Comparison of Sagittal Plane Realignment and Reduction with Posterior Instrumentation in Developmental Low or High Dysplastic Spondylolisthesis

İ. TEOMAN BENLİ[1] , HAKAN ÇİÇEK[2], ALPER KAYA[3]

[1]*Prof., M. D., Surgeon of Orthopaedics and Traumatology, Ufuk University, Faculty of Medicine, Department of Orthopaedics and Traumatology, Ankara, Turkey.   [2] Resident, S.B. Ankara Diskapi Yildirim Beyazit Hospital, 3rd Department of Orthopaedics and Traumatology, Ankara, Turkey.   [3] Surgeon of Orthopaedics and Traumatology, Ufuk University, Faculty of Medicine, Department of Orthopaedics and Traumatology, Ankara, Turkey.*

BACKGROUND CONTEXT: In situ fusion is the gold standard method of treatment of spondylolisthesis. There is no study in the literature evaluating the effect of sagittal contour realignment on clinical outcomes in comparison with the addition of anterior slippage reduction.

PURPOSE: The correction of sagittal plane vs. reduction with instrumentation in the patients with low or high dysplastic spondylolisthesis.

STUDY DESIGN/SETTING: A prospective randomized study in patients treated with the same surgical team at the same center.

PATIENT SAMPLE: 40 patients, 20 with low and 20 with high dysplastic spondylolisthesis (mean age: 33.1±10.6; average follow-up: 37.9±11.9 Mo.).

OUTCOME MEASURES: The extent of displacement, lumbosacral angle values, lumbar sagittal contours, correction rates, JOA scores, SRS-22 questionnaire were evaluated preoperatively, postoperatively, and at the final visit. Fusion rates, complications and quality of fusion were recorded.

METHODS: 4 groups of patients were generated. Only posterolateral fusion, neural decompression, and sagittal plane correction with posterior instrumentation using 3rd generation instrumentation system transpedicular screws was accomplished in 20 patients (low dysplastic: 10 patients, high dysplastic: 10 patients). Additional reduction of anterior slippage was done in the remaining 20 patients (low dysplastic: 10 patients, high dysplastic: 10 patients).

RESULTS: No statistically significant difference was found between low vs. high dysplastic patients and between patients with sagittal contour realignment vs. patients with additional anterior slippage reduction (*p*>0.05). The correction rates for displacement were statistically similar at the final visit. Postoperative and final JOA and SRS scores were similar between in situ fusion and reduction groups (*p*>0.05). A solid fusion mass of 77.5 % was achieved in both groups.

CONCLUSIONS: A high percentage of fusion was achieved with posterolateral in situ fusion with or without reduction; and an additional reduction procedure did not have a statistically detectable impact on clinical outcomes. Successful fusion and neural decompression were the most important parameters that have an impact on clinical

Tel. : 90 312 435 09 14   e-mail: cutku@ada.net.tr

outcomes in patients with developmental spondylolisthesis, irrespective of the extent of preoperative displacement and the type of listhesis.

Spondylolisthesis is defined as the forward displacement of a vertebral body with its pedicles and transverse processes over the adjacent vertebra (8). For a long time, pars articularis has been known to be the place where basic pathological process occurs in spondylolisthesis (2,7-8,12,17,21,23). Wiltse et al. in their patho-anatomic and morphological classification of the disease, suggested the presence of a defect at pars, or a dysplasia resulting in bone hook insufficiency of facet articulation (2,8,21,23). Pars defect was attributed to congenital or stress fractures. In 1982, Marcetti and Bertolozzi classified spondylolisthesis into two groups: acquired and developmental. In 1994 they finalized their classification so that lysis, elongation and dysplasia were considered as developmental and traumatic, degenerative, postoperative and pathological types were grouped as acquired (2). According to Marchetti and Bertolozzi, pathology is not present at birth in dysplastic type with the only congenital characteristic being high or low degree dysplasia. High dysplasia onsets during adolescence mostly located at L5-S1 and there is local kyphosis angulation. This type is progressive and leads to severe instability. Low dysplasia has a slow progression and may be seen at higher levels; end plates of slipping vertebrae are parallel or have lordotic angulation (2,8,21,23) Conservative methods are the first treatment of choice (21). Indications for surgical treatment include pain unresponsive to conservative treatment, development of neurological deficits or neural instability, progressive displacement, and progressive nature of concomitant pathologies (2,8,23).

Surgical methods mainly aim at stabilizing the vertebral column and releasing neural structures. Most frequently used method for the stabilization of vertebral column is the fusion of the unstable vertebral segment. In patients having root compression as the primary symptom, Gill and manning established the decompression technique with excision of posterior elements. Gill method is suitable for low degree spondylolisthesis with painful radiculopathy, however it has the disadvantage of destabilization (4).

Traditionally, in situ fusion has been the most widely used method for the surgical treatment of spondylolisthesis (8,21). Other fusion techniques include posterolateral fusion, interbody fusion and circumferential fusion. The reported incidence of fusion for these techniques differs between 60% and 100% (4-6,11,15-16,18,24,28).

Recently, instrumentation gained popularity for the stabilization of the fusion. It was first used by Harrington during 60's for the reduction of the deformity and stabilization of the fusion area (21). High success rates are reported in association with instrumentation (2,8,21,23). However, Müller and Hedlung (2000) reported in their study that instrumentation does not have any additional contribution to the development of fusion (24).

Another treatment modality for spondylolisthesis is reduction of anterior vertebral slippage. Reductions aim to ensure the normal vertebral arrangement and reconstructing the normal anatomic continuity of spinal canal (2,8-9,21,23). Closed methods or surgical methods employing instrumentation accomplish reduction of the displacement (2,9,13,23). Recently, owing to the development of lysthesis screws and third generation modern instrumentation systems, reduction procedure became easier. However, the role of reduction in the treatment is still debated (9,13,29). For a long time, we personally observed that when lumbar sagittal contours were corrected to the normal physiological ranges by using posterior instrumentation in spondylolisthesis patients, clinical results were better compared to patients without instrumentation, regardless of reduction was performed or not. This observation prompted us about the possible role of sagittal contour realignment in the

treatment. Our literature search did not reveal any study on the importance of the correction of impaired sagittal contours in the surgical treatment of this disease.

Therefore, in the present study, using a prospective study design, patients were classified radiologically as high and low dysplastic according to Marchetti and Bertolozzi classification and assigned to two different treatment groups with equal numbers: only correction of sagittal contours with posterior instrumentation or reduction. Third generation transpedicular screws were used. In addition to radiological findings, SRS-22 questionnaire (a novel tool for the evaluation of spondylolisthesis surgery results) and Japanese Orthopedics Association (JOA) low back pain scale were used for the assessments of the results. In spondylolisthesis several tools for assessing clinical outcomes are used (20); among them SRS questionnaire was developed for patients with scoliosis, and this questionnaire has been reported to be useful in young patients for the assessment of results from patient's perspective. (1,14). Ishihara et al. and Kimura et al. previously demonstrated the correlation between JOA scores and radiological results in spondylolisthesis patients (15-16). However, considering the insufficiency of the scoring system in demonstrating cauda equina signs, a modified form was used. Present study also investigated the correlation between clinical results and preoperative age, slippage ratio, correction rate, presence of either high or low dysplasia and lumbosacral angles.

PATIENTS AND METHODS

Patients:

Forty consecutive developmental dysplastic spondylolisthesis patients with radiologically demonstrated pars articularis defect and facet joint dysplasia, without any previous trauma or vertebral operation history and without any degenerative or pathological changes were included in this study. The mean age of participants was 33.1 ± 10.6 years at the time of operation, with a male/female ratio of 8/32. The average duration of follow up was 37.9 ± 11.9 months. The spondylolisthetic displacement was at the level of L5-S1 in 28 patients (70 %), L4-L5 in 12 patients (30 %). All patients were Grade II according to Meyerding classification, and according to Taillard they had a slippage between 25% and 50%.

Preoperative evaluation:

In all patients a detailed medical history was obtained, physical and neurological examinations were performed, and routine laboratory tests, conventional X-ray examinations and magnetic resonance imaging (MRI) of the lumbosacral region were obtained upon hospitalization. Information regarding past trauma, sports injury, operation, or tumors were collected. The localization, nature and the duration of pain, and its response to conservative methods were recorded. Also, neural claudication was questioned. Sensory or motor deficits were examined.

The displaced surface and the displacement rate (according to Meyerding's method) were determined by the radiological examination, and lumbosacral angle (LSA) was measured (8,25). Bone hook dysplasia, pars defect and elongation in the pars were assessed by the oblique and lateral X-ray images to exclude spondylolisthesis due to trauma, postoperative instability, local pathologies or degeneration. MRI was used to assess disc degeneration, and the conditions of spinal canal and neural foramina.

Patients were classified into two groups based on their LSA (25); if the LSA was $0°$ or negative the patient was considered low dysplastic (lordotic), if positive, patient was considered high dysplastic (kyphotic) (2,8,21,23). Preoperative LSA indicated that 20 patients had high and 20 patients had low dysplastic developmental spondylolisthesis.

Study Design:

In order to evaluate the effects of sagittal contour correction and reduction of anterior slippage on clinical results, and to compare them, patients with definite diagnosis of developmental dysplastic type spondylolisthesis on the basis of radiological findings, age of onset and similar criteria, with similar slippage ratios (between 25% and 50%) according to Meyerding grading system were randomized and prospectively evaluated. For all patients, neural decompression, posterolateral fusion and correction of sagittal contours by posterior instrumentation was planned in order to ensure normal physiological lumbar arrangement. Only two variables were selected. First variable was the reduction of anterior vertebral slippage, which was performed in half of the patients. Second variable was the type of the dysplastic spondylolisthesis (either low or high dysplastic). Besides several other criteria, sagittal plane angulation between endplates of slipping vertebrae was the main criteria for differentiating between these two types. High dysplastic type had kyphotic, low dysplastic type had lordotic angulation. Four different groups each having 10 patients were formed accordingly. As stated above, main surgical treatment performed in all groups were similar and included neural decompression, posterolateral fusion and correction of sagittal contours with posterior instrumentation. The only difference between the first two groups was the inclusion of low dysplastic patients in Group A and high dysplastic patients in group B. The two other groups similarly included low dysplastic (Group C) and high dysplastic patients (Group D); however, reduction of anterior slippage was also performed for these two groups, which was not the case for Group A and B. By comparing the results of Group A vs. Group B and Group C vs. Group D, the possible effect of the spondylolisthesis type on the clinical results was planned to test in patients with only sagittal balance correction or with additional reduction. By comparing the results of Group A vs. Group C and Group B vs. Group D, possible effects of additional anterior slippage correction on the clinical results were planned to test in patients with the same type of spondylolisthesis. The groups were firstly compared with respect to preoperative and operative parameters (age, female/male, the proportion of patients with listhesis at L5-S1 to those with listhesis at other levels (L3-4, L4-5), operating time, volume of bleeding, the number of mobile segments instrumented, preoperative displacement rate) and the length of follow up. Local sagittal angulation (Lumbosacral angle – LSA) and L1-L5 lumber region sagittal contour angle values were used for comparison of radiological results. SRS-22 questionnaire results and modified JOA scale was used to compare clinical results.

SRS-22 evaluates the domains of mental status, self-image, function, pain (5 questions for each) and patient's satisfaction with treatment (2 questions) with a 5-point scale. Japanese Orthopaedic Association's (JOA) evaluation system for low-back pain syndrome was used to evaluate the preoperative pain and functional status (10,12). The *Japanese Orthopaedic Association low back score* (JOA score) assesses subjective symptoms (low back pain, leg pain, and walking ability) and clinical signs (sensory and motor disturbance, angle of positive straight-leg raising test). Tests had a maximum score of 20. It was modified in order not to overlook cauda equina findings, particularly in patients with a slippage at L5 – S1 levels (JOA system does not include related symptoms) (Table-1).

The correlation between age, preoperative displacement rate, postoperative correction of displacement, preoperative lumbosacral angle, and correction rate in postoperative lumbosacral angle and the percent improvement in postoperative and final JOA scores and in the pain, mental status, function, self-image and patient satisfaction domain scores of SRS-22 were also explored with Pearson's correlation regression test.

Table –1. The Japanese Orthopaedic Association's (JOA) evaluation system for low back pain syndrome and the formula for the recovery rate following surgery [10].

A. SUBJECTIVE SYMPTOMS
   I. Low back pain :
      0. Continuous severe pain
      1. Occasional severe pain
      2. Occasional mild pain
      3. None
   II. Radiculopathic pain (Radiating to hip and thigh) :
      0. Continuous severe pain (Unresponsive to treatment and all day long)
      1. Occasional severe pain
      2. Occasional mild pain
      3. None
   III. Leg pain, tingling, or both
      0. Continuous severe symptoms
      1. Occasional severe symptoms
      2. Occasional mild symptoms
      3. None
   IV. Walking ability
      0. Able to walk less than 10 m.
      1. Able to walk more than 100 m but less than 500 m.
      2. Able to walk more than 500 m., but with some leg pain or tingling
      3. Normal

B. CLINICAL SIGNS
   I. Straight-leg raising test (including tight hamstring)
      0. Less than 30º
      1. More than 30º, but less than 70º
      2. Normal
   II. Sensory
      0.   Marked disturbance
      1.   Slight disturbance (not subjective)
      2.   Normal
   III. Motor
      0.   Motor disturbance (MMT*: 3 to 0)
      1.   Slight disturbance (MMT: 4)
      2.   Normal
   IV. Sphincter function (Bladder and bowel):
      0. Marked disturbance (no voluntary control)
      1. Slight disturbance (not subjective)
      2. Normal

   - RECOVERY RATE : [(Postoperative JOA score – Preoperative JOA score) / (20 (full score)- Preoperative JOA score)] x 100
   *MMT : Manual motor testing

155

Indications for surgical treatment and surgical techniques:

Indications for surgical treatment included pain unresponsive to conservative treatment, presence of neurological deficits or neurological claudication, and displacement greater than 25% and associated vertebral instability.

Neural decompression with modified Gill's method was used in both groups of patients for their neural claudication and neural impairment. At slippage area, hypermobile posterior lamina was removed, facet joints were elevated and roots were completely liberated by the help of foraminotomy. Also, all patients had fusion with local autologous grafts and allografts placed at posterolateral region.

In 10 low dysplastic patients and in 10 high dysplastic patients (total 20 patients) sagittal plane correction was performed following the placement of posterior transpedicular screws, without any intervention to the anterior slippage of the vertebra. In low dysplastic patients, prebended rods in conformity with normal lumbar contours were placed on the screws, in the hypolordosis patients, compression and in the hyperlordotic patients, distraction was done. For high dysplastic patients, prebended rods according to the local kyphotic angulation were first rotated until lordotic contour, then compression was applied (Figure-1). For all the patients in this group, Texas Scottish Rite Hospital System (TSRH) was used.

In 10 low dysplastic patients and in 10 high dysplastic patients (total 20 patients) initially slippage was reduced and then sagittal contours were corrected. In low dysplastic patients, correction could be easily achieved by listhesis screws. In 10 of these patients, Isola instrumentation was used. For high dysplastic patients, rods prebend in conformity with sagittal contours were placed on the screws by the help of cantilever maneuver. As recommended by Harms, first, reduction was achieved by a mild distraction, and then sagittal contours were corrected by application of compression.

All operations were performed by the same team. An average of 826.2±83.0 cc blood was drawn from each patient by the cell saver auto-transfusion device, and an average of 1.6±1.2 units of blood was given. Except for 1 patient, who lost 1100 cc of blood during the procedure, no cases of extra blood transfusion was needed, and 1 unit of fresh blood was added to this patient's own blood collected.

Intraoperatively, transcranial cortical magnetic evoked motor potentials (TCMEP) and somato-sensorial evoked potentials (SSEP) were recorded for neural monitoring.

Postoperative follow-up:

Postoperatively, patients were turned on their sides on Day 1, were allowed to sit on Day 2, and were encouraged to walk on Day 3. Follow-up visits were scheduled on the 1st, 2nd, and 3rd postoperative months, and 6-monthly thereafter, together with monitoring clinical and radiological signs.

For antibacterial prophylaxis, ampicillin/sulbactam 2 g was given intravenously before the procedure, and the same treatment (0.5 g, bid) was continued for 3 days postoperatively.

In December 2004, the final evaluation including the assessment of radiological success of fusion, the displacement rate and LSA was performed. Also, preoperatively administered JOA pain and functional assessment scale and SRS-22 questionnaire adapted for Turkish by Alanay et al. were administered (1,10).
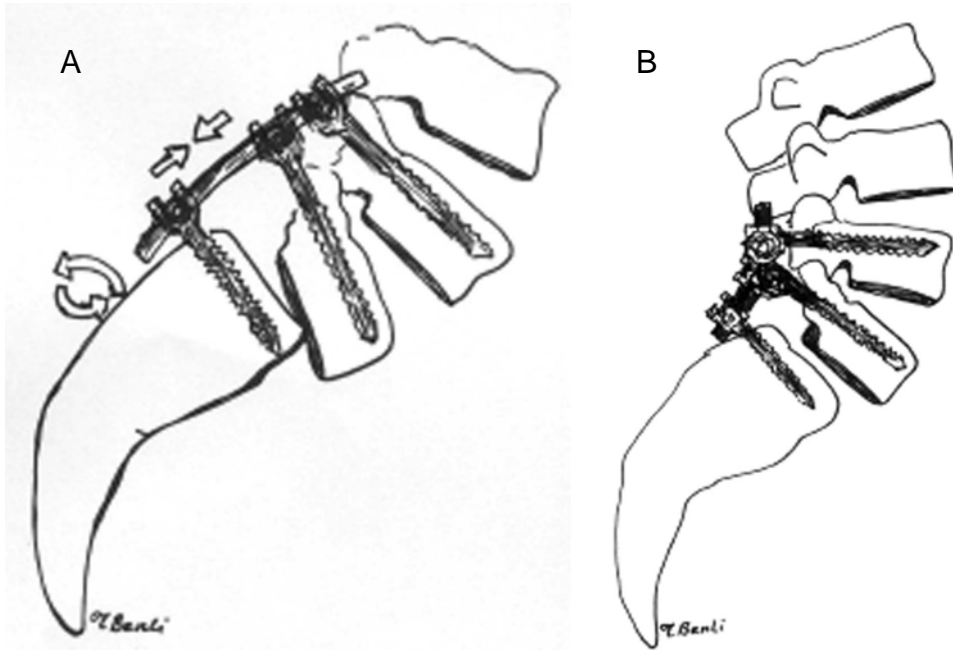
Figure -1. Sagittal plane correction technique with posterior instrumentation in the patient with high dysplastic developmental spondylolisthesis.

Evaluation of fusion :

Bony block image in postero-anterior and lateral X-rays, a correction loss not greater than 5% in vertebral displacement and not greater than 5º in LSA, and absence of implant insufficiency were the criteria used to assess the fusion rates at the last visit. In addition, Ferguson graphies were obtained and the fusion scale recommended by Lenke et al. was used (21). The four fusion grades as judged from the Ferguson anteroposterior radiograph were as follows: grade A is definitely solid with bilateral stout fusion masses present; grade B is probably solid with a unilateral stout fusion mass and contralateral thin fusion mass; grade C is probably not solid with a thin unilateral fusion mass and a probable pseudoarthrosis on the contralateral side; and grade D is definitely not solid with thin fusion masses bilaterally with obvious pseudoarthrosis or bone graft dissolution bilaterally. To minimize any possible errors regarding the interpretation of X-rays, all graphies were also evaluated by an other orthopedist and radiologist, in addition to the evaluation by the operating team. Also, peri- and post-operative complications were recorded.

Statistical assessment:

SPSS 9.0 for Windows was used for statistical evaluations. Difference for paired samples, student's t-test and Pearson correlation test were used for statistical analyses and the *p* value was set at 0.05.

RESULTS

Preoperative and intraoperative comparisons:

Low dysplastic (Group A) and high dysplastic (Group B) spondylolisthesis patients for whom neural decompression, posterolateral fusion and sagittal plane correction by posterior instrumentation were performed did not differ significantly in terms of preoperative age (29.3 ± 6.2 and 34.9 ± 11.4), female to male ratio (2/8 and 2/8), mean duration of follow-up (37.2 ± 12.8 and 38.2 ± 12.3 months), ratio of L5-S1 involvement (7/3 and 7/3), duration of operation (2.4 ± 0.5 and 2.4 ± 0.4 hours), amount of intraoperative bleeding (833.0 ± 74.4 and 828.0 ± 80.2 cc) and number of instrumented mobile segments (2.0 ± 0.7 and 2.1 ± 0.7) ($p > 0.05$) (Table-2). Similarly, Group C (low dysplastic) and Group D (high dysplastic) patients for whom anterior-posterior slippage reduction was performed did not differ in terms of abovementioned preoperative and perioperative characteristics (preoperative age: 32.6 ± 12.1 and 32.4 ± 12.2, female to male ratio: 2/8 and 2/8, mean duration of follow-up: 39.8 ± 14.5 and 36.6 ± 9.4 months, ratio of L5-S1 involvement: 7/3 and 7/3, duration of operation: 2.3 ± 0.4 and 2.3 ± 0.4 hours, amount of intraoperative bleeding: 826.0 ± 81.1 and 846.0 ± 83.0 cc and number of instrumented mobile segments: 2.0 ± 0.7 and 2.1 ± 0.7) ($p > 0.05$). When two low dysplastic and two high dysplastic patient groups were compared, groups with same type of listhesis patients were also statistically similar ($p > 0.05$) (Table-2,3).

Spondylolisthetic slippage:

The preoperative displacement rates in Group A, B, C and D were 30.5 ± 5.5 %, 30.0 ± 5.8 %, 32.3 ± 8.1 % and 40.6 ± 5.9 %, respectively (Table-4). Preoperative slippage rates were statistically similar for Group A vs. Group B (patients with sagittal plane correction) and for Group A vs. Group C (patients with low dysplastic spondylolisthesis) ($p > 0.05$). Postoperatively, slippage rates did not change in Group A and Group B patients with only sagittal contour realignment and no increase in slippage was observed in any of the two groups (Figure-2). On the other hand, statistically significant postoperative and final correction was observed in Group C and Group D patients (for group C, 84.7 ± 32.5 % and 83.4 ± 32.6 %, respectively; for group D, 87.9 ± 15.2 %, 87.1 ± 16.1 %, respectively) ($p < 0.01$).

In Group C and D patients with reduction, postoperative and final correction rates for the spondylolisthetic displacement were not associated with the age, preoperative displacement rate and preoperative LSA ($p > 0.05$).

Table-2. Preoperative and operative data of patients with high dysplastic spondylolisthesis.

No. *	N-P*	Age	Sex	Follow-up (months)	Operation time (hours)	Bleeding (cc.)
1	AK	35	M	36	2.1	840
2	RC	40	M	60	2.6	810
3	TK	29	F	48	2.4	950
4	SS	55	M	28	2.0	810
5	AL	20	M	38	3.0	800
6	ET	52	M	54	2.0	800
7	DR	36	M	36	3.0	650
8	HL	28	M	24	1.9	900
9	ML	25	M	24	2.5	890
10	RK	29	F	34	2.4	830
11	MM	33	F	48	2.4	840
12	MY	24	M	36	2.0	800
13	NB	41	M	24	1.9	820
14	HY	55	M	28	2.8	1100
15	GE	30	F	34	2.0	790
16	FU	32	M	24	2.0	810
17	AT	54	M	36	2.2	890
18	TB	24	M	48	2.6	900
19	DK	41	M	40	2.9	810
20	KK	20	M	48	2.2	700

No. *		IMS*	Preop. Slippage	Postop. Slippage	Final Slippage	Preop. LSA*	Postop. LSA*	Final LSA*
1		2.0	30	30	30	6º	0º	0º
2		2.0	25	25	25	10º	0º	0º
3		2.0	40	35	35	18º	2º	2º
4		3.0	30	30	30	16º	2º	2º
5		3.0	30	30	30	6º	0º	2º
6		2.0	40	40	40	8º	0º	0º
7		2.0	30	30	30	12º	2º	3º
8		1.0	25	25	25	10º	0º	0º
9		1.0	25	25	25	8º	-5º	-5º
10		3.0	25	25	25	6º	-10º	-8º
11		3.0	28	10	10	6º	-10º	-10º
12		2.0	45	11	11	45º	8º	10º
13		2.0	45	5	7	15º	-3º	-3º
14		2.0	45	0	0	20º	0º	0º
15		2.0	40	0	0	17º	-10º	-10º
16		2.0	37.5	0	0	17º	-8º	-8º
17		3.0	42	5	5	10º	0º	0º
18		2.0	40	0	0	14º	10º	10º
19		3.0	48	18	20	26º	18º	20º
20		2.0	35	0	0	14º	0º	0º

*No.: number of patients, N-P: Name of the patients, IMS: intrumentad mobile segments, LSA : lumbosacral angle,   M: male, F: female
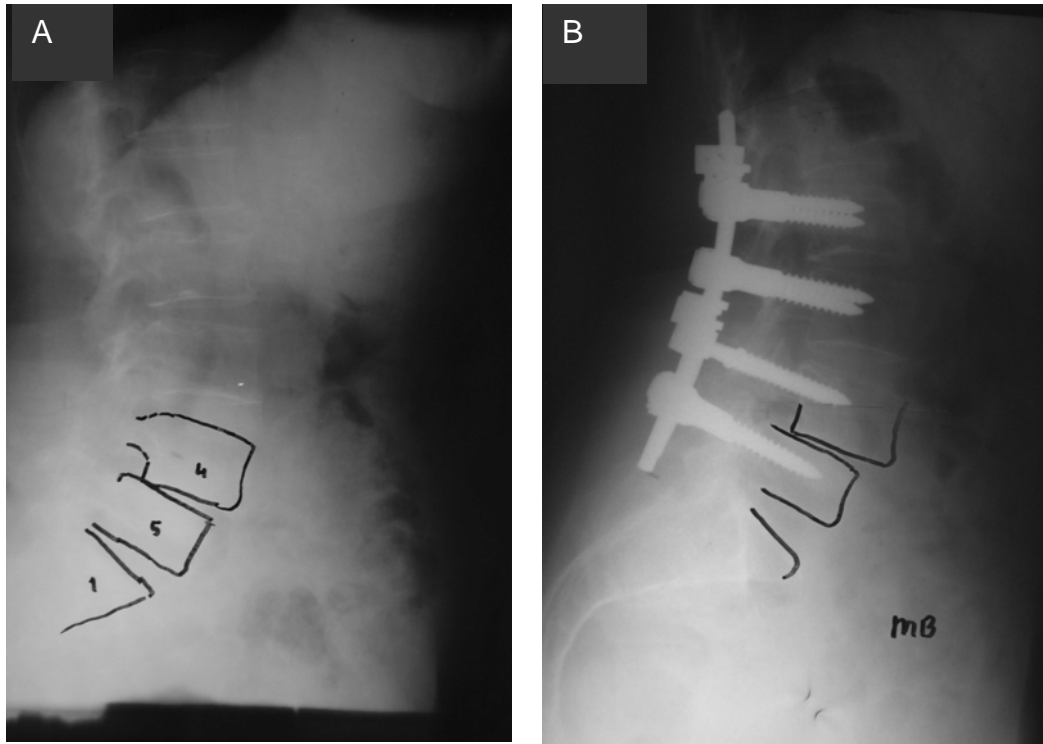
Table-3. Preoperative and operative data of patients with low dysplastic spondylolisthesis.

No. *	N-P*	Age	Sex	Follow-up (months)	Operation time (hours)	Bleeding (cc.)
1	TT	22	M	60	2.9	900
2	GA	36	F	52	2.8	860
3	DM	38	F	48	1.8	860
4	PL	20	M	44	3.0	840
5	AS	34	M	28	2.1	910
6	TH	22	M	34	3.0	810
7	PH	28	M	30	1.9	900
8	IM	32	M	28	2.2	660
9	NS	31	M	24	2.1	790
10	OT	30	M	24	2.6	800
11	MB	34	M	28	2.4	840
12	DS	28	M	36	2.8	990
13	AN	36	M	48	2.1	810
14	AY	45	M	60	2.4	760
15	EY	44	F	36	2.4	800
16	FT	54	M	54	2.6	890
17	UF	22	M	60	2.1	890
18	AB	24	F	24	2.0	800
19	CR	20	M	28	2.1	700
20	AC	19	M	24	2.0	780

No. *		IMS*	Preop. Slippage	Postop. Slippage	Final Slippage	Preop. LSA*	Postop. LSA*	Final LSA*
1		2.0	30	30	30	-4º	0º	0º
2		2.0	25	25	25	-10º	0º	0º
3		1.0	25	25	25	1º	0º	0º
4		2.0	30	30	30	-4º	0º	0º
5		1.0	40	40	40	1º	-10º	-10º
6		2.0	30	30	30	-3º	-10º	-10º
7		2.0	30	30	30	1º	-10º	-10º
8		3.0	40	40	40	-11º	0º	0º
9		2.0	30	30	30	-4º	-10º	-10º
10		3.0	25	25	25	-2º	0º	0º
11		2.0	27	0	0	-3º	0º	0º
12		2.0	40	5	10	-2º	0º	0º
13		2.0	25	0	0	-15º	-10º	-10º
14		3.0	49	20	20	-4º	0º	0º
15		3.0	25	25	25	-6º	0º	0º
16		2.0	32	0	0	-11º	-10º	-10º
17		2.0	25	0	0	-3º	-10º	-10º
18		2.0	30	0	0	-14º	-4º	-4º
19		2.0	40	0	0	-10º	0º	0º
20		2.0	30	0	0	-10º	0º	0º

*No.: number of patients, N-P: Name of the patients, IMS: intrumentad mobile segments, LSA : lumbosacral angle,   M: male, F: female

Figure -2. Preoperative (a) and 48th month follow-up (b) visit lateral X-ray images of the 34 years old female patient with L4-5 low dysplastic spondylolisthesis

Table-4. Preoperative, postoperative and final slippage values and correction rates of patients

		Preoperative slippage	Postoperative slippage	Final slippage	Postoperative correction rate of slippage (%)	Loss of correction
SAGITTAL PLANE CORRECTION n: 20	Group-A LOW DYSPLASTIC n: 10	30.5	30.5	30.5	0.0	0.0
	Group-B HIGH DYSPLASTIC n: 10	30.0	29.5	29.5	1.3	0.0
REDUCTION OF ANTERIOR SLIPPAGE n: 20	Group-C LOW DYSPLASTIC n: 10	32.3	5.0	5.5	84.7	0.5
	Group-D HIGH DYSPLASTIC n: 10	40.6	4.9	5.3	87.9	0.4

Lumbosacral Angle (LSA):

Pre-operative LSA was 4.23°±12.4° and postoperatively it fell down to -1.9°±6.1°, with a significant improvement in all of the patients (p < 0.05). The preoperative average LSA in Group A and C patients with low dysplastic spondylolistesis were -3.5°±4.2° and -7.8°±4.8°, respectively (Table-5). In patients with low dysplastic disease and sagittal contour correction, LSA angle did not change, however in the reduction group, it decreased to –3.4°±4.7°. At the final visit, no significant change in postoperative figures was detected (*p* >0.05).

Table-5. Preoperative, postoperative and final lumbosacral angle (LSA) values and correction rates

		Preoperative LSA	Postoperative LSA	Final LSA	Loss of correction
SAGITTAL PLANE CORRECTION n: 20	Group-A LOW DYSPLASTIC n: 10	-3.5°	-4.0°	-4.0°	0.0°
	Group-B HIGH DYSPLASTIC n: 10	10.0°	-0.9°	-0.4°	0.5°
REDUCTION OF ANTERIOR SLIPPAGE n: 20	Group-C LOW DYSPLASTIC n: 10	-7.8°	-3.4°	-3.4°	0.0°
	Group-D HIGH DYSPLASTIC n: 10	18.4°	0.5°	0.9°	0.4°

In Group B and D patients with high dysplastic spondylolisthesis, preoperative average LSA's were 10.0°±4.2° and 18.4°±10.8°, respectively. Postoperatively, these were significantly reduced to -0.9°±3.8° and 0.5°±9.2°, and in 15 patients (75 %) the pathological preoperative kyphotic pattern was transformed into a lordotic pattern postoperatively. At the final visit, minimal correction losses of 0.5°±0.8° and 0.4°±0.8° were observed, respectively.

In Group A and C (low dysplastic patients), the postoperative and final correction rates were not associated with the age, preoperative displacement rate and preoperative LSA (*p*>0.05). In Group B and D (high dysplastic patients), a similar finding was observed (*p*>0.05).

Overall the average global sagittal contour in the lumbar region pre- and post-operatively were -29.8°±13.7° and –39.5°± 4.8°, respectively. At the last visit, these were maintained. In Group A, B, C and D the preoperative angle of lumbar lordosis was –32.2°±10.7°, -20.8°±3.5°, -46.6°±9.9° and –19.6°±8.1°, respectively, while the corresponding postoperative values were -38.2°±4.8°, 38.6°±3.3°, -43.0°±5.4° and -38.1°±4.5°. Normal physiological lumbar lordosis (40°-60°) was present in 8 (40 %) of 20 patients with preoperative low dysplastic spondylolisthesis, and in none of the patients with high dysplastic

spondylolisthesis. On the other hand, normal pattern of lordosis was present in all patients with postoperative low dysplastic spondylolisthesis and in 14 (70 %) of patients with high dysplastic spondylolisthesis; and a lumbar lordosis between 25º and 40º was achieved in the remaining 6 patients (30 %). At the final visit, the correction in lumbar sagittal contours was maintained (Group A, B, C and D: 37.9º±5.5º, 37.7º±3.5º, 43.0º±5.4º and 37.0º±6.8º).

Clinical outcomes:

In the overall patient group, a significant improvement in JOA score (from 6.9±2.1 preoperatively to 18.8±4.1 postoperatively) was observed (t: -21.5, $p < 0.01$) and at the final visit this improvement was maintained (16.8±2.3). The improvements percent in postoperative and final JOA scores (reduction rate - RRJOA) were 73.3±13.8 % and 70.0±14.6 %, and similar (t: 3.05, $p >0.05$).

In all groups, statistically significant improvements in JOA scores were observed (Table-6) ($p < 0.05$). Percent correction rates were statistically similar across all groups ($p>0.05$). Final correction rates were also similar with postoperative correction rates ($p>0.05$).

Overall, in the final visit the average scores for the domains of pain, mental status, function, self-image and patient satisfaction of the Turkish version of SRS-22 were 4.04±0.58, 4.06±0.64, 4.09±0.61, 4.02±0.67 and 4.21±0.52, respectively. In patients with low or high dysplastic spondylolisthesis who underwent sagittal plane correction or reduction of anterior slippage, Turkish SRS-22 questionnaire scores were greater than 4 in all groups, and patient satisfaction was particularly high (Table-6).

Table-6. Clinical outcomes of patients

		JOA			SRS-22				
		Preop.	Postop.	Final	*Pain*	*Mental*	*Function*	*Self -image*	*Satisfac- tion*
SAGITTAL PLANE CORRECTION n: 20	Group-A LOW DYSPLASTIC n: 10	6.7	17.6	17.1	4.04	4.05	4.05	4.00	4.21
	Group-B HIGH DYSPLASTIC n: 10	6.8	17.6	17.2	4.00	4.04	4.08	4.00	4.20
REDUCTION OF ANTERIOR SLIPPAGE n: 20	Group-C LOW DYSPLASTIC n: 10	6.9	17.4	16.6	4.08	4.06	4.11	4.05	4.25
	Group-D HIGH DYSPLASTIC n: 10	6.7	17.4	16.1	4.05	4.08	4.14	4.01	4.17

The improvement in pain, mental status, function, self-image and patient satisfaction domains were independent of the surgical technique applied and the type of spondylolisthesis and were similar ($p>0.05$). For all groups, rate of satisfaction from the treatment was higher compared to other domains.

No correlation between clinical outcomes and age was observed ($p>0.05$). Although a negative association between clinical outcomes and preoperative displacement and lumbosacral angle existed, no correlations could be detected ($p>0.05$). In all 4 groups, a positive correlation between postoperative/final JOA scores and SRS-22 domain scores and preoperative displacement and lumbosacral angle ($p>0.05$) was found. Postoperative and final JOA scores also correlated with SRS-22 scores, with parallel results in terms of clinical outcomes in both assessments ($p>0.01$).

Evaluation of fusion :

When Ferguson graphies were evaluated, 2 patients (5%) had grade D fusion according to Lenke classification (i.e. pseudoarthrosis). Pseudoarthrosis developed in one patient (2.5 %) with high dysplastic spondylolisthesis who underwent only sagittal plane correction and in one patient (2.5 %) with low dysplastic spondylolisthesis who underwent reduction of anterior slippage. Re-fusion was performed 1 year after the operation in both cases and solid fusion mass was observed 2 years after the first operation, with a final percent improvement of 70% in JOA, average SRS-22 domain score of 3, and patient satisfaction domain score of 3. Three patients (7.5 %) had grade C and 4 patients (10%) had grade B fusion. These 7 patients had only mild symptoms and they did not have remarkable complaints. In the remaining 31 patients (77.5%) development of solid fusion mass was demonstrated.

Neurological status:

Preoperatively all patients had neural claudication in addition to neurogenic pain on movement limiting functions. Also one patient (2.5%) with high dysplastic spondylolisthesis and 70% displacement had motor loss during dorsiflexion of the foot, 16 patients (40 %; 11 high dysplastic, 5 low dysplastic) had unilateral hypoesthesia, and the remaining 23 patients (57.5%) had paresthesias. Except for one patient, neurological symptoms were ameliorated in all patients (97.5 %). In that patient, two of the screws were found to have been oriented in an erroneous direction within the disc spaces, and this was corrected with a re-operation at Day 3. Apart from that, no other early or late postoperative neurological deficits were observed.

Complications:

No local or systemic complications such as deep infection or implant insufficiency were seen in any patient. Two cases (4%) had superficial infections causing a delay in the wound healing which were eradicated completely with local debridement and antibiotic treatment.

DISCUSSION

Surgical treatment is indicated for severe and resistant pain and neurological impairment, progressive displacement, and vertebral instability (8). With this respect, the main objective of the surgical treatment is rather to preserve the mobile segment while correcting lumbar hypermobility, to achieve the lumbar vertebral alignment at a normal axis with physiological sagittal contours, to reconstruct the disc height, and to relieve pain and neurological impairment (2,8,23).

In situ fusion is the most widely applied method of surgical treatment in spondylolisthesis, and it consists of stabilizing the vertebrae by generating vertebral fusion with no attempt at modifying the vertebral displacement (8). In recent years, due to the limited space for fusion in the posterior region caused by neural decompression, combination

of posterolateral fusion with interbody fusion to obtain a circumferential vertebral fusion has gained popularity (5-6,15,18). On the other hand, during the last two decades, instrumentation has also been incorporated into in situ fusion procedures, particularly following the development of 3rd generation instrumentation systems (8,21). According to Lenke and Bridwell instrumentation is the most efficient means of achieving vertebral stabilization, however it has no role in increasing the fusion rates (21). Kimura et al. have suggested that instrumentation may improve the fusion rates; in that study, fusion and satisfactory outcome were achieved in 82.1% and 72.4% of patients undergoing in situ fusion without instrumentation, and in 92.8% and 82.8% of patients undergoing in situ fusion with instrumentation (16). However, Möller and Hedlung have reported no effect of instrumentation on clinical outcomes, with no significant differences between instrumentation vs. no-instrumentation (24).

Several guidelines have been issued regarding the appropriate timing and patient selection for reduction procedures in spondylolisthesis (8). Marchetti and Bertolozzi have suggested that no reduction is necessary for a displacement rate more than 30% because of neurological deficit risk (23). According to Edwards, main advantages of reduction are to prevent the progression of deformity, to permit complete neural decompression, to limit the fusion area, to correct the posture and biomechanics, and to provide a significant improvement in appearance and self-image (9). Harms et al. have reported a complete (100%) correction of vertebral displacement in 87.5% of their cases and an average correction rate of 92.3% in slippage (13). Evidently, reduction is employed in conjunction with spinal fusion, and for the last few decades reduction with instrumentation has been preferred over manipulative methods (9,13).

In spondylolisthesis, hypolordosis or hyperlordosis may accompany anterior slippage. According to Marchetti and Bertolozzi, in low dysplastic type endplates are mostly parallel at the vertebral level of slippage, whereas in high dysplastic type a local kyphosis deformity is observed (2,8,21,23). This disturbance of sagittal contours initially may lead to mechanical pain, then it may increase slippage and may lead to severe neurogenic pain and neurological signs due to the compression of neural structures (21). Our literature search did not reveal any studies investigating the effects of sagittal contour correction on clinical outcomes and comparing sagittal realignment with anteroposterior reduction of slippage among similar patient groups. Thus, a prospective study was planned, and patients were randomized to undergo posterolateral fusion, neural decompression with modified Gill's method and sagittal plane correction with posterior instrumentation, or, in addition to these, to reduction of anterior slippage with posterior instrumentation. In the final evaluation, patients were assigned into two groups depending on the presence of low or high dysplastic spondylolisthesis. Therefore 4 groups similar in terms of age, demography, preoperative radiological and clinical findings, and operative findings were generated ($p>0.05$, for the statistical differences). Furthermore, the comparison between Group A and C (low dysplastic) and Group B and D (high dysplastic) revealed no significant differences with respect to preoperative average displacement and LSA ($p>0.05$).

The preoperative slippage rates in low or high dysplastic groups who underwent only correction of sagittal contours were found with no change postoperatively and at the final visit. In low or high dysplastic groups who underwent reduction with instrumentation, a statistically significant reduction in slippage rates was achieved with high average percent corrections of 84.7±32.4% and 87.9±15.2%. In the last evaluation visit, reduction was maintained with minimal correction loss.

A kyphotic pattern greater than 25º is considered as a very important risk factor by Edwards, who strongly recommends the correction of kyphotic lumbosacral angle in high dysplastic patients (9). Restoration of sagittal contours by instrumentation is considered more practical by Lenke and Bridwell, and these authors suggest that with this technique, sagittal alignment can be successfully corrected during reduction (21). Harms et al. have reported that they could reduce the slippage angle to 0º in 87% of their patients (13). Helenius et al. have studied 108 patients with low grade spondylolisthesis (mean age: 15.9 y) who underwent in situ fusion with instrumentation; the average preoperative LSA and lumbar sagittal contours were 10.4º and -35.8º, respectively, and postoperatively, the average LSA was reduced to -7.2º and average lumbar lordosis was increased to -41.9º (14).

In our study, a significant correction in sagittal contours was achieved for all 4 patient groups. In patients with low dysplastic spondylolisthesis (Groups A and C) LSA was lordotic preoperatively, and LSA was either unchanged or decreased (hyperlordotic patients), restoring the lumbar lordotic angle (-40º to -60º) to normal physiological range. Patients with high dysplastic spondylolisthesis (Groups B and D) had kyphotic preoperative LSA with decreased lordotic pattern in the lumbar region. Whether reduction was performed or not, a statistically significant correction was achieved in LSA for both groups, with an improvement. Preoperatively, all of the patients in this group had lumbar hypolordotic pattern (out of the normal range), with 70 % of them achieving normal lumbar lordosis postoperatively. The average LSA, lumbar lordotic angle and correction rates in sagittal contours postoperatively and at the last visit were statistically similar in all patient groups. Thus, sagittal contours could be successfully treated in all patients whether they had high or low dysplastic spondylolisthesis or whether they underwent reduction or not. Pearson correlations did not reveal any significant associations between the correction rates in sagittal contours and preoperative LSA and extent of displacement (p>0.05). This also seems to support our conclusion regarding the impact of instrumentation on the outcome of surgical treatment regardless of the type of spondylolisthesis and extent of displacement.

Disability scales have been used for many years for assessing the clinical outcomes in patients with spondylolisthesis (20,22). As in our study, Ishara et al. used the Japanese Orthopaedic Association low-back syndrome assessment scale in patients with isthmic spondylolisthesis. In that study in which patients were followed for a minimum duration of 10 years, the preoperative, postoperative and follow-up JOA scores were 9.7, 13.6, and 13.8, respectively (15). Kimura et al. used the same scoring for degenerative spondylolisthesis (16). In recent years, the importance of evaluating the patient-oriented clinical outcomes is increasingly recognized. Among them, SRS is considered the most important assessment tool (10). Helenius showed that SRS questionnaire correlated with Oswersty disability score (14). The Turkish version of SRS-22 (1) used in our study has also been shown to correlate with JOA scale (p < 0.05).

The 4 groups consisting of patients with low or high dysplastic spondylolisthesis were compared with respect to the impact of reduction on the clinical outcome using SRS-22 and JOA scores. In all groups, a statistically significant (p < 0.05) improvement in JOA scores occurred postoperatively, with only minimal loss at the final visit. Similarly the average domain scores for pain, function, self-image, mental status and patient's satisfaction with the treatment in the SRS-22 questionnaire were greater than 4 for each of these domains.

When groups were compared with regard to JOA and SRS-22 scores (i.e. clinical outcomes), there were no significant differences between the 4 groups in the SRS-22. The surgical treatment with instrumentation and posterolateral fusion were associated with successful clinical outcomes, regardless of the type of spondylolisthesis and whether or not

they underwent reduction. The improvement in JOA and SRS-22 scores were not significantly associated with age, preoperative displacement rate, LSA, and the postoperative improvement in displacement ($p>0.05$). Clinical outcomes were significantly associated with postoperative improvement in the LSA only ($p < 0.05$). These results suggest that the reduction in displacement does not influence the clinical outcomes, and rather the correction in sagittal contours accounts for the improvement in clinical outcomes. The possibility that restoring the normal vertebral alignment will reduce the pain, at least biomechanically, needs to be evaluated in the long-term; therefore with the available data, it would be inappropriate to comment on this subject.

Main challenging issues regarding spondylolisthesis are the decrease in the fusion area due to the application of decompression and difficulty of determining the fusion mass during follow-up due to the presence of instrumentation. Recommended and most helpful method for the detection of fusion mass is utilization of Ferguson graphies (21). In the present study, in addition to Ferguson graphies, increase in pain, implant failure and any increase in slippage were also taken into consideration. Csecsei et al. have reported a fusion rate of 95.7% in 46 patients who underwent posterolateral fusion (6). In their study, Grzegorzewksy and Kumar have reported no case of pseudoarthrosis with posterolateral fusion (11). In our study, pseudoarthrosis developed in 2 patients (5 %). 7 patients had Lenke grade B and C insufficient fusion. On the other hand, a solid mass was obtained in 77.7% of patients.

Ishara et al. have reported a fusion rate of 83% with anterior interbody fusion; in this study (n=35) pain scores deteriorated after postoperative year 5 and degeneration was noted in the upper and lower adjacent facets and intervertebral joints (15). These findings are supported by the results of Lai et al. (19). After an average follow-up of 37.9±11.9 months, none of our patients had degenerative changes and associated pain. However, definitive conclusions cannot be drawn with our limited follow-up.

Lenke and Britwell considers neural decompression as a natural component of the surgical treatment of spondylolisthesis, and the extent of decompression depends on the location of compression and the severity of neurological impairment (21). Generally, decompression narrows the fusion area, but complete decompression is the most effective means of achieving neurological recovery (8). Theoretically, reduction may reduce the need for neural decompression (9), however a total reduction is also associated with the risk of causing neurological deficits (28). Schoeneker suggests that the risk of developing cauda equina syndrome during reduction is approximately 6% (27). In our study, we preferred to use bilateral modified Gill neural decompression, in order to avoid narrowing the fusion area. While all patients preoperatively had neural claudication, paresthesia, and hypoesthesia, neurological symptoms significantly improved in all patients but one (97.5 %). Furthermore, no patients had additional neurological impairment at the last visit.

Booth et al. employed posterior instrumentation in 49 patients with spondylolisthesis and reported implant insufficiency in 2 % of these cases (4). No cases of implant insufficiency were observed in our study, though 2 patients (4%) had superficial infections that were eradicated with local debridement and antibiotic treatment and resulted in a delay in wound healing. No other systemic or local complications were noted.

CONCLUSION

In this study, satisfactory clinical results were obtained by neural decompression, sagittal contour correction with posterior instrumentation and posterolateral fusion in patients with low and high dysplastic spondylolisthesis. Anterior slippage reduction did not have any additional favorable effect on clinical results. Patient age, level or type of listhesis, amount of

slippage and certain operative variables (eg. bleeding) did not show a correlation with clinical outcomes. LSA value showing the degree of local angulation at the level of spondylotic vertebrae significantly correlated with clinical outcomes. Present findings indicate that sagittal contour correction by posterior instrumentation is an effective treatment of choice in developmental dysplastic spondylolisthesis with mild to moderate slippage.

REFERENCES:

1. **Alanay A, Cil A, Berk H, Acaroglu RA, Yazici M, Akcali O, Kosay C, Genc Y, Surat A, 2005.** Reliability and validity of adapted Turkish version of Scoliosis Research Society-22 (SRS-22) questionnaire. Spine; **30 (21)**: 2464-2468.

2. **Bartolozzi P, Sandri A, Cassini M, Ricci M, 2003.** One-stage posterior decompression-stabilisation and trans-sacral interbody fusion after partial reduction for severe L5-S1 spondilolisthesis. Spine ; **28**: 1135-1141.

3. **Benli IT, Tüzüner M, Kıs M, Aydin E, Gürses L, Bavbek M, 1997.** The results of posterior instrumentation and PLIF in the patients with spinal stenosis. J Turkish Spine Surg.; **8**: 101-105

4. **Booth KC, Bridwell Klt, Eisenberg BA, Baldus CR, Lenke LG, 1999.** Minimum 5-year results of degenerative spondylolisthesis treated with decompression and instrumented posterior fusion. Spine ; **24**: 1721-1727.

5. **Christensen FB, Laursen M, Gelineck J, Hansen ES, Bünge, CE, 2001.** Posterolateral spinal fusion at unintended levels due to bone-graft migration. Acta Orthop Scand.; **72**: 354-358.

6. **Csecsei G, Klekner AP, Dobai J, Lajgut A, Sikula J, 2000.** Posterior interbody fusion using laminectomy bone and transpedicular screw fixation in the treatment of lumbar spondylolisthesis. Surg Neural.; **53**: 2-7

7. **Cunningham BW, Lewis SJ, Long J, Dmitriew AE, Linville DA, Bridwell KH, 2002.** Biomechanical evaluation of lumbosacral reconstruction techniques for spondilolisthesis. Spine ; **27**: 2331-2327.

8. **DeWald RL, 1997.** Spondylolisthesis. In: Bridwell KH, DeWald RL, eds. The Textbook of Spinal Surgery, 2nd Ed. Philadelphia: Lippincott-Raven Publishers, pp: 1201-1210.

9. **Edwards CC, 1997.** Reduction of spondylolisthesis. In: Bridwell KH, DeWald RL, eds. The Textbook of Spinal Surgery, 2nd Ed. Philadelphia: Lippincott-Raven Publishers, pp: 1317-1335.

10. **Haher TR, Gorup JM, Shin TM, Homel P, Merola AA, Grogan DP, et al, 1999.** Results of scoliosis Research Society instrument for evaluation of surgical outcome in adolescent idiopathic scoliosis. Spine; **24**: 1435-1440.

11. **Grzegorzewski A, Kumar J, 2000.** insitu posterolateral spine arthrodesis for grades 3, 4 and 5 spondilolisthesis in children and adolescent. J Ped Orthop.; **20**:506-511.

12. **Ha KY, Chang CH, Kim KW, Kim YS, Na KH, Lee JS, 2005.** Expression of estrogen receptor of the facet joints in degenerative spondylolisthesis. Spine 2005; **30**: 562-566.

13. **Harms J, Jeszensky D, Stultze D, Bühm H, 1997.** True spondylolisthesis reduction and mono segmental fusion in spondylolisthesis. In: Bridwell KH, DeWald RL, eds. The Textbook of Spinal Surgery, 2nd Ed. Philadelphia: Lippincott-Raven Publishers, pp: 1337-1356.

14. **Helenius I, Lamberg T,　Österman K, Schlenska D, Yrjünen T, Tervaharticalla P, et al, 2005.** Scoliosis research Society outcome instrument in evaluation of long-term surgical results in spondylolysis and low-grade isthmic spondylolisthesis in young

patients. Spine ; **30**: 336-341.

15. **Ishihara H, Osada R, Kanamori M, Kawaguchi Y, Ohmori K, Kimura T, Matsui H, Tsuji H, 2001.** Minimum 10-year follow-up study of anterior lumbar interbody fusion for isthmic spondylolisthesis. J Spin Disorders ; **14**: 91-99

16. **Kimura I, Shingu H, Murata M, Hashiguchi H, 2001.** Lumbar posterolateral fusion alone or with transpedicular instrumentation in L4-5 degenerative spondylolisthesis. J Spin Disorders 2001;**14**:301-310.

17. **Kumar R, Niall D, Walsh A, Khalilullah K, McCormack D, 2002.** Spina bifida occulta in isthmic spondylolisthesis: a surgical trap. Eur Spine J. ; **11**: 159-161.

18. **Kwon BK, Berta S, Daffner SD, Vaccaro AR, Hilibrand AS, Grauer JN, et al, 2003.** Radiographic analysis of transforaminal lumbar interbody fusion for the treatment of adult isthmic spondylolisthesis. J Spin Disorder Tech.; **16**: 469-476.

19. **Lai PL, Chen LH, Niu CC, Fu TS, Chen WS, 2004.** Relation between laminectomy and development of adjacent segment instability after lumbar fusion with pedicle fixation. Spine; **29**: 2527-2532

20. **Lawlis GF, Cuencaas R, Selby D, McCoy CE, 1989.** The development of the Dallas Pain Questionnaire. An assesment of the impact of spinal pain on behavior. Spine; **14**: 511-516.

21. **Lenke LG, Bridwell KH, 1997.** Adult spondilolisthesis with lysis. In: Bridwell KH, DeWald RL, eds. The Textbook of Spinal Surgery, 2nd Ed. Philadelphia: Lippincott-Raven Publishers, pp: 1269-1298.

22. **Louisia S, Antact P, Babinet A, Tomeno B, Revel M, Poiraudeau S, 2001.** Long term disability assessment after surgical treatment of low grade spondylolistesis. J Spin Disorders; **14**: 412-426.

23. **Marchetti PG, Bartolozzi P, 1997.** Classification of spondylolisthesis as a guideline for treatment. In: Bridwell KH, DeWald RL, eds. The Textbook of Spinal Surgery, 2nd Ed. Philadelphia: Lippincott-Raven Publishers, pp: 1211-1254.

24. **Müller H, Hedlund R, 2000.** Instrumented and noninstrumented posterolateral fusion in adult spondylolisthesis. A prospective randomised study: Part 2. Spine; **25**: 1716-1721.

25. **O'Brein MF, Kuklo T, Blanke KM, Lenke LG, 2004.** Spinal Deformity Study Group. Rediographic Measurement Manual. Medtronic Sofamor Danek USA, pp: 95-110.

26. **Rombold C, 1966.** Treatment of spondylolistesis by posterolateral fusion, resection of the pars interarticularis, and prompt mobilization of the patient. J Bone Joint Surg. (Am.) ; **48**: 1282-1300

27. **Schoenecker PL, 1997.** Developmental spondylolisthesis without lysis. In: Bridwell KH, DeWald RL, eds. The Textbook of Spinal Surgery, 2nd Ed. Philadelphia: Lippincott- Raven Publishers pp: 1255-1261

28. **Smith JA, Deviren V, Berven S, Kleinstveck F, Bradford DS, 2001.** Clinical outcome of trans-sacral interbody fusion after partial reduction for high-grade L5-S1 spondylolystesis. Spine; **26**: 2227-2234.

29. **Wiltse LL, Rotman SLG, 1993.** Spondylolisthesis: classification diagnosis, and natural history. Semin Spinal Surg.; 264.