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Clinical Studies

Assessment of pedicle screw malposition in uniplanar versus multiplanar spinal deformities in children

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ABSTRACT

Background: Spinal deformities can either be uniplanar or multiplanar. The current study aims to compare mal-positioned pedicle screw assessment on radiographs versus CT in children <12 years with multiplanar and uniplanar spinal deformities.

Methods: A cohort of 15 children, mean age 10.1 years, who underwent posterior spinal fusion using free-hand pedicle screw insertion for multiplanar (M) or uniplanar (U) deformities with post-operative radiograph and CT evaluation of 154 screws. The outcome measures included the assessment of malpositions detected on plain radiographs versus CT scans in U and M deformities. The overall breaches in post-operative plain radiographs and CT in each group were compared and analyzed by two independent observers.

The mal-positioned screws were graded on extent of cortical breach on CT. Inter and intra-observer variability was calculated with Kappa(k) method. Sensitivity, Specificity and Positive Predictive Value (PPV) and Negative Predictive Value (NPV) were calculated by comparing breaches on radiographs versus CT considered the gold standard.

Results: In total,154 pedicle screws were analyzed, 65 in U group and 89 in M group. There were 23 (14.9%) malpositioned screws identified on plain radiographs and 43 (27.9%) on CT (p = 0.008). There were 17/154 (11.03%) Grade 1 breaches, 16/154 (10.38%) Grade 2 breaches and 10/154(6.49%) Grade III breaches.

Among the 43 CT breaches, 12/65 (18.46%) were in U group, 31/89 (34.83%) were in M group (p = 0.013).The overall Sensitivity, Specificity and PPV of plain radiographs compared to CT in detecting malpositions were 32.56%, 91.89% and 60.87% respectively.

Conclusions: There was a significant discrepancy in identification of pedicle screw malposition based on plain radiographic versus CT based assessment, more so in multiplanar deformities. The ability to detect a breach on plain radiographs is lesser in multiplanar versus uniplanar deformities.

Background

The use of pedicle screw instrumentation in spinal deformity correction surgeries has gained popularity in recent years, as it provides high degree of anchorage, increased stability and high amount of correction even in short segment stabilization [1,2]. Based on three-dimensional assessment, most pediatric spinal deformities have a predominant scoliotic, kyphotic or a kypho-scoliotic component.

Apart from the spinal malalignment, there may be structural changes in the vertebral anatomy affecting the body or the pedicles [3,4]. The nature of the spinal deformity needs to be considered during pedicle screw placement in scoliosis versus kyphosis as the orientation of the vertebrae differs.

Anatomical anomalies due to a misaligned vertebra or a malformed/atrophic pedicle also makes the pedicle screw placement more challenging and thereby increases the risk of screw misplacement and loosening, during and after insertion [5–8]. Difficulties and complications in the form of symptomatic as well as asymptomatic malpositions in pedicle screw fixation in children and adults is well reported in literature, especially in multiplanar spinal deformities like kypho-scoliosis [9–12].

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Different methods of pedicle screw application include free-hand placement (anatomical or straightforward trajectory), funnel, slide, in and out technique, fluoroscopy guided insertion, navigation guided and robotic techniques [13]. Although considered safe, the rate of asymptomatic misplacement of the pedicle screws was found to be considerably high with the use of free-hand technique alone [14]. Screw malposition is defined as the detection of a breach in the pedicle in any of its walls (Lateral, Medial, Superior, Inferior and Anterior). There is no previous study on assessment of pedicle screw malposition on radiographs versus CT, specifically analyzing the influence of the three-dimensional nature of the pediatric spinal deformity, more so in young children.

The free-hand technique is the preferred method for the placement of pedicle screws for the pediatric spinal deformities at our institution. The study aims to compare the pedicle screw malpositions assessed on plain radiographs versus CT scans in younger children below 12 years with predominantly multiplanar versus predominantly uniplanar deformities.

Methods

Study design

Case series, retrospective comparative study.

Patient sample

Institutional Review Board approval (IRB No. IEC-BJWHC/AP/2018/001-V1) was obtained prior to the commencement of the study. We retrospectively reviewed the charts of children below the age of 12 years who underwent posterior spinal deformity correction and fusion surgery with pedicle screws for multiplanar deformities (scoliosis) or uniplanar deformities (kyphosis) between 2015 and 2017. Patients with complete records, radiographs and post-operative CT scans were included. Those who did not undergo post-operative CT scans were excluded from the study.

Indications for post-operative CT scans were post-operative neurological complaints (weakness, numbness and paraesthesia), suspected screw malposition on assessment of post-operative radiographs and for fusion assessment. All the CT scans were done within six months of the index surgical procedure.

Based on the three-dimensional nature of the spinal deformity, the children were divided into two groups – Uniplanar deformity group (U) and Multiplanar deformity group (M). The etiologies for U group included post-tubercular (TB) and congenital kyphosis(CK) while that of M group included congenital(CS) and idiopathic scoliosis(IS). Sub group analysis of the breaches in the groups was performed.

Outcome measures

Postoperative radiographs were assessed for number of levels of fixation, number of screws placed at each level and primary angle of deformity. The post-operative radiographs and CT scans were analyzed for pedicle screw malpositions (anterior, superior, inferior, medial and lateral breaches) [15].

Plain radiographs were analyzed for malpositions (medial, lateral, superior and inferior) using the method described by Choma et al. while, grading of breaches on CT scans was done depending upon the extent of cortical breach in the pedicle [Fig. 1], that is grade 1:<2 mm breach, grade 2:<2–4 mm breach, grade 3:>4 mm breach [16,17].

The number of breaches on radiographs and the CT scans in total and in each group were analyzed and compared. CT was used as the gold standard for detecting a breach and identifying true positives and true negatives. Sensitivity, specificity, positive predictive value (PPV) and Negative Predictive Value (NPV) were calculated for the total number of breaches as well as individually among the U group and M group.

The radiographic analysis was done by two independent observers – fellowship trained pediatric orthopaedic surgeons, who were not involved in the surgeries. The inter-observer and intra-observer variability were calculated using Kappa(k) method.

Demographic data

Pre-operative details, operation and instrumentation details, other demographic data including complications were noted from the charts.

Surgical details

All patients underwent posterior spinal instrumented fusion (PSIF). All surgeries were performed by two fellowship-trained spine surgeons, with independent experience in pediatric spinal deformity surgery of five years and 15 years who were routinely involved in pediatric spine surgery at the mentioned children's hospital, either alone or as a team.

The pedicle screws were placed using free hand (anatomical) technique [7]. Some patients underwent vertebrectomy (*V*+PSIF). Routine assessment of the screw placement was done with fluoroscopy at the end of the procedure with antero-posterior and lateral imaging.

The numbers of pedicle screws and number of levels of fixation were recorded. Anchor (implant) density was calculated (number of instrumented vertebral levels divided by number of pedicle screws). Neurovascular complications, need for secondary procedures or revision surgeries were noted from the clinical charts.

Statistical analysis

Analysis was done using the Statistical Package for Social Sciences (SPSS) for Windows software (version 22.0; SPSS Inc, Chicago). Descriptive statistics such as mean and standard deviation (SD) for continuous variables were determined.

Comparison between the two groups was done using Chi-Square test for categorical variables and unpaired t-test for quantitative variables after checking normality of data. The breaches in plain radiographs and CT scans were studied and Specificity, Sensitivity, PPV and NPV were calculated accordingly. Kappa(k) method with the interpretation by Landis and Koch was used for calculating inter-observer and intra-observer variability.

Results

In total, 35 children under the age of 12 years underwent spinal deformity correction during the study period, of which 15 were included in the study after fulfilling inclusion criteria, with seven in the U group and eight in M groups. Patients were a heterogeneous group that included congenital, idiopathic and post tuberculous etiologies. Table 1 provides the demographic data of the patients in both groups, the surgical procedure performed (PSIF – Posterior Spinal Instrumentation and Fusion, *V*+PSIF – vertebrectomy+ PSIF), levels of spinal fixation, the number of levels of fixation, number of screws and implant density.

The mean age at surgery was 10.16±1.91 years (6 to 12). Mean age in group U was 9.43±2.57 years while group M was 10.83±0.7 years (P value = 0.17). Mean primary deformity angle in U group and M group were 40±23.72° and 62±19.4° respectively and this was not statistically significant ($p = 0.05$). The groups were similarly matched with respect to age, gender, number of fixation levels (Table 2) and primary angle of deformity.

A total of 154 pedicle screws were analyzed, 65 screws in the U group and 89 screws in the M group. Overall, there were 23 (14.9%) malpositioned screws detected on plain radiographs and 43 (27.9%) malpositioned screws on CT scans. The difference in breaches detected on radiographs and CT was statistically significant ($p = 0.008$). Table 3 and 4 illustrate the patterns, grading and level of malposition in the pedicle screws applied in both groups in plain radiographs and CT scans.

Among the 23 breaches on radiographs, 9/65 (13.8%) were in the U group and 16/89 (17.9%) were in the M group, ($p = 0.257$) which was

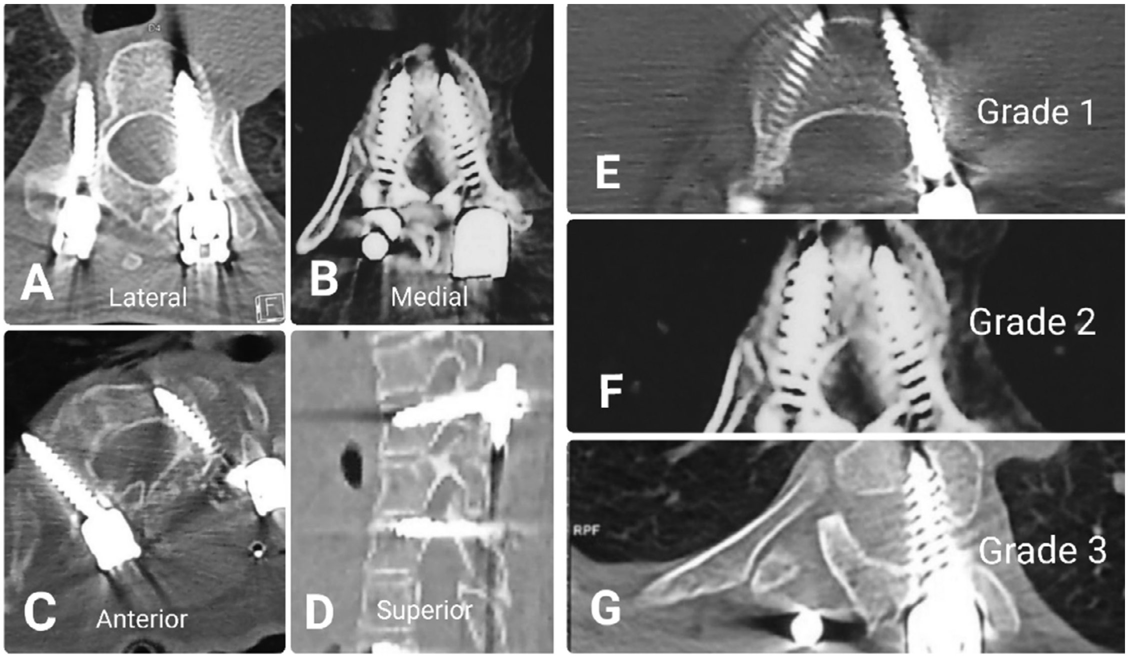

Fig. 1. Types and Grading of Malpositions on CT
1A – Lateral Breach, 1B – Medial Breach, 1C – Anterior Breach,
1D – Superior Breach, 1E – Grade 1 Breach, 1F – Grade 2 Breach,
1 G – Grade 3 Breach.

Table 1
Demographics and Surgical details.

Pt	Age at surgery	Sex	Diagnosis	Surgery	Fixation levels	No. of Levels	No. of Screws	Implant Density
1	12	M	U TB	PSIF	T3 to T9	7	9	1.28
2	8	M	U TB	PSIF	T12 to L5	6	10	1.6
3	6	F	U TB	PSIF	T8 to L3	8	10	1.25
4	9	F	U TB	PSIF	T4 to T9	6	8	1.33
5	7	F	U TB	PSIF	T8 to T12	5	8	1.6
6	12	F	U TB	PSIF	T2 to T7	7	8	1.14
7	12	F	U CK	V+PSIF	T6 to L2	9	12	1.33
8	11	F	M CS	PSIF	T11 to L4	6	9	1.5
9	9.5	F	M CS	V+PSIF	T3 to L2	12	14	1.16
10	11	M	M CS	V+PSIF	L1 to S1	6	10	1.6
11	10.5	F	M CS	PSIF	T7 to L4	10	12	1.2
12	10	F	M IS	PSIF	T4 to L1	10	11	1.1
13	11.5	F	M IS	PSIF	T10 to L3	6	9	1.5
14	12	F	M IS	PSIF	T3 to L2	12	13	1.08
15	11	F	M IS	PSIF	T3 to T10	8	11	1.37

Table 2
Comparison of uniplanar and multiplanar groups.

Parameter		U Group(n = 7)	M Group(n = 8)	P value
Mean age at surgery(in yrs)		9.43±2.57	10.8 ± 0.7	0.17*
Sex	Male	2	1	0.5692#
Distribution	Female	5	7	
No. of Screws/Location	Thoracic[T]	47	54	
	Lumbar[L]	18	33	
	Sacral[S]	0	2	
	Total	65	89	
No. of levels of fixation		6.86±1.35	8.75±2.6	0.108*

* Calculated using the unpaired *t*-test. P<0.05 considered statistically significant.
\# Calculated using the chi-square *t*-test. P<0.05 considered statistically significant.

statistically not significant. But, among the 43 (Grade I,II,III) breaches identified on CT scans, 12/73(18.46%) were in the U group and 31/89 (34.83%) were in the M group, (p = 0.0296) which was statistically significant, showing higher rates of malposition in the M group. There were 17/154 (11.03%) Grade 1 breaches, 16/154 (10.38%) Grade 2 breaches and 10/154(6.49%) Grade III breaches. Amongst the Grade III breaches, 2/65 (3.07%) were identified in the U group and 8/89 (8.9%) in the M group, (p value=0.192) which was not statistically significant. Table 5 depicts patterns of malpositions in numbers in both groups, showing more lateral, medial and anterior breaches. Fig. 2 and 3 are examples of U and M group.

On comparison of the breaches in plain radiographs versus the CT scans, the overall number of True Positives and False Positives were 14 and 9, while the number of False Negatives and True Negatives

Table 3
Details of screw malpositions on plain radiographs.

Pt.	No. of Screws	No. of Malpositions	Medial	Lateral	Anterior	Superior	Inferior
1	9	2		T3 (R), T5 (L)			
2	10	0					
3	10	2				2 T10 (L) & (R)	
4	8	2	1 T4 (R)	1 T4 (L)			1 T4 (L)
5	8	0					
6	8	0					
7	12	1					1 T12 (R)
8	9	3		2(T12 Rt. And L4 Lt.)		1(L1 Lt.)	
9	14	4		4(T4 Rt., T7 Rt., T10 Rt., T12 Rt.)			
10	10	1				1(Rt sacrum)	
11	12	4		4(T7 Rt., T8 Rt., L3 Rt., L4 Rt.)			
12	11	2		1(T4 Rt.)		1 T6 (L)	
13	9	0					
14	13	0					
15	11	2					1 T3 Lt., 1 T4 Lt.

Table 4
Details of screw malpositions on CT scans.

Pt.	No. of Screws	No. of Malpositions	Medial	Lateral	Anterior	Superior	Inferior
1	9	4	grade I T4 (R)	grade II T3 (R), T5 (L)			grade I T4 (L)
2	10	1	grade I L5 (L)				
3	10	2				Grade II T10 (L) & (R)	
4	8	2	grade III T4 (R)	grade II T4 (L)			grade II T4 (L)
5	8	0					
6	8	0					
7	12	3	grade III T12 (R)		grade I T6 (L)		grade I T8 (L)
8	9	4		grade II L1 (L), L4 (L)	grade II T11 (L), T12 (L), L4 (L)		
9	14	8		grade III T4 (R), grade I T5 (R)	grade I T3 (L), T5 (R), T7 (R), T12 (L), L1 (L)&(R), L2 (R)		
10	10	0					
11	12	6	grade II L3 (L), L4 (L)	grade II T7 (R), grade III T8 (R), L3 (R), L4 (R)			
12	11	2		grade III T4 (R)		grade I T6 (L)	
13	9	0					
14	13	5	grade I L2(L), grade II T9 (R), grade III T3 (L)	grade I T3 (R), T5 (R)			grade I T3 (R), T9 (R)
15	11	6	grade II T7 (L), grade III T3 (L), T4 (L)			grade I T3 (R)	grade II T3 (R), T7(R)

Table 5
Analysis of malpositioned screws.

Parameter (Breachs/Malpositions)	U Group $n = 65$	M Group $n = 89$	P value
All Malpositions (X-rays)	7	16	0.257#
All Malpositions in CT Scans (Grade I, II and III)	12(18.46%)	31(34.83%)	0.029#
DATA(numbers)	TP-6; FP-1 FN-6; TN-52	TP-8; FP-8 FN-23;TN-50	
Sensitivity	50%	25.81%	0.16#
Specificity	98.11%	86.21%	0.11#
Positive Predictive Value	85.71%	50%	
Negative Predictive Value	89.66%	68.49%	
Lateral Breach	3	11	
Medial Breach	4	9	
Anterior Breach	1	11	
Superior Breach	2	2	
Inferior Breach	3	4	

* Calculated using the unpaired *t*-test. $P<0.05$ considered statistically significant.
# Calculated using the chi-square *t*-test. $P<0.05$ considered statistically significantTP-True Positives; FP-False Positives; FN-False Negatives; TN-True Negatives.

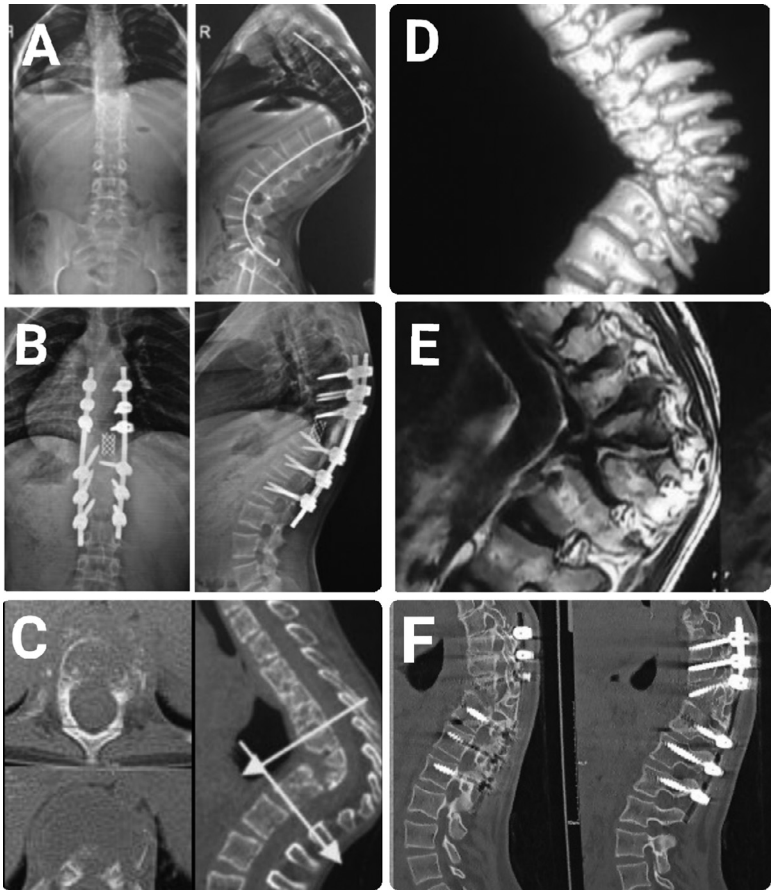

Fig. 2. Case illustration (Case 7) under U-CK Group, a 12-year-old girl who underwent *V*+PISF showing
(A) Pre-operative radiographs, (B) Post-operative radiographs,
(C) Pre-operative sagittal CT (D) Pre-operative CT with 3D reconstruction, (E) Pre-operative sagittal MRI and (F)Post-operative sagittal CT.

were 29 and 102 respectively. The overall plain radiographic sensitivity was 32.56% and specificity was 91.89%, while the PPV and NPV were 60.89% and 77.86% respectively.

In the U group, Sensitivity was found to be 50% while the specificity was 98.11%. The PPV and NPV were 85.71% and 89.66%. In the M group, Sensitivity was 25.81%, specificity was 86.21% while the PPV and NPV were found to be 50% and 68.49%. Although the sensitivity, specificity and positive predictive value were higher in the U group in comparison to M group, this was not statistically significant($P>0.05$).(Table 5)

More breaches were noted in upper and mid-thoracic regions (25/43; 58%) as compared to lower thoracic and lumbar regions (18/43; 42%), which was not significant ($p = 0.28$). Moreover, higher number of malpositions were found on left side (24/43, 55.8%) when compared to right side (19/43, 44.2%); ($p = 0.3$; NS). 11 significant breaches (Grade II and III) was found in patients with congenital vertebral anomalies in the M-CS group and 9 in M-IS group. Although the significant breaches were higher in the M-CS group, the data was not statistically significant ($p>0.05$).

The value of inter-observer variability for plain radiographs and CT scans was found to be 0.91 and 0.98; for intra-observer variability, the values were 0.90 for observer 1 and 0.97 for observer 2 indicating substantial agreement.

Complications

Two patients in the M group with CS had focal paresthesia postoperatively and their symptoms improved with oral Gabapentin without any need of intervention. One CS patient who underwent *V*+PSIF had transient neurological deficit with monoplegia. The patient underwent a CT scan and MRI immediately after surgery and a lateral breach was detected. As there was no significant medial breach, revision surgical intervention was not required (Fig. 3). The patient was treated with injectable methyl prednisolone and recovered gradually within six months although there was mild persistent lower limb spasticity. No screws needed revision due to neurovascular complications. None of the patients in the U group had complications.

Discussion

Complex pediatric spinal deformities can pose a major challenge with the placement of pedicle screws for surgical correction. Screw malposition is a known complication in these scenarios. There are a few CT scan-based studies describing screw malpositions in children and adolescents as summarized in Table 6. The lowest incidence of malpositions was found with concomitant use of CT scan and navigation [22]. None of the studies compare the rates of malposition in different types of spinal deformities.

Mueller et al. and Harimaya et al. analyzed the safety of pedicle screws in young children with radiographic assessment [24,25]. Their overall complication rates were 13.4 and 10.2% respectively. Ruf and Harms similarly investigated 16 children with a mean age of 2.1 years and found the presence of screw malpositioning in three out of the 91 screws (3.3%) [23]. However, the lack of postoperative CT scans in these studies may, in fact underestimate the actual screw mal-position rate.

There are a few studies which used CT scan assessment of the pedicle screw malpositions. The overall malposition rates in these studies which included predominantly young children(less than 12 years) ranged between 5.4 and 9 percent [15,27–28]. In a systematic review by Chan et al., the authors analyzed the screw-related complications and breach rates following posterior spinal instrumentation for adolescent idiopathic scoliosis with a background comparison of intra-operative

Fig. 3. Case illustration (Case 9) under M-CS Group, a 9.5 year old girl who underwent *V*+PISF showing
(A) Pre-operative radiographs, (B) Post-operative radiographs,
(C) Post-op CT scan axial cut T5 vertebra (anterior and lateral breach) immediate post-op, (D) Post-op CT scan axial cut of T7 vertebra (anterior breach).

Table 6
Summary of literature review in adolescents and children.

Authors	No. of Patients	No. of Screws	Malposition rate	Avg. age	Etiology	Technique	Analysis of breach
Kim et al.[18]	49	789	8.2%	All age groups	All deformities	Free hand screws, fluoroscopy	CT
Smorgick et al.[19]	25	112	12.5%	23 years (11–59)	Al etiologies	Free hand screws, fluoroscopy	CT
Rajasekaran[20]	16	236	22.9%	17(±7.43 year)	All etiologies/ deformities	Free hand screws, fluoroscopy	CT
Liu et al.[21]	92	712	21.6%	14 years	AIS	Free hand screws, fluoroscopy	CT
Rajasekaran et al.[20]	17	242	5%	17 years	All etiologies/ deformities	Intra-op CT + navigation	CT
Liu et al.[21]	46	344	8.3%	15.6 years	AIS	Intra-op O-Arm navigation	CT
Cui et al.[22]	31	577	10.58%	18.65 years	All deformities	Intra-op CT	CT
Cui et al.[22]	28	483	5.2%	23.61 years	All deformities	Intra-op CT + navigation	CT
Ruf et al.[23]	16	91	3.3%(3/91)	2yrs1month	All deformities	Free hand + Fluoroscopy	X-rays
Mueller et al.[24]	206	2488	NA(13.4% complications)	9.9 yrs	All types of deformities and instrumentation	Free hand + Fluoroscopy	X-rays
Harimaya et al.[25]	88	948	0.84%(10.2% complications)	6.8 years	All deformities	Free hand + Fluoroscopy	X-rays
Li et al.[26]	16	74	6.8%(5/74)	34 months	Hemivertebrae, Post TB	Free hand + Fluoroscopy	CT scan
Seo et al.[15]	31	261	5.4%(14/261)	7yrs10months	only scoliosis	Free hand + Fluoroscopy	CT scan
Ranade et al.[27]	16	88	6.8%(6/88)	Less than 8yrs	All etiologies	Free hand + Fluoroscopy	CT scan

image guidance with that of free-hand method of pedicle screw application. The authors proposed that there was moderate evidence that, with use of image guidance/CT-guidance, the breach rates were lower. While with the screw related complications, image guided approach did not show much advantage over free-hand technique [29]. Also, prior studies have reported that 5–17% pedicle screws are malpositioned, but these studies were not purely focused on children with younger age groups(12 years and less) [30].

Previous studies have shown that plain radiographs may not be reliable in determining pedicle screw breaches accurately in comparison to CT scan, especially the medial breaches [17,31–33]. We identified pedicle screw malpositions on plain radiographic as well as CT based assessment and found a significant discrepancy between the two techniques, 23 (14.9%) versus 43 (27.9%)with a statistically significant difference($p = 0.008$).

On comparing malpositions noted on plain radiographs with CT scans, the sensitivity and PPV were 32.56% and 60.87% respectively, which were low. Although the sensitivity and PPV were relatively higher in the U group when compared to M group, the values were not statistically significant($p>0.05$). This suggests that plain radiographs under report pedicle screw breaches in comparison to CT scans.

The sensitivity determined by number of True positives when both radiographs and CT scan showed breach was found to be low overall as well as in both groups. Other important variables in consideration are Specificity and Negative Predictive value. They were found to be higher in U group(98.11% and 89.66%) although statistically not significant. Plain radiographs were found to be less reliable in detecting and well as ruling out screw malpositions in M group compared to U group.

We assessed the accuracy of identifying breaches on plain radiographs compared to CT scans in the M versus U groups to determine if the 3-dimensional nature of the deformity is a factor in the estimation of screw malpositions. This was more pronounced in the M group when compared to the U group, demonstrating the importance and accuracy of CT scan in the identifications of screw malpositions in spinal deformities, especially in the multiplanar variants. Moreover, it was found that the difference in malpositions on plain radiographs between the two groups was not statistically significant ($p = 0.247$) while the difference in breaches identified on CT scans were significant ($p = 0.029$) between the groups. This does underline the real time possibility of underestimating screw misplacement with radiographs.

The current study provides some insight on misplaced pedicle screws in the age group 12 years and under. Intra-operative screw assessment with antero-posterior and lateral fluoroscopy can be misleading in multiplanar deformities and necessitates detailed fluoroscopic evaluation with true AP views in the plane of the deformity for all levels to avoid missing a malposition, especially if there is a high index of suspicion.

Newer technologies like 3D printed models based on preoperative CT scans and the use of intra-operative CT navigation and robotics do provide valuable assistance [14,22]. A distinct advantage of the free-hand screw placement is the biofeedback and tactile feedback of the probe pressure as well as the ability to sense a breach or an altered trajectory, something not possible with the robotic technique. Along with the universal utilization of the technique, it does not require expensive technologies which are not available at many centers worldwide. However, there is a possibility for error in screw placement which may not be recognized by the surgeon intra-operatively. The use of navigation may offset this as an intra-operative CT after placement of screws allows the surgeon to remove or replace any screw with a pedicle breach.

Although the patients were a heterogeneous group, the deformities were basically divided as uniplanar and multiplanar groups based on the three-dimensional orientation. Complicated spinal deformities, irrespective of the etiology are known to negatively affect the precision of pedicle screw placement in the pediatric age group [3,4]. To our knowledge no previous study has specifically compared radiographic assessment of malpositioned screws from the perspective of multiplanar versus uniplanar deformities in younger children. Both the groups were evenly matched with respect to age at surgery, follow up duration, gender and number of levels of fixation. It was found that the screw malpositions were significantly higher in the multiplanar group. Also there was a higher incidence of the significant pedicle breach (grade II & III) in congenital scoliosis in the multiplanar group which may also be attributed to the greater incidence of dysplastic and malformed pedicles in these patients as compared to a more normal pedicle anatomy in the idiopathic scoliosis patients. The surgeon should have other instrumentation options available for salvage if pedicle screw placement is difficult and there is a suspicion of a breach or be prepared to skip these levels and use a lower implant density in multiplanar deformities especially those with congenital etiologies.

Although both the groups were comparable and matched in most of the demographic parameters, they were different in anatomical aspects. Most of the children in U group had normal posterior elements(mostly post TB sequelae) while in M group half of them had congenital anomalies. There could be various factors that contribute to the higher malpositions. As all screws were assessed independently in order to compensate for the low number of subjects included and because these pedicles come from a small batch of spines, a spine that is complicated to instrument will have several difficult pedicles. On the other hand, an easier spine to instrument will have near zero breach. Therefore, a screw malposition may impact the success rate of the next screw if it is in the same patient.Other factors are multiplanarity, congenital nature of the deformity, selection bias in including patients with CT as by definition, a patient who has a CT ordered post-operatively is much more likely to show instrumentation misplacement.

Although CT scan was considered as the gold standard to identify the pedicle breach, there can be some uncertainty in the determination of grade I pedicle breaches on the CT scan due to the implant artifact. This aspect has also been discussed in the study by Choma et al. [16]. In our study, a large proportion of the pedicle breaches on the CT scan were Grade I and this could be a significant limitation to this study. Grade 1 breaches may not be clinically relevant. The level of instrumentation upper thoracic, mid thoracic, lower thoracic and lumbar along with the axial deformity and etiology are confounders that may influence accuracy and assessment of pedicle screw placement.

Another potentially important confounding factor to be considered is the surgeon experience [34]. In this study, although both the surgeons were spine fellowship trained with independent experience in pediatric spinal deformity surgery of five years and 15 years and were routinely involved in complex pediatric spine surgery at the mentioned children's hospital, either alone or as a team, it is possible that screw malpositions may vary and be lower with different surgeons and experience especially at high volume centers. The institutional algorithm for the requisition for a CT evaluation for the patients under consideration was standardized in both groups. However, we have not compared malposition rates due to possible over-estimation as CT was not done post-operatively in all patients due to radiation hazards in children [35,36]. Consecutive CT scans done would have probably yielded a lower breach rate. This aspect is clinically relevant, especially as surgeon experience and institutional protocols are critical to the appropriate management of complicated conditions like pediatric spinal deformities [37,38].

Although our inter-observer variability for breach detection on CT was good, possible reasons being the similar training background of the observers, uniform use of titanium screws, smaller diameter screws which have less tendency to scatter and a smaller sample size, this contrasts with a study by Lavelle et al. [39] who found an inter-observer variability of 0.45 and intra-observer variability of 0.49 with four experienced surgeon observers. They considered pedicle screw placement as 'In' when the screw was fully contained and/or the pedicle wall breach was ≤2 mm and 'Out' as a breach in the medial or lateral pedicle wall >2 mm. In contrast in our study, <2 mm breach was also considered 'out' and defined as a grade 1 breach so there is a distinct possibility of overestimating breach rates due to the scatter hence our findings cannot be generalized to other scenarios. We used lateral and AP views instead of PA films described by Choma et al. for detection of the pedicle breach on plain radiographs and it was difficult to visualize the pedicle shadow in certain multiplanar deformities in the apical region where there was significant residual rotation and possibly one of the reasons for the underestimation of the breaches on plain films [16].

In spite of above limitations, this research contributes meaningful information. Although our study has a smaller sample size, there is no previous literature analyzing pedicle screw malposition assessment with radiographs and CT in uniplanar versus multiplanar pediatric spinal deformities. Hence surgeons should be mindful about the possibility of malpositioned screws more so in multiplanar pediatric congenital deformities and underestimation of the screw misplacements on radiographs and fluoroscopy.

Conclusions

The study emphasizes on the radiographic evaluation of malposition of pedicle screws in younger children below 12 years based on the three-dimensional type of the spinal deformity. The authors identified a significant discrepancy in the identification of pedicle screw malposition based on plain radiographic versus CT assessment, more so in multiplanar deformities. The ability to detect a breach on plain radiographs is lesser in multiplanar versus uniplanar deformities. A larger prospective multicenter study will be ideal for further evaluation of this topic.

Declaration of Competing Interest

There are no disclosures and no funding was received for the study.

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