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# The Margin of Stability in Case of Dynamic Equilibrium in Patients with Lenke1 Adolescent Idiopathic Scoliosis: Effect of Spine Deformities and Age. A Pilot Study

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## 1. Introduction

Appropriate motor responses depend on sensorimotor integration through the dynamic weighting of sensory inputs (vision, proprioception, vestibular system). During development, the relative contributions of different types of sensory information to the control of balance change. The use of proprioception and the vestibular system gradually improves during adolescence, and multisensory integration becomes more stable and flexible during adulthood (Yelnik 2021). In idiopathic scoliosis (or IS), spinal deformities may appear or worsen during adolescence. IS patients also display abnormalities of sensory integration (Delpierre et al. 2020; Delpierre and Vernet 2020), suggesting a dysfunction of multisensory integration processes.

The margin of stability (MoS) quantifies the instantaneous mechanical stability of the body as the distance between the base of support (BoS) and the extrapolated CoM (XCoM) (Watson et al. 2025). This study of patients with IS aimed: (1) to determine the link between the intensity of spinal deformities and the MoS and (2) to define the link between age and the MoS.

## 2. Methods

### *2.1 Population*

In this retrospective study, we followed a cohort of 15 patients with IS (mean age: 15.73 years (1.71); height: 1.64 m (0.07); body mass: 57.61 kg (18.56); Cobb angle: 50.67° (14.32)). The Cobb angle is a radiographic measurement of spinal curvature (Delpierre et al. 2020). We limited the heterogeneity of curve type in our subjects by including only adolescents and young adults with a single main lateral curve of T5-T12 (Lenke 2007). All the patients or their families were informed of this study and gave consent for participation. The local ethics committee (Angers) approved the study. We used the Risser sign to assess skeletal bone maturity. The inclusion criteria for this study were: patients with IS who had undergone quantified gait analysis, had complete radiological images of the spine, were classified as Risser 3 or higher, had no inequalities in the length of the lower limbs and had not undergone spinal surgery.

### *2.2 Experimental setup*

We recorded anteroposterior oscillations with the subject standing on a freely oscillating platform (Fig. 1). The experimenter held the platform, obscuring a marker placed on the platform, while the subject mounted the platform and stood in the requested position. The experimenter then let go of the platform, defining the starting point of the trial. Each subject was asked to remain in equilibrium for 10 seconds in a prescribed position. The experimenter then took hold of the

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platform again, corresponding to the end of the trial. Three positions were tested: with the eyes open and feet in a parallel position on a surface defined by a rectangle (condition 1); with the eyes closed and feet in a similar position (condition 2); with the eyes open and a heel-to-toe foot position (condition 3). Each subject was given one minute to rest between tests.

**Figure1:** Free oscillating platform for two conditions. Left: feet in a parallel position; Right: heel-to-toe foot position. Credit: Y. Delpierre

A 3D motion capture system (ViconT10, Oxford, UK, 100 Hz) was used to record data for 34 passive markers (14 mm). These markers were placed on bony landmarks for application of the "Plug-in gait" model. Each subject performed two trials. A filtering procedure with a second-order Butterworth filter (6 Hz) was applied to data for the markers. CoM was extracted from Nexus. The MoS was calculated with Matlab, using the markers on the toes and heels as the BoS:

$$MoS = BoS - XCoM$$

where BoS is the base of support and XCoM is the extrapolated CoM. The XcoM was calculated as follows:

$$XCoM = CoM + V_{CoM} / \sqrt{g / l}$$

where $V_{CoM}$ is the CoM velocity, $g$ is gravitational acceleration (9.8 m/s) and $l$ is the pendulum height (CoM height).

### 2.4 Statistical analysis

All statistical analyses were performed with Statistica (version 13, Statsoft, California, USA). The data are presented as the mean (standard deviation). Shapiro-Wilks tests were performed to check the normality of the distributions. Bravais-Pearson correlation was used to quantify the relationship between the MoS and clinical parameters. Values of $p \leq 0.05$ were considered significant.

## 3. Results and discussion

One patient was classified as Risser 3, four patients as Risser 4, eight patients with Risser 4+ and two patients as Risser 5. The MoS was 0.60 m (0.22) in condition 1, 0.44 m (0.26) in condition 2 and 0.93 m (0.06) in condition 3. We observed only a moderate correlation between MoS and Cobb angle in condition 3. There was no significant correlation between MoS and age.

**Table 1.** Correlations between MoS and clinical parameters.

| | Cobb angle | Age |
|---|---|---|
| Condition 1 | r=0.21 (*p*=.24) | r=-0.04 (*p*=.43) |
| Condition 2 | r=0.35 (*p*=.21) | r=-0.35 (*p*=.11) |
| Condition 3 | r=0.47 (*p*=.04)* | r=-0.25 (*p*=.18) |

*: significant correlation.
Credit: Y. Delpierre

Condition 3 combines spinal deformities and a low level of stability. Spinal deformities appeared to increase instability moderately when subjects were in the heel-to-toe foot position with their eyes open. Compensation occurred in the other two sets of conditions.

The sensorimotor system matures with age, but motor experience, learning, and the environment could explain the lack of correlation between MoS and age in this study.

## 4. Conclusions

This study demonstrated an influence of spinal deformities on MoS, but a comparative study including control subjects is now required to confirm these findings.

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## Contributor Roles

YD: Conceptualization, Supervision, Methodology, Funding acquisition, Writing original draft; SK: Validation, Writing – review; VC: Validation, Writing-review & editing; JFC: Validation, Writing- review; PV: Validation, Writing – review.

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