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Frontal and Sagittal Balance Analysis of Late Onset Idiopathic Scoliosis Treated with Third Generation Instrumentation

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As scoliotic curve is a rotational deformity, derotation maneuvre was used as the corrective factor, but recent studies demonstrated spinal imbalance and decompensation problems in patients treated with this method. This study evaluates 217 late onset idiopathic scoliosis patients surgically treated with third generation instrumentation (Texas Scotish Rite Hospital System - TSRH) from September 1991 to November 1996 with a minimum 2 years follow up. Preoperative and postoperative Cobb angles in the frontal plane and thoracic kyphosis and lumbar lordosis angles in the sagittal plane are measured. The balance was analyzed clinically and radiologically by measurement of the lateral trunk shift (LT), shift of head (SH) and shift of stable vertebra (SS) in vertebral unit (VU). At final follow - up correction loss, infection and other complications were documented. Mean age of the patients was 14.8 ± 2.3 and mean follow up period 55.8 ± 29.5 months. When all the patients were included, preoperative mean Cobb angles of major curves in the frontal plane was 59.1° ± 20.7°. Major curves that were corrected by 34.8 ± 20.5 % in the bending radiograms were achieved by 58.9 ± 19.5 % correction postoperatively. At the last control, 7.3° ± 6.4° of correction loss was recorded in major curves in the frontal plane. Also postoperative kyphosis angle and lumbar lordosis angles were 31.4° ± 11.6° and 30.6° ± 10.9° respectively. Postoperatively, a statistically significant correction was obtained in LT, SH and SS values. None of the patients had complete balance (SH: 0 VU, SS: 0 VU) preoperatively. Only 39.2 % of the patients had clinically balanced curves (0 VU < SH < 0.5 VU and 0 VU < SS < 0.5 VU). Postoperatively, 47.9 % of the patients were found to be completely balanced, while 43.8 % had a balanced curve. Overall 91.7 % of the patients had a trunk balance after surgical intervention. The remaining 8.3 % imbalanced curve rate raised up to 16.6 % at final follow up, but the loss of correction rates in SS and SH values were found to be insignificant. The postoperative "imbalance" problem was mostly seen in Type II and Type IV curves. However, at final follow up, the imbalance problem due to overcorrection which became evident especially by "shift of head" to opposite side was seen in all types of curves. It is established that high correction rates can be obtained in scoliotic curves with third - generation instrumentation. No undue effects were observed in the uninstrumented lumbar curves. Thoracic sagittal contours of the hypokyphotic patients were improved. Use of this instrumentation system causes minimal imbalance problems and with proper preoperative planning high correction rates can be achieved.

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In recent years, the development of "three plane deformity concept" in scoliosis surgery has led to the popularization of the Cotrel-Dubousset Instrumentation (CDI) throughout the world. This system utilizes a rigid frame with multiple hooks placed on the strategic vertebrae, double rods, and direct transverse traction (DTT) system. In the frontal plane, especially in flexible thoracic lordoscoliosis, this system has high correction rates in all curve patterns. High success in reconstituting physiological sagittal contours and correction of rotational deformity by the derotation maneuvre with minimal loss of correction at follow-up has been reported with this system [1,5,10,11].

Surgeons of the Texas Scottish Rite Hospital (TSRH) developed a spinal instrumentation system which is basically a modification of CDI. The most important differences of TSRH system from other systems are that elements such as connectors and blockers are eliminated and the hooks are connected to the rods with a "three point locking system" [2]. In 1994, they reported the first results in the treatment of adolescent idiopathic scoliosis [25].

Although high correction rates with CD instrumentation in scoliosis patients are reported, studies showing decompensation and imbalance problems have cast doubt on the value of this system because derotational effect also affects neutral vertabrae [20,23-24,30-31,34]. Technically, the same disadvantages are also relevant for TSRH instrumentation because selection of strategic vertebrae and corrective maneuvers are similar; however, only a few studies of this system are reported in the literature. This study evaluates the success of third generation instrumentation in correcting scoliotic deformity, investigates its effect on trunk balance, and discusses the results in terms of the literature.

MATERIAL AND METHODS

The first TSRH instrumentation in our clinic was performed in September 1991. From September 1991 to November 1996, 217 patients were operated on at the treatment of idiopathic scoliosis at the 1st Department of Orthopaedics and Traumatology of Ankara Social Security Hospital for the treatment of idiopathic scoliosis using TSRH instrumentation. Mean follow-up period was 55.8 ± 29.5 months. Eighty-five (39.2 %) of the patients were male and 132 (60.8 %) female. Mean age of patients undergoing operation was 14.8 ± 2.3 years.

Preoperatively, patients were evaluated in detail by clinical, radiological and laboratory examinations. Preoperatively, in addition to standing posterioanterior and lateral radiographs, radiograms were taken of the patients lying on right and left sides bending and standing traction. In these radiograms, the most rigid curve with the highest rotation at apical vertebra and wide angle was considered as the major curve and the angles of the curves were measured by Cobb method. The Cobb angles of the upper and lower secondary curves were also measured with a similar method. On lateral radiograms, sagittal contours between T2 to T12 and L1 to L5 vertebra were measured, again by Cobb method. Normal thoracal physiological kyphosis and physiological lumbar lordosis was regarded as 30° to 50° and 40° to 60° , respectively [4]. All measurements were made together with radiologists. Sagittal contours were given (+) and (-) angle values if they had kyphotic and lordotic patterns, respectively. Besides, the patients were evaluated with MR imaging to detect any congenital abnormality.

Preoperatively, early postoperatively and at the latest follow-up, anteroposterior, lateral and bending radiograms of the patients in erect position taken, Cobb angles in both frontal and sagittal planes measured and their correction percentages calculated.

Curves were grouped according to King Classification [15]. In the Type I curve, lumbar curve is larger than the thoracic curve or is less flexible on side bending radiographs. In the Type II curves, where the lumbar curve is more flexible than the thoracic curve. The Type III curves represent a true right flexible thoracic scoliosis. The Type IV curves are usually long thoracic curves. The patient with the Type V curve has double thoracic curve. Appropriate planning in use of the third-generation system was done in accordance with the conclusions of the studies reported by Herring and Johnson [2,25]. Anterior discectomy and release was performed in patients with major curves above 70° which was corrected less than 50 % in the bending radiograms and in patients who had spontaneous fusion and severe vertical structural changes. Disc space at the planned number (minimum 3, maximum 6) was excised and anterior release performed. Preoperatively, it was decided that, as well as discs in the proximity of the apex of the curve, discs found to be fixed in bending radiograms: that is, discs with marked asymmetrical narrowing and those between the vertebra, should be released. The number of discs planned for release varied with the angle of rigidity of the curve. Discs were totally removed without a substantial difference between preoperative planning and intraoperative application. To this end, a very thin chips bone was removed from end plates with a fine chisel. Vertebral arteries at these levels were not ligated. If the rib deformity was significant (> 4 cm), thoracoplasty was added to the levels by resecting 2 -3 cm of the costa on which discectomy was performed and one or two staged posterior instrumentation and fusion were performed. Of ninety patients with type I curve, 3 had one staged, of 67 patients with Type II curve, 4 had one staged, 7 had two staged of 24 patients with Type IV curve, 3 had one staged, one had two staged anterior release and fusion and posterior instrumentation and only posterior instrumentation and posterior fusion was performed to the remaining 200 patients. Two stage patients had also halo-traction for about 10 to 21 days; a halo chair was used to prevent osteoporosis and any complication was not observed during traction. In patients with Type I curves, the secondary thoracic curve was also included in the fusion area with posterior instrumentation and posterior fusion. In patients with Type II curves, selective thoracic posterior instrumentation and posterior fusion was performed if the lumbar curve was below 40°. In 29 patients with Type II curves and a lumbar curve more than 40°, the lumbar curve was included in the fusion and instrumentation to prevent decompensation. The remaining 38 patients had a large flexible minor lumbar curve, and a selective thoracic fusion and instrumentation was done. In Type III curves, distal neutral vertebra was instrumented with a reverse hook with compression on the concave side to prevent decompensation. In patients with Type IV curves, a long instrumentation was performed that spanned entire curve and particular attention was given for not ending the instrumentation at the apex of the thoracal curve. The first 46 patients had only hooks and the following 171 patients had both hooks at the thoracic region and transpedicular screws at the thoracolumbar and lumbar region. The upper vertebra where transpedicular screws were placed was T-11. All patients underwent a posterior fusion with a mixture of their local and iliac autologous grafts and allogenic bone grafts (From Bone Bank: 75, cadaver tutoplast bone graft: 33 and University of Florida Bone Bank graft: 109).

Autologous blood transfusion was done in all patients using the "cell-saver" (Electromedics) system. Intraoperatively, the autotransfusion unit saved an average of 810 ± 145 cc of blood, and an average of 1.7 ± 0.8 units of saved blood was transfused. None of these patients needed homologous blood transfusion. The hematocrit value was reduced to 0.7 ± 0.6 mg/dl on average, which was found to be statistically significant ($p < 0.05$). The mean operation time was 1.3 ± 0.9 h. Wake-up test was performed in the first 20 patients. After it has become available, the "somatosensory evoked potentials" (SSEP) were monitored in 90 patients (using the Cadwell-Quantum 80 system). For the last 107 patients of this study, SSEP and "Transcranial cortical magnetic stimulation-motor evoked potentials" (TkMMEP) were combined for neurologic intraoperative monitoring.

Antibiotic prophylaxis was administered in all patients preoperatively with 2g first-generation cephalosporine or 1g sulbactam amphycilline and maintained during postoperative 3 days, dose being reduced to 0.5 gr daily. The patients were turned to their sides during the first postoperative day and were seated on the second day. On the third day, they were encouraged to walk. No postoperative cast or brace was utilized.

Balance analysis of patients was done clinically and radiologically. Shoulder asymmetry and distance from the center of gravity measured by a plumb line swinging from C7 and intergluteal crisis was determined. In addition, the subjective complaints of the patients were recorded. Three radiologic parameters were analyzed on the radiographs taken preoperatively, soon after surgery and at the last follow up for analysis of trunk balance: Lateral Trunk shift (LT), Shift of Head (SH) and Shift of Stable vertebra (SS). (Figure 1). LT was measured as the

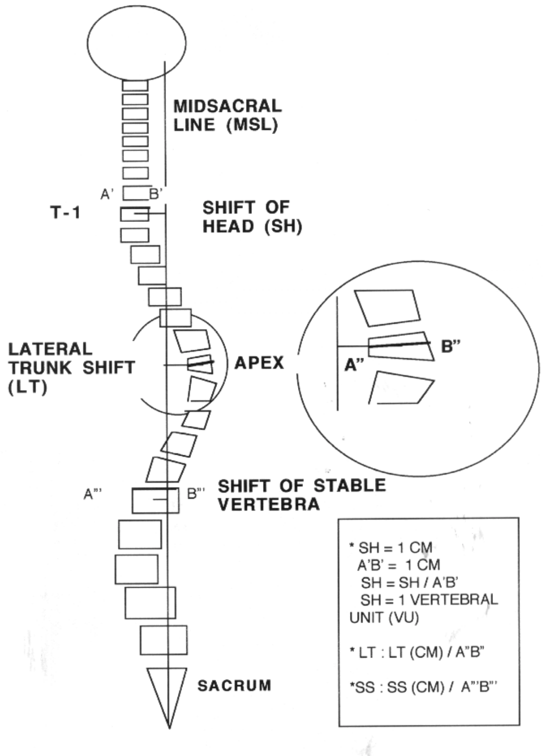

Figure 1. Radiologic parameters of trunk balance. Lateral trunk shift (LT) is the distance between the midpoint of apical vertebra and mid-sacral line. Shift of stable vertebra (SS) is the distance between midpoint of stable vertebra and mid-sacral line. Shift of head (SH) is the distance between mid-sacral line and mid-point of seventh cervical vertebra.

distance from midpoint of apical vertebra of major curve to the mid-sacral line (MSL). SH was measured as the distance between the MSL and mid point of the seventh cervical vertebra. SS was measured as the distance between midpoint of stable vertebra and the MSL. All measurements were divided by the transverse diameters of vertebra to account for the variations in X-rays magnification and patient size. This new standardized measurements, the "Vertebral Unit" (VU) was obtained to allow for comparison between patients [6]. If SH and SS were close to 0 VU, i.e., if the vertebra is in the middle line, that curve is considered a "completely balanced" one. If the SH and SS are higher than 0 VU but lower than 0.5 VU, as a clinically recognizable imbalance was not noticed, it was regarded as clinically "balanced". The Cobb angles of secondary curves below and above the curves were measured to determine decompensation. In addition, the effect of surgical treatment on these curves was also investigated.

Last evaluation were done in November 2000 and patients with a minimum follow-up of two years were included in this study. At the last visit, the patients were evaluated clinically, radiologically and frontal and sagittal plane Cobb angles and correction loss of balance values were noted. Additionally, subjective complaints of the patients related to balance, implant failure, and other complications were recorded. The statistical evaluation was made using the "Difference Between Means For Paired Observations" test and the "Chi-Square" test.

RESULTS

A. Frontal and Sagittal Plane:

1) Type I Curves:

In this group there were 19 patients. The mean preoperative Cobb angle was 56.3° ± 13.5° in the lumbar and 33.9° ± 17.3° in the thoracic curve. Postoperative correction rates in the thoracic and lumbar curves were 54.5 ± 22.3 % and 59 ± 36.2 % respectively. The correction rates achieved postoperatively were higher than those measured in bending radiograms (t: 3.21, $p < 0.05$) with a statistically significant difference (t-lumbar: 3.99, $p < 0.05$; t-thoracic: 3.66, $p < 0.05$). Preoperative thoracic kyphosis angle and lumbar lordosis angles were corrected to 31.9° ± 10.2° and 37.4° ± 10.9° respectively. Thus, normal physiological thoracic kyphosis (30°-50°) was restored in 14 (73.7 %) and lumbar lordosis (40°-60°) in 13 (68.4 %) patients (Table I).

2) Type II Curves:

There were 67 patients in this group. Mean preoperative Cobb angle was 76.1° ± 23.6° in the thoracic region and 45.6° ± 18.7° in the lumbar region. Postoperatively, mean 51.8 ± 19.9 % correction was obtained, which was more than that measured in the bending radiograms (t: 6.32 , $p < 0.05$) (Figure 2). Mean 49.9 ± 24.5 % correction was achieved in lumbar curves (t-thoracic: 6.61, $p < 0.05$; t-lumbar: 7.55, $p < 0.05$). Preoperative mean thoracic kyphosis

Table I . Breakdown of cases according to deviation from physiological thoracal (T) (30°-50°) and lumbar (L) (40°-60°) sagittal contours after instrumentation with TSRH.

SAGITTAL CONTOUR	Type I		Type II		Type III		Type IV		Total	
	T	L	T	L	T	L	T	L	T	L
Within Normal limits	14 (73.7 %)	13 (68.4 %)	44 (65.7 %)	21 (31.3 %)	69 (64.5 %)	25 (23.3 %)	15 (62.5 %)	4 (16.7 %)	142 (65.5 %)	65 (29.9 %)
Deviation Less than 10°	2 (10.5 %)	1 (5.3 %)	19 (26.9 %)	33 (49.3 %)	32 (29.9 %)	43 (40.2 %)	7 (29.2 %)	9 (37.5 %)	60 (27.6 %}	84 (38.7 %)
11°-20° deviation	2 (10.5 %)	4 (21 %)	3 (4.5 %)	10 (14.9 %)	5 (4.7 %)	19 (17.8%)	2 (8.3 %)	9 (37.5 %)	12 (5.5 %)	42 (19.4 %)
Deviation more than 20°	1 (5.3 %)	1 (5.3 %)	1 (2.9 %)	3 (4.5 %)	1 (0.9 %)	20 (18.7 %)	0 (0.0 %)	2 (8.3 %.)	3 (1.4 %)	26 (12.0 %)
TOTAL	19 (100 %)	19 (100 %)	67 (100 %)	67 (100 %)	107 (100 %)	107 (100 %)	24 (100 %)	24 (100 %)	217 (100 %)	217 (100 %)

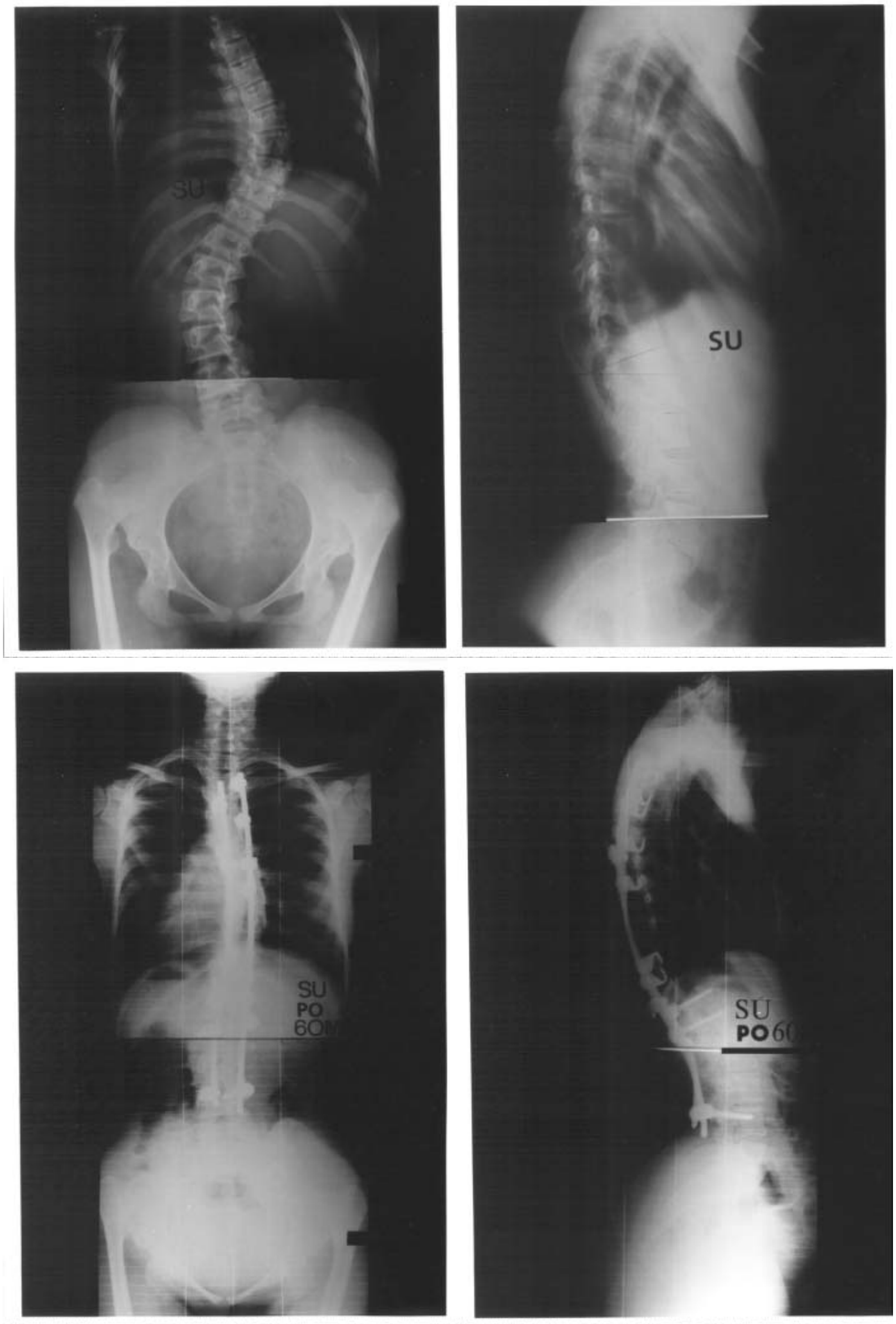

Figure 2. The patient (SU) had Type II curve. His preoperative (a (upper left), b (upper right)), and postoperative 60th month follow - up control (c (lower left), d (lower right)) PA and lateral radiographies. There was 82 % correction in Cobb angle postoperatively.

angle was 32° ± 26.4° and postoperatively it was 35.6° ± 13.6° (t: 1.51, $p > 0.05$). But in 44 (65.7 %) patients this value was in the physiological sagittal range limits in the thoracic region (30°-50°) (Table Ⅰ).

Preoperative lumbar lordosis was 26.8° ± 16.8° and corrected to 35.9° ± 10.1° postoperatively (t: 3.90, $p < 0.05$). Normal physiological lumbar lordosis (40°-60°) was obtained in 21 (31.3 %) patients in this group (Table I). In order to understand whether the lower correction rate in lumbar region compared to thoracic region was related to extension of instrumentation to lumbar region, we divided the Type II patients to two groups: (1) selective instrumentation and (2) long instrumentation.

Table II . Preoperative (PR) and postoperative (PO) Cobb angles of major curves, thoracal kyphosis (TK) and lumbar lordosis (LL) of the patients with Type II idiopathic scoliosis treated with TSRH instrumentation and their correction percentages (CP %*)*, in the frontal and sagittal plane according to the type of instrumentation (Selective fusion and instrumentation : SF -I, Long fusion and instrumentation : LF -1) (±SD : standard deviation).

TYPE OF CURVES	PR-Cobb	PO-Cobb	t	p	CP % Cobb	PR-TK	PO-TK	t	p
SF-I (n: 22)	41.8°±25.6°	38.0°±24.4°	4.21	<0.05	67.9±21.8	27.7°±19.7°	34.2°±12.9°	1.06	>0.05
LF-I (n: 45)	47.3°±32.7°	46.5°± 30.7°	6.21	<0.05	54.1 ±18.6	31.6°± 18.8°	35.9°± 10.3°	0.92	>0.05
Total (n: 67)	76.1°±23.6°	38.4°± 22.9°	7.55	<0.05	51.8±19.9	32.0°± 26.4°	35.6°± 13.6°	1.51	>0.05

TYPE OF CURVES	PR-LL	PO-LL	t	p
SF-I (n: 22)	24.6°± 14.6°	27.6°± 10.3°	1.43	>0.05
LF-I (n: 45)	27.3°± 18.1°	34.7°± 10.0°	3.82	<0.05
Total (n: 67)	26.8°± 16.8°	35.9°±10.1°	3.91	<0.05

Twenty-two patients (32.8 %) had selective fusion (Table II). The correction rate obtained in the frontal plane was statistically significant (t: 4.21, $p < 0.05$) but the correction so thoracic kyphosis and lumbar lordosis was not sufficient (t-thoracic: 1.06, $p > 0.05$, t-lumbar: 1.43, $p > 0.05$). In fourty-five patients with Type II curves, the lumbar curve was also instrumented as well. Postoperative correction rate at the sagittal plane in the lumbar region was statistically significant (t: 3.82, $p < 0.05$) (Table II). Although difference in correction was not observed in the thoracic frontal and sagittal planes, there was a statistically significant difference in lumbar lordosis in the selective instrumentation group compared to the short instrumentation using.

The postoperative thoracic and lumbar sagittal contour angles, correction rates and standard deviations are shown in Table III with and without lumbar curve instrumentation. In both groups, the number of patients had the physiological thoracic kyphosis (30°-50°) was comparable postoperatively (Selective instrumentation: 68.2 %, long instrumentation: 66.7 %). Distribution of the patients according to deviation from physiologic thoracic sagittal contours was not statistically significant ($p > 0.05$). Yet, 9.1 % physiologic lumbar lordosis was achieved with short instrumentation, compared to 46.7 % with long instrumentation.

Type II patients were divided into four groups according to preoperative thoracic kyphosis angles and classified as (1) lordotic (below 10°), (2) hypokyphotic (between 10°-30°), (3) normokyphotic (30°-50°) and (4) hyperkyphotic (50° and over). Effect of instrumentation on frontal and sagittal contours was investigated. Preoperative and postoperative values and

Table Ⅲ. Breakdown of cases of Type II with selective fusion and instrumentation (SF -1) or with long fusion and instrumentation (LF -1) according to deviation from physiological thoracal (T) (30°-50°) and lumbar (L) (40°-60°) sagittal contours after instrumentation with TSRH.

SAGITTAL CONTOUR	SF-I		LF-I		Total	
	T	L	T	L	T	L
Within normal limits	15 (68.2 %)	2 (9.1 %)	30 (66.7 %)	21 (46.7 %)	44 (65.7 %)	23 (34.3 %)
Deviation less than 10°	6 (27.3 %)	11 (50.0 %)	11 (24.5 %)	20 (44.4 %)	19 (26.9 %)	3 (4.5 %)
11°-20° deviation	1 (4.5 %)	7 (31.8 %)	2 (4.4 %)	3 (6.7 %)	3 (4.5 %)	10 (14.9 %)
Deviation more than 20°	0 (0.0 %)	2 (9.1 %)	2 (4.4 %)	1 (2.2 %)	1 (2.9 %)	3 (4.5 %)
TOTAL	22 (100 %)	22 (100 %)	45 (100 %)	45 (100 %)	67 (100 %)	67 (100 %)

correction rates in the frontal and sagittal planes of these four groups and statistical analysis is seen in TableⅣ. All correction rates in frontal plane were statistically significant ($p < 0.05$) with highest correction rate in hypokyphotic patients (58.8 ± 20.7 %), followed by normokyphotic patients (53.2 ± 15.9 %). There was statistically significant difference in thoracic sagittal contours in all groups ($p < 0.05$). Normal physiological kyphosis (30°-50°) was achieved in 88.9 % of lordotic patients and 44.4 % of hypokyphotic patients (TableⅤ). Distributions of all four groups were found to be statistically significant and best results were obtained in lordotic patients.

3) Type III Curves:

In this group, all of the 107 patients underwent posterior surgery. Mean preoperative Cobb angle was 50.1° ± 12.9°. Postoperatively major thoracic curve was corrected by 64.8 ± 17.3 % with a decrease to 18.4° ± 11.0° (t: 9.86, $p < 0.05$) (Figure3). The correction rate achieved with surgery was higher than that with the bending radiograms with a statistically significant difference (t: 7.81, $p < 0.05$).

Preoperative mean kyphosis angle was 21.3° ± 18.8° and mean lumbar lordosis was 23.1° ± 12.6°. Postoperatively, mean thoracic kyphosis angles were corrected to 31.9° ± 9.7° with statistically significant correction (t: 5.16, $p < 0.05$). In 69 (64.5 %) patients, thoracic physiological kyphosis (30°-50°) was restored and it was achieved in 32 (29.9 %) patients with 10° of deviation (Table Ⅰ). Postoperative mean lumbar lordosis was 33.6° with a statistically significant correction. However, the correction rate in lumbar curve was not as high as in the thoracic curves and only 25 patients (23.3 %) were brought within physiological lumbar sagittal limits (Table Ⅰ)

As in Type II patients, Type III patients were also divided into 4 different groups according to preoperative status of thoracic sagittal contours and the effect of instrumentation on frontal and sagittal contours are investigated. Preoperative and postoperative mean frontal and sagittal curve angles, their correction rates and statistical analysis are outlined in TableⅣ. Correction rates in frontal plane in all four groups were found to be statistically significant as in Type II patients ($p < 0.05$). Highest correction rate in this group was obtained in patients with lordotic preoperative sagittal pattern. In all groups except normokyphotic group, the correction rate in thoracic sagittal contours was statistically significant. The distribution of the patients

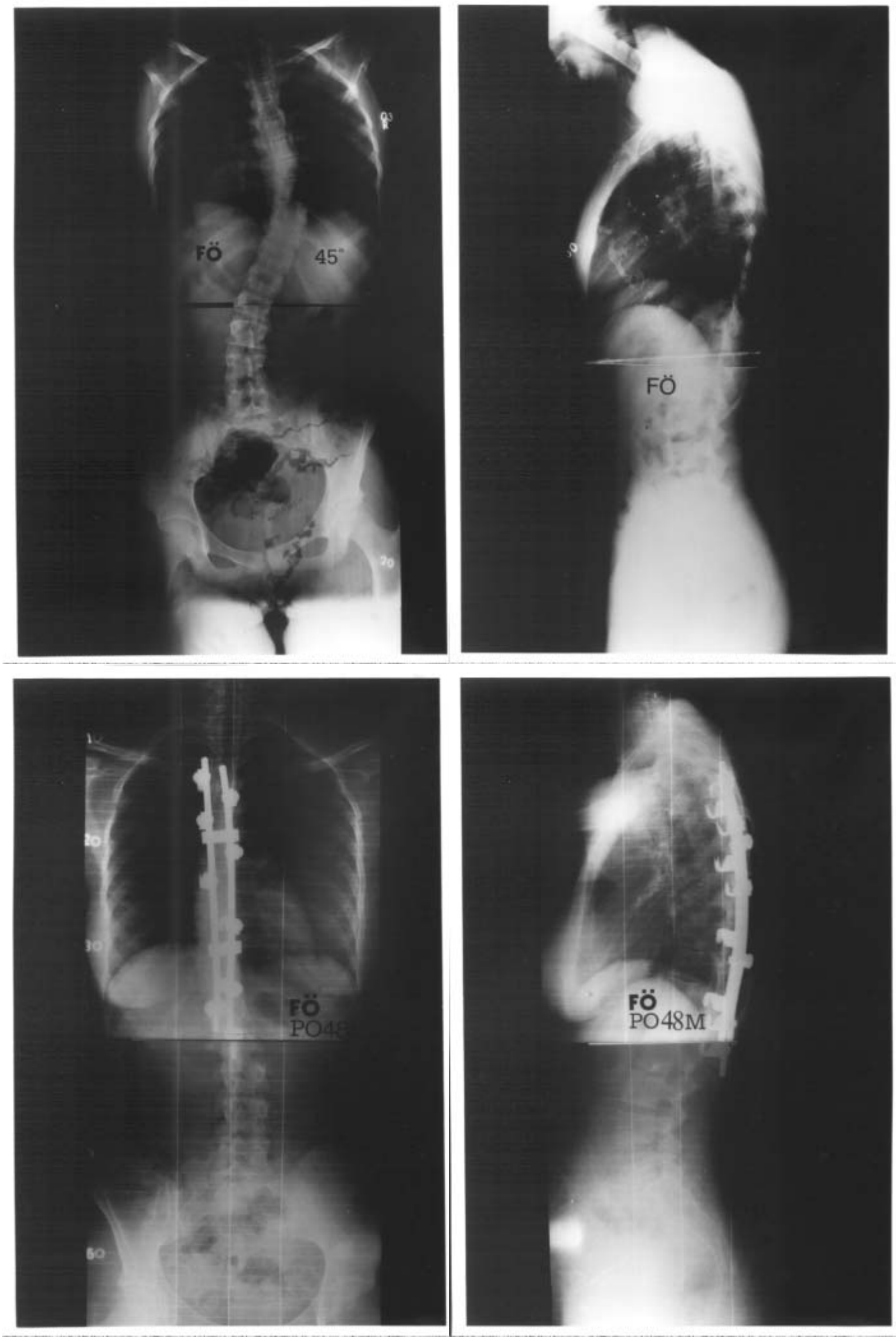

Figure 3. The patient (FO) was a 16 years old girl, with Type III curve. Her preoperative (a (upper left), b (upper right)), and postoperative 48th month follow - up control (c (lower left), d (lower right)) PA and lateral radiographies. There was 87 % correction in Cobb angle postoperatively and 4° correction loss at the last control.

TableIV. Preoperative (PR) and postoperative (PO) Cobb angles of major curves, thoracic kyphosis (TK) and lumbar lordosis (LL) of the patients with Type II and Type III idiopathic scoliosis treated with TSRH instrumentation and their correction percentages (CP %), in the frontal and sagittal plane according to the type of preoperative thoracal sagittal pattern (PRE-SAG.) (Lordosis : LOR, Hypokyphosis : HYPO, Normokyphosis : NOR, Hyperkyphosis : HYPER) (±SD : standard deviation).

TYPE – II									
PRE- SAG.	PR - Cobb	PO - Cobb	t	p	CP % Cobb	PR-TK	PO-TK	t	p
LOR (n: 9)	83.9° ± 31.5°	48.8° ± 36.6°	2.61	<0.05	48.3 ± 23.7	(-2.56° ±9.4°)	34.8° ± 7.1°	2.81	<0.05
HYPO (n: 27)	65.7° ± 17.1°	26.8° ± 14.2°	4.8	<0.05	58.8 ± 20.7	17.3° ± 6.1°	26.5° ± 8.4°	3.52	<0.05
NORM (n: 15)	76.4° ± 18.9°	37.9 ± 17.8°	3.55	<0.05	53.2 ± 15.9	37.9° ± 7.1°	43.3° ± 6.4°	2.07	>0.05
HYPER (n : 16)	88.9° ± 25.9°	52.5° ± 20.6°	3.5	<0.05	40.8 ± 15.4	70.7° ± 13.4°	48.6° ± 10.5°	3.23	<0.05
Total (n : 67)	76.1°± 23.6°	38.4° ± 22.9°	7.55	<0.05	51.8 ± 19.9	32.0° ± 26.4°	35.6° ± 13.6°	1.51	>0.05
TYPE – III									
PRE – SAG.	PR – Cobb	PO – Cobb	t	p	CP % Cobb	PR-TK	PO-TK	t	p
LOR (n : 24)	51.5° ± 10.9°	19.0° ± 11.5°	4.61	<0.05	62.8 ± 18.4	(-1.2° ± 7.9°)	35.0° ± 5.2°	4.63	<0.05
HYPO (n: 57)	46.1° ± 9.8°	15.4° ± 8.9°	7.21	<0.05	67.7 ± 15.6	19.7° ± 6.6°	27.9° ± 9.2°	5.14	<0.05
NORM (n: 18)	55.3° ± 15.1°	23.6° ± 12.3°	3.85	<0.05	58.9 ± 21.9	37.1° ± 5.5°	37.7° ± 6.9°	0.27	>0.05
HYPER (n: 8)	62.5°± 21.1°	26.4° ± 13.5°	2.61	<0.05	62.5 ± 11.1	64.5° ± 13.3°	39.3° ± 15.7°	2.63	<0.05
Total (n: 107)	50.1° ± 12.9°	18.4° ±11.0°	9.86	<0.05	64.8 ± 17.3	21.3° ± 18.8°	31.9° ± 9.73°	5.16	<0.05

TableV. The breakdown of Type II and Type III patients according to thoracal sagittal contours achieved postoperatively in different kyphosis patterns (Within normal limits : 30°-50°).

SAGITTAL CONTOUR	LORDOSIS		HYPOKYPHOSIS		NORMOKYPHOSIS		HYPERKYPHOSIS		TOTAL	
	Type II	Type III	Type II	Type III	Type II	Type III	Type II	Type III	Type II	Type III
Within normal limits	8 (88.9 %)	21 (87.5 %)	12 (44.4 %)	26 (45.6 %)	14 (93.3 %)	17 (94.4 %)	10 (62.5 %)	5 (62.5 %)	44 (65.7 %)	69 (64.5 %)
Deviation less than 10°	1 (11.1 %)	3 (12.5 %)	12 (44.4 %)	26 (45.6 %)	1 (6.7 %)	1 (5.6 %)	5 (31.3 %)	2 (25.0 %)	19 (26.9 %)	32 (29.9 %)
11°-20° deviation	0 (0.0 %)	0 (0.0 %)	2 (7.4 %)	4 (7.6 %)	0 (0.0 %)	0 (0.0 %)	1 (6.2 %)	1 (12.5 %)	3 (4.5 %)	5 (4.7 %)
Deviation more than 20°	0 (0.0 %)	0 (0.0 %)	1 (3.8 %)	1 (1.8 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	1 (2.9 %)	1 (0.9 %)
TOTAL	9 (100 %)	19 (100 %)	27 (100 %)	57 (100 %)	15 (100 %)	18 (100 %)	16 (100 %)	8 (100 %)	67 (100 %)	107 (100 %)

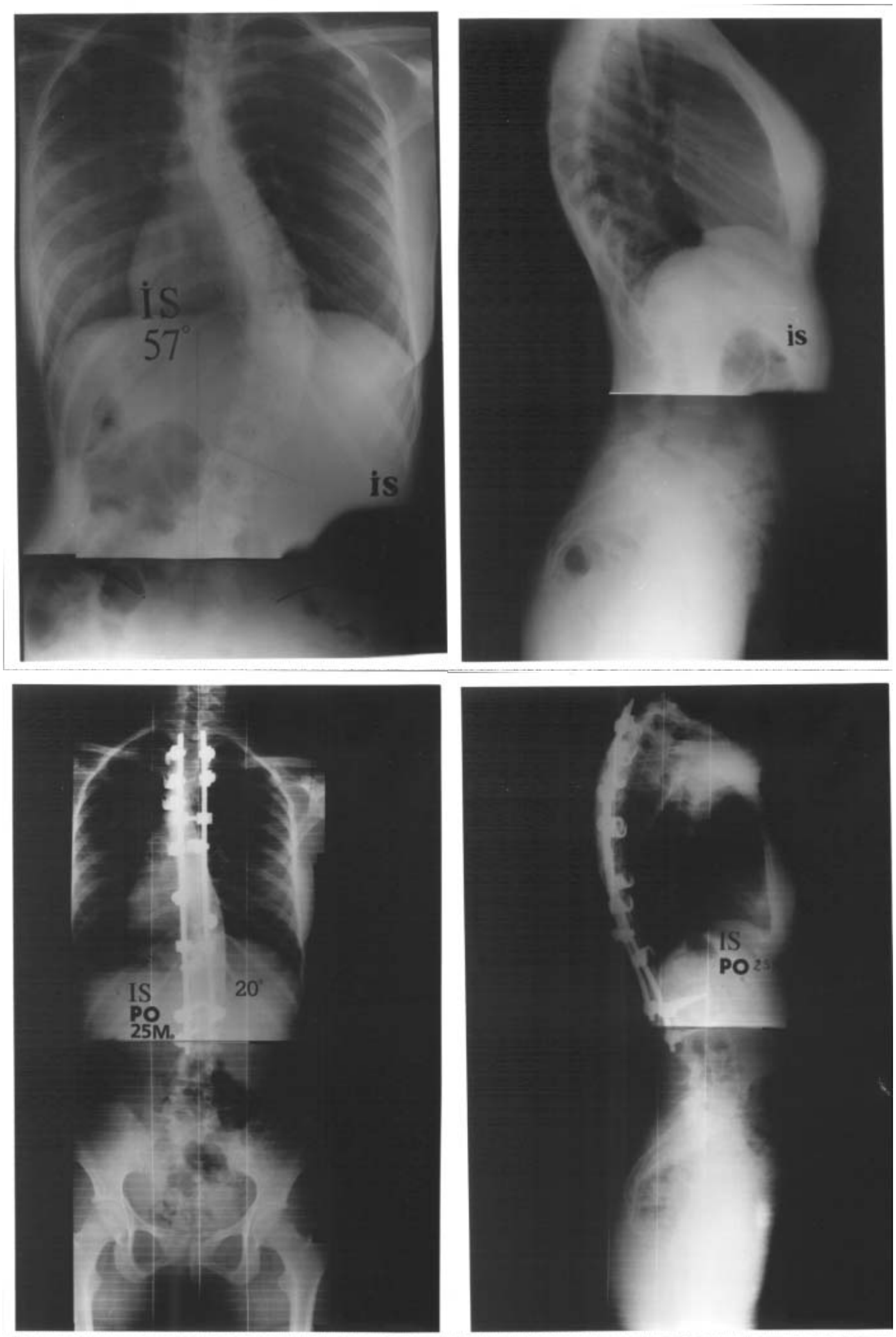

Figure 4. The patient (IS) had Type IV curve. Her preoperative (a (upper left), b (upper right)), and postoperative 25th month follow - up control (c (lower left), d (lower right)) PA and lateral radiographies. There was 80.7 % correction in Cobb angle postoperatively and 9° correction loss at the last control.

according to postoperative thoracic kyphosis is seen in Table V. The frequency of distribution was statistically significant as in Type II patients ($p < 0.05$).

4) Type IV Curves:

In this group, there were 24 patients. Mean Cobb angle of thoracolumbar curves was 54.4° ± 16.4° preoperatively, with a correction rate of 57.8 ± 18.7 % postoperatively that was statistically significant (t: 3.93, $p < 0.05$) (Figure 4). Preoperative mean thoracic kyphosis and lumbar lordosis angles were 28° ± 21.3° and 23.2° ± 11.9° respectively and they were corrected to 31.9° ± 11.8° and 28.2° ± 8.9° postoperatively. Their correction rates were not statistically significant ($p > 0.05$). Physiological sagittal contours were obtained in 15 (62.5 %) patients at the thoracic region (30°-50°) and in only 4 (16.7 %) in the lumbar region (40°-60°). Nevertheless, thoracolumbar junction kyphosis (mean 16.4° ± 7.4°) accompanying these curves was reduced to 14.4° ± 6.0° after instrumentation and this correction rate in junctional kyphosis (22.4 ± 11.4 %) was not significant. This was seen particularly in patients with only posterior instrumentation. Preoperative mean thoracolumbar junction kyphosis of 20.5° ± 2.2° was corrected by 94.8 % postoperatively in 3 patients with combined anterior release and posterior instrumentation and in 1 patient with anterior release and instrumentation with Cotrel-Dubousset-Hopf instrumentation.

5) Overall Assessment:

Overall, the mean Cobb angle of the major curves at the frontal plane was 59.1° ± 20.7°. While there was 34.8 ± 20.5 % correction in the bending radiograms, the postoperative correction rate was higher than that shown in the bending radiograms (58.9 ± 19.5 %) with a statistically significant difference (t: 11.15, $p < 0.05$). When all the groups were compared, the highest correction rate was obtained in Type III curves (64.8 %), followed by Type IV curves (57.8 %). Overall, mean correction loss was 7.3° ± 6.4° and highest loss rate was 7.9° ± 7.3° and 7.1° ± 6.9° in Type II and Type I curves respectively.

The preoperative thoracic kyphosis of 25.6° ± 21.7° and lumbar lordosis of 24.5° ± 14.3°, were corrected to 31.4° ± 11.6° and 30.6° ± 11.2° respectively with statistically significant correction rates (t-thoracic: 3.47, $p < 0.05$; t-lumbar: 5.02, $p < 0.05$). Overall, normal physiological sagittal contours (30°-50°) were achieved in 142 of the patients (65.5 %) at the thoracic and 65 of the patients (29.9 %) at the lumbar region (40°-60°) (Table I). Inclusion of patients with 10° of deviation from normal limits showed 93.1 % of correction at the thoracic and 68.6 % at the lumbar region.

B. Balance Analysis:

Clinically, the shoulder asymmetry became less in all patients, and there was no complaint in this respect. The distance between the plumbline and the intergluteal crisis was brought to 0.8 ± 0.6 cm postoperatively, while it was 3.6 ±1.9 cm preoperatively ($p < 0.05$).

Preoperative LT, SS and SH values of all patients were 1.59 ± 0.75 VU, 0.53 ± 0.48 VU and 0.66 ± 0.56 VU and corrected by 54.4 ± 28.5 %, 53.8 ± 45.6 % and 56.9 ± 41.5 % respectively (Table VI), all being statistically significant (t-LT: 11.4, $p < 0.05$; t-SS: 8.77, $p < 0.05$; t-SH: 8.73, $p < 0.05$). All preoperative and postoperative balance parameters and correction rates of the groups are seen in Table VI. The preoperative LT values in Type I, II, III and IV curves were 1.16 ± 0.47 VU, 2.03 ± 0.91 VU, 1.40 ± 0.51 VU and 1.55 ± 0.80 VU were brought to 0.89 ± 1.3 VU, 1.14 ± 0.80 VU, 0.54 ± 0.47 VU and 0.71 ± 0.51 VU respectively. The correction rates were found to be statistically significant in all types of curves except Type I curves. Correction rates obtained in LT values correlated the correction rates in Cobb values of the curves in frontal plane. The highest correction rate was found in Type III curves which was followed by Type IV curves.

TableⅥ. According to the type of curves, preoperative (PR) and postoperative (PO) trunk balance values of the patients treated with TSRH. (LT : Lateral trunk shift, SS : Shift of Stable vertebra, SH : Shift of Head, COR % : rates of correction, LC : loss of correction, t: probability, n : number of the patients, ±SD : standard deviation)

TYPE OF CURVES	TYPE I (n:19)	TYPE II (n:67)	TYPE III (n:107)	TYPE IV (n:24)	TOTAL (n:217)
PR-LT	1.16 ± 0.47 VU	2.03 ± 0.91 VU	1.40 ± 0.51 VU	1.55 ± 0.80 VU	1.59 ± 0.75 VU
PO-LT	0.89 ± 1.3 VU	1.14 ± 0.8 VU	0.54 ± 0.47 VU	0.71 ± 0.51 VU	0.78 ± 0.74 VU
t	0.87	6.61	9.21	3.86	11.43
p	>0.05	<0.05	<0.05	<0.05	<0.05
COR%-LT	45.2 ±28.5	46.2 ±27.2	61.9 ± 28.1	50.7 ± 26.5	54.4 ± 28.5
LC-LT	0.12 ± 0.23 VU	0.31 ± 0.67 VU	0.52 ± 0.48 VU	0.06 ± 0.32 VU	0.37 ± 0.41 VU
PR-SS	0.52 ± 0.44 VU	0.68 ± 0.60 VU	0.44 ± 0.39 VU	0.45 ± 0.38 VU	0.53 ± 0.48 VU
PO-SS	0.33 ± 0.46 VU	0.33 ± 0.53 VU	0.15 ± 0.26 VU	0.19 ± 0.23 VU	0.23 ± 0.39 VU
t	2.54	4.89	6.15	3.22	8.77
p	<0.05	< 0.05	<0.05	<0.05	<0.05
COR % - SS	45.9 ± 38.9	54.2 ± 42.9	54.5 ± 50.0	55.9 ± 38.2	53.8 ±45.6
LC-SS	0.08 ± 0.12 VU	0.07 ± 0.22 VU	0.03 ± 0.2 VU	0.05 ± 0.27 VU	0.05 ± 0.21 VU
PR-SH	0.81 ± 0.80 VU	0.82 ± 0.61 VU	0.55 ± 0.49 VU	0.62 ± 0.40 VU	0.66 ± 0.56 VU
PO-SH	0.45 ± 0.83 VU	0.34 ± 0.38 VU	0.20 ± 0.30 VU	0.26 ± 0.31 VU	0.27 ± 0.40 VU
t	2.83	4.89	5.92	3.31	8.73
p	<0.05	<0.05	<0.05	<0.05	<0.05
COR %-SH	54.2 ± 0.17	52.7 ± 41.8	60.0 ±42.3	56.6 ± 40.0	56.9 ± 41.5
LC-SH	0.08 ± 0.16 VU	0.10 ± 0.40VU	0.14 ± 0.98 VU	0.11 ± 0.34	0.12 ± 0.73

The correction rate in SS and SH values of all types of curves was statistically significant ($p < 0.05$) (TableⅥ). All types of curves distributed as "completely balanced" (SH: 0 VU and SS: 0 VU), "balanced" (0 VU < SH < 0.5 VU and 0 VU < SS < 0.5 VU), or "imbalanced" (SH > 0.5 VU, SS > 0.5 VU) are seen in TableⅦ. None of the patients were completely balanced preoperatively. Totally 85 patients (39.2 %) had clinically balanced curves, while 132 patients (60.8 %) had abnormal balance patterns.

Postoperatively the patients with Type I, II, III and IV curves were balanced or completely balanced with a rate of 89.4 %, 91.1 %, 93.5 % and 97.5 % respectively. Overall 95 patients (43.8 %) were found to be balanced, while 104 patients (47.9 %) had a complete balance in which SS and SH values were brought to 0 VU. The best results were obtained with type III curves. Totally 199 of all patients in our series (91.7 %) had either a "completely balance" or a "balanced curve".

Although the instrumentation had an affirmative effect on the balance values of the curves, imbalance continued in 10.6 % of the patients with Type I curves, 8.9 % of the patients with Type II curves, 6.5 % of the patients with Type III curves, and 12.5 % of the patients with Type IV curves (overall 8.3 % of the patients) (Table Ⅶ). Among these, 2 of the patients (10.5 %) with Type I curves, 4 of the the patients (5.9 %) with Type II curves, 4 of the patients (3.7 %)

Table VII. Distribution of the patients regarding curve types according to preoperative (PR), postoperative (PO) and final follow up OFF) values of shift of stable vertebra (SS) and shift of head (SH). (CB: complete balance [SH: OVU.SS: OVU],B: balanced curve [0 VU < SH < 0.5 VU,0<SS< 0.5 VU],CB+B: sum of patients with balanced curve, IB ; imbalanced curve [SH>0.5VU, SS>0.5 VU]).

	TYPE I (n : 19)			TYPE II (n : 67)			TYPE III (n : 107)		
	PR	PO	FF	PR	PO	FF	PR	PO	FF
CB	0 (0%)	7 (36.8%)	6 (31.6%)	0 (0%)	29 (43.3%)	12 (17.9%)	0 (0%)	56 (52.3%)	53 (49.5%)
B	6 (31.6%)	10 (52.6%)	10 (52.6%)	20 (29.9%)	32 (47.8%)	43 (64.2%)	50 (46.7%)	44 (41.2%)	44 (41.1%)
CB+B	6 (31.6%)	17 (89.4%)	16 (84.2%)	20 (29.9%)	61 (91.1%)	55 (82.1%)	50 (46.7%)	100 (93.5%)	97 (90.6%)
IB	13 (68.4%)	2 (10.6%)	3 (15.8%)	47 (70.1%)	6 (8.9%)	12 (17.9%)	57 (53.3%)	7 (6.5%)	10 (9.4%)
TOTAL	19 (100%)	19 (100%)	19 (100%)	67 (100%)	67 (100%)	67 (100%)	107 (100%)	107 (100%)	107 (100%)

	TYPE IV (n : 24)			TOTAL (n : 217)		
	PR	PO	FF	PR	PO	FF
CB	0 (0%)	12 (50%)	6 (25%)	0 (0%)	104 (47.9%)	77 (35.5%)
B	9 (37.5%)	9 (37.5%)	7 (25-9%)	85 (39.2%)	95 (43.8%)	104 (47.9%)
CB+B	9 (37.5%)	21 (87.5%)	13 (50.9%)	85 (39.2%)	199 (91.7%)	181 (83.4%)
IB	15 (62.5%)	3 (12.5%)	11 (49.1%)	132 (60.8%)	18 (8.3%)	36 (16.6%)
TOTAL	24 (100%)	24 (100%)	24 (100%)	217 (100%)	217 (100%)	217 (100%)

with Type III curves, and 2 of the patients (8.3 %) with Type IV curves (totally 12 patients - 5.5 %) had decreasement in SH and SS values although imbalance continued. Two of the patients (2.9 %) with Type II, and one of the patients (4.2 %) with Type IV curves increasement in SH and SS values, because the instrumentation was one to three levels lower than it should be, when the bending radiograms of these patients were evaluated retrospectively. When bending radiograms were re-evaluated three of the patients with Type III curves whom had an increasement in SH and SS values were actually found to be Type V curves, because the cervicothoracic major curves were missed. The SH and SS values improved because the instrumentation was lower than it should be. Finally because of wrong planning and application, 8 (3.7 %) patients developed "imbalance" problems.

Correction loss in LT, SS and SH values at final follow up are seen in TableVI. Overall correction loss of patients in LT, SS and SH values were 0.37 ± 0.41 VU, 0.05 ± 0.21 VU and 0.12 ± 0.73 VU respectively. At final follow up, the loss of correction in LT, SS and SH values was statistically insignificant in all types of curves ($p < 0.05$). One of the patients with Type I curves, 17 of the patients with Type II curves, 3 of the patients with Type III curves and 6 of the patients with Type IV curves had an increasing in SS and SH values at final follow up, although they were completely balanced curves postoperatively. Therefore the rate of completely balanced curves regressed from 47.9 % to 35.5 %. However, the increase in SH and SS values were less than 0.5 VU, so the curves remained "balanced". As a result 199 (91.7 %) patients were either balanced or completely balanced postoperatively, this was found to be in 181 (83.4 %) patients at final follow up. This correction loss was mostly seen in Types II and IV curves which had the most rigid curves. Overall the number of 8 imbalanced patients (8.3 %) postoperatively raised up to 36 (16.6 %) at final follow up. Eighteen of these 36 imbalanced patients remained imbalanced. Ten of the postoperatively balanced patients had an increasement in SS and SH values (> 0.5 VU) and became imbalanced. Three of these patients had Type II curve and 7 of them had Type IV curves.

SH and SS values increased in one patient with Type I curve and after 53 months of follow up correction loss in the major curve was 5°. Lumbar curve was corrected by 58 %, and thoracic curve by 100 %. It was noted that overcorrection caused the superior cervicothoracic half curve to increase and head shifted by 0.25 VU to the opposite direction, with slight shoulder asymmetry. Also at follow up, SS and SH values of 3 patients with type II curve (4.3 %) shifted to opposite direction of the correction due to over correction. In addition, in 3 (2.8%) patients with Type III curves. SS and SH values shifted in the opposite direction at final follow up. Only in one patient with Type IV curves (4.2 %) SS and SH values shifted towards the opposite direction.

Examination of patients at last evaluation, for subjective complaints in balance revealed that derotation maneuver did not cause a rotational effect on pelvis.

C. Complications:

1) Pseudoarthrosis and Implant Failure:

Two lumbar screws were broken in one patient (5.3 %) with Type I curve. As 5° of correction loss and a solid fusion mass was observed in this patients, after 53 months of follow -up, implants were not removed and revised. Implant failure was noted in three (4.4 %) patients with Type II curves with one rod breakage, one proximal and one distal convex hook dislodgement. In the former patient, implant was removed in the postoperative month 24. At the last evaluation, this patient had 30° of correction loss. The implant of the patient with proximal hook dislodgement in the postoperative third month was removed in postoperative month 36. Correction loss was 22°. In the latter patient, hooks were re-implanted in postoperative month 4, 19° of correction loss was noted at last control (month 85).

Distal hooks of one patient with Type III curve were dislodged in postoperative month 6. Implants of this patient were removed in month 17, with 15° of correction loss at the final follow up. Proximal convex claw hooks were dislodged in one patient with Type IV curve (4.2 %) whose implants were removed in postoperative month 47 and 10° of correction loss was noted at last control. Overall, 6 patients (2.8 %) had implant failure.

Radiologically, presence of significant consolidation, and absence of implant failure and correction loss and clinically pain relief was considered as the proof of a posterior solid fusion mass. Including 6 patients with implant failure and 6 patients with correction loss over 15° at the frontal plane, 12 (5.5 %) patients were thought to have pseudoarthrosis. These patients were reoperated and refusion was performed. In 10 patients with correction loss between 10° - 14° reoperation was not considered and they were only followed until consolidation was observed radiologically.

2) Infection:

Early superficial infection was observed in 5 (2.3 %) patients. Slight wound opening and serohemorrhagic leakage was seen in these patients and was eradicated with medical treatment and dressing. Deep late wound infection was seen in 3 (1.4 %) patients and Staphylococcus Aureus was isolated. Sulbactam Ampisilin 0.5 gr twice daily was instituted. Irrespective of medication, implants were removed and debridment done. After 6 weeks of chemotherapy, infection was totally eradicated and as solid fusion occurred in these patients, revision was not indicated.

3) Neurologic deficit:

Four (1.8 %) patients among first 20 patients had neurologic deficit. Only wake up test was used for neurologic monitoring had in these patients. In one patient with Type II curve, late distal paraplegia occurred on the second postoperative day, attributed to hypovolemia and hypoxia. Implants were removed in the same day and 4x4 gram of Dexamethasone was instituted. With active rehabilitation, this patient is now mobilized with walking orthosis.

In 3 patients with incomplete neurological deficit implants were not removed. Two were totally treated in second week with postoperative steroid therapy. In remaining one patient all neurological disorders were treated except slight dorsiflexion loss. In the early postoperative period this patient had incomplete neurologic deficit below L1 level. After the rehabilitation program the neurological status of the patient improved and the deficit remained limited to the L5-S1 level. Later on the dorsiflexion loss was minimalized by tendon transfer to the dorsum of the foot. In the 197 patients in whom intraoperative neurological monitorization with SSEP and TkMMEP was conducted, no neurological deficit occurred.

DISCUSSION

In the last decade, the three-plane deformity concept of idiopathic scoliosis has led to the evolution of spinal instrumentations correcting the deformity in all three planes. Multiple level fixation with wires or hooks at strategic vertebrae, double rods and transverse connecting devices have become the state-of-the-art technology in addressing this complex problem [(8,9)].

Cotrel-Dubousset system has found a wide utilization in spinal surgery in the recent years and there are a number of reports suggesting its high correction potential in all planes when compared to other systems [(7,10,11,23)] with the derotation maneuvre, correction of rotational deformity in the transverse plane, which is a revolution in spinal surgery, can be achieved [(5,10)].

Third-generation systems are technologically and metalurgically improved systems and also has developed application strategies. Multiple hook applications to the strategic vertebrae, "claw" applications to the proximal and distal part of the curve, new locking mechanisms and improved transverse connectors made these systems biomechanically safer and led higher correction rates to be achieved [(10,25-27)]. One of these third-generation systems is Texas Scottish Rite Hospital (TSRH) system [(2)].

Richards and coworkers presented the results obtained with 103 patients treated with TSRH system that basically uses a correction maneuver similar to CD instrumentation but builds a rigid frame with 3 - point locking system and "cross link" plates. Richards et al. were the first publication about posterior application of the system and reported 65 % of correction in thoracic curves and 48 % correction in lumbar curves in the frontal plane. They suggested that this system yields satisfactory correction results in thoracic curves in the frontal and sagittal planes [(25)].

Benli et al. reported 49.6 % of correction in major curves with CD instrumentation in 45 idiopathic scoliosis patients [(6)]. Antuno et al reported 56 % correction in thoracic and 57 % in lumbar curves of 50 patients, with 14 % to 15 % correction loss after 5-years of follow up [(1)]. Labella et al also reported 50 % correction with CD instrumentation [(16)]. In our study, overall preoperative mean cobb angle of the major curves at the frontal plane using third generation instrumentation was 59.1° corrected by 58.9 % with a statistical significance ($p < 0.05$). Mean correction loss was 11.3° after minimum follow up of 2 years.

Richards et al. reported that they exclusively used anterior instrumentation in 9 patients with Type I curve [25]. In our study, there were 19 patients in this group and we used discectomy and anterior fusion in only 3 patients whose lumbar curve exceeds 60° followed by posterior instrumentation with third-generation instrumentation as in the remaining 16 patients. Correction of 54.5 % was obtained in the thoracic and 59 % in the lumbar curves. The outcome was statistically significant ($p < 0.05$). Also in this group of patients normal physiological sagittal contours were provided in 73.7 % of patients in the thoracic region and in 68.4 % of those in the lumbar region.

Surgical planning and determination of fusion and instrumentation sites are controversial in Type II curves as postoperative sagittal plane problems are encountered [23,24]. According to King, there is a curve pattern in which the thoracic curve is larger than the lumbar curve requires fusion only of the thoracic curve [15]. Ibrahim et al. suggested inclusion of the lumbar curves exceeding 35° to the instrumentation in Type II curves [14] whereas Benli et al. and Large et al. proposed selective fusion and instrumentation could be used in lumbar curves below 40° and 50°, respectively [6,17]. In the present study including 67 patients with Type II curves, 22 patients with thoracic curves over 60° had certainly anterior release and discectomy. After surgery, patients with Type II curves were corrected by 51.8 % in the thoracic and 49.5 % in the lumbar curves, a statistically significant difference. If lumbar curve was measured over 40°, instrumentation and fusion was extended to the lumbar vertebrae. Although it wasn't statistically significant ($p > 0.05$), physiological or nearly normal thoracic sagittal contour was achieved in 92.6 % of the patients. Postoperative mean lumbar lordosis was 35.9° and the correction rate was statistically significant ($p < 0.05$). Lumbar lordosis in normal limits, however, was obtained in only 31.3 % of the patients. Correction rates in the lumbar region both in the frontal and the sagittal planes were higher in patients who had undergone extended instrumentation than those who had undergone short instrumentation. The mean correction rate in the thoracic curves in the frontal plane was 67.9 % and statistically significant ($p < 0.05$), but that in the sagittal contours was not so in contrast to sagittal correction rates obtained by long instrumentation. Normal physiological lumbar lordosis was achieved in 9.1 % of the patients undergoing short instrumentation and 46.7 % normal lordosis was achieved in patients undergoing long instrumentation.

Benli et al. reported that the highest correction rate was obtained in Type III curves by 69.4 % in patients with CD instrumentation [6]. Richards et al. reported 65 % correction in 59 Type III patients with TSRH instrumentation [25]. In the present study 107 patients with Type III patients using third-generation instrumentation were corrected by 64.8 %. Also physiological thoracic kyphosis was obtained in 94.4 % of the patients ($p < 0.05$). Sagittal contours in the lumbar region was not statistically significant, albeit with 10° of deviation from normal, lordosis was present in 63.5 % of the patients; this may be related to reverse hook pattern used at the concave side of the instrumentation. According to Bridwell, derotation maneuver could cause complications in Type II patients and only minimal correction could be obtained in the thoracic kyphosis in hypokyphotic patients [7]. In the present study, the effect of the status of the preoperative thoracic sagittal contours on the postoperative correction rates following derotation maneuver was also investigated. The highest correction rates in the frontal plane were achieved in the patients with hypokyphotic pattern, but the highest correction rates in the sagittal plane were achieved in the patients with lordotic pattern, indicating the effect of derotation maneuver on the sagittal contours when compared to other curve patterns.

Benli et al. reported 51.4 % correction with CD instrumentation in Type IV patients [6]. In the present study, 57.8 % correction was obtained in the frontal plane with a statistically significant difference ($p < 0.05$). The correction in the thoracic and lumbar sagittal contours was not statistically significant ($p > 0.05$). However, in 4 Type IV patients, that had anterior release or instrumentation previously, 54.9 % correction was achieved.

Shufflebarger found no loss of correction using CD instrumentation [27]. Puno found 12 % loss of correction in King Type II curves and 8 % loss in King III curves [22]. Richards et al. reported 33° of correction loss in Type I, 37° in Type II and 27° in Type III and IV patients [25]. In the present study, after 55.8 months follow up, 7.1° , 7.9°, 5.4° and 13.5° correction loss was noted in Type I, Type II, Type III and Type IV curves, respectively. In all curve types, correction of the secondary curves were statistically significant ($p < 0.05$) without the formation of any new secondary curves.

The report of Transfeldt and colleagues in 1989 raised a controversy about the derotational effect of CDI. Thompson and coworkers introduced the concept of "en bloc" derotation of the spine. Although the maximum derotation was seen in the apical vertebra, more derotation occurred in the neutral vertebrae when compared with the intermediate vertebrae. They observed that a "junctional kyphosis" occurred in the vertebra adjacent to the instrumentation and especially in the thoraco-lumbar junction [30-31]. Wood et al. reported that, when the pelvis was taken as the reference point, the overall derotation of the spine was very small with the greatest improvement in Type II curves and the reflection of the derotation effect to uninstrumented vertebrae caused imbalance problems. They pointed out that imbalance problems were seen in the coronal and sagittal planes in Type II and IV curves and in the axial plane in Type III curves [34-35]. Gray et al. reported that the derotational effect was not correlated with curve type and was unpredictable [12]. Mason and Corango found that decompensation was 4 % in those treated with Harrigton rod and 41 % in patients instrumented with CDI [20]. Steib et al. reported that derotational effect corrected intervertebral rotation extensively but had minimal effect on segmental rotation [28]. Richards et al. suggested that overdistraction in King Type III patients and selective fusion instead of fusion in Type II patients caused decompensation [24]. Lenke et al. reported that selective fusion was successful if LT ratio of thoracic and lumbar curves was over 1.2 and that over-correction in Type II curves was the major cause of decompensation [18]. Bridwell put forth the idea that the major causes of decompensation in Type II curves were [9] : (1) inability to detect double major curves, (2) inappropriate selection of fusion and instrumentation levels, (3) progression of the lumbar secondary curve in skeletally immature patients, (4) insufficiency of structural superior thoracic curve. Benli et al. stated that the highest correction rate in LT balance values was found in Type III patients with CD instrumentation, while the highest correction loss occurred in Type IV curves [6].

TSRH Instrumentation uses the same maneuvers as CD for the correction of scoliosis (distraction, compression, and derotation) and, therefore, is susceptible to the same problems of postoperative decompensation. However, there are only a few reports about this system. In our study, overall, high correction was obtained in LT, SS and SH values respectively with a statistically significant difference ($p < 0.05$). The correction rates in LT values were correlated with the correction rates of the Cobb angles of major curves in the frontal plane. When the postoperative correction rates in the Cobb angles were evaluated it is found that the higher the correction rates of the major curves in the frontal plane the better the rates of correction in the LT values. It is also easy to explain this because the degree of the deformity in the frontal plane is the Cobb angle, the diminishing of which brings the apical vertebra to the midline and this means the lessening of the LT values. None of the patients had a complete balance preoperatively. Eighty-five of the patients (39.2 %) had clinically "balanced" curves and the remaining 132 (60.8 %) patients were imbalanced. Surgically very significant correction was obtained by means of instrumentation, as 104 of the patients (47.9 %) were "completely balanced", and 95 patients (43.8 %) had "balanced" curves. Only in 18 patients (8.3 %) of the patients, imbalance persisted. Twelve of these patients had still imbalanced curves although SH and SS values decreased.

Lenke et al. pointed out that the upper thoracic secondary curve could be structural in Type II and III curves and shoulder asymmetry and decompensation could be prevented if superior end plate of T2 vertebra is horizontal in the bending radiograms. Otherwise, this curve should be instrumented as well; if not shoulder asymmetry and decompensation would be inevitable [(18)]. In this present study, there was an insufficient preoperative planning or wrong application in 2 of the patients with Type II curves and one patient with Type IV curve, while the instrumentation level was one to 3 levels lower than it should be. The SH and SS values got worse in these patients.

Hamzaoglu et al. reported a cervicothoracic major curve in bending radiograms of some of the Type III considered curves. They found that if these patients were operated as Type III curves, the imbalance problems and an increasement in cervicothoracic major curve was likely to happen [(13)]. In our series, 3 patients with Type III curves with postoperative imbalance problem were analyzed retrospectively and considered to be actually Type V curves as reported by Hamzaoglu et al.

At final follow up, mean loss of correction in LT, SH and SS values were statistically insignificant, but the ratio of the patients with completely balanced curves decreased to 35.5 % and ratio of the patients with "balanced" curves increased to 47.9 %. Overall either completely balanced or balanced curves rate decreased from 91.7 % to 83.4 % at final follow up. Eighteen of the thirty-six patients with "imbalanced" curves at final follow up had also imbalance problems in the postoperative period with minimal loss of correction in their SH and SS values. Otherwise, 10 patients with Type II or Type IV curves became imbalanced at final follow up while they had balanced curves postoperatively. The remaining 8 patients with imbalance problems had a shift of head to opposite side (Type I: 1 patient. Type II: 3 patients. Type III: 3 patients. Type IV : 1 patient).

A major advantage of the third-generation systems is that they allow quicker mobilization of the patient and generally do not require any postoperative bracing or casting [(9-10,24)]. No casting and bracing was used in our patients. One of the major advantages of TSRH is its ease of instrumentation and revision. In CD, if the screws are broken, hooks can be removed only by cutting the rod. Because placement of the nuts are lateral in TSRH, cosmetic complaints are not heard because there are no prominent hooks and rods under the skin [(2)]. In this study, patients with distal hook dislodgement of TSRH instrumentation was easily revised. Various implant failure rates are reported in many different systems [(3,19)]. Richards et al. reported hook dislodgement in 3 patients with TSRH [(25)]. According to Bridwell, a rod rotation maneuver on the lumbar curve puts a posteriorly directed force on the last hook on the convex side and may make pulling out of that hook easier [(9)]. In our study one patient had screw breakage but correction loss was not observed until final follow up. Overall, 4 hook dislodgements were observed and implant failure rate was determined to be 2.3 %. Consistent with Bridwell's observation, hook dislodgements in our series were seen in distal hooks (3 patients).

In our study, 5.5 % of the patients had correction loss over 15°. These patients were regarded as pseudoarthrosis and these patients were reoperated and posterior fusion was performed. A solid fusion was noted in 195 (89.9 %) patients with below of correction loss at the last evaluation in our overall assessment. As a radiological consolidation was not in the remaining 10 patients with 10° between 14° of correction loss, thus, these patients were only followed up.

Richards et al. reported late infection rate to be 10 % in patients with TSRH instrumentation [(25)] who needed primary or late closure following chemotherapy. In the present study, superficial infection was observed in 2.3 % of the patients and was eradicated only with dressing and chemotherapy. Late infection was noted in 3 patients (1.4 %) of the patients. In those patients, implants were removed and debridment was done, wounds were secondarily closed and infection was eradicated with chemotherapy. Despite a substantial correction loss, a solid fusion mass was seen in all patients.

Thompson et al. in 1985 reported 16.3 % neurologic deficit with Luque wiring in scoliosis treatment [(29)]. Wilbur et al. reported 17 % neurologic deficit with 3 complete paraplegia in their series of 137 scoliosis cases [(32)]. Recently, the use of sublaminar wiring decreased, but at present neurologic deficits related to pedicular screws are being reported. Yuan et al. reported 1.5 % of paraplegia risk with pedicular screw [(36)]. In 1993, a subcommittee of SRS evaluated 6237 cases and reported that risk of neurologic deficit was reduced to 0.03 % [(33)]. Richards et al. reported no neurologic complications in their patients treated with TSRH [(25)]. In our study, we noted neurologic deficit in 4 (1.8 %) patients. Three patients with incomplete neurologic deficit improved completely. Mineiro and Weinstein reported late neurologic deficit occurring 30 hours after the operation that healed with slight motor strength loss in only extensor hallucis longus [(21)]. In our study total paraplegia was seen in one patient at the postoperative hour 48 related to hypovolemia and hypoxia. This patient was immediately reoperated and implants were removed. In spite of marked correction loss, neurologic deficit healed significantly and the patient was mobilized with active rehabilitation program.

CONCLUSION

High correction rates in the frontal plane were obtained and physiological contours were achieved significantly in all curves with third-generation instrumentation, with the highest one in Type III. In Type II curves, although lumbar lordosis was achieved in patients undergoing long instrumentation, selective instrumentation was inadequate in this respect. In type II and III curves, it was found that preoperative sagittal plane pattern in thoracic region determined postoperative sagittal contours and that normal thoracic kyphosis could be achieved in more patients in lordotic group. Yet, the best results were achieved in hypokyphotic patients in frontal plane. In type IV curves, the correction in thoracolumbar junction kyphosis was inadequate, but it could be improved by anterior release and/or anterior instrumentation. The highest correction loss was in type IV curves. In all curve types, lateral shift of apical and stable vertebrae and head had a statistically significant correction. Postoperatively great majority of the patients (91.7 %) were either "balanced" or "completely balanced". The imbalance problem persisted in 8.3 % of the patients, and the most imbalanced group was found to be Type IV curves. There was an imbalance problem appeared by increase in SH and SS values in especially Types II, III, and Type IV curves, and this problem was considered to happen due to short level instrumentation at proximal region of the curvature. At final follow up, overall imbalanced curve rate raised up to 16.6 % (36 patients). The majority of the "new" imbalanced group (10 patients) was found to be Type II and IV patients, which lost their balance with an increasement in SH and SS values. The remaining 8 patients (3.7 %) was developed imbalance problems due shift of head to opposite side. Selection of the fusion and instrumentation levels were reevaluated and they were found to be correct only one negative sign was shift of head to opposite side in these patients were considered to happen because of overcorrection during the instrumentation maneuver. It is our conviction that frontal and sagittal imbalance and decompensation problems in the patients with idiopathic scoliosis can be avoided and minimized by good preoperative planning and avoidance of overcorrection.

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REFERENCES

1. **Antuno, S.A., Mendez, J.G., Lopez-Fanjul, J.C., and Paz-Jimenez, J.** 1997. Cotrel-Dubousset instrumentation in idiopathic scoliosis at 5 - year follow - up. Acta Orthop Belg. **63**:74-81.
2. **Ashman, R.B., Herring, J.A., and Johnston. C.E.** 1992. Texas Scottish Rite Hospital (TSRH) Instrumentation System, pp: 219-248. In: The Textbook of Spinal Surgery, Eds.: Bridwell, K.H., DeWald, R.L., JB Lippincott Company, Philadelphia.
3. **Barr, S.J., Schuettke, A.M., and Emans, J.B.** 1997. Lumbar pedicle screws versus hooks. Results in double curves in adolescent idiopathic scoliosis. Spine **22**:1369-1379.
4. **Benhardt, M.** 1997. Normal spinal anatomy: normal sagittal plane alignment. Pp: 188-189. In: The Textbook of Spinal Surgery, Eds.: Bndwell, K.H., DeWald, R.L. Lippincott - Raven Publishers, Philadelphia.
5. **Benli, I.T., Akalin, S., Tuzuner, M.M., Tandogan, N.R., Citak, M., and Mumcu, E.F.** 1994. Three-dimensional analysis treated with Cotrel - Dubousset Instrumentation. GICD'93, Sauramps Medical, Montpellier. 26-35.
6. **Benli, I.T., Tuzuner M., Akalin, S., Kis, M., Aydin, E., and Tandogan, R.** 1996. Spinal imbalance and decompensation problems in patients treated with Cotrel -Dubousset instrumentation. Euro. Spine J. **5**:380-386.
7. **Bridwell, K.H., Betz, R., Capelli, A.M., Hum, G., and Harvey, C.** 1989. Sagittal plane analysis in idiopathic scoliosis patients treated with Cotrel - Dubousset instrumentation. In: 6th International Congress on CDI, Sauramps Medical, Montpellier. 65-71.
8. **Bridwell, K.H.** 1994. Spine update. Surgical treatment of adolescent idiopathic scoliosis: the basics and the controversies. Spine **19**:1095-1100.
9. **Bridwell, K.H.** 1997. Spinal instrumentation in management of adolescent idiopathic scoliosis. Clin. Orthop. Rel. Res. **335**:64-72.
10. **Chopin, D. and Morin, C.** 1992. Cotrel-Dubousset instrumentation (CDI) for adolescent and pediatric scoliosis. In: The Textbook of Spinal Surgery, Eds.: Bridwell KH, DeWald RL, JB Lippincott Company, Philadelphia, 183-217.
11. **Dubousset, J. and Cotrel, Y.** 1991. Application technique of Cotrel-Dubousset Instrumentation for scoliosis deformities. Clin. Orthop. Rel. Res. **264**: 103-110.
12. **Gray, J. M., Smith, B.W., Ashley, R.K., et al.** 1991. Derotational analysis of Cotrel-Dubousset Instrumentation in idiopathic scoliosis. Spine **16 (Suppl)**: 303-391.
13. **Hamzaoglu, A., Sar, U., Talu, U., Eralp, L., and Basturk, S.** 1994. Problems in the diagnosis and surgical treatment for King Type V idiopathic scoliosis and new classification for King Type V curves. GI CD'93, Sauramps Medical, Montpellier. 65-69.
14. **Ibrahim, K., Benson, L., and Goldberg, B.** 1989. Cotrel - Dubousset instrumentation for right thoracic type curves; compensation versus decompensation. In: 6th International Congress on CDI, Sauramps Medical, Montpellier. 59-63.
15. **King, H.A.** 1988. Selection of fusion levels for posterior instrumentation and fusion in idiopathic scoliosis. Orthop. Clin. North Am. **19**:247-55.
16. **Labella, H., Dansereau, J., Bellefleur, C., Guise, J., Rivard, C.H., and Poitras, B.** 1995. Preoperative three-dimensional correction of idiopathic scoliosis with the Cotrel -Dubousset procedure. Spine **20**:1406-1409.
17. **Large, D.F., Doig, W.G., Dickens, D.V., Torode, I.P., and Cole, W.G.** 1991. Surgical treatment of double major scoliosis. Improvement of the lumbar curve after fusion of the thoracic curve. J. Bone Joint Surg. **73-B**:121-124.
18. **Lenke, L.G., Bridwell, K.H., O'Brien. M.F. Baldus, C., and Blanke, K.** 1995. Recognition and treatment of the proximal thoracic curve in adolescent idiopathic

scoliosis treated with Cotrel - Dubousset instrumentation. Spine **19**:1589-1597.

19. **Liljenqvist, V.R., Halm, H.F., and Link, T.M.** 1997. Pedicle screw instrumentation of the thoracic spine in idiopathic scoliosis. Spine **22**:2239-2245.
20. **Mason, D.E. and Carango, P.** 1991. Spinal decompensation in Cotrel-Dubousset Instrumentation. Spine **16**:S394-403.
21. **Mineiro, J. and Weinstein, S.L.** 1997. Delayed postoperative paraparesis in scoliosis surgery. A case report. Spine **22**:1668-1672.
22. **Puno, R.M., Grussfeld, S.L., Johnson, J.R. et al.** 1992. Cotrel - Dubousset instrumentation in idiopathic scoliosis. Spine **17**:S258-262.
23. **Richards, B.S., Birch, J.G., Herring, J.A., Johnston, C.E., and Roach, J.W.** 1989. Frontal plane and sagittal plane balance following Cotrel - Dubousset instrumentation for idiopathic scoliosis. Spine **14**:733-737.
24. **Richards, B.S.** 1992. Lumbar curve response in Type II idiopathic scoliosis after posterior instrumentation of the thoracic curve. Spine **17**:S282-286.
25. **Richards, B.S., Herring, J.A., Johnston, C.E. et al.** 1994. Treatment of adolescent idiopathic scoliosis using Texas Scottish Rite Hospital Instrumentation. Spine **19**:1598-1605.
26. **Sawatzky, B.J., Tredwell, S.J., Jang. S.B., and Black, A.H.** 1998. Effect of three -dimensional assessment on surgical correction and hook strategies in multi - hook instrumentation for adolescent idiopathic scoliosis. Spine **23**:201-5.
27. **Shufflebarger, J.L. and Crawford, A.H.** 1988. Is Cotrel - Dubousset instrumentation the treatment of choice for idiopathic scoliosis in the adolescent who has an operative thoracic curve? Orthopaedics **11**:1579-1588.
28. **Steib, J.P., Ducrocq, X., Aveins, Ch., and Bogorin, I.** 1998. The importance of measuring the intervertebral rotation in the estimation of lumbar scoliosis reduction. Presented in: 5th International Meeting on Advanced Spine Techniques (IMAST), Sorento, Italy, May 1-3.
29. **Thompson, G.H., Willbur, R.E., Shaffer, J.W et al.** 1985. Segmental spinal instrumentation in idiopathic scoliosis: a preliminary report. Spine **10**:623-630.
30. **Thompson, J.P., Transfeldt, E.E., Bradford, D.S., Ogilvie, J.W., and Boachie-Adjei, O.** 1990. Decompensation after Cotrel Dubousset instrumentation of idiopathic scoliosis. Spine **15**:927-931.
31. **Transfeldt, E., Thompson, J., and Bradford, D.** 1989. Three dimensional changes in the spine following CDI for adolescent idiopathic scoliosis. In: 6th International Congress on Cotrel-Dubousset Instrumentation, Sauramps Medical, Montpellier. 73-80.
32. **Willbur, G., Thompson, G.H., Shaffer, J.W. et al.** 1984. Postoperative neurologic deficits in segmental spinal instrumentation. J. Bone Joint Surg. **66-A**: 1178-1187.
33. **Winter, R.B.** 1997. Spine update: neurologic safety in spinal deformity surgery. Spine **22**:1527-1533.
34. **Wood, K.B., Transfeldt, E.E., Ogilvie, S.W., et al.** 1991. Rotational changes of the vertebral-pelvis axis following Cotrel-Dubousset Instrumentation. Spine **16**:S404-408.
35. **Wood, K.B., Obewski, J.M., Schendel, M.S., Boachie-Adjei, O., and Gupta, M.** 1997. Rotational changes of the vertebral pelvis axis after sublaminar instrumentation in adolescent idiopathic scoliosis. Spine **22**:51-57.
36. **Yuan, H.A., Garfin, S.R., and Dickman, C.A.** 1994. Mardjetko, S.M. A historical cohort study of pedicle screw fixation in thoracic, lumbar and sacral spinal fusion. Spine **19**:S2279 - 2296.