Minimally Invasive Surgery for Mild-to-Moderate Adult Spinal Deformities: Impact on Intensive Care Unit and Hospital Stay

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OBJECTIVE: **To compare circumferential minimally invasive (cMIS) versus open surgeries for mild-to-moderate adult spinal deformity (ASD) with regard to intensive care unit (ICU) and hospital lengths of stay (LOS).**

METHODS: **A retrospective review of 2 multicenter ASD databases with 426 ASD (sagittal vertical axis <6 cm) surgery patients with 4 or more fusion levels and 2-year follow-up was conducted. ICU stay, LOS, and estimated blood loss (EBL) were compared between open and cMIS surgeries.**

RESULTS: **Propensity matching resulted in 88 patients (44 cMIS, 44 open). cMIS were older (61 vs. 53 years, $P = 0.005$). Mean levels fused were 6.5 in cMIS and 7.1 in open ($P = 0.368$). Preoperative lordosis was higher in open than in cMIS (42.7° vs. 40.9°, $P = 0.016$), and preoperative visual analog score back pain was greater in open than in cMIS (7 vs. 6.2, $P = 0.033$). Preoperative and postoperative spinopelvic parameters and coronal Cobb angles were not different. EBL was 534 cc in cMIS and 1211 cc in open ($P < 0.001$). Transfusions were less in cMIS (27.3% vs. 70.5%, $P < 0.001$). ICU stay was 0.6 days for cMIS and 1.2 days for open ($P = 0.009$). Hospital LOS was 7.9 days for cMIS versus 9.6 for open ($P = 0.804$).**

CONCLUSIONS: **For patients with mild-to-moderate ASD, cMIS surgery had a significantly lower EBL and shorter ICU stay. Major and minor complication rates were lower in cMIS patients than open patients. Overall LOS was shorter in cMIS patients, but did not reach statistical significance.**

Key words
- Deformity
- Length of stay
- Minimally invasive
- MIS
- Scoliosis
- Spinal deformity

Abbreviations and Acronyms
ACR: Anterior column realignment
ASD: Adult spinal deformity
cMIS: Circumferential minimally invasive surgery
ICU: Intensive care unit
MIS: Minimally invasive surgery
ODI: Oswestry disability index
PI-LL: Pelvic incidence and lumbar lordosis
PSO: Pedicle subtraction osteotomy
PT: Pelvic tilt
SVA: Sagittal vertical axis
VAS: Visual analog score

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INTRODUCTION

As more knowledge is gained about adult spinal deformity (ASD) surgery, patient outcomes have improved in terms of quality of life and alleviation of disability.[1-3] Although the morbidity has decreased in the era of modern surgery compared with historical controls, the magnitude of ASD surgery nonetheless still has a significant impact on the patient.[4-7] Multilevel fusions, osteotomies, significant blood loss with subsequent fluid shifts, large areas of muscle dissection, and open anterior surgery all disrupt a patient's homeostasis and demand a more intense recovery.[6,8-10] Moreover, many patients with ASD go to the intensive care unit (ICU) after their surgery for pain control, blood volume resuscitation, blood pressure management, and airway precaution.[6,8-10] Concomitantly, the cost of such surgeries is in part increased because of the increased cost of ICU stay.[11,12] Thus, the "intensity of stay"—as characterized by the length of hospitalization and the length of ICU stay—is a major factor in ASD surgery. Trying to decrease this intensity of stay can potentially decrease the morbidity, complication rate, and costs.

It has been shown that minimally invasive spine (MIS) surgery can decrease morbidity by decreasing blood loss, hospital stay, infection, and cost compared with open surgery.[13-15] As MIS surgery has made technical advances, its application has gone beyond routine, straightforward conditions into the realm of complex ASD correction. With this advance in MIS, the potential to significantly decrease the intensity of stay in ASD surgery has become promising. We wished to compare the intensity of stay during open ASD surgery with circumferentially MIS (cMIS) surgery to see if there is a difference with regard to the intensity of stay.

Objective of the Study and Research Question

The purpose of this study was to evaluate the impact of minimally invasive surgery on patients undergoing ASD corrective surgery compared with open surgery.

METHODS

A retrospective review of 2 multicenter ASD databases with similar inclusion criteria was conducted. The first database included patients with ASD from 11 institutions in the United States who underwent traditional, open posterior-only, or anterior-posterior spine surgery (open) and were enrolled into a prospective registry.

The second database is a retrospective registry of patients from 10 institutions in the United States who underwent minimally invasive spinal deformity surgery that includes cMIS, posterior-only MIS, stand-alone lateral interbody fusions, and hybrid techniques such as lateral interbody fusions with open posterior surgery. Patients who underwent hybrid surgery (minimally invasive anterior surgery followed by open posterior surgery) were excluded. Patients underwent adult deformity surgery during the time period of October 1, 2009, to September 30, 2013.

cMIS surgery is defined as anterior minimally invasive surgery (either MIS lateral surgery or miniopen anterior lumbar interbody fusion surgery) followed by posterior percutaneous pedicle screw fixation without any open detachment or stripping of the posterior spinal musculature. Open surgery is defined as traditional posterior stripping and exposure of the spine with standard retractors. Staged surgery is defined as surgery performed over 2 separate days. For fusion in cMIS patients, the majority of fusions were achieved in the disc space via anterior interbody fusion. This generally obviates the need for a posterior fusion and only requires that the posterior column be instrumented without bone grafting. With regard to fusion material in the cMIS surgeries, the fusion material in the anterior interbody space was generally allograft material. This could be either standard allograft, stem-cell based allograft, or bone morphogenic protein. Rarely was autograft used in the anterior interbody space. For posterior fusions, if there was an anterior interbody fusion, only instrumentation was performed; no posterior grafting was performed. However, in areas where there were no interbody grafts, such as T10 to L1, the pedicles were cannulated, and the facets were exposed with minimally invasive retractors, such as a tube or a speculum. Through this minimally invasive approach, the facets were denuded, decorticated, and grafted with bone graft in the facets, and the pedicle screws are placed after grafting.

Inclusion criteria for both databases were age >18 years and at least one of the following radiographic measurements: sagittal vertical axis (SVA) $\geq$ 5 cm, pelvic tilt (PT) $\geq 25^\circ$, lumbar scoliosis $\geq 20^\circ$, or a pelvic incidence and lumbar lordosis mismatch (PI-LL) of $\geq 10^\circ$. Patients with a minimum of 4 levels fused and had a minimum of 2-year follow-up were included for analysis in this study. Patients who did not have minimum 2-year follow-up were excluded. In an attempt to create a more homogeneous study population, cMIS patients were propensity-matched by the number of levels fused to the open cohort (Table 1). Measurements taken were pre- and postoperative 3-foot standing films that included all lumbopelvic parameters, visual analog score (VAS), Oswestry disability index (ODI), perioperative parameters such as blood loss and operative, neurologic status, length of stay, and reoperation rates. Major complications were life-altering complications such as heart attack, stroke, or neurologic damage or a complication requiring a significant intervention such as take back to the operating room, repositioning implants, or deep wound infection requiring washout. Minor complications resolved without permanent effects, such as urinary tract infection, skin abrasions from positioning, or blood loss anemia.

Matching was done by assigning a propensity score using linear regression. Scores were then ranked, and 3 groups were created with similar propensity scores. Random sampling of the larger group was used to create an equal sample size in both groups. χ^2tests and Mann-Whitney U tests were used to assess significant differences between the 2 groups, and significance was set at $P < 0.05$. All statistical analyses were done using IBM SPSS Statistics v. 23 (Armonk, New York, USA). This study has IRB approval #14-13558.

RESULTS

There were 44 patients in the cMIS group and 44 in the open group from a total of 88 patients. Mean age was 61 years in the cMIS group and 53 years in the open group ($P = 0.005$). Mean levels fused were 6.5 in the cMIS group and 7.1 in the open group ($P = 0.368$). Preoperative spinopelvic parameters were not different between groups. The preoperative PI-LL difference was 11.3° for the cMIS group and 15.3° for the open group ($P = 0.444$); the postoperative PI-LL difference was 8.2° and 7°, respectively ($P = 0.69$). Preoperative PT was 22.1° for the cMIS group and 23.2° for the open group ($P = 0.576$); postoperative PT was 22.5° and 22.6°, respectively ($P = 0.992$). Preoperative SVA was 34.5 mm in the cMIS group and 49.4 mm in the open group ($P = 0.893$); postoperative SVA was 32.1 mm and 33.7 mm, respectively ($P = 0.53$). The maximum mean preoperative coronal Cobb angle was 38.2° in the cMIS group and 39.3° in the open group ($P = 0.791$). The maximum mean postoperative Cobb angle was 17.9° in the cMIS group and 22.7° in the open group ($P = 0.518$).

Twenty-one (47.7%) of the cMIS patients underwent staged surgery, whereas 8 (18.2%) of the open patients underwent staged

Table 1. Characteristics of patients undergoing MIS and open adult deformity surgery

	MIS (n = 44)	Open (n = 44)	*P* Value
Age, years	61.1	53	**0.005**
Percentage of females	75.0	86.4	0.181
EBL, cc	533.5	1210.7	**<0.001**
Transfusion rate, %	27.3	70.5	**<0.001**
Operative time, minutes	433.4	378.8	0.15
Levels fused	6.5	7.1	0.368
ICU stay, days	0.6	1.2	**0.009**
Total LOS, days	7.9	9.6	0.804
Staged surgery	21 (47.7%)	8 (18.2%)	0.003
Preoperative			
PT, °	22.1	23.2	0.576
LL, °	40.9	42.7	0.530
PI-LL, °	11.3	15.3	0.444
SVA, mm	34.5	49.4	0.578
ODI	44.1	38.8	0.244
VAS back pain	6.2	7	**0.033**
VAS leg pain	5.6	4.7	0.273
Preoperative maximum Cobb	38.2	39.3	0.791
Postoperative			
PT, °	22.5	22.6	0.992
LL, °	44.3	52	**0.016**
PI-LL, °	8.2	7	0.69
SVA, mm	32.1	33.7	0.893
ODI	24.4	21.7	0.293
VAS back pain	2.8	3.7	0.393
VAS leg pain	2.8	2.3	0.199
Postoperative maximum Cobb	17.9	22.7	0.518

Bold values indicate statistical significance $P < 0.05$.
EBL, estimated blood loss; ICU, intensive care unit; LL, lumbar lordosis; LOS, length of stay; MIS, minimally invasive surgery; ODI, Oswestry disability index; PI-LL, pelvic incidence and lumbar lordosis; PT, pelvic tilt; SVA, sagittal vertical axis; VAS, visual analog score.

surgery (P = 0.003). Estimated blood loss was 534 cc in the cMIS group and 1211 cc in the open group (P < 0.001). The transfusion rate was less in the cMIS group (27.3% vs. 70.5%, P < 0.001). Operative time was 433 minutes for the cMIS group versus 379 minutes for the open group (P = 0.15), and this included staged and nonstaged surgeries. Average ICU stay was 0.6 days for cMIS patients and 1.2 days for open patients (P = 0.009). Overall hospital length of stay was 7.9 days for the cMIS group versus 9.6 for the open group (P = 0.804).

Preoperative VAS back pain was slightly greater in the open group than in the cMIS group (7 vs. 6.2, P = 0.033), but postoperative VAS back pain was not (2.8 vs. 3.7, P = 0.393) (Table 1). Charlson cormobidity score was 1.5 in the cMIS group and 1 in the open group (P = 0.505). Preoperative ODI was 44.1 in the cMIS group and 38.8 in the open group (P = 0.244); postoperative ODI was 24.4 and 21.7, respectively (P = 0.293). Preoperative VAS leg was 5.6 in the cMIS group and 4.7 in the open group (P = 0.273); postoperative VAS leg was 2.8 and 2.3, respectively (P = 0.199).

The overall complication rate was 63.6% (28/44) in the open group and 29.5% (13/44) in the cMIS group (P = 0.001). Major complications occurred in 36.4% (16/44) in the open group and 13.6% (6/44) in the cMIS group (P = 0.014), and minor complications occurred in 43.2% (19/44) in the open group versus 20.5% (9/44) in the cMIS group (P = 0.022). Reoperation rates were not significant between groups (open 18.2% [8/44] vs. cMIS 9.1% [4/44], P = 0.214) (Table 2).

DISCUSSION

There have been significant advances in assessing outcome variables in ASD, and such advances must be incorporated into planning MIS adult deformity surgery. Early data showed the importance of the SVA, but spinopelvic parameters were not accounted for.[1,16] The PI-LL mismatch and PT have become critical when planning ASD surgery.[2,17] Moreover, lateral listhesis and spondylolisthesis have also been associated with increased disability as a result of the radiculopathy secondary to stenosis.[2] As techniques and technology have advanced, the complication rates have decreased compared with their historical norms, but they still remain as high as 35% or more, even in the hands of experts.[4,5,8,10,18-20]

MIS surgery had traditionally been applied to degenerative cases of the spine that had relatively straightforward surgical solutions. Outcomes of these types of surgeries have shown that MIS surgeries have a lower infection rate and lower blood loss than traditional open surgery.[13,14] Moreover, MIS surgery has been shown to preserve the posterior spinal musculature because it avoids the posterior stripping and dissection of the paraspinal muscles.[21,22] As MIS techniques became more advanced, the applications began to expand into ASD given the large prevalence of ASD in the aging population and the morbidity of ASD surgery in general. More and more complicated cases of ASD were performed, and eventually, ASD cases were being treated completely with MIS techniques, also known as cMIS surgery.[23] Such cMIS techniques implemented minimally invasive anterior surgery followed by percutaneous pedicle screw instrumentation, thus providing a "circumferential" minimally invasive procedure.

Although there are many studies comparing MIS with open degenerative spine surgery, there are few studies comparing MIS with open surgery for ASD specifically. Deukmedjian et al[24,25] demonstrated their early corrective series, noting that although the coronal correction was significant, the sagittal correction was not always adequate. Anand et al[26,27] also published some early series on MIS correction of adult scoliosis with good results, but again, the majority of correction was the coronal plane. As technology advanced, more and more centers were performing the MIS treatment of ASD, and the experience with MIS deformity

Table 2. Complications of Patients Undergoing MIS versus Open Adult Deformity Surgery

	MIS (n = 44)	Open (n = 44)	*P* Value
Complication	13 (29.5%)	28 (63.6%)	0.001
Major complication	6 (13.6%)	16 (36.4%)	0.014
Minor complication	9 (20.5%)	19 (43.2%)	0.022
Reoperation	4 (9.1%)	8 (18.2%)	0.214
Major			
Cardiopulmonary	0 (0.0%)	2 (4.5%)	0.153
DVT	0 (0.0%)	2 (4.5%)	0.153
Implant failure	1 (2.3%)	5 (11.4%)	0.091
Neurologic	0 (0.0%)	3 (6.8%)	0.078
Infection	1 (2.3%)	1 (2.3%)	0.999
Sepsis	0 (0.0%)	1 (2.3%)	0.315
Visceral	1 (2.3%)	0 (0.0%)	0.315
Wound dehiscence	0 (0.0%)	2 (4.5%)	0.153
Pseudoarthrosis	1 (2.3%)	3 (6.8%)	0.306
PJF	0 (0.0%)	3 (6.8%)	0.078
Minor			
Infection	1 (2.3%)	2 (4.5%)	0.557
Radiculopathy	5 (11.4%)	3 (6.8%)	0.458
Delirium	2 (4.55)	0 (0.0%)	0.153
Cardiopulmonary	2 (4.55)	4 (9.1%)	0.398
Gastrointestinal	1 (2.3%)	8 (18.2%)	0.014
Renal	1 (2.3%)	0 (0.0%)	0.315

DVT, deep venous thrombosis; MIS, minimally invasive surgery; PJF, proximal junctional failure.

treatment had advanced until more and more complex deformities were being done with MIS surgery.[23,28-38]

Historically, lateral interbody fusion techniques have provided approximately 3° of lordosis per level, even though the coronal Cobb angle correction has been much greater in magnitude.[39] Newer techniques for ASD correction have been published, such as anterior column realignment (ACR) and the mini-open pedicle subtraction osteotomy (PSO).[31,38,40,41] Such techniques may provide significantly more lordosis than the traditional lateral interbody surgery; however, our series did not include any of such patients who had either ACR or mini-open PSO.

In our series, the open and MIS cohorts were well-matched with regard to the number of fusion levels, preoperative lumbopelvic parameters, SVA, and disability scores. With this matching, we were able to directly compare similar types of pathologies. Moreover, it was important that the spinopelvic parameters, fusion levels, and SVA were matched to ensure that the magnitude of corrective surgeries performed and the treated pathologies were similar. With this matching, we were able to directly compare the cMIS versus open cohorts. Thus, even though the SVA in the open group was slightly higher than the cMIS group, this was not statistically significant. Moreover, the postoperative SVA after correction in both groups was not statistically different. In addition, the average difference between the SVA in the open group and the cMIS group was approximately 1.5 cm, and this was not statistically different from the cMIS group. Thus, even though one could make the point that the open group had a higher SVA, necessitating more correction needed (resulting in more morbidity, or more "intensity of stay"), the difference in SVA was not statistically significant. Furthermore, we could not account for the difference in the outcomes based on SVA alone. Similarly, even though the ODI was higher in the open group, this difference was not statistically significant. In addition, the PI-LL mismatches in both groups were similar preoperatively. Although postoperatively, the open group had slightly higher lumbar lordosis, the postoperative ODI, VAS back, and VAS leg were not different. Thus, even though there was statistically slightly more lordosis induced in the open group, this did not result in any clinical difference in the outcome measures. Thus, the patients in both groups were effectively treated with a similar number of fusion levels despite a slightly higher PI-LL mismatch in the cMIS group postoperatively. We rationalize that this similarity in outcomes measures is that the patients in both groups had only mild-to-moderate sagittal plane deformities. That is, other factors such as back pain secondary to listhesis, radiculopathy secondary to up-down stenosis, or neurogenic claudication drove the patients to surgery, not necessary sagittal imbalance and flat back syndrome symptoms per se. We illustrate the case example of a patient who underwent surgery for radicular symptoms in the presence of ASD (**Figures 1 and 2**). With propensity matching, we found that treating similar cohorts of patients with either cMIS or open surgery with similar fusion levels resulted in similar reduction of leg pain, back pain, and disability.

Although in other published studies, analyses of hybrid surgeries (MIS anterior with open posterior surgery) were included, in this series, all the MIS patients had cMIS surgery for both anterior and posterior approaches—no hybrid cases were included. Because of the cMIS surgeries, this may have resulted in the shorter ICU stay and lower blood loss. Because there is no stripping of the posterior muscles, the postoperative muscular pain may be less. Moreover, by not stripping the muscles, there may be a concomitant lower release of cytokines and other inflammatory mediators, thereby decreasing pain and increasing mobility. In addition, the lower blood loss, less fluid shift necessitating resuscitation, and potentially less pain from decreased posterior muscle dissection may be the primary reasons why the ICU stay was shorter. Because of the lack of an open exposure, there were fewer bleeding surfaces during the surgery, and this may be the main reason why the blood loss is less.

There was a higher percentage of the MIS cohort who underwent staged procedures compared with the open group (47.7% vs. 18.2%, $P = 0.003$). This difference in the number of staged patients may have also affected the ICU stay rates in the MIS cohort. Because patients who were not staged may have undergone anterior-posterior surgery all in 1 day, there may have been a surgeon preference to keep such patients in the ICU postoperatively for monitoring. However, Passias et al[42] evaluated over 11,000 circumferential spine surgeries, and they showed that staging in spine surgery actually increases complications and

Figure 1. (**A**) Pre- and (**B**) 2-year postoperative AP standing x-rays of a 61-year-old woman treated for severe radiculopathy from stenosis and scoliosis. She was treated with L3-S1 ALIF followed by minimally invasive L3-S1 posterior fusion. ALIF, anterior lumbar interbody fusion; AP, anterior-posterior.

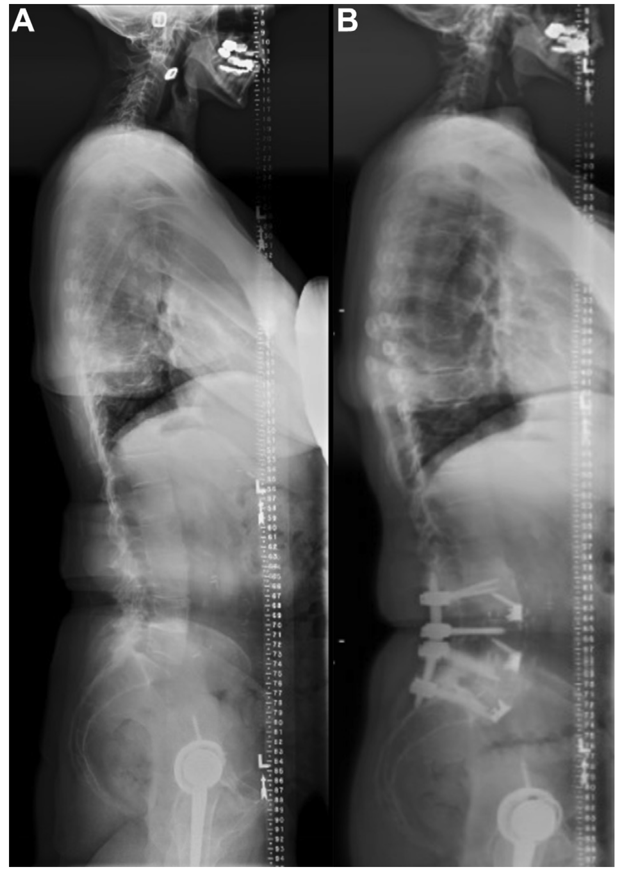

Figure 2. (**A**) Pre- and (**B**) 2-year postoperative lateral radiographs of the patient in Figure 1A who underwent minimally invasive posterior surgery for scoliosis.

morbidity. Thus, it is unlikely that the staging alone accounted for the decrease in cMIS patient cohort morbidity.

Because of the current limitations of cMIS spinal deformity correction, we chose to exclude severe sagittal imbalance cases and include only mild-to-moderate deformities in both cohorts. Because deformity and SVA are values on a spectrum, we wished to only address cases in which there was no severe sagittal imbalance to keep the population uniform. We recognize that there are limits of MIS deformity surgery, and we wanted to include only those patients who could be successfully treated with current MIS technology. Because 4.7-cm SVA has historically been the cutoff for normal spinopelvic parameters, we chose 6 cm to account for elderly patients and because we did not want to exclude elderly patients for whom 6 cm may be normal.[43] Although the inclusion criteria for both groups of deformity patients included measurements of spinopelvic parameters, these were not primarily sagittal imbalance cases; coronal plane scoliosis was a large component of both cohorts. Severe sagittal deformities were excluded, and a coronal Cobb angle of greater than 20° was included in this cohort. Thus, these patients may have been treated for an adult degenerative scoliosis with severe stenosis or lateral listhesis causing radiculopathy, but they may have been well balanced in the sagittal plane, with normal PI-LL mismatch and normal SVA. Thus, we specifically excluded patients who had very high SVA and mismatch, and tried to make the focus of this study on adult coronal scoliosis patients, not severe sagittal imbalance cases.

There are limitations to this study. First, this is a retrospective study, and prospective studies generally are more robust. Second, the deformities in this series did not have significant sagittal plane deformities (mean preoperative SVA was less than 5 cm in both the cMIS and open groups). The lack of sagittal imbalance is important to consider because without a 3-column osteotomy, multiple posterior column osteotomies, or an ACR,[28,31,38,41] there are limitations to the amount of lordosis that can be achieved with current technologies for cMIS surgery for ASD. Although lordosis-inducing MIS techniques are being pioneered (the ACR and mini-open PSO), these were not included in this current study. Third, MIS deformity surgery is relatively new, and the techniques used have primarily been developed for degenerative cases. Thus, the full potential of MIS deformity surgery has not yet been realized, and only after more iterations and optimization of techniques can the impact of MIS on adult deformity be fully defined. This shorter intensity of stay and reduced complication rate may reduce overall costs, but further studies are warranted to specifically analyze cost data. Another consideration is the patient expectation with regard to MIS versus open surgery. Certainly, there can be a placebo effect about MIS versus open surgery, and this certainly can alter the patients' feelings about their surgical outcome. It can affect the patients' perception of their surgery and potentially influence their recovery. Unfortunately, there is no way to eliminate the effect of patient perception of receiving MIS surgery or open surgery, but certainly, this can be a consideration when interpreting the data.

CONCLUSIONS

For patients undergoing surgical correction of mild-to-moderate spinal deformity, patients undergoing cMIS surgery had a significantly lower estimated blood loss, shorter ICU stay, and fewer major and minor complications. However, it is important to keep in mind that these are not severe sagittal plane deformities, and as such, this must be taken into consideration when interpreting the data.

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