Operative treatment of isthmic spondylolisthesis in children: a long-term, retrospective comparative study with matched cohorts

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Abstract The purpose of the present study was to compare the long-term clinical, functional and radiographic outcomes of young patients operated on before or at the onset of puberty (Children) and those operated on after that (Adolescents). The study group consisted of 298 patients operated on under the age of 20 years; 55 of them were operated on before or at the onset of growth spurt (29 females <12.5 years, 26 males <14.5 years). Preoperative data were retrieved from patients' records. After mean follow-up of 17 years (10.7–26.3), physical

examination, radiographic measurements and functional testing were performed by independent observers. SRS-24, Oswestry Disability Index (ODI), and Visual Analogue Scale (VAS) were utilised to evaluate health-related quality of life. The data were compared between the two age groups in the whole study population and in 41 pairs of patients matched by gender, operative method, severity of preoperative slip, and age at follow-up. Preoperatively, one-third of children did not have significant pain symptoms. They were operated upon for resistant postural anomalies in combination with high risk of slip progression. All of the adolescents had low-back pain as the main clinical symptom. The outcomes were satisfactory in both groups in the whole population (children vs. adolescents; low-grade slip: SRS-24: 95.9 vs. 92.0, ODI: 5.2 vs. 7.5, VAS low-back pain: 18.9 vs. 21.2; high-grade slip: SRS-24: 95.6 vs. 90.6, ODI: 3.4 vs. 6.9, VAS low-back pain: 10.5 vs. 22.1). The differences were statistically significant for ODI and VAS in high-grade patients in favor of the children. The clinical relevance of these differences seems to be minimal. The results of the comparison of the matched cohorts were comparably good. One-fifth of the whole study group had a non-union which did not affect the final outcome. In the children with high-grade slips, there was a mean slip improvement of 14 percentage points due to remodelling. The overall complication rate in the whole population was 7.7%. In conclusion, spinal fusion can be carried out at an early age for low- and high-grade spondylolisthesis with good long-term clinical, functional, radiographic and health-related quality-of-life outcomes when the indications are met.

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Introduction

The incidence of spondylolysis and spondylolisthesis is approximately 5% in children between the ages of 5 and 6 and 6–7% in adults [3, 7, 9, 30]. The natural history of spondylolysis and low-grade spondylolisthesis (<50% slip) is commonly benign, and most symptoms resolve with conservative treatment. Progression of the slip and changes in the sagittal alignment of the spine are more often seen in high-grade (>50% slip) spondylolisthesis [7, 17, 25]. Usually these deformities do not respond well to non-operative treatment [26].

The overwhelming majority of sources from the literature dealing with this entity in growing individuals present children and adolescents as one group [15, 16, 18, 24–26]. There are only a few publications reporting results on young children and even in them, the patients are generally postpubertal at the time of surgery [5, 6, 15, 23]. Remodelling of the fusion area has been noted to decrease the slip in younger children [6]. The effect of spinal growth on the outcomes of lumbosacral spinal fusion remains unclear.

The purpose of the present study was to compare the long-term clinical, functional and radiographic outcomes of surgical treatment between patients operated on at or before the onset of puberty (children) and those operated on after that (adolescents).

Patients and methods

Patients

Between 1977 and 1991, 351 consecutive patients with isthmic spondylolisthesis (72% low grade and 28% high grade) below the age of 20 were operated on at the senior author's institution. Two patients were deceased for reasons unrelated to surgery. Of the remaining 349 patients, 298 (85%) accepted to participate in the spondylolisthesis study. Reasons for refusing to participate ($n = 51$) were: lack of interest ($n = 20$; 39%), excessive travelling distances (9; 18%), pregnancy, recent delivery or difficulties with childcare (3; 6%), unknown address or abroad (11; 22%), business commitments (4; 8%) and other disease (4; 8%). The clinical and radiographic results of the whole study population have been partially published previously [11, 12, 19–21].

The pubertal growth spurt begins in Finnish girls on average at 12 years and in boys at 14 years of age [28]. Therefore, the threshold between children and adolescents was selected to be 12 (<12.5) years for females and 14 (<14.5) years for males. Fifty-five (18%) patients of the

study group ($n = 298$) were children. In order to further scrutinise the results and evaluate the effects of age and growth as reliably as possible, two matched cohorts were formed. For every child (females ≤ 12 years; males ≤ 14 years at the time of surgery; $n = 55$) an adolescent control patient (females >12 years; males >14 years), who matched the best for gender, operative method, severity of slip and age at the time of final follow-up was selected from the rest of the original study population ($n = 243$). The age at follow-up was chosen as one criterion to discard the effect of age-related spinal degeneration for back pain, spinal mobility and trunk strength. Fourteen children could not be matched sufficiently and they had to be excluded (Table 1). After the matching, the preoperative status and postoperative outcomes of these 41 matched pairs were analysed further and compared with the results of the original study population.

Table 1 Preoperative data of the children excluded from the matched cohorts

	Excluded patients
Patients	14
Sex	
Males	5 (36%)
Females	9 (64%)
Age at surgery (years)	12.1 (6.9–14.3)
Follow-up time (years)	16.2 (10.8–23.6)
Age at follow-up (years)	28.3 (20.9–37.2)
Severity of slip	
Low grade	6 (43%)
High grade	8 (57%)
Preoperative vertebral slip	45% (10–100%)
Preoperative lumbosacral kyphosis	−2.1 (−42–18)
SRS 24	98.6 (87–112)
ODI	4.4% (0–12%)
VAS	
Low back pain	10.5 (0–33)
Operative methods	
Direct repair	3 (21%)
Posterior/posterolateral	5 (36%)
Anterior	4 (29%)
Circumferential	1 (7%)
Reduction	1 (7%)
Reasons for exclusion	
No control with similar age at FFU	5 (36%)
No control with similar slip (LG or HG)	2 (14%)
No control with similar operative method	3 (21%)
No sufficient preoperative data	3 (21%)
L4 olisthesis & therefore no control	1 (7%)

Values are mean (range or standard deviation)

Study design

The study design was a retrospective comparison of two matched cohorts whose outcomes were reflected to the original study population from which they were extracted from. The outcomes of the matched pairs were evaluated after the match-up was made. The preoperative and immediate postoperative clinical data were collected from the patients' medical records. For the final follow-up examination, the patients were invited to come to the hospital. The study was carried out by independent observers from May 2002 to November 2004.

Operative procedures

In both of the matched cohort groups (children and adolescents) there were 22 (54%) patients with low-grade and 19 (46%) patients with high-grade slip. Low-grade spondylolisthesis patients ($n = 44$) were treated with uninstrumented posterior ($n = 11$) or posterolateral fusion in situ ($n = 29$) or direct repair ($n = 4$). In patients with high-grade spondylolisthesis ($n = 38$), the selection between three operative techniques represents an evolution in operative strategy at the institution. Posterolateral fusions were performed at an earlier time period. Anterior spine surgery was introduced later. Thereafter, uninstrumented anterior and circumferential in situ fusions and instrumented reductions were performed depending on the preference of the operating surgeon. Decompressions were performed primarily in seven patients (three children and four adolescents; all high grade). The details of the operative techniques have been reported previously [12, 13]. The reduction procedure was performed after bilateral L5 laminectomy and root exploration using a pedicle screw construct and combined fusion.

Clinical evaluation

Medical records were available from each patient from the time of diagnosis to the present. At final follow-up (FFU), a standardised clinical evaluation was performed including straight leg raising (SLR), sensory and motor defects (L3–S1 roots) and abnormalities in posture and ambulation. In addition, BMI, low back and thigh pain, and radicular pain were recorded.

Radiographic evaluation

Standard standing posteroanterior, lateral and lateral flexion–extension radiographs of the lumbar spine were

obtained preoperatively and at FFU. The slip was measured according to Laurent and Einola as the percentage of the width of the slipped vertebral body [15]. The lumbosacral kyphosis angle was measured between a line drawn along the posterior border of the body of S1 and another line drawn along the anterior border of the body of L5. Lumbar lordosis was measured between the lower endplates of L1 and L5. Disc height above the fusion area was assessed according to Saraste et al., as a semiquantitative comparison of the disc height at the operated level to the disc at L2–3 considered to be normal [22]. More than 3° of angular motion in the fusion area in the flexion–extension radiograph was considered a non-union.

Questionnaires

The Scoliosis Research Society 24 (SRS-24) and Oswestry Disability Index (ODI) questionnaires were translated into Finnish and mailed to all patients before their follow-up visit [8, 10]. Patients were also asked to evaluate separately their low back pain and radiating pain to lower extremities by using the visual analogue scale (VAS).

Spinal mobility and non-dynamometric trunk performance tests

Spinal mobility was determined by measuring lumbar flexion and extension in degrees with a goniometer. Trunk side-bending was measured with a tape measure from the fingertips on the thigh to the knee joint in centimetres [1]. Non-dynamometric trunk strength was evaluated by repetitive sit-up, arch-up, and squatting tests. The trunk strength results were scored from 1 (poor; < -1 SD) to 5 (excellent; > 1 SD) [2].

Statistical analysis

Statistical comparisons for quantitative data were performed by the Mann–Whitney U test for the whole study population and by Wilcoxon signed rank test for the matched cohorts. The χ^2 test or Fisher's exact test was used in categorical data depending on the cell frequency. P values equal to or below 0.05 were considered statistically significant.

Ethical aspects

The written informed consent of all participants was obtained. The authors obtained permission to perform this

study from the Ethics Committee of the hospital where the study was conducted.

Results

Whole study population

The mean follow-up time was 17 years (range, 10.7–26.3). The preoperative data of the whole study population can be seen in Table 2. At the time of surgery, there were 29 females ≤ 12 years and 26 males ≤ 14 years old. There were relatively more high-grade patients in children when compared to adolescents (51% vs. 23%; $p = 0.0009$). Therefore, relatively more children than adolescents were operated upon using the circumferential or anterior method (16/55, 29% vs. 35/243, 14%) ($p = 0.016$).

At final follow-up, in the low-grade patients, the mean SRS-24 total score was 95.9 (78–112) for the children and 92.0 (55–112) ($p = \text{NS}$ 0.125) for the adolescents. The ODI scores were 5.2 (0–22) and 7.5 (0–68) ($p = \text{NS}$) and VAS (low back pain) 18.9 (0–67) and 21.2 (0–100), respectively ($p = \text{NS}$). In the high-grade patients, the mean SRS-24 total score was 95.6 (62–112) and 90.6 (38–114) ($p = \text{NS}$ 0.143), ODI score 3.4 (0–24) and 6.9 (0–30) ($p = 0.035$) and VAS (low back pain) 10.5 (0–100) in the

children and 22.1 (0–90) in the adolescents ($p = 0.042$). There were 8 non-unions (15%; 3 reoperations) in children and 16 non-unions (7%; 9 reoperations) in the adolescents. Complication rates were 7.3 and 7.8%, respectively.

Matched cohorts

There were 22 matched pairs of patients with low-grade slips and 19 pairs of patients with high-grade slips.

Preoperative symptoms

In the low-grade children, the indication for operative treatment was low back pain interfering with daily activities and not resolving after at least 6 months of conservative treatment and modifications of sports activities in 15 (68%; 1 with radiculopathy). Of the remaining seven patients (four females and three males), five did not have pain at all; one had insignificant occasional low-back pain and the other had mild radiating pain. Their mean age at operation was 10.9 (8–13) years. The surgical procedures were performed because of high risk of slip progression in six patients (mean slip 34%, range 25–46). Three of them had documented slip progression of 10 percentage points or

Table 2 Preoperative data of the whole study population

	Whole study population ($n = 298$)					
	Low grade ($n = 214$)		p	High grade ($n = 84$)		p
	Children	Adolescents		Children	Adolescents	
Number of pts	27 (13%)	188 (87%)		28 (33%)	56 (67%)	
Sex						
Males	13 (48%)	81 (43%)	NS	13 (46%)	20 (36%)	NS
Females	14 (52%)	107 (57%)	NS	15 (54%)	36 (64%)	NS
Mean age at surgery (range)	11.8 (6.9–14.4)	15.9 (12.5–19.7)	0.0001	12.0 (7.5–14.3)	15.6 (12.7–19.6)	0.0001
Mean follow-up time (range)	18.6 (13.0–24.0)	16.8 (14.3–26.3)		17.6 (10.8–25.0)	16.5 (10.7–25.8)	
Mean age at follow-up (range)	30.4 (20.9–30.0)	32.7 (28.0–45.1)		29.7 (22.7–39.3)	32.1 (23.9–45.1)	
Mean preoperative slip (range)	27.8% (8–49%)	33.8% (0–49%)		67.0% (51–107%)	70.5% (50–103%)	
Mean preoperative lumbosacral kyphosis (range)	−18.9 (−42 to 28)	−12.4 (−42 to 51)		16.8 (−12 to 59)	16.6 (−24 to 50)	
Operative methods						
Direct repair	5 (19%)	12 (6%)	0.033	0 (0%)	0 (0%)	NS
Posterior	10 (37%)	43 (23%)	NS	0 (0%)	0 (0%)	NS
Posterolateral	11 (41%)	133 (71%)	NS	10 (36%)	13 (23%)	NS
Anterior	0 (0%)	0 (0%)	NS	9 (32%)	17 (30%)	NS
Circumferential	1 (4%)	0 (0%)	NS	6 (21%)	18 (32%)	NS
Reduction	0 (0%)	0 (0%)	NS	3 (11%)	8 (14%)	NS

Values are mean (range or standard deviation)

more. Additional preoperative symptoms in those six patients were: stiff spine ($n = 4$), hamstring tightness ($n = 4$), scoliosis ($n = 2$), paraesthesia ($n = 1$) and limp ($n = 1$). The patients were operated upon after a mean outpatient follow-up of 14 (6–24) months. Only one patient in this group of six, a 12-year-old female, was operated upon without further observation. She had a 40% slip at admission with bilateral hamstring tightness and a secondary scoliosis. The seventh patient, a girl of 11 years, had a slip of 17%. She had no pain but spinal imbalance, walking difficulties, unilateral hamstring tightness of 20 degrees and an absent Achilles reflex. She was followed and treated conservatively for 9 months before the operation. In the low-grade adolescents, the indication for operative treatment was low back pain, not responding to conservative treatment, in all 22 patients (100%; 1 with radicular pain).

In the high-grade children, the preoperative symptoms were low back pain in 12 (63%; 8 with radicular pain) and abnormal posture and/or gait in 10 (53%). Five (26%; 1 with radicular pain) of these patients had both of the symptoms, posture anomaly and low back pain. In high-grade adolescents, the symptoms were low back pain in all 19 (100%; 6 with radicular pain) patients and abnormal posture and/or gait in 1 (5%) (Table 3).

Clinical and functional tests

Preoperatively, in the low-grade patients, a positive SLR was observed in two (10%; one due to hamstring tightness) children but none in the adolescents. At the FFU, SLR was negative in all patients in both groups. Preoperatively, one of the children had an S1 nerve root motor deficit. Preoperatively, one adolescent but none of the children had significant sensory deficit in the lower extremities. At FFU, none of the patients had marked motor or sensory deficits. Scoliosis was noted preoperatively in 6 (27%) children but in none of the adolescents ($p = 0.021$). None of these patients underwent surgical scoliosis correction during follow-up. One patient from the children's group had a scoliosis at FFU. No gait and/or postural abnormalities were observed in any patient at the FFU. The average trunk side-bending on both sides at FFU was 20.4 cm (17–24) in the children and 19.4 cm (12–25) in the adolescents (Table 4).

In the high-grade patients, a positive preoperative SLR was observed in 14 (74%; 9 due to hamstring tightness) children and in 5 (all due to hamstring tightness) adolescents ($p = ?$). At the FFU, SLR was negative in all patients in both groups. Scoliosis was noted preoperatively in 8 (42%) children and 4 (22%) adolescents ($p = \text{NS}$). Two children underwent operative scoliosis correction during

Table 3 Preoperative data of the matched cohorts

	Matched cohorts					
	Low grade (<i>n</i> = 44)		<i>p</i> value	High grade (<i>n</i> = 38)		<i>p</i> value
	Children	Adolescents		Children	Adolescents	
Number of pts	22	22		19	19	
Sex						
Males	11 (50%)	11 (50%)	NS	6 (32%)	6 (32%)	NS
Females	11 (50%)	11 (50%)	NS	13 (68%)	13 (68%)	NS
Mean age at surgery (years)	12.0 (8.1–14.4)	16.8 (14.4–19.5)	0.0001	11.8 (8.5–14.4)	16.0 (12.9–19.3)	0.0001
Males	13.1 (12.0–14.4)	17.4 (14.9–19.5)	0.003	13.6 (12.5–14.4)	16.7 (15.8–18.6)	0.028
Females	10.9 (8.1–12.2)	16.2 (14.4–19.5)	0.003	10.9 (8.5–12.4)	15.7 (12.9–19.3)	0.001
Mean follow-up time (years)	19.2 (13.0–25.0)	16.0 (11.1–20.4)	0.0001	18.2 (12.5–25.0)	14.9 (11.0–25.8)	0.0001
Mean age at follow-up (years)	31.2 (24.3–38.0)	32.8 (25.9–39.7)	0.0001	30.0 (22.7–39.3)	30.9 (23.9–41.8)	0.076
Preoperative clinical findings						
Postural and/or gait abnormality	4 (18%)	0 (0%)	NS	10 (53%)	1 (5%)	0.019
SRA positive	2 (9%)	0 (0%)	NS	14 (74%)	5 (26%)	0.009
Scoliosis	6 (27%)	0 (0%)	0.021	8 (42%)	4 (22%)	NS
Operative methods						
Direct repair	2 (9%)	2 (9%)	NS	0 (0%)	0 (0%)	NS
Posterior	8 (36%)	3 (14%)	NS	0 (0%)	0 (0%)	NS
Posterolateral	12 (55%)	17 (77%)	NS	5 (26%)	5 (26%)	NS
Anterior	0 (0%)	0 (0%)	NS	6 (32%)	6 (32%)	NS
Circumferential	0 (0%)	0 (0%)	NS	6 (32%)	6 (32%)	NS
Reduction	0 (0%)	0 (0%)	NS	2 (11%)	2 (11%)	NS

Table 4 Functional test results of the matched cohorts

Characteristic	Low-grade		<i>p</i> value	High-grade		<i>p</i> value
	Children (<i>n</i> = 22)	Adolescents (<i>n</i> = 22)		Children (<i>n</i> = 19)	Adolescents (<i>n</i> = 19)	
Mean (SD) sit-up score	3.8 (2–5)	3.8 (2–5)	NS	3.2 (1–5)	3.6 (1–5)	NS
Mean (SD) arch-up score	4.4 (3–5)	4.6 (4–5)	NS	3.7 (1–5)	4.2 (3–5)	NS
Mean (SD) squatting score	4.4 (3–5)	4.8 (3–5)	NS	3.9 (1–5)	4.1 (2–5)	NS
*Abnormal lumbar flexion, <i>n</i> (%)	4 (18%)	5 (23%)	NS	10 (53%)	14 (74%)	NS
*Abnormal lumbar extension, <i>n</i> (%)	5 (23%)	1 (5%)	NS	7 (37%)	7 (37%)	NS
*Abnormal trunk sidebending, <i>n</i> (%)	0 (0%)	0 (0%)	NS	0 (0%)	0 (0%)	NS

* Abnormal when below the mean–2SD of the age- and sex-adjusted normal population values

Table 5 Radiographic outcomes of the matched cohorts

	Low grade		<i>p</i>	High grade		<i>p</i>
	Children (<i>n</i> = 22)	Adolescents (<i>n</i> = 22)		Children (<i>n</i> = 19)	Adolescents (<i>n</i> = 19)	
Vertebral slip (range)						
Preoperative	29.0% (9–49%)	26.0% (9–43%)	NS	69.5% (51–107%)	66.7% (53–93%)	NS
Final follow-up	24.4% (5–48%)	25.7% (3–49%)	NS	55.6% (23–89%)	65.2% (45–87%)	0.043
SRA (range)						
Preoperative	–20.0 (–40 to 36)	–15.6 (–30 to 16)	0.085	19.4 (–12 to 59)	14.3 (–10 to 38)	NS
Final follow-up	–12.6 (–38 to 20)	–12.7 (–29 to 5)	NS	21.5 (–11 to 48)	11.6 (–12 to 35)	0.028
Lumbar lordosis (range)						
Preoperative	48.2 (22–72)	50.9 (38–75)	NS	60.7 (26–85)	66.2 (50–97)	NS
Final follow-up	62.9 (36–88)	59.5 (36–83)	NS	72.9 (50–96)	69.6 (48–93)	NS
Non-unions at follow-up	3 (14%)	7 (32%)	NS	5 (26%)	3 (16%)	NS
Disc degeneration above the fusion						
None	13 (59%)	11 (50%)	NS	9 (47%)	11 (58%)	NS
Less than 50%	9 (41%)	11 (50%)	NS	8 (42%)	7 (37%)	NS
More than 50%	0 (0%)	0 (0%)	NS	2 (11%)	1 (5%)	NS

follow-up. At FFU, three patients from the children's group and one patient from the adolescents' group had a scoliosis. The average trunk side-bending to both sides was 18.7 cm (11–26) in the children and 20.5 cm (14–27) in the adolescents ($p = 0.086$) (Table 4). No gait and/or postural abnormalities were observed.

Radiographic measurements

Preoperatively, in the low-grade patients, the vertebral slip averaged 29% (9–49%) in the children and 26% (9–43%) in the adolescents. On average, the vertebral slip improved postoperatively 5% points in the children, and it remained unchanged in the adolescents ($p = 0.115$). According to flexion–extension radiographs, three (15%; direct repair points excluded) children and seven (35%) adolescents had a non-union at the FFU ($p = \text{NS}$). The mobility of the spinal segment above the fusion area averaged 16 (2–26) and 15 (2–22) degrees, respectively.

The mean preoperative vertebral slip in the high-grade patients was 70% (51–107%) in the children and 67% (53–93%) in the adolescents. The vertebral slip improved, postoperatively, on average 14 and 2% points, respectively ($p = 0.009$). Radiographic non-union was observed at FFU in 5 (26%) children and 3 (16%) adolescents with high-grade slips. The mobility of the spinal segment above the fusion area averaged 15 (0–32) and 14 (0–25) degrees, respectively (Table 5).

Quality-of-life outcomes–SRS-24, ODI, VAS

In the low-grade patients at the FFU, the SRS-24 total score averaged 97.1 (78–112) in the children and 91.7 (73–111) in the adolescents ($p = 0.046$) (Fig. 1). The mean ODI score was 4.4% (0–22%) and 4.3% (0–16%) in the children and adolescents, respectively. The VAS for low back pain averaged 15.4 mm (0–67 mm) in the children and 21.0 mm (0–61 mm) in the adolescents ($p = \text{NS}$).

Fig. 1 Seven domains of SRS-24 of the matched cohorts. The bars represent ranges. **a** Low-grade patients. **b** High-grade patients

In the high-grade children, the SRS-24, ODI and VAS (low back pain) mean scores were 92.3 (67–110), 4.5% (0–24%) and 9.0 mm (0–35 mm), respectively. In the adolescents, the scores were 93.9 (65–105), 8.7% (0–32%) and 25.1 mm (0–84). The *p* value for ODI was 0.108 and for VAS it was 0.009 (comparison between the children and adolescents).

Outcome of seven low-grade children who did not have significant pain preoperatively

Clinically, all had a normal posture and none had a scoliosis at follow-up. One patient had mild residual bilateral

hamstring tightness of 75 degrees. The mean SRS-24 score was 92.9 (78–104), ODI 6.5 (0–22). VAS for low-back pain was 0 mm in five patients, 48 and 67 mm, respectively in the remaining two. These two patients had also the poorer results in SRS-24 (86 and 78) and ODI (6 and 18). On radiographs, two patients had a slip progression of 2 and 7 percentage points during follow-up; of the remaining five patients, one was unchanged and four had slip improvement of 3–28 percentage points. The fusion area was stable in six patients. One female patient had a symptomless non-union (flexion–extension ROM 4 degrees). Her SRS-24 was 95, ODI 0, VAS for LBP 0. There was no correlation between the radiographic result and the clinical outcome in this subgroup.

Complications and re-operations

There was one re-operation in the low-grade children due to symptomatic non-union after the index surgery. Post-operative complications in adolescents consisted of one re-operation due to non-union and one temporary quadriceps muscle weakness. Overall complication rates were 5 and 9%, respectively.

In the high-grade children, there were three later re-operations due to symptomatic non-union, and one transient L5 paresis; in the high-grade adolescents, one re-operation for non-union; two later surgical decompressions for S1 root compressions, and one superficial wound infection. Complication rate was 21% in both groups.

Discussion

To the best of the authors' knowledge, this is the first long-term study attempting to analyse the long-term outcome after surgery for isthmic spondylolisthesis in a significant number of patients operated upon before the growth spurt in comparison to patients operated upon during adolescence. Looking at the whole study population as well as the matched cohorts, the outcome is very satisfactory in both the groups, children and adolescents. No clinically or functionally important differences in outcome between the groups could be found. Patients operated upon at or before the pubertal growth spurt had statistically better outcomes in low back pain scores when compared to adolescents at final follow-up. These findings hold true for both, for the whole study population and for the matched cohorts' comparisons between the two age groups. However, the differences are small and not necessarily clinically important at this point of time. It remains to be seen as to whether this changes with further follow-up.

As a retrospective analysis, this study has several shortcomings. The preoperative symptoms, status and indications for operative treatment were elicited from patients' medical records. Therefore, incomplete notes may create bias. The ODI, VAS and SRS-24 were not in use at the time when the patients were operated upon. This makes the exact evaluation of the development of symptoms impossible. Furthermore, there was no control group of untreated patients available. Final follow-up assessment and data analysis were performed by independent observers. The two cohorts were carefully matched for gender, severity of the slip, operative method and age at FFU. Because patients were of similar age at final follow-up but of different age at surgery, the children had a significantly longer follow-up time. The surgical method was matched to prevent the bias that advanced surgical technique would explain possible differences. Age and gender adjusted

reference values were used in the spinal mobility and trunk strength measurements.

The fact that in the whole study population of 298 patients, only 55 (18%) were operated upon before the pubertal growth spurt indicates that the need for surgical treatment is rarer in children than in adolescents. The growth spurt may play role in the development of symptoms in spondylolisthesis. It is, however, not possible to say whether this is a consequence of the growth itself or due to changes in lifestyle during puberty. One has also to consider that the incidence of low-back pain is significantly increasing during puberty in non-olisthetic youngsters.

In the whole population, the gender distribution and mean vertebral slip were relatively equal in children and adolescents. But there were more high-grade slips in the children and due to that, among the children there were significantly more patients treated by anterior or combined fusion, which are used mainly in severe slips. The study showed interesting differences in the preoperative clinical picture between children and adolescents with low-grade slips. All adolescents were operated on for low-back pain as the main symptom. In the children, about one-third (7 out of 22) did not have pain at all or only insignificant pain. They were operated on because of postural anomalies and muscle tightness in combination with a slip of 25% or more, i.e. a high risk of slip progression. In the authors' opinion their clinical symptoms are an expression of root irritation and/or certain instability during slip progression when the pelvis is realigned to maintain sagittal balance and to relieve root compression/tension. The observation of more postural anomalies and less severe pain symptoms in children has also been made by other authors [4, 5, 14, 21, 29].

Taillard [29] found preoperative low-back pain in only 32% of children from 5 to 15 years and "lumbo-sciatique" symptoms in 68%. In the age group 16 to 20 years, 68% had low-back pain. In a series of 58 operated young patients published by Laurent [14], 37% of 5 to 15-year-old had low-back pain as the leading symptom, but 56% of the 16 to 19-year old patients. Bell et al. [4] analysed 28 patients, mean age 11.4 (5.7–15.2) years, with grade 1 and 2 slips. Of them, 17 (61%) had low-back pain. In 8 (29%) patients, the leading symptom was scoliosis and or poor posture. Clinically, 53% had hamstring tightness, 25% increased lumbar lordosis, and 14% had a scoliosis.

The question arises whether one should operate on pain-free patients. In our opinion, a long lasting postural anomaly and hamstring tightness resistant to conservative measures is a significant disability. It bears also the risk to develop into a fixed deformity. We see that the operation is justified especially when, as in our cases, the slip is 25% or more which means a considerable risk of further progression in patients before the pubertal growth spurt [26]. The

Fig. 2 The radiographs of a high-grade patient, who was operated on by the anterior approach at the age of 11 years. Her vertebral slip improvement was 35% points. **a** Preoperative lateral. **b** FFU lateral

patients' outcome in this subgroup was very satisfactory and comparable to the remaining patients.

In the literature, few data is available concerning the outcome of surgery in patients operated on before the growth spurt. Seitsalo et al. analysed retrospectively 56 patients with isthmic spondylolisthesis who were under the age of 12 years (mean 9.8; range 10 months to 11 years) at admission [23]. Thirty-two of them were treated operatively at a mean age of 12.3 years, 24 were treated conservatively. The operatively treated patients had a significantly higher slip at admission (average, 39% vs. 16%). After a mean follow-up time of 14.5 years (range, 5–30 years), the clinical result was judged excellent in 68%, good in 11%, fair in 19% and poor in 2%. No difference in outcome could be found if comparing operatively and conservatively treated patients. A direct comparison with the results of the present study is not possible as different outcome measures were used. These findings suggest that there are no reasons to postpone surgery for later age if the indications are met. As the data shows, significant remaining spinal growth is not a risk factor for progression of the slip after uninstrumented spinal fusion. In the opposite, it seems that the slip decreases after fusion due to lumbosacral bony remodelling and this effect seems to be more profound in high-grade spondylolisthesis (Fig. 2). Similar finding has also been made in the study by Boxall et al. [6].

The non-union rate was rather high, especially in adolescents with low-grade slips (32%). There might be some over diagnosis because the criterion for non-union (segmental flexion–extension motion of three degrees or more)

is very strict. However, the presence of non-union did not have any negative effect on the patients' outcome in long-term. This observation has been made earlier [27]. There are several possible explanations: A non-union stabilises the olisthetic segment to a certain degree. The operation (posterolateral fusion via Wiltse's approach) may denervate the isthmus area which is one possible source of pain. The natural history of spondylolisthesis is benign and also untreated young patients become usually symptom-free with time. But, on average, the duration of symptoms is shorter in operated patients [24]. This does not mean that the operation was unnecessary in the given cases. The patients had had disturbing symptoms for a significant period of time and were not ready to wait longer or e.g. refrain from their sports activities. On the other hand, uninstrumented posterolateral fusion is a low-risk procedure with a predictable clinical outcome.

Six patients were re-operated for non-union during the follow-up period, and even one of those had a non-union still at FFU. Therefore, circumferential in situ fusion is recommended for high-grade spondylolisthesis to increase the chance of spinal fusion. The use of spinal instrumentation could also reduce the pseudarthrosis rate. Only if reduction is attempted in high-grade slips or spondyloptosis instrumentation is unavoidable.

Conclusions

The indication for surgical treatment of isthmic spondylolisthesis is rare in children in comparison to adolescents.

The clinical picture in symptomatic children differs from adolescents. Children do have more often posture anomalies and muscle tightness and less low-back pain than adolescents. After long-term follow-up of patients who underwent uninstrumented fusions, the outcome was equally satisfactory in children and adolescents. Remodelling of the fusion area seems to reduce high-grade spondylolisthesis during follow up in young children. The non-union risk is significant also in children. Non-union, however, does not affect the final outcome. When the indications are met, spinal fusion can be carried out at an early age for low- and high-grade spondylolisthesis with good long-term clinical, functional, radiographic and health-related quality-of-life outcomes.

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