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ORIGINAL ARTICLE

# Asymmetrical trunk movement during walking improved to normal range at 3 months after corrective posterior spinal fusion in adolescent idiopathic scoliosis

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**Abstract**

**Purpose** To investigate the effects of posterior spinal fusion (PSF) and curve type on upper body movements in Adolescent Idiopathic Scoliosis (AIS) patients during gait.

**Methods** Twenty-four girls (12–18 years) with AIS underwent PSF. 3D-Gait-analyses were performed preoperatively, at 3 months and 1 year postoperatively. Mean position (0° represents symmetry) and range of motion (ROM) of the trunk (thorax-relative-to-pelvis) in all planes were assessed. Lower body kinematics and spatiotemporal parameters were also evaluated.

**Results** Mean trunk position improved from 7.0° to 2.9° in transversal plane and from 5.0° to − 0.8° in frontal plane at 3 months postoperative ($p < 0.001$), and was maintained at 1 year. Trunk ROM in transverse plane decreased from 9.6° to 7.5° ($p < 0.001$) after surgery. No effects of PSF were observed on the lower body kinematics during the gait cycle. Patients with a double curve had a more axial rotated trunk before and after surgery ($p = 0.013$).

**Conclusion** In AIS patients, during gait an evident asymmetrical position of the trunk improved to an almost symmetric situation already 3 months after PSF and was maintained at 1 year. Despite a reduction of trunk ROM, patients were able to maintain the same walking pattern in the lower extremities after surgery. This improvement of symmetry and maintenance of normal gait can explain the rapid recovery and well functioning in daily life of AIS patients, despite undergoing a fusion of large parts of their spine.

**Keywords** Adolescent idiopathic scoliosis · Spinal fusion · Upper body kinematics · Three-dimensional analysis · Gait · Curve type

## Introduction

Scoliosis is the most common type of spinal deformity. The three-dimensional deformity of the spine causes a geometric asymmetry of the upper body, and also influences the orientation of the head. Previous studies indicate that Adolescent Idiopathic Scoliosis (AIS) induces asymmetrical kinematics of the upper body, whereas kinematics of the lower limbs are relatively normal in level walking [1–6].

Spinal fusion focuses on (partly) restoring the asymmetric upper body, in order to improve biomechanical geometry, to reduce back pain, to prevent progression for degenerative spine changes and improve cosmesis [7]. However, a surgical correction and fusion significantly reduce the mobility of a major part of the spine [8, 9]. Nevertheless, only a slightly reduced walking speed without any change in lower kinematics has been observed after surgery [8, 10]. Moreover, several studies investigated the effects of spinal fusion on trunk motion in AIS patients during walking [8–11] and found a more symmetrical but reduced axial motion of the acromion-pelvis (C7-S2). These previous studies were limited because the upper body was analyzed as a single segment and/or in 2D [8–11] whereas 3D kinematic data are required to accurately analyze human kinematics [12, 13].

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We used a more detailed two segment 3D-model of the trunk (thorax relative to pelvis) which allowed us a more accurate and detailed study of the upper body kinematics (position and range of motion) in all three planes. Furthermore, previous studies studied heterogeneous patient groups (e.g., gender, curve type, and type of fusion).

Knowledge of upper body movements and compensatory strategies after spinal fusion is clinically important to predict and avoid additional problems as a result of spinal fusion (e.g., adjacent segment degeneration, junctional kyphosis and "adding-on"). It helps to improve patient outcomes, patient counselling and possibly rehabilitation programs. The purpose of this study was to investigate the effects of posterior spinal fusion during walking on upper body kinematics and compensatory strategies by the lower extremities in a homogeneous group of AIS patients. We hypothesize that after surgery axial trunk rotation becomes more symmetrical, but the range of motion will be reduced. It is expected that the reduced axial trunk range of motion depends on the curve type; patients with double curves show smaller ROM than patients with single curves.

## Materials and methods

### Participants

Twenty-six AIS participants with a thoracic right-sided curve were recruited. The study was approved by the local medical ethics committee (Independent Review Board Nijmegen, IRBN, IRBN2010026) and written informed consent was obtained from all participants and their parent(s) or guardian(s).

A detailed description of the single institute cohort, and inclusion/exclusion criteria used in this study has been previously published [14], and is briefly described in Table 1. Patients with main thoracic curves (Lenke 1a, 1b, 2a) were referred to as 'single curve' and patients with a thoracic and lumbar component (Lenke 1c, 3c, 4c, 6) were referred to as 'double curve'. Surgery was performed by two specialized pediatric spine surgeons and consisted of a posterior instrumented spinal fusion, predominantly pedicle screw based (Universal Spine System, Synthes, Oberdorf, Switzerland), using local spinous process bone graft mixed with tri-calcium phosphate (Chronos, Synthes, Oberdorf, Switzerland) under motor-evoked potential spinal cord monitoring. All patients received the standard hospital care.

### Experimental setup and protocol

All participants underwent three assessments in a gait laboratory: before surgery (T0), at 3 months (T1) and at 1 year after surgery (T2). Measurements of level walking were conducted with ten infrared cameras of the 3D VICON system (Vicon, Oxford, Metrics) at a sample frequency of 100 Hz [15]. The experimental set up consisted of a 10-m walkway. The marker configuration of Vicon's Plug-in-Gait model of the lower and upper body was used. To minimize bias, one person performed all measurements. Subjects were instructed to walk barefoot at their self-selected comfortable walking speed. At least four strides of each foot were recorded in which the foot was correctly placed on a force platform.

### Data analysis

The marker on the heel was used to calculate the basic spatiotemporal gait parameters. A single stride (i.e., one gait cycle) was defined as heel strike of a left or right foot to next heel strike of the same foot. The following spatiotemporal gait parameters were calculated: walking velocity, step time, step length and double support time (% of stride). The mean angle and Range of Motion (ROM) of lower body kinematic angles (hip, knee and ankle angles) in the sagittal plane and of the hip in frontal plane during the entire gait cycle were calculated.

Kinematics of the upper body in the transverse, frontal and sagittal plane were calculated using Vicon's Plug-in-Gait model. Position and motion of the thorax (segment defined by markers acromioclavicular joints, C7, sternum and T10) and pelvis (segment defined by markers on iliac spines) in the global coordinate system were measured as

**Table 1** Demographic and clinical data; median and (range)

| | Single curve ($n = 18$) | Double curve ($n = 6$) | $p$ value* |
|---|---|---|---|
| Age (years) | 14.7 (11.9–16.5) | 15.0 (12.7–18.5) | 0.48 |
| Cobb-angle before surgery (°) | 56 (36–71) | 59 (50–79) | 0.48 |
| Cobb-angle after surgery (°) | 22 (10–34) | 22 (10–30) | 0.92 |
| Number of fused vertebrae | 9 (7–12) | 12.5 (11–14) | **< 0.001** |
| Upper instrumented vertebrae | T5 (T3–T6) | T4 (T3–T5) | **0.042** |
| Lowest instrumented vertebrae | T12 (T10–L2) | L4 (L3–L4) | **< 0.001** |

* and bold text indicates significant difference between groups were tested with the Mann–Whitney rank sum test ($p < 0.05$)

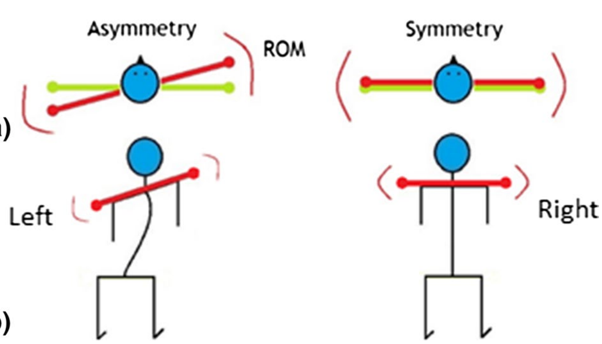
well as the position and movement of the thorax in relation to the pelvis, which will be referred to as "trunk" motion. Mean position of the trunk, thorax and pelvis was calculated, defined as the angular orientation of the segment averaged over the entire gait cycle. This variable quantified the amount of (a)symmetry of the upper body (see Fig. 1). ROM was calculated as the absolute difference between the maximum and minimum position during the gait cycle.

All kinematic data were normalized to 100% of the time of the gait cycle. At least three strides of the left and right foot were calculated and used for analysis. The thorax and pelvis were considered as rigid segments, indicating that the minimal rotation from one side is identical to the maximal rotation of the other side. Therefore, left and right strides were taken together for the upper body analysis.

### Statistical analysis

For the upper body parameters, a two-way repeated measures ANOVA was used to determine the effect of Time (effect of surgery; within-subjects), Curve (single vs double; between-subjects), and the interaction Time-Curve. For the lower extremities and spatiotemporal gait parameters, a three-way repeated measures ANOVA was used in which Side (left vs right; within-subjects variables) was added as third factor including interaction effects (Time-Side, Time-Curve, Curve-Side and Time-Curve-Side). All analyses were performed with the statistical package of SPSS 20 (IBM SPSS Statistics, version 20), with a significance level of $p < 0.05$. Post hoc $t$ tests were performed with an adjusted $p$ level ($p < 0.01$).

(a)




(b)

**Fig. 1** Schematic view of the mean thorax position and range of motion in the transverse (**a**) and frontal (**b**) plane. Left panel shows an asymmetric thorax position and the right panel a symmetric thorax position. A negative value indicated a more posteriorly (lower) located left shoulder in the transverse (frontal) plane

## Results

Two of the twenty-six patients declined further participation postoperative because of time and motivational reasons and were excluded from the analysis. Another patient declined the 1-year postoperative measurement and her data were imputed by carrying the last observation forward. Demographic and clinical data are presented in Table 1. The double curve group had significantly more fused vertebrae and a more distally ($p < 0.001$) and proximally ($p = 0.04$) instrumented vertebrae compared to the single curve group (Table 1). The preoperative Cobb-angle significantly decreased to 22° after surgery in both groups ($p < 0.001$). None of the other demographic and clinical variables were significantly different between the groups. No malunions were observed.

### Kinematics of upper body

The mean kinematic data of the thorax, pelvis and trunk in the three planes (transverse, frontal and sagittal) across all subjects during the gait cycle are shown in Fig. 2. Mean position and ROM of the three upper body angles for the three planes at the three different measurement times were used as outcome parameters and are depicted in Figs. 3 and 4. Two-way repeated measures ANOVA showed a significant change to zero degrees (= symmetric) in mean trunk and thorax position in transverse and frontal plane between preoperative and both follow-up measurements (effect of Time: $p < 0.001$). The double curve group showed a more axial rotated trunk and a more lateroflexed thorax at all measurement times (effect of Curve $p = 0.013$ and $p = 0.017$, respectively; Fig. 3). No significant *Time-Curve* interaction in any of the segments was found.

A significant reduction in ROM was found in the trunk in transverse and sagittal plane between preoperative and both follow-up measurements (effect of Time: $p < 0.001$; Fig. 4). The thorax had a significant reduction in ROM in the sagittal plane between 3 months postoperative and preoperative (effect of Time: $p < 0.04$). The ROM in the pelvis in sagittal plane significantly decreased at 3 months postoperative, but increased again at 12 month follow-up ($p = 0.005$). At all measurement points, the single curve group demonstrated a significantly larger thorax ROM in frontal plane compared to the double curve group (effect of Curve: $p = 0.04$). No significant Time-Curve interactions were found.

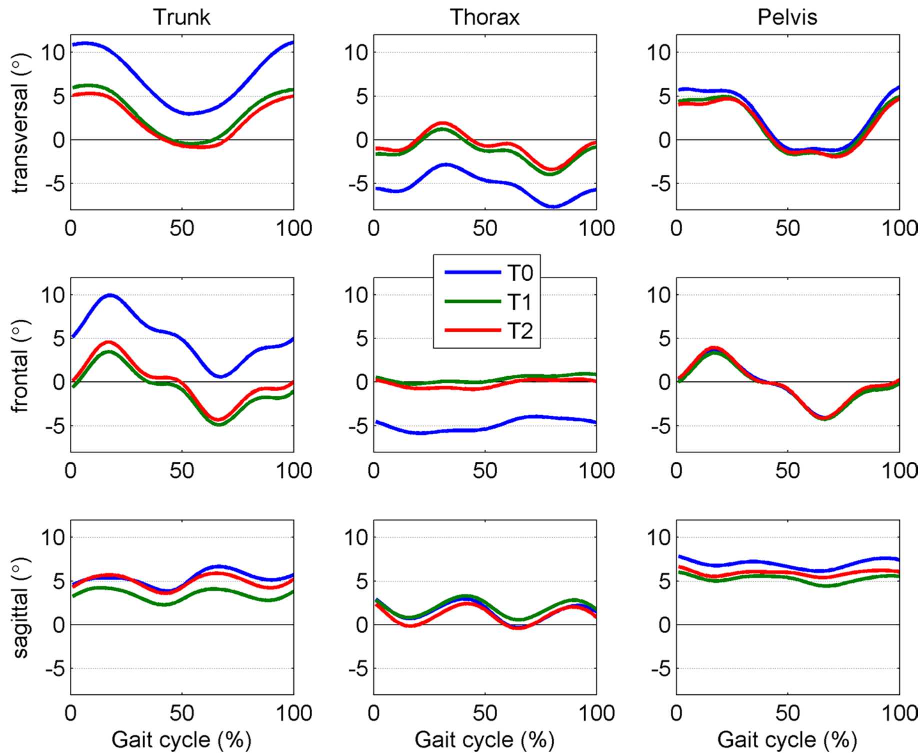



**Fig. 2** Mean kinematic data across all subjects of the left side of the upper body segments in all planes during one gait cycle at preoperative (T0), 3 months postoperative (T1) and 1 year postoperative (T2)

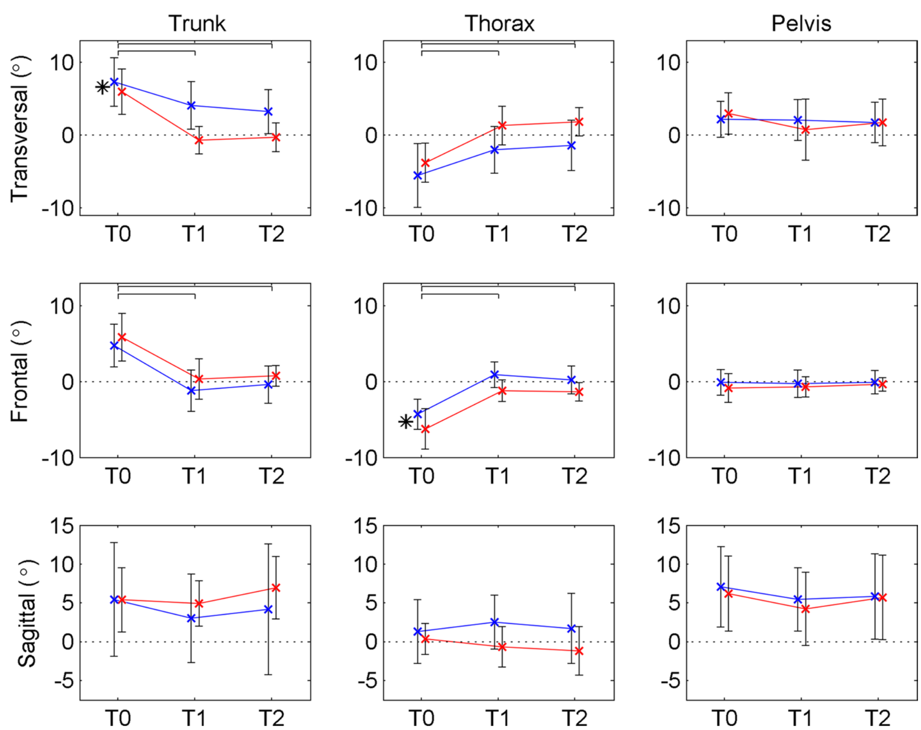



**Fig. 3** Mean position of the left side of the upper body segments in all three planes at preoperative (T0), 3 months postoperative (T1) and 1 year postoperative (T2) for single (red) and double (blue) curve types. Symmetric mean position is 0°. A negative value indicated a more posteriorly (lower) located left shoulder in the transverse (frontal) plane

## Spatiotemporal parameters and lower body kinematics

Mean and standard deviation values for the single and double curve groups of the spatiotemporal parameters and kinematics of the lower body of the left and right step are presented in Tables 2, 3 and 4. Three-way repeated measures ANOVA revealed no significant main nor interaction effects for velocity, step length and percentage double support. Only a significant effect of Time ($p = 0.045$) and Time-Side interaction ($p = 0.044$) for step time was found. Post hoc analysis showed a significantly longer step

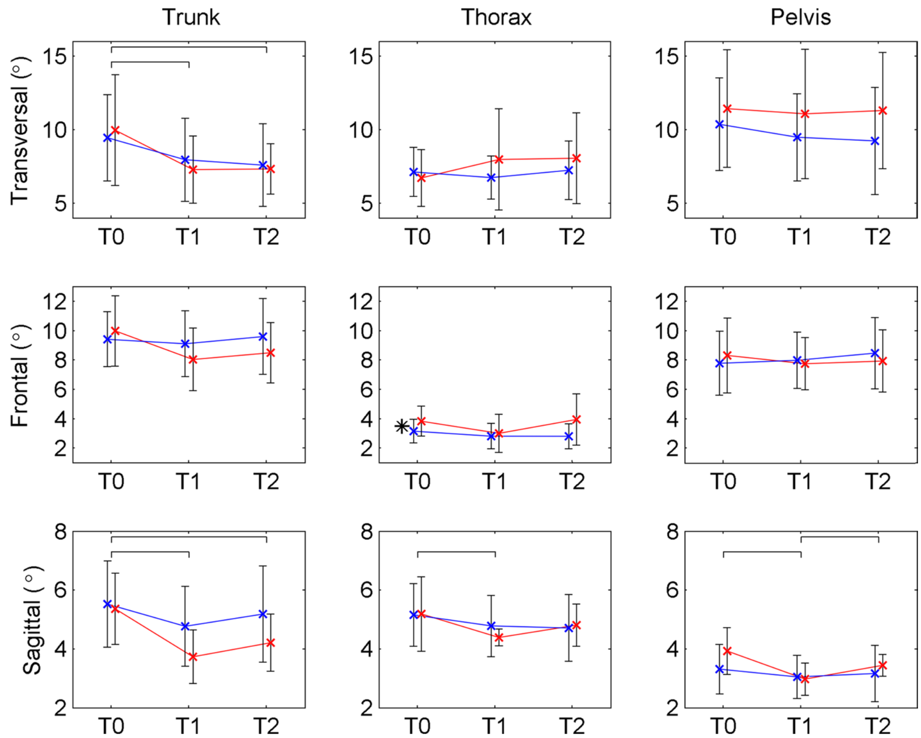



**Fig. 4** Range of motion of the left side of the upper body segments in all three planes at preoperative (T0), 3 months postoperative (T1) and 1 year postoperative (T2) for single (red) and double (blue) curve types

**Table 2** Spatiotemporal parameters for left and right leg; mean and (SD)

| | (T0) | | T1 (3 months) | | T2 (1 year) | | Statistics (*p* value) | |
|---|---|---|---|---|---|---|---|---|
| | Left | Right | Left | Right | Left | Right | Mean effects[a] | Interaction |
| Velocity (m/s) | | | | | | | T: 0.92 | NS |
| Single | 1.25 (0.15) | 1.25 (0.14) | 1.20 (0.15) | 1.20 (0.13) | 1.20 (0.13) | 1.21 (0.14) | S: 0.99 | |
| Double | 1.20 (0.18) | 1.19 (0.16) | 1.23 (0.21) | 1.23 (0.20) | 1.25 (0.28) | 1.23 (0.28) | C: 0.96 | |
| Step length (m) | | | | | | | T: 0.23 | NS |
| Single | 0.66 (0.06) | 0.64 (0.04) | 0.65 (0.06) | 0.64 (0.05) | 0.66 (0.06) | 0.65 (0.05) | S: 0.19 | |
| Double | 0.63 (0.09) | 0.64 (0.07) | 0.66 (0.08) | 0.65 (0.07) | 0.68 (0.10) | 0.66 (0.10) | C: 0.94 | |
| Step time (s) | | | | | | | T: 0.14 | **TS: 0.044** |
| Single | 0.53 (0.04) | 0.52 (0.04) | 0.55 (0.04) | 0.54 (0.03) | 0.55 (0.04) | 0.54 (0.03) | **S: 0.045** | |
| Double | 0.53 (0.03) | 0.54 (0.03) | 0.54 (0.03) | 0.53 (0.03) | 0.55 (0.05) | 0.55 (0.06) | C: 0.97 | |
| Double support (%) | | | | | | | T: 0.31 | NS |
| Single | 21.9 (3.7) | 21.3 (3.2) | 23.5 (4.6) | 22.9 (4.4) | 23.5 (4.7) | 23.2 (4.9) | S: 0.87 | |
| Double | 22.4 (3.7) | 23.1 (3.7) | 23.4 (5.4) | 23.7 (5.4) | 23.7 (5.9) | 24.5 (7.4) | C: 0.70 | |

Significant values ($p < 0.05$) are bold

*NS* means not significant

[a]*T* time, *S* side, *C* curve

time for the left leg compared to the right leg for follow-up measurements and a longer left step time between 12 months postoperative compared to preoperative.

No clear differences were observed in hip, knee and ankle angles during the gait cycle between the three measurements (Fig. 5). The mean angle and ROM of the ankle had no significant main nor interaction effects with significant post hoc differences. The knee was more extended in the double curved group compared to the single curved group ($p = 0.04$) as well as in the right leg compared to the left leg ($p = 0.02$). A significant smaller right hip ROM in sagittal plane was found preoperatively compared to the left hip ($p < 0.001$). In addition, a significant increased ROM of only the right hip between preoperative and both follow-up measurements was found (effect of Time: $p = 0.01$ and Time-Side: $p < 0.001$). The

**Table 3** Mean angle of the lower body for left and right leg (°); mean and (SD)

| | T0 | | T1 (3 months) | | T2 (1 year) | | Statistics (*p* value) | |
|---|---|---|---|---|---|---|---|---|
| | Left | Right | Left | Right | Left | Right | Mean effects[a] | Interaction |
| Sagittal | | | | | | | | |
| Hip | | | | | | | T: 0.48 | NS |
| Single | 13.6 (6.9) | 12.9 (7.1) | 11.9 (5.3) | 12.0 (5.0) | 11.1 (6.4) | 11.1 (6.2) | S: 0.39 | |
| Double | 12.2 (5.8) | 12.9 (6.0) | 11.3 (5.1) | 11.9 (6.2) | 10.6 (7.4) | 11.7 (8.2) | C: 0.89 | |
| Knee | | | | | | | T: 0.20 | NS |
| Single | 23.0 (3.2) | 23.8 (3.4) | 21.9 (3.9) | 23.5 (2.9) | 19.9 (2.7) | 21.6 (2.8) | **S: 0.02** | |
| Double | 24.1 (2.3) | 24.2 (3.7) | 24.5 (3.6) | 26.0 (4.3) | 22.9 (4.2) | 25.2 (3.6) | **C: 0.04** | |
| Ankle | | | | | | | T: 0.20 | **TS: 0.027** |
| Single | 3.2 (2.5) | 3.5 (3.3) | 3.0 (1.9) | 3.9 (3.3) | 2.0 (2.5) | 2.7 (3.1) | S: 0.26 | |
| Double | 4.4 (1.9) | 3.3 (1.4) | 4.2 (2.8) | 5.8 (1.2) | 3.8 (3.4) | 5.0 (3.3) | C: 0.18 | |
| Frontal | | | | | | | | |
| Hip | | | | | | | T: 0.23 | NS |
| Single | 0.4 (4.3) | 1.8 (4.4) | 0.9 (2.5) | 3.2 (2.5) | 0.3 (3.7) | 2.1 (5.3) | S: **< 0.001** | |
| Double | − 0.3 (3.3) | 3.9 (2.5) | 0.0 (1.7) | 3.4 (2.2) | − 2.4 (6.6) | − 0.1 (5.7) | C: 0.53 | |

Significant values ($p < 0.05$) are bold

*NS* means not significant

[a] *T* time, *S* side, *C* curve

**Table 4** Range of motion of the lower body for left and right leg (°); mean and (SD)

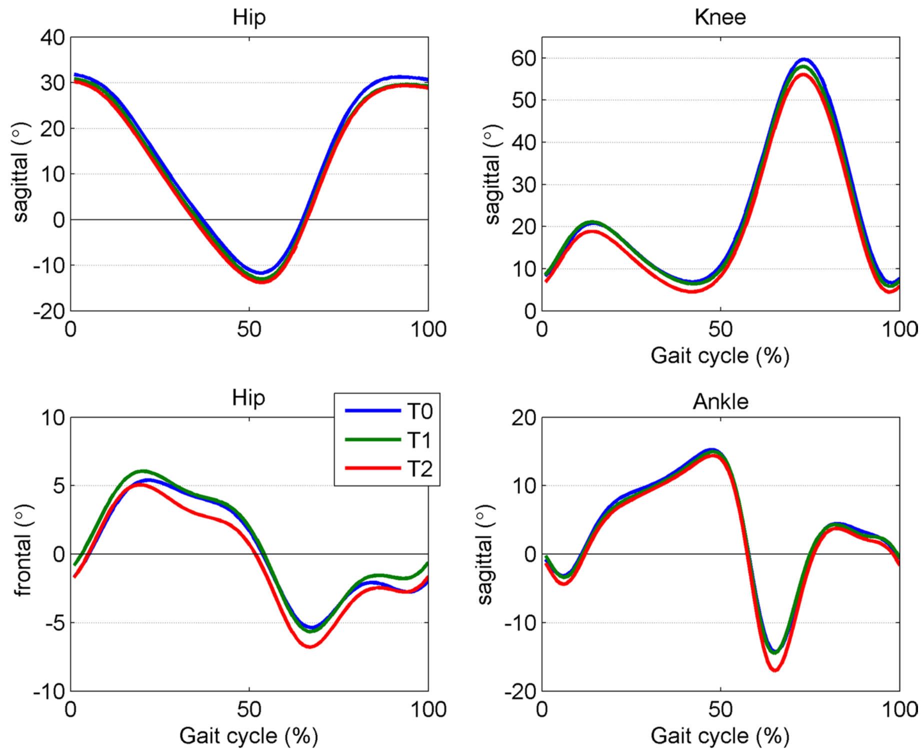
| | T0 | | T1 (3 months) | | T2 (1 year) | | Statistics (*p* value) | |
|---|---|---|---|---|---|---|---|---|
| | Left | Right | Left | Right | Left | Right | Mean effects[a] | Interaction |
| Sagittal | | | | | | | | |
| Hip | | | | | | | T: **0.011** | **TS: < 0.001** |
| Single | 45.1 (4.4) | 41.8 (4.5) | 44.8 (4.6) | 43.9 (4.4) | 44.5 (3.2) | 43.6 (3.1) | S: **< 0.001** | |
| Double | 43.7 (4.8) | 39.3 (5.2) | 44.4 (7.5) | 44.0 (4.5) | 46.1 (7.2) | 44.6 (4.7) | C: 0.90 | |
| Knee | | | | | | | T: 0.22 | NS |
| Single | 56.8 (4.8) | 56.8 (4.9) | 55.4 (3.9) | 57.4 (3.6) | 54.9 (4.9) | 56.6 (4.4) | S: 0.46 | |
| Double | 56.0 (4.6) | 54.9 (3.7) | 54.3 (6.6) | 55.4 (6.2) | 53.8 (5.4) | 53.3 (8.2) | C: 0.39 | |
| Ankle | | | | | | | 0.076 | NS |
| Single | 31.0 (5.1) | 29.8 (5.6) | 30.8 (4.8) | 30.5 (5.1) | 33.1 (5.3) | 30.7 (5.7) | 0.051 | |
| Double | 32.2 (3.9) | 30.9 (3.7) | 33.8 (4.1) | 32.5 (2.9) | 37.0 (5.4) | 33.1 (4.0) | 0.22 | |
| Frontal | | | | | | | | |
| Hip | | | | | | | T: 0.29 | NS |
| Single | 11.9 (2.3) | 13.0 (2.7) | 12.6 (2.9) | 14.2 (3.0) | 13.1 (2.8) | 14.3 (2.5) | **S: 0.047** | |
| Double | 11.4 (2.3) | 12.2 (2.8) | 12.4 (2.2) | 11.5 (2.6) | 11.3 (2.9) | 12.2 (3.9) | C: 0.24 | |

Significant values ($p < 0.05$) are bold

*NS* means not significant

[a] *T* time, *S* side, *C* curve

**Fig. 5** Mean kinematic data across all subjects of the left hip in the frontal plane and of the hip, knee and ankle in the sagittal plane during one gait cycle at preoperative (T0), 3 months postoperative (T1) and 1 year postoperative (T2)




right hip showed a significant larger ROM in frontal plane in both groups (effect of Side: $p = 0.047$). None of the outcome measures had significant interactions.

## Discussion

In a homogenous cohort of AIS patients, the effects of spinal fusion during level walking were investigated and showed a reduction in trunk asymmetry, minimally affected lower body kinematics and a decreased trunk ROM. At all measurements, single curved patients were less asymmetrical and had more ROM compared to double curved patients.

Walking velocity and step length were not affected by spinal fusion whereas a small increase of 0.02 s in step time in the left leg was found in our study. In contrast, previous studies observed some small differences in gait parameters after surgery; cadence (steps/min) [8–11] and stride length decreased [10] whereas step length increased [11]. Our values for walking velocity and step length before and after surgery were in the range of previous studies [8–11]. Interestingly, a significant larger hip flexion/extension ROM of the left side in combination with an increased abduction in the right side was found preoperatively. We assume that this asymmetry was used as a compensation mechanism in the right curved scoliosis in which the center of mass is located more to the right [14], which became smaller after fusion. Furthermore, a minimal asymmetry in step time at the follow-up measurements was found. For the knee and ankle kinematics, no significant effect of fusion was found. Hence, spinal fusion does slightly improve the asymmetry in the hip and has minimal measurable effect on spatiotemporal parameters and lower limb kinematics, which was supported by our previous study [16].

The current study was the first with a 3-dimensional approach to describe the position and motion of the thorax, pelvis and trunk before and after surgery in all planes. Preoperatively, all patients showed an asymmetrical trunk motion which was in range with the AIS patients studied by Nishida et al. [6]. A clear shift of an asymmetrical preoperative trunk position to an almost symmetrical postoperative situation in transverse and frontal plane was found at 3 months after surgery. The symmetry in trunk position was due to a shift in the thorax position since the pelvic position was unaffected by the surgery. It has to be mentioned that a discrepancy between the positions of the shoulder is missed when the thorax is considered as a rigid segment and this could result in a minimal over- or underestimation of the thorax position for the more forward or backward positioned shoulder, respectively. Nevertheless, the significant improvement in trunk symmetry may lead to a more equal load distribution in the unfused spine when compared to the preoperative asymmetrical situation. Moreover, a more symmetrical gait pattern induces a more efficient gait pattern, thereby reducing the energy expenditure, since pathological gait usually leads to an increased energy cost [17, 18].

In line with previous studies, a minimal decrease in the ROM in all upper body segments in the sagittal plane was observed [10, 11]. The trunk ROM decreased in the transverse plane after surgery whereas the ROM in the frontal plane was not affected. Interestingly, almost no difference in ROM in any of the planes was found between 3 and 12 months after surgery indicating a stable situation already at 3 months postoperatively. The decrease in ROM after surgery indicates a stiffened spine. Angular displacement in the fused vertebrae is no longer possible and needs to be compensated by the non-fused lower vertebrae and/or the lower extremities. Since the lower extremities were minimally affected, we infer that the non-fused vertebrae will have an increased motion after surgery. We conclude that spinal fusion reduces the ROM in the transversal and sagittal plane. Considering the risk of late lumbar disc degeneration, the improved lumbar symmetry might be beneficial, but the increased rotation lumbar load might be detrimental.

The selection of a homogeneous right-sided curve AIS patients all treated with a posterior fusion enables to study the clinically important effects of curve type and consequently the number of fused vertebrae on gait (see Table 1). Although a larger posterior fusion may theoretically result in a stiffer spine, surprisingly, we did not find any significant interaction between curve type, fusion length and surgery in any of the kinematics (upper body and lower body). However, we found greater symmetry in axial trunk motion, more asymmetry in lateroflexion of the thorax and less knee flexion for the single curve group during all measurements. More symmetry in frontal plane in the double curved group is most likely due to the opposite direction of the two curves whereas the larger axial asymmetry is the result of the larger number of vertebrae involved. It should be noted that the small sample sizes of the double curved group might underestimate the effects of curve type. For example, the difference between the two groups in axial thorax position was approximately the same in axial trunk position, but no significant differences were found (see Fig. 3). Nevertheless, the differences between the curve groups support the conclusion of Nishida et al. [6] that the global postural control strategy differs according to the curve pattern in patients with AIS.

This study was performed with the patient walking at preferred speed, on a level ground. The spatiotemporal parameters and lower body kinematics in the current AIS group were in the same range as reported in previous studies with healthy controls [19], which supports the validity of the current study. Since fusion had no relevant effect on walking speed and lower extremity kinematics, differences found between pre- and postoperative in upper body kinematics can be mainly attributed to the spinal fusion. A single assessor was used to diminish the variability in the marker placement and only fixed anatomical landmarks were used for placing the markers. No studies are available which examined the variability in marker placement on the trunk kinematics. We expected that this variability is similar to the known marker placement variability in lower extremities [20]. The differences found in both mean position and Range of Motion are larger than the estimated markers variability, so we could conclude that the differences found are correct. Moreover, challenging and demanding tasks such as walking at higher speeds or uphill may demonstrate surgery-related differences.

## Conclusion

In a cohort of AIS patients evident asymmetrical trunk movement before surgery improved to an almost symmetric movement at 3 months after spinal fusion and remained the same at 12 months. Despite a decreased ROM of the fused spine, AIS patients are surprisingly still able to maintain the same walking pattern in the lower extremities after surgery within normal range. Finally, although curve type has an effect on walking pattern, a larger number of fused vertebrae did not seem to affect the walking pattern.

### Compliance with ethical standards

**Conflict of interest** We have no potential conflict of interest.

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