The Variability of Pelvic Obliquity Measurements in Patients with Neuromuscular Scoliosis

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Background: Pelvic obliquity (PO), or pelvic alignment in the coronal plane, is an important radiographic parameter to indicate fusion levels and judge success of scoliosis correction in patients with neuromuscular scoliosis. There are multiple commonly used techniques to measure PO that have good to excellent interrater and intrarater reliability, but these different methods yield inconsistent values when used on the same radiograph. This study evaluates the inconsistency in the magnitude of PO measurements for patients with neuromuscular scoliosis among 5 common measurement techniques.

Methods: Radiographs of 63 patients with neuromuscular scoliosis were evaluated by 5 raters. Each rater measured PO on each radiograph using the Osebold, O'Brien, Allen and Ferguson, Lindseth, and Maloney techniques. Patients were divided into 2 cohorts based on coronal balance or imbalance. Interrater and intrarater analyses were performed using a 2-way random effects model to calculate absolute agreement. The mean difference in PO between all possible pairs of the techniques was compared using a 2-tailed t test.

Results: The Maloney and Osebold techniques demonstrated excellent interrater reliability, and the Maloney, Osebold, and O'Brien techniques demonstrated excellent intrarater reliability. Significant differences in PO measurement were found in 6 of the 10 comparisons for the balanced spines and 8 of the 10 comparisons for the unbalanced spines. Variability in measurement was captured by best-fit lines, which demonstrated greater dispersion between the means for the Osebold and Maloney techniques in the unbalanced spines than in the balanced spines.

Conclusions: To our knowledge, this study is the first to evaluate mean differences in magnitude of PO among common measurement techniques while accounting for coronal imbalance. Although there is no gold standard for measuring PO, the Maloney and Osebold techniques are the most consistent. This study suggests that those 2 techniques can be used interchangeably when the spine is coronally balanced, but the Osebold technique becomes more inconsistent than the Maloney technique when coronal imbalance exceeds 2 cm.

Clinical Relevance: This information is relevant to surgeons using PO to plan fusion levels and striving for objective ways to judge correction intraoperatively as well as for researchers compiling PO data from multiple centers or studies.

The prevalence of progressive spinal deformities in children with neuromuscular disorders such as cerebral palsy is between 50% and 80%, with nonambulatory children most commonly affected[1]. Neuromuscular curves are typically long, extending into the sacrum, and associated with pelvic obliquity (PO)[2]. According to the Spinal Deformity Study Group's *Radiographic Measurement Manual,* PO is defined broadly as pelvic alignment in the coronal plane and may be flexible or fixed[3]. PO may have suprapelvic causes such as scoliosis and/or infrapelvic causes such as hip contracture and/or displacement[4]. Substantial PO is thought to contribute to seating imbalance, pain from impingement of the pelvis on the ribs, and ischial decubitus ulcers[2,5,6]. Achieving a well-balanced spine over a level pelvis is the goal of treatment for progressive curves[4].

There are 5 commonly used techniques to measure PO, and these different methods can yield inconsistent values when

used on a single radiograph. Prior studies have examined the reliability of individual techniques of measuring PO[5,7,8]; however, to our knowledge none have assessed the variability among the magnitudes of PO measured with multiple techniques or evaluated the accuracy of the techniques, as there is no gold standard with which to compare them. The primary purpose of this study was to investigate the variability in PO measurements among 5 commonly used techniques—namely, those described by Maloney et al.[9], Osebold et al.[10], O'Brien et al.[3], Allen and Ferguson[11], and Lindseth[12]—in a cohort of patients with neuromuscular scoliosis progressing to the surgical range. We hypothesized that there are significant differences in the magnitude of PO greater than measurement error that can be accounted for by measurement technique. Secondarily, we hypothesized that these differences are exacerbated by coronal imbalance.

Materials and Methods

Following institutional review board approval, we performed a retrospective review of patients with neuromuscular scoliosis who underwent posterior spinal fusion at a tertiary care center from 2014 to 2018. Considering 5 raters with a type-1 error rate of 0.05 and a power of 0.80, 39 patients were required to detect a medium difference (f = 0.25) in the primary outcome (mean difference in calculation between methods). Intrarater analysis required 17 patients per group for pairwise comparisons. The sample size exceeded these minimums. Demographic data including ambulatory status were collected by chart review. Preoperative posteroanterior seated spine radiographs made when surgery was recommended to a patient were collected. To meet inclusion criteria, a patient had to have a seated spine radiograph that showed all landmarks needed to apply the 5 PO measurement techniques, including the center of the T1 vertebral body, center of S1, superior aspect of both iliac crests, L4 and L5 spinous processes, and superior margins of the acetabula or inferior margins of the ischial tuberosities. Of 85 patients identified in our neuromuscular scoliosis database, 63 (74%) met the inclusion criteria. The reasons for excluding the remaining 22 patients (26%) were poor-quality radiographs because multiple landmarks were blurred or cropped out (11 patients; 50%), a lack of visualization of the superior aspect of the iliac crest(s) alone (3; 14%), a lack of visualization of the superior margin of the acetabulum and the superior aspect of the iliac crest(s) (7;
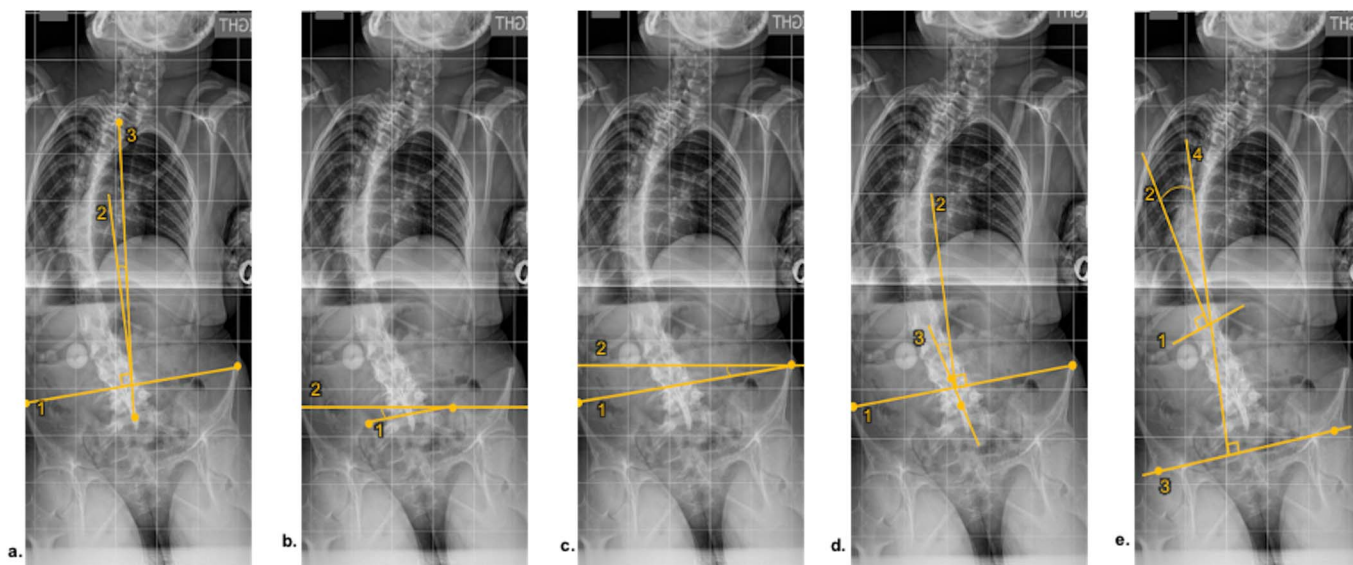

Fig. 1

Pelvic obliquity (PO) measurements demonstrated on a single patient's seated posteroanterior spine radiograph. With the Maloney technique (**Fig. 1-A**), line 1 is drawn across the superior aspects of the iliac crests, and line 2 is drawn perpendicular to that line. Line 3 is drawn from the center of T1 to the center of S1. The PO is the angle where line 3 intersects with line 2. With the O'Brien technique (**Fig. 1-B**), line 1 is drawn across the tips of the sacral alae, the iliac crests, or the greater sciatic notch (in order of priority, depending on visibility), and line 2 is drawn parallel to the upper or lower edge of the radiograph. The PO is measured at the intersection of lines 1 and 2. With the Osebold technique (**Fig. 1-C**), line 1 is drawn between the superior aspects of the iliac crests and line 2 is drawn parallel to the lower end of the radiograph. The PO is measured at the intersection of lines 1 and 2. With the Allen and Ferguson technique (**Fig. 1-D**), line 1 is drawn across the superior aspects of the iliac crests, line 2 is drawn perpendicular to line 1, and line 3 is drawn through the spinous processes of L4 and L5. The PO is the angle created by lines 2 and 3. With the Lindseth technique (**Fig. 1-E**), line 1 is drawn along the superior surface of the top vertebra of the lumbosacral curve if there is a distinct lumbosacral curve (as described in the original publication[12]), or at L1 if there is a sweeping thoracolumbar curve as is found in many patients with neuromuscular disease (set by convention in this study for the purpose of standardizing techniques among raters), and line 2 is drawn perpendicular to that line. Line 3 is drawn along either the superior margins of the acetabula or inferior margins of the ischial tuberosities (in order of priority, depending on visibility), and line 4 is drawn perpendicular to that line. The PO is the angle created by the intersection of lines 2 and 4.

TABLE I Interclass Correlation Coefficients for Each Technique

Technique/Coronal Balance Cohort	ICC	95% CI	P Value*
Maloney			
Overall	0.909	0.846-0.946	
Balance	0.909	0.826-0.956	0.895
Imbalance	0.899	0.820-0.945	
O'Brien			
Overall	0.866	0.785-0.917	
Balance	0.893	0.790-0.950	0.575
Imbalance	0.845	0.749-0.911	
Osebold			
Overall	0.954	0.934-0.969	
Balance	0.957	0.951-0.971	0.912
Imbalance	0.951	0.924-0.971	
Allen and Ferguson			
Overall	0.647	0.539-0.746	
Balance	0.575	0.385-0.753	0.368
Imbalance	0.687	0.565-0.798	
Lindseth			
Overall	0.702	0.601-0.791	
Balance	0.699	0.541-0.834	0.992
Imbalance	0.700	0.572-0.810	

*The p values are for the comparison of the balance and imbalance cohorts.

32%), and the presence of a growth-friendly implant before the index operation (1; 5%). Radiographs were available in IntelliSpace PACS Enterprise, version 4.4 (Royal Philips Electronics).

Patients were divided into 2 cohorts: those with coronal imbalance of >2 cm and those with coronal balance (≤2 cm between a vertical line through the center of C7 and the center sacral vertical line). PO measurements were performed by 5 raters, including 3 board-certified pediatric orthopaedic surgeons with post-fellowship experience ranging from 2 to 22 years and 2 pediatric orthopaedic surgery fellows. Five techniques, described by Maloney et al.[9], O'Brien et al.[3], Osebold et al.[10], Allen and Ferguson[11], and Lindseth[12], were used to measure PO on each radiograph. The techniques included those most commonly used by the participating raters and those included in previous similar studies[5,7,8]. Raters were instructed on PO measurements using a guide created for this study containing diagrams as illustrated in Figure 1.

The raters performed measurements for all 63 patients using 1 technique at a time in following order: Maloney, O'Brien, Osebold, Allen and Ferguson, and Lindseth. After performing the measurements on all radiographs with the first technique, they used the next technique a week later, continuing at weekly intervals until all techniques were applied to each radiograph. The raters were blinded to the measurements

performed by the other raters. The radiographs of all 63 patients were used for interrater reliability testing, whereas the radiographs of 20 patients were later selected using a random number generator for each rater to remeasure 1 month later, to assess intrarater reliability. After measurements were complete, the raters were surveyed about their preferred techniques, difficulty identifying landmarks, and time to completion for each technique.

To assess the interrater and intrarater reliability of the PO measurements, correlation coefficients were calculated using a 2-way random effects model with absolute agreement. To assess the magnitude of the differences among the measurement techniques, the mean difference in PO between each pair of techniques (e.g., the Maloney and Osebold techniques) was calculated as the difference between the 6 raters' mean PO for all 63 radiographs measured with 1 technique (in this case, the Maloney technique) and the 6 raters' mean PO for all 63 radiographs measured with the other technique (in this case, the Osebold technique); the significance of the mean difference was assessed using a 2-tailed Student t test. Each pair of techniques represented 1 of the 10 possible ways that the 5 techniques in this study could be compared with one another: Maloney versus O'Brien, Maloney versus Osebold, Maloney versus Allen and Ferguson, Maloney versus Lindseth, O'Brien versus Osebold, O'Brien versus Allen and Ferguson, O'Brien versus Lindseth, Osebold versus Allen and Ferguson, Osebold versus Lindseth, and Allen and Ferguson versus Lindseth. All statistical analyses were performed using SPSS Statistics for Windows, version 22.0 (IBM).

Results

The study population consisted of 63 patients (33 male and 30 female) with a mean age of 13 years (range, 9 to 20 years) at the time that the radiograph used for the measurements was obtained. Fifty-seven patients (90%) were non-ambulatory. Coronal balance was noted in 24 patients, and coronal imbalance was noted in 39 patients. The mean Cobb angle (and standard deviation) of the major scoliotic curve was 81° ± 21°.

The interclass correlation coefficients (ICCs) for each technique in the overall cohort as well as in the coronal balance and imbalance cohorts are listed in Table I. The ICCs were highest for the Maloney and Osebold techniques (0.909 and 0.954, respectively) but did not differ significantly between the 2 (p = 0.317). The ICCs were lowest for the Allen and Ferguson technique and Lindseth technique (0.647 and 0.702), respectively. No significant difference in agreement was noted between the measurements in balanced and those in unbalanced spines with any technique. Similarly, the Maloney and Osebold techniques had excellent intrarater reliability, 0.922 (95% confidence interval [CI] = 0.886, 0.947) and 0.955 (95% CI = 0.934, 0.970), respectively, and the Allen and Ferguson technique and the Lindseth technique had the lowest intrarater reliability, 0.721 (95% CI = 0.583, 0.813) and 0.777 (95% CI = 0.685, 0.844), respectively. The O'Brien technique had excellent intrarater reliability as well: 0.940 (95% CI = 0.892, 0.964).

TABLE II Mean Difference in PO for Each Comparison of Techniques in the Coronal Balance and Imbalance Cohorts			
Paired Technique Comparison/Coronal Balance Cohort	Mean Difference (°)	Standard Deviation (°)	P Value*
Maloney vs. O'Brien			
Balance	**−4.56**	5.02	**<0.001**
Imbalance	−0.825	9.90	0.606
Maloney vs. Osebold			
Balance	−0.0825	3.01	0.895
Imbalance	**3.62**	9.67	**0.025**
Maloney vs. Allen and Ferguson			
Balance	−2.17	11.1	0.347
Imbalance	**5.84**	17.1	**0.039**
Maloney vs. Lindseth			
Balance	**−12.2**	13.0	**<0.001**
Imbalance	**−9.73**	13.8	**<0.001**
O'Brien vs. Osebold			
Balance	**4.48**	3.90	**<0.001**
Imbalance	**4.44**	3.60	**<0.001**
O'Brien vs. Allen and Ferguson			
Balance	2.39	11.4	0.315
Imbalance	**6.66**	14.7	**0.007**
O'Brien vs. Lindseth			
Balance	**−7.68**	14.2	**0.014**
Imbalance	**−8.91**	17.2	**0.003**
Osebold vs. Allen and Ferguson			
Balance	−2.09	10.4	0.333
Imbalance	2.22	16.0	0.391
Osebold vs. Lindseth			
Balance	**−12.2**	13.3	**<0.001**
Imbalance	**−13.3**	17.7	**<0.001**
Allen and Ferguson vs. Lindseth			
Balance	**−10.1**	15.0	**0.003**
Imbalance	**−15.6**	18.9	**<0.001**
*Bolding indicates significance.			

Significant differences in PO measurement were found in 6 of the 10 comparisons for balanced spines and 8 of the 10 comparisons for unbalanced spines (Table II). The magnitude of these differences was >5° in 4 of the 10 comparisons for balanced spines and 6 of the 10 comparisons for unbalanced spines. The results of some comparisons differed significantly between the balanced spines and unbalanced spines. Dispersion in measurement, also known as variability or scatter, was captured by best-fit lines as shown in Figure 2, which compares the average rater measurement for each technique casewise against the Maloney technique. When each was compared with the Maloney technique, the O'Brien (Fig. 2-A) and Osebold (Fig. 2-B) techniques showed less dispersion than did the Allen and Ferguson (Fig. 2-C) and Lindseth (Fig. 2-D) techniques. Less dispersion was found when the Osebold and Maloney techniques were compared in the balanced spines (residuals, or the vertical distances from data points to the best-fit line, ranging from −5.8° to 6.9°; Fig. 3-A) than when they were compared in the unbalanced spines (residuals ranging from −16.5° to 18.0°; Fig. 3-B).

The survey results are listed in Table III. Four of the 5 surgeons preferred the Maloney technique. Surgeons reported the most difficulty with identifying the center of S1, the spinous processes of L4 and L5, and the superior margins of the acetabula. They considered the Lindseth technique the most time-consuming, and the Osebold and O'Brien techniques the least time-consuming.

Discussion

PO is an important parameter of neuromuscular scoliosis in terms of preoperative planning, intraoperative decision-making, and postoperative evaluation of surgical success. Prior studies showed that extending instrumentation to the pelvis improves scoliosis correction and sitting balance if the PO exceeds 10° to 15°, especially in nonambulatory children[5,13-15].
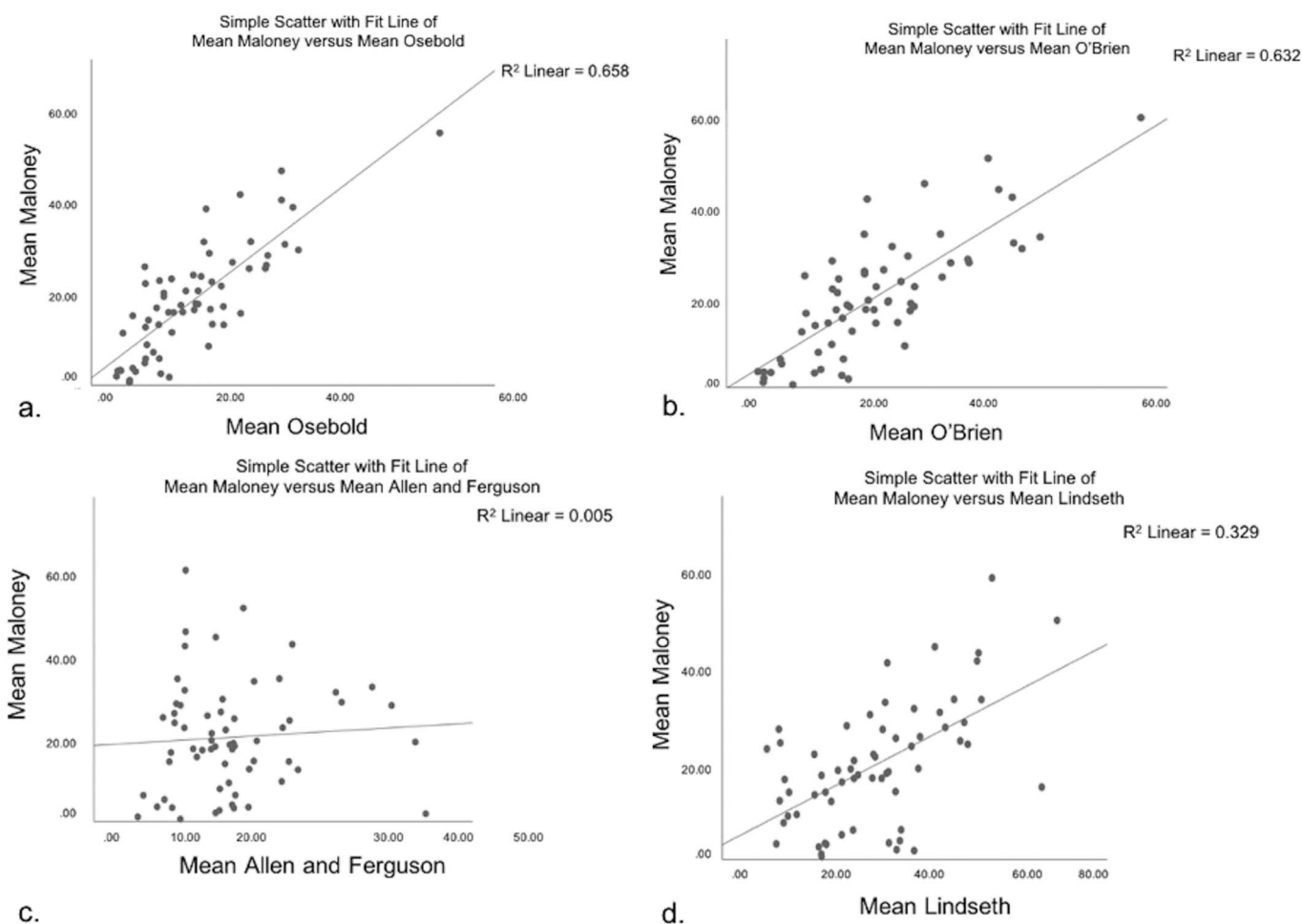
Fig. 2

Best-fit lines with residuals for mean differences between the Maloney technique and the O'Brien (**Fig. 2-A**), Osebold (**Fig. 2-B**), Allen and Ferguson (**Fig. 2-C**), and Lindseth (**Fig. 2-D**) techniques.
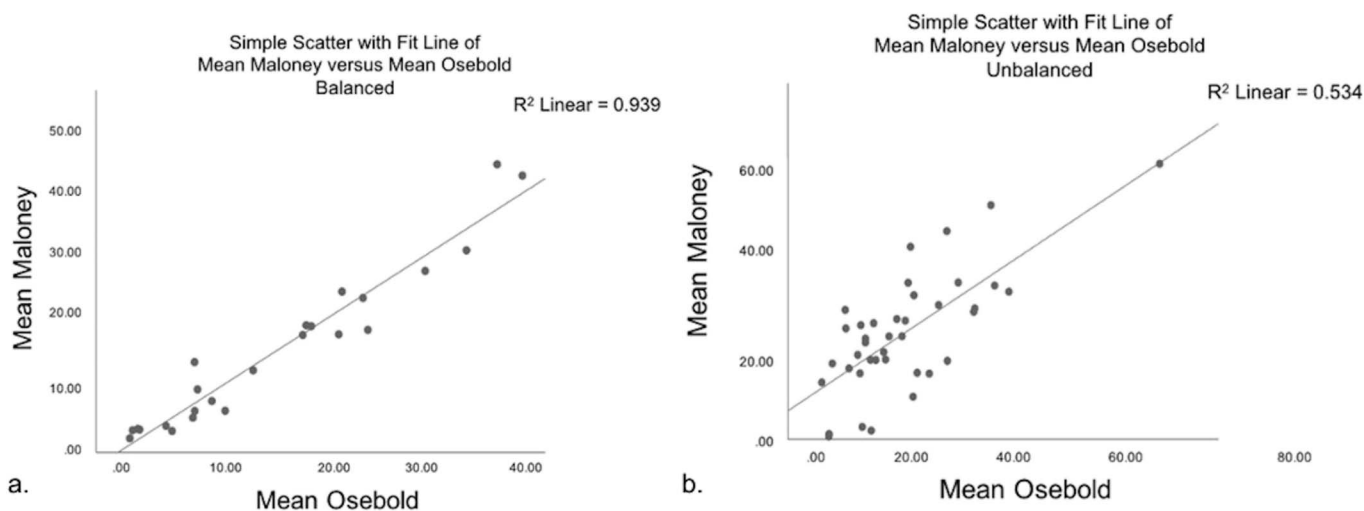

Fig. 3

Best-fit lines with residuals for the mean differences between the Maloney and Osebold techniques in the balanced (**Fig. 3-A**) and unbalanced (**Fig. 3-B**) cohorts.

TABLE III Surgeon Satisfaction Survey Results	
Question	Response
What is your preferred technique in this study?*	Maloney (4/5)
	Osebold (1/5)
Did you have difficulty identifying any of the following landmarks?*	Superior margins of the acetabula (5/5)
	Spinous process of L4 (4/5)
	Spinous process of L5 (4/5)
	Center of S1 (3/5)
	Superior aspect of both iliac crests (2/5)
	Inferior margins of ischial tuberosities (2/5)
	Center of T1 vertebral body (0/5)
Rank your time to completion for each technique, with 1 being the shortest and 5 being the longest†	O'Brien (1, 1, 2, 2, 2), mean ranking 1.6
	Osebold (1, 1, 1, 2, 3), mean ranking 1.6
	Maloney (2, 3, 3, 3, 4), mean ranking 3
	Allen and Ferguson (3, 4, 4, 4, 4), mean ranking 3.8
	Lindseth (5, 5, 5, 5, 5), mean ranking 5
*The numbers in parentheses indicate the number of surgeons choosing the answer/the total number of surgeons. †The numbers in parentheses indicate the rankings of the time given by each of the 5 surgeons.	

This is a weighty decision because pelvic fixation is not without complications, including increased blood loss, surgical time, wound complications, and surgical site infection[16]. PO is a well-accepted radiographic measure of success that neuromuscular spine surgeons can use intraoperatively and postoperatively to judge correction.
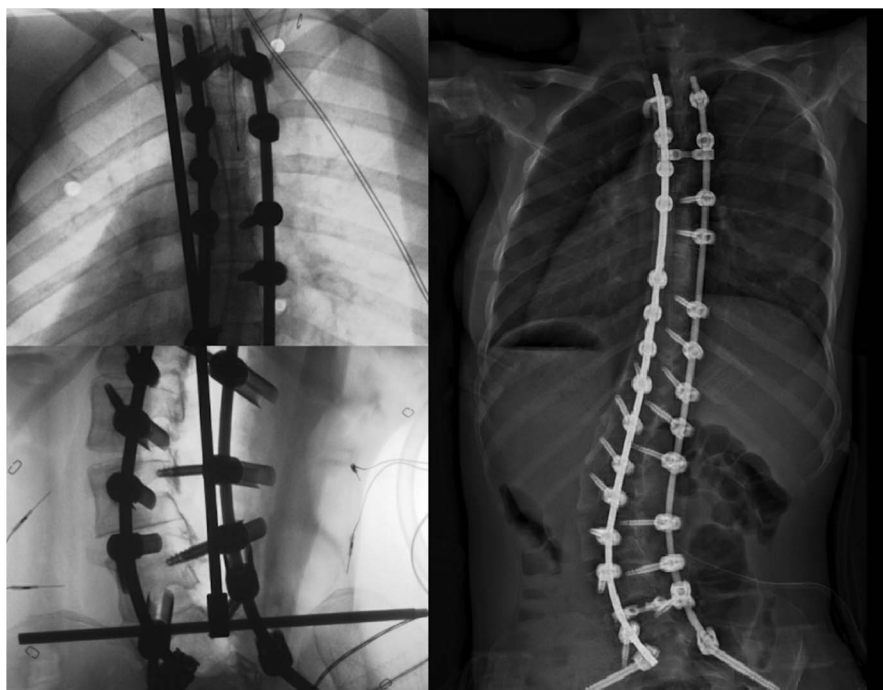

Fig. 4
A "T of Tolo" construct is built with 2 rods and a T-connector and used to apply the Maloney technique intraoperatively. The "T of Tolo" is placed over the patient with the T-connector as close as possible to the center of S1, and the more horizontal limb of the T is placed parallel to the superior aspects of the iliac crests. The surgeon can then visualize the degree of correction of pelvic obliquity based on where the more vertical limb of the T is relative to the center of T1.

Maloney: 28° PO   O'Brien: 14° PO   Osebold: 7° PO
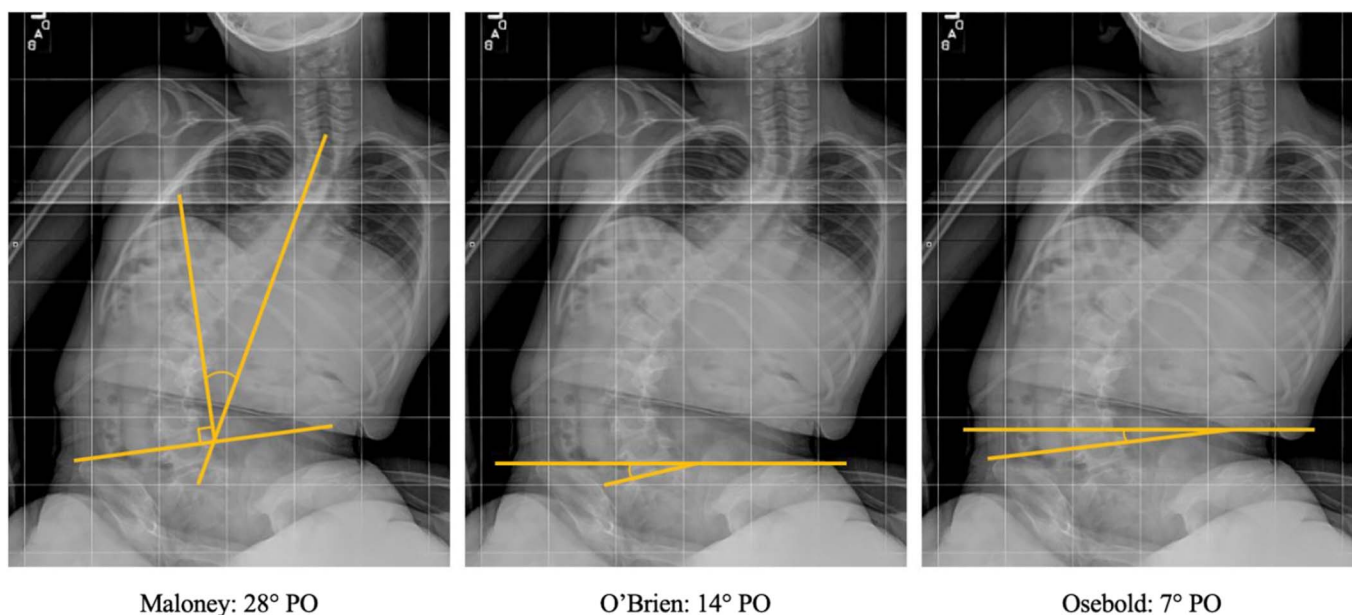
Fig. 5

Variability in the magnitude of PO when measured with the Maloney, O'Brien, and Osebold techniques in a patient with severe coronal imbalance.

Outcome studies of neuromuscular spine fusions are numerous, and the importance of correcting PO to improve sitting balance is well known. However, there is no consensus on which PO measurement technique is most accurate or which should be used in a given clinical setting. Surgeons who are using PO for vertebral level selection and/or to judge the success of surgery may make different clinical decisions depending on the measurement technique that they use. Studies reporting correction of PO can be misleading if the chosen measurement technique is not reported or if the results of multiple techniques are compiled in multicenter studies or meta-analyses. Prior similar studies have evaluated the reliability of only 1 PO measurement technique at a time. It has been previously reported that the Maloney technique has the highest interrater and intrarater reliability and the Lindseth and Allen technique and Ferguson technique have the lowest[5,7]. In our results, the Osebold technique had the highest interrater reliability (highest ICC), followed by the Maloney technique, although their ICCs were statistically similar. The Osebold, Maloney, and O'Brien techniques all had excellent interrater and intrarater reliability, while the Lindseth technique and the Allen and Ferguson technique were only fair in this regard[17].

To our knowledge, no prior study has focused on the actual magnitude of the difference in PO values among different techniques. We believe that we are the first to compare the mean differences in the magnitude of PO measured using different techniques to determine if any technique consistently overestimates or underestimates PO. The majority of the comparisons showed significant measurement error between techniques. Although there is no published measurement error for PO, to our knowledge, the Cobb angle measurement error has been reported to be approximately ≤5°[18-20]. If we consider that PO may have a similar measurement error, then it is worth noting that 4 of 10 comparisons of PO measurements in balanced spines and 6 of 10 comparisons in unbalanced spines showed an error of >5°. Our reliability data suggest that the Maloney and Osebold techniques are the most consistent. With the comparison of these 2 techniques, the Osebold method underestimated the magnitude of PO in the unbalanced cohort; this was statistically significant but likely within measurement error as the mean difference was 3.62°. Best-fit lines for these 2 techniques illustrated a greater dispersion in measurement on the basis of larger residuals (Figs. 3-A and 3-B) in unbalanced spines, with average differences up to 18° (the worst-case scenario of the residual). This has implications for multicenter studies and meta-analyses because at first it may seem that PO data acquired with the Maloney or Osebold technique can be compiled and analyzed interchangeably. However, this would result in greater variance in measurement, particularly for unbalanced spines, introducing measurement error that would likely bias results toward the null hypothesis.

The Maloney technique has excellent intrarater and interrater reliability and also captures coronal balance by using T1 and S1 landmarks rather than just measuring tilt relative to the horizontal axis. The Maloney technique is the only method in this study incorporating a landmark superior to the lumbar spine, making it useful to a surgeon whose goal is to also improve coronal balance in a patient with neuromuscular scoliosis. While PO is measured as an angle and coronal imbalance is measured as a horizontal distance, improving both is key to improving postoperative sitting balance. Our preference is to use both PO measured via the Maloney technique and coronal imbalance to judge the degree of decompensation in neuromuscular scoliosis for preoperative and intraoperative decision-making. PO can be measured intraoperatively with the Maloney technique by using the "T of Tolo" method shown in Figure 4[21]. Also, there are cases in

which severe coronal imbalance results in a clinical difference between the PO measured using the Maloney technique and the PO measured with the Osebold and O'Brien techniques. The patient shown in Figure 5 has a coronal imbalance of +10 cm with a mean PO of 28° according to the Maloney technique, 14° according to the O'Brien technique, and 7° according to the Osebold technique. In this case, these are clinically meaningful differences because a PO value exceeding 10° to 15° is a common indication for sacropelvic fixation[14].

This study adds both new objective and new subjective information to the literature that surgeons can use to improve their practice. Our survey indicated that most (4) of the 5 surgeons preferred the Maloney method. Additionally, the surgeons reported difficulty identifying necessary landmarks, including the center of S1 (Maloney technique), the spinous processes of L4 and L5 (Allen and Ferguson technique), and the superior margins of the acetabula (Lindseth technique). Survey results, albeit subjective, are important to consider because surgeons may be less likely to use a difficult and/or time-consuming radiographic measurement to make clinical decisions. Additionally, this study highlights the importance of having quality radiographs as each PO technique relies on specific landmarks. Half (11) of the 22 exclusions in the study were due to radiographs without visible landmarks because they had been either cropped out or were blurry. Non-visible landmarks needed for the Lindseth technique were responsible for almost a third (32%) of the exclusions in the study. Patients with worse pelvic obliquity or sitting balance may have more difficulty sitting independently and/or staying still, resulting in more blurred radiographs, but because PO and coronal imbalance were not measured on excluded patients we could not confirm this. This study can equip surgeons to make an informed choice of their preferred PO measurement technique, and they can work with their radiology departments to improve radiograph quality. The simplest change would be for surgeons to notify radiology technicians which landmarks should be in the field of view to avoid landmarks being cropped out or obscured.

Strengths of this study include the fact that 5 pediatric orthopaedic surgeons performed the measurements, which is the largest sample size of any similar study, and its inclusion of multiple measurement techniques. The study is applicable to clinical practice because the radiographs that were measured were actually used in the care of the study patients. Raters were blinded to their own measurements with the other techniques by separating the measurements using each technique by 1-week intervals, to avoid biasing the mean difference in PO magnitudes. A key limitation of the study was the quality control performed to exclude inadequate radiographs, which may introduce selection bias. The higher quality of the study radiographs may have increased reliability in our study compared with clinical practice. In addition, any study of this kind uses only frontal plane measurements, but patient positioning and rotation can affect PO measurement. Pelvic position may be influenced by suprapelvic deformities such as scoliosis, infrapelvic deformities such as hip contractures with or without hip displacement, or the need for assistance with sitting. PO is therefore only one component of a complex 3-dimensional deformity and the possibility of incorporating 3-dimensional measurements may improve future studies.

There is no gold standard for measuring PO. Without a consensus among spinal deformity surgeons establishing a standard against which to measure PO, the accuracy of any given measurement technique cannot be determined. Previous literature suggests that the Maloney and Osebold techniques have the highest intrarater and interrater reliability, and the reliability findings in our study are similar[5]. Our study adds new information in that the Maloney and Osebold techniques can be used interchangeably when the spine is coronally balanced, but the Osebold technique becomes more variable as coronal imbalance exceeds 2 cm. Additionally, the Maloney technique has several key advantages, including more closely representing the goal of neuromuscular scoliosis surgery; however, it requires excellent seated imaging because the centers of T1 and S1 must be well visualized. The Osebold technique is easier to use as it requires only the iliac crests to be visualized. To our knowledge, this study is the first to evaluate mean differences in the magnitude of PO among the common measurement techniques while also accounting for coronal imbalance. This information is useful for surgeons who use PO preoperatively to determine indications for sacropelvic fixation as well as for those who strive for objective ways to judge their correction intraoperatively. Researchers can also use these findings to support compiling PO data from multiple centers or studies with the understanding that the measurement technique and coronal balance must also be recorded. ■

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