mean + 4°) ($p = 0.06$), but especially a greater SK angle (+ 6°) ($p < 0.001$), irrespective of observation time or treatment received (Tables 4, 5).

Discussion

A recent meta-analysis [14] has confirmed that traumatic thoracolumbar fractures can be effectively treated using minimally invasive surgical techniques. However, it is still unclear whether there are any real differences among the

different minimally invasive methods available, and there is no consensus as to their precise indications.

Before discussing the results obtained in this study, it is necessary to point out its limitations, which could have influenced clinical outcomes. The first is that the analysis was carried out retrospectively, on patients recruited over a long period of time (2005–2015). The second involves the comparability of populations undergoing the two treatments, which may only be suggested by a retrospective study—i.e. weak evidence that would need to be confirmed by a specifically designed randomised clinical trial.

Nevertheless, in the current study we set out to evaluate and compare the efficacy of two minimally invasive surgical methods (PPSIS vs. PPSK) in terms of segmental kyphosis and vertebral kyphosis correction following trauma in the immediate post-operative period, and in the short- and medium-term. Bearing in mind the retrospective collection of data and the non-randomised choice of treatment (also due to the unclear definition of the most suitable population for each of the techniques investigated), we found no statistically significant differences between the two types of minimally invasive surgery in terms of the distribution of the major clinical features of the patient or lesion characteristics.

In the immediate post-operative period, minimally invasive surgery enabled reduction and direct stabilisation of thoracolumbar vertebral fractures, ensuring restoration of the vertebral body height and correction of post-traumatic kyphosis. In the immediate post-operative period (T1), there was no particular difference in Cobb angle correction between the two groups in terms of either single vertebrae (VK) or segments (SK). In other words, according to our results, there was no statistically significant difference in efficacy between percutaneous stabilisation of fractured vertebrae by means of pedicle screw associated with intermediate screw, as compared to pedicle screw associated with kyphoplasty.

As expected—considering the physiological balancing of the vertebral column on the sagittal plane—the trauma resulted in increased kyphosis when a thoracic vertebrae was involved; in fact, in the thoracic group the vertebral kyphosis was greater by almost 4°, and the segmental kyphosis by almost 6°, as compared to lumbar group. This difference was statistically significant, irrespective of the minimally invasive surgical treatment received.

Despite the abovementioned limitations, therefore, we believe that reflection on the trend in the segmental kyphosis angle of thoracic lesions is warranted, in particular regarding the long-term efficacy and stability of minimally invasive surgical treatment. Indeed, in our sample we observed that segmental kyphosis was similar to pre-operative levels 1 year after the intervention, irrespective of whether kyphoplasty or an intermediate screw was used to fix the fractured thoracic vertebrae. It is likely that this progressive loss of correction is therefore largely determined by a physiological tendency towards kyphosis at the thoracic level of the spine rather than the type of surgery performed.

This confirms the trends in the literature [15, 16]. Undoubtedly, the fracture pattern is one of the most involved parameters correlated with the loss of segmental kyphosis correction, but other clinical factors might contribute to it.

Recently Formica et al. [17] noted that short-segment fixation with intermediate screws is a viable technique with positive clinical and radiological outcomes at 1-year follow-up. However, these authors suggest to carefully use this surgical technique in patients with BMI > 30 because it could be associated with an increased risk of loss of the correction of segmental kyphosis.

Another interesting finding, however, was the observation of a difference in the short- and medium-term trends displayed by the two minimally invasive surgical techniques, especially with regard to segmental kyphosis correction. Indeed, the PPSIS group maintained the segmental kyphosis values achieved by surgery throughout 1 year of follow-up, whereas in the PPSK group, at 1 year follow-up the segmental kyphosis angle was almost 3° greater on average than in the immediate post-operative period. This seems to confirm the recent literature regarding the efficacy of intermediate screws in reducing the risk of segmental kyphosis correction loss in fractured vertebrae [17–20].

Mahar et al. [11] noted that segmental fixation of burst fractures with screws at the level of the fracture improved the biomechanical stability of the construct. Theoretically, the segmental fixation provides an additional fixation point that may act as an anterior vector creating a "lordorising" force, which helps in the reduction in the fracture and in kyphosis correction. Guven et al. [21] randomised 72 patients with unstable thoracolumbar burst fractures into four groups (conventional long-segment fixation, conventional short-segment fixation, and long-segment and short-segment fixation with intermediate screws). They stated that reinforcement with fracture-level screws, particularly for short-segment stabilization, enables a better kyphosis correction and adequate spinal stability in patients with thoracolumbar burst fractures. Kanna et al. studied the radiological and clinical results at 2 years from short-segment stabilization with intermediate screws for severe thoracolumbar spine fractures with load sharing classification scores ≥ 7 [15, 22]. These authors showed an improvement in both clinical and radiological outcomes after surgery and considered acceptable a minimal loss of segmental kyphosis correction.

Short-segment fixation is considered a viable option for the management of thoracolumbar spine fractures, even though there is no unanimous consensus regarding their optimal treatment [23]. The performance of short or long fixation is one issue that is currently debated, and either kind

of instrumentation is associated with specific advantages and disadvantages.

Tezeren et al. [24] prospectively evaluated the clinical and radiological outcomes of two groups of patients treated by long- or short-segment fixation for thoracolumbar spine fractures. Measurements of local kyphosis, sagittal index and anterior vertebral height loss showed that the long-segment group had better radiological outcomes at the final follow-up. However, despite the better radiological outcomes in the long-fixation group, no differences in clinical outcomes were observed between the two groups. Long-segment instrumentations provide optimal stability despite prolonged operative time and increased blood loss, but they increase the stiffness of the spine by immobilising several motion segments. Wei et al. [25] evaluated the efficacy of mono-segmental transpedicular fixation (one level below and at the fracture level) in comparison with short-segment stabilisation. Eighty-five patients were included and randomised into two groups. Radiographical and clinical parameters showed no statistically significant differences between these two approaches. The failure rate was 6.38% in the mono-segmental group and 5.26% in the short-segment group.

Short-segment and mono-segmental implants shorten operative time and decrease blood loss. However, implant failure and loss of reduction after short-segment posterior fixation are well-studied complications, and a number of reports are associated with high rate of failure. Kramer et al. [26] reported that four of 11 patients who were treated by bilateral short-segment transpedicular instrumentation had breakage or disengagement of the caudal screws. Scholl et al. [27] reported a 40% instrumentation mechanical failure rate in such patients. To avoid similar complications, several authors proposed to support the anterior column, above all when load sharing classification [22] scores ≥ 7. Therefore, transpedicular bone grafting, vertebroplasty or kyphoplasty by a posterior approach have all been proposed to avoid a separate anterior surgery [15, 28, 29]. In fact, despite positive results, surgery at the anterior column adds morbidities and increases the surgical time and blood loss.

Considering the variables examined in this study, this trend may also have been influenced by the greater screw density in patients undergoing PPSIS (on average 7 screws vs. 4.8 screws in the kyphoplasty group). Indeed, without fusion long-segment fixation is more effective than short-segment fixation in achieving and maintaining correction on the sagittal plane [15, 24].

Ultimately, it may be that longer instrumentation with intermediate screws positioned in the fractured vertebrae is more effective than shorter instrumentation with kyphoplasty in preventing progressive deformation of the disc space. As argued in the past [30], this progressive deformation is likely to be the root cause of vertebral collapse and the anterior column insufficiency responsible for the progressive segmental kyphosis and will occur regardless of whether or not the vertebra maintains the height restored by minimally invasive surgery.

Conclusion

In conclusion, we can confirm that both percutaneous pedicle screw with intermediate screw and percutaneous pedicle screw with kyphoplasty are efficacious and largely stable means of correcting post-traumatic kyphosis, although percutaneous pedicle screw with intermediate screw appears to be more efficacious in the long term, likely due to the greater stability offered by the greater density of fixation screws in our percutaneous pedicle screw with intermediate screw group. Nevertheless, it also appears that fractured thoracic vertebrae are more susceptible to greater segmental kyphosis than lumbar vertebrae, displaying greater correction loss over time, irrespective of the minimally invasive technique used for vertebral fracture fixation.

Compliance with ethical standards

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