INTRODUCTION
In severe postural disorders, surgery may be indicated to correct balance. Spinal osteotomy techniques, which consist in cutting one or several wedges in the spinal column, have been described. Surgery planning includes estimating the adequate angle and location of the wedge, in order to achieve correct postoperative balance. Evaluating the impact of local modification on global balance is therefore of paramount importance. Several biomechanical and clinical studies shed lights on the mechanisms underlying balance. In particular, analyses on asymptomatic volunteers [1,2] highlighted correlations between the spinal curvatures and the shape and orientation of the pelvis. But if results are well commented in terms of correlation, direct use of the formula to predict postural balance has less been reported. The current study explores the ability of two previously published formulas [1] to predict pelvic tilt from other balance descriptors.

METHODS
23 patients, operated with an osteotomy were retrospectively included in this study. Inclusion required preoperative and post-operative EOS biplanar X-rays (EOS-imaging, Paris, France). Mean follow-up was 10 months. Maximum follow-up reached 20 months.

3D patient specific reconstruction from biplanar X-rays of the spine (T1-L5) and the pelvis were performed using previously described methods [3]. Maximal thoracic kyphosis (MTK), maximal lumbar lordosis (MLL), pelvic incidence (PI) and pelvic tilt (PT) were assessed according to Vialle et al. [1]

Pelvic tilt was then estimated using two previously published formulas:
- from pelvic incidence only (Model A)
  \[ PT = -7 + 0.37 \, PI \]
- from pelvic incidence, maximal thoracic kyphosis and maximal lumbar lordosis (Model B)
  \[ MLL = -2.72 - 1.1 \, PI + 1.1 \, PT - 0.31 \, MTK \]

Difference between predicted and measured pelvic tilt using both formulas was calculated for each exam. Error on postoperative exams was quantified using mean, standard deviation and maximum difference between measured and estimated pelvic tilt.

For both models, difference between predicted and measured pelvic tilt was plotted against follow-up time. Preoperative radiographs were assigned a follow-up time of 0.

RESULTS AND DISCUSSION
In all 46 cases, Model A (using only pelvic incidence) was able to predict pelvic tilt while model B failed to predict 13 cases (all preoperative). These failures are imputable to the absence of curvatures (flat back) or multiple inflexions in the spine instead of the classic thoracic kyphosis and lumbar lordosis pattern.

In case of postoperative exams, errors of prediction are summarized in Table 1. Estimation is more accurate in terms of systematic error and dispersion using model B than model A.

This result extends on figure 2. Dispersion of the results is lower using model B than model A. Maximal error using Model B reaches once 20° (which seems to be an isolated result). All other reported errors remain below 15°. On the contrary, error using model A is 21 times above 15°, (16 times on preoperative and 5 times on postoperative exams).
Over follow-up time, the 3-predictor model (B), estimation of pelvic tilt remains similar. This formula seems therefore adapted whether economic balance is achieved (successful Postoperative exams) or not (Preoperative exams). On the contrary, error of the 1-predictor model (A) is higher on preoperative exams (reaching 38°) than it is on postoperative exams. We fear this formula to be less likely to model the cases of incorrect balance.

Immediate postoperative balance is known to be poorly reliable since antalgic positioning may modify the patient’s balance strategy. Surprisingly, neither model is affected by a degradation of the estimation below a certain time-threshold. This suggests there is no need for long follow-up to evaluate the reliability of these models.

Figure 2: Absolute difference between predicted and measured tilt. Lines link exams for patients on which all exams were predictable using both models.

The current study also underlines the need for a very strong correlation to expect good result from the prediction. A correlation coefficient of 0.6 is indeed often qualified of “good” when looking for correlations, but may be insufficient when used as a predictor.

Further investigation may improve prediction of borderline cases (20° makes the prediction useless) but the 3-predictor model (B) could build a good basis to plan surgery of lumbar osteotomies. Indeed, post-operative lumbar lordosis can be estimated from its preoperative value and the intended surgical gesture. Providing no modification of the thoracic kyphosis (stiff thoracic cage) and pelvic incidence (morphologic parameter), pelvic tilt can then be estimated using this model.

Integrated use of this model in combination with the automatic assessment of the spinal (kyphosis, lordosis) and pelvic (pelvic tilt) configurations may yield an estimate of the whole post-operative geometric configuration from T1 to the femoral heads. Retrospective evaluation and prospective use of these models are currently performed to explore the full potential of such simulations tools.

CONCLUSIONS

The current study explored the use of previous analyses of balance in order to help the planning of spinal osteotomies. Further studies may improve balance prediction but these formulas already provide a useful basis to infer postoperative global balance from preoperative parameters and intended gesture.

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REFERENCES


Table 1: Error of prediction of pelvic tilt on post-ops exams (last exam available).

<table>
<thead>
<tr>
<th>Model</th>
<th>Formula</th>
<th>Correlation</th>
<th>Mean Error</th>
<th>Error SD</th>
<th>Max Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>PT = -7 + 0.37 PI</td>
<td>r = 0.66</td>
<td>6.6°</td>
<td>9.2°</td>
<td>26°</td>
</tr>
<tr>
<td>B</td>
<td>MLL = –2.72 – 1.1 PI + 1.1 PT – 0.31 MTK</td>
<td>r = 0.9</td>
<td>2.2°</td>
<td>6.7°</td>
<td>20°</td>
</tr>
</tbody>
</table>