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Original article

Mismatch between rod bending and actual post-operative lordosis in lumbar arthrodesis with poly axial screws

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A B S T R A C T

Background: The question of rod bending is essential during posterior lumbar fusion. The role of posterior instrumentation during spinal surgery remains to be defined. Despite an appropriate bending, a mismatch between rod lordosis and lumbar lordosis can occur. There is no study on the link between rod bending and lordosis. The purpose of this study was to evaluate parameters that explain the mismatch between lumbar lordosis and rod bending in lumbar surgery using polyaxial screws.
Hypothesis: Radiological parameters explain the mismatch between the rod and the lordosis.
Methods: This study was monocentric, retrospective, descriptive and analytic. All patients with posterior L3L5 fusion in an university-affiliated hospital in 2017 were included. Patients with past surgical history of anterior fusion on the levels L3L5, Coronal malalignment with a Cobb angle superior to 5°, the use of dynamic fixation systems were excluded. We measured on immediate post-operative standing profile x-ray: pelvic incidence, lumbar lordosis, lordosis of the instrumented segment, the distance between posterior wall and rod (EcarT) which reflect how homogeneously the screws are put in depth, the angle between screw and rod (thetaMA), the angle between screw and superior endplate (lambdaMA), the rod lordosis. Univariate and multivariate analysis were conducted to see if there was a link between all those parameters and the mismatch: vertebral lordosis-rod lordosis.
Results: A total of 74 patients were included, mean age was 67. Eighteen were 360° fusion and 56 were postero-lateral fusions. There was no statistical association between demographic data, pelvic parameters, use of interbody devices and the mismatch. There was a statistical association between thetaMA, lambdaMA, EcarT and the mismatch ($P < 0{,}0001$). A multivariate linear regression model was developed to create a new index: Mismatch analysis index.
Conclusion: Our study is the first on the link between rod bending and lumbar lordosis. Three radiologic factors are involved in not obtaining the planned lordosis in short lumbar fusion with polyaxial screws. Two factors depend on the way the surgeon positions screw parallel to the superior vertebral endplate(lambdaMA), and with a homogeneous depth (EcarT). And the last factor: ThetaMA is depending on the surgical technique (compression on screws, osteotomies, monoaxial screws, use of interbody devices).
Level of evidence: IV.

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1. Introduction

Restoring sagittal balance is a common goal in modern spine surgery[1,2]. Failing is known to be the first risk factor of developing adjacent segment disease even in short fusions [3,4]. That is why spino-pelvic parameters must be analysed before spinal fusion [5]. Pelvic parameters predict spinal curves and a theoretical lumbar lordosis (LL) [6,7] that surgeons must try to restore during fusion [8].

The role of posterior instrumentation during spinal surgery remains to be defined: just maintaining the correction or also helping to get the good angles to fuse the operated segment in a proper curve. Despite a good rod bending, sometimes a mismatch occurs with the actual lordosis of the fused segment. To our knowledge there is no study analysing the link between rod contouring and lordosis of the fused segment. The goal of the study was to highlight parameters that influence the mismatch between rod bending and lumbar lordosis of the fused segment, in lumbar surgery for degenerative diseases with polyaxial screws.

2. Methods

2.1. Study design and population

The study was monocentric, analytic and retrospective. All patients who underwent L3L5 posterior fusion for degenerative (spondylolisthesis, central, foraminal and lateral stenosis, discopathy, and vertebral instability) disease in an university-affiliated hospital during 2017 were included. All cases were discussed during the weekly meeting with the 10 surgeons of the unit. Fusions were performed with polyaxial screws, with or without facetectomies, with or without interbody devices. Arthrodesis were performed with a 5.5 titanium rod and polyaxial screws with 30 degrees of head mobility.

Exclusion criteria were: past surgical history of anterior fusion on the levels L3L5, coronal or sagittal malalignment with a Cobb angle superior to 5° or and SVA superior to 10 mm, the use of dynamic fixation systems.

Demographic data were collected (Age, gender, Body mass index).

Radiological parameters were measured on standing lateral view X-rays performed on day one or two after surgery. Then the mismatch between rod lordosis and vertebral lordosis could not be influenced by screw loosening, pseudarthrosis, plastic or elastic deformation of the rod. Several parameters were measured on postoperative loading profile x-rays: L1S1 lumbar lordosis, lordosis of the fused segment, pelvic incidence, distance between posterior wall and the rod for each vertebra (the standard deviation of the three distance was calculated and called EcarT) (Fig. 1), angle between the rod and screws corps for each screw [mean of the three was calculated and called theta Mismatch Angle (MA)] (Fig. 2), angle between screws and superior endplate for each instrumented vertebra [mean of the three was calculated and called lambdaMA)] (Fig. 3), global lordosis of the rod. The difference between post-operative vertebral lordosis and the lordosis of the rod was calculated and called diffL (Fig. 4).

2.2. Statistical analysis

The anthropometric and radiographic parameters were summarised by their mean and standard deviation (SD) or by their frequency and number. Univariate analysis was conducted to study the link between the diffL and the other variables using Spearman correlation test in case quantitative variables or the Mann-Whitney test or Kruskal-Wallis test in case of categorical

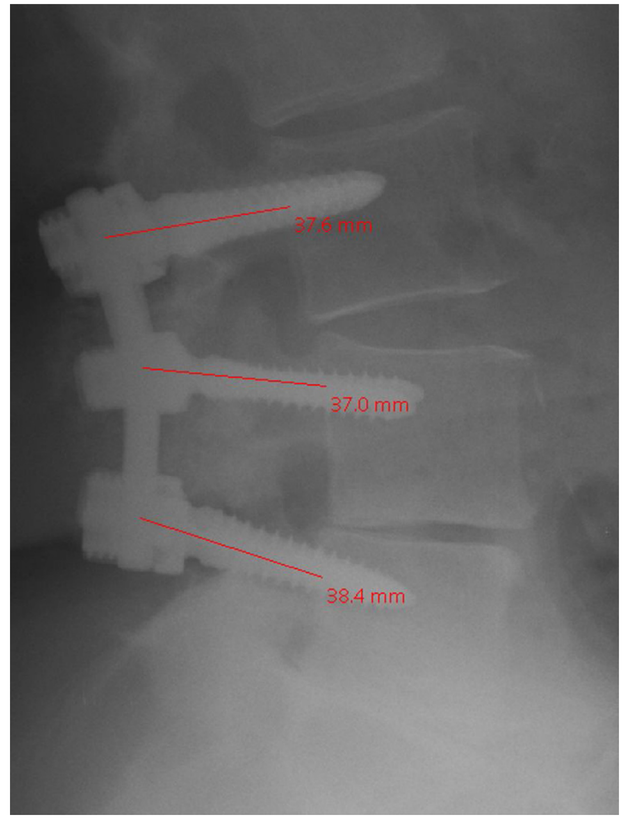

Fig. 1. Measurement of the distance between the rod and the posterior wall of the vertebral body (EcarT).

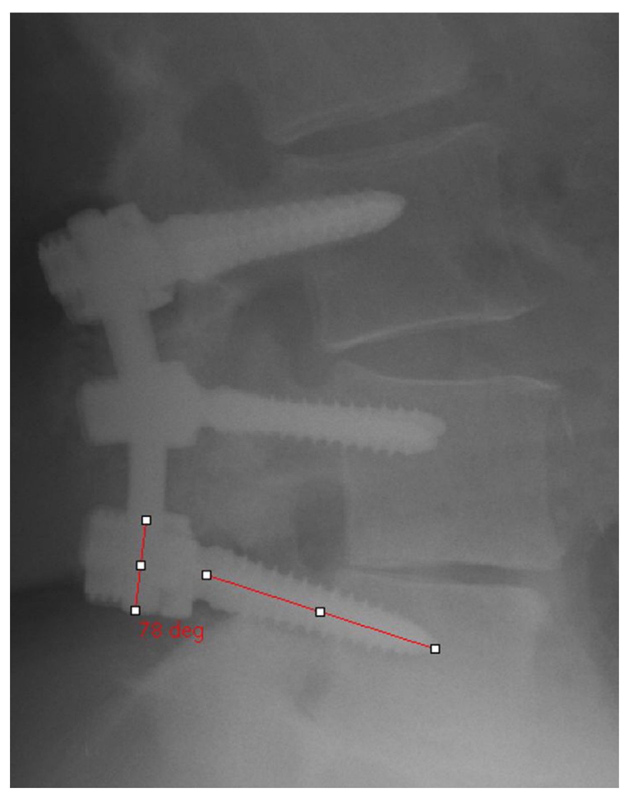

Fig. 2. Angle between the screw and the rod (ThetaMA).

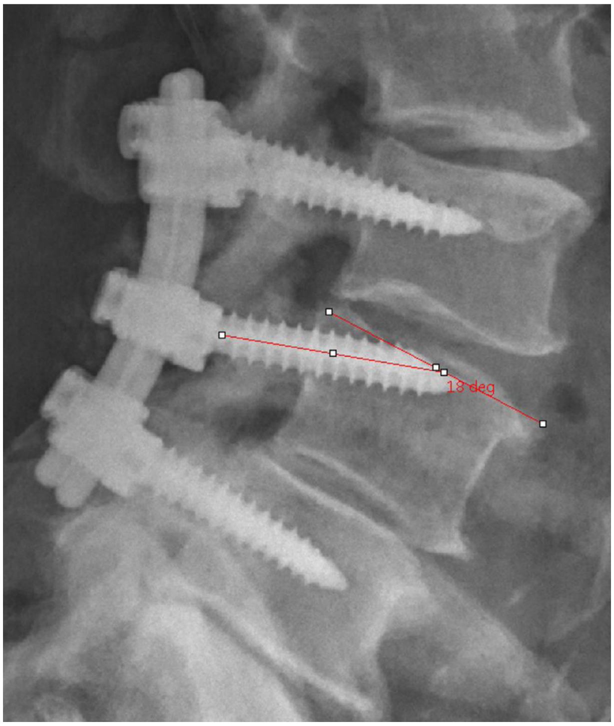

Fig. 3. Angle between superior endplate and the screw (LambdaMA).

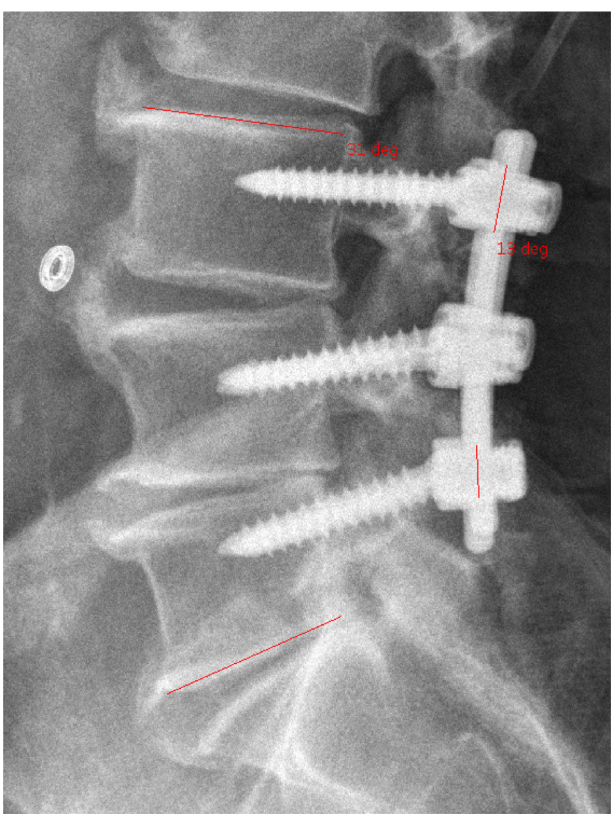

Fig. 4. Difference between lordosis of the fused segment and lordosis of the rod (DiffL).

variables. A multivariate linear regression model was developed to create a new index named MAI (Mismatch analysis index) including the variables linked with the diffL. ROC curves were plotted for each index for the prognostic of a diffL greater than 5°. These ROC curves were used to estimate an optimal prognostic cut-point and the Area under roc Curve (AUC) and its 95% confidence interval associated with each index. Results with a p-value smaller than 0.05 were considered statistically significant. Statistical analyses were conducted in R version 3.3.2 [R Development Core Team (2008). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria].

Table 1
Population characteristics.

Variable	Mean (standard deviation)	Number (percentage)
Age	67.5 (9.7)	
Gender		
male		36 (48.6%)
female		28 (51.4%)
BMI	26.8 (6.5)	
Fusion		
Postero-lateral		56 (75.7%)
TLIF		18 (24.3%)
Rod lordosis	25.9 (9.5)	
TetaMA	83.9 (4.3)	
LambdaMA	4.7 (2.6)	
EcarT	2.8 (1.8)	
PI	56.3 (13)	
DiffL	8.4 (7.4)	

3. Results

A total of 89 cases were studied. Fifteen patients were excluded (5 scoliosis, 10 dynamic stabilizations). Seventy-four patients were included of whom 38 (51.4%) are women. The mean age of the study sample was 67 (8). 56 (75.7%) postero-lateral arthrodesis and 18 (24.3%) circumferential arthrodesis were performed. The mean diffL was 8.4° (7.4°). Descriptive analyses are summarized in Table 1.

The minimal difference we fund between rod lordosis and the spine lordosis of the fused segment was 0, so polyaxial screws can allow a match between planification and result. But the maximum of difference was above 25° which shoes us the huge mismatch poly-axiality can allow.

Demographic variables had no statistically significant effects on the difference between the rod and the vertebral lordosis. Lumbar Roussouly classification, pelvic parameters and the lordosis severity did not show a significant correlation with the outcome.

Statistically significant correlation was found between the fact that screws are put with a homogeneous depth (EcarT) and the diffL ($R = 0.47$ [0.27, 0.63] $P < 0.0001$) (Fig. 5). Similarly, the diffL is correlated with the positioning of the screws parallel to the superior vertebral endplate (Lambda MA) ($R = 0.43$ [0.23, 0.61] $P = 0.0001$). The correlation between ThetaMA and the diffL was also significantly and negatively correlated with the diff L ($R = -0.46$ [0.26, 0.62] $P < 0.0001$).

The diffL is smaller when:

- screws are perpendicular to the rod;
- screws are parallel to the superior vertebral endplate;
- all screws have the same depth.

Optimal cut-offs of each index for predicting if the diffL is greater than 5° were determined by the ROC curves. The estimated cut-offs of EcarT, LambdaMA and ThetaMA for the prognostic of a diffL greater than 5° are respectively 2.8, 4.7 and 86.

EcarT has the better predictive power for predicting a diffL greater than 5°, based on the AUC (AUC = 0.82 [0.72, 0.92]). LambdaMA and the negative of ThetaMA have an AUC of 0.68 and 0.71 respectively.

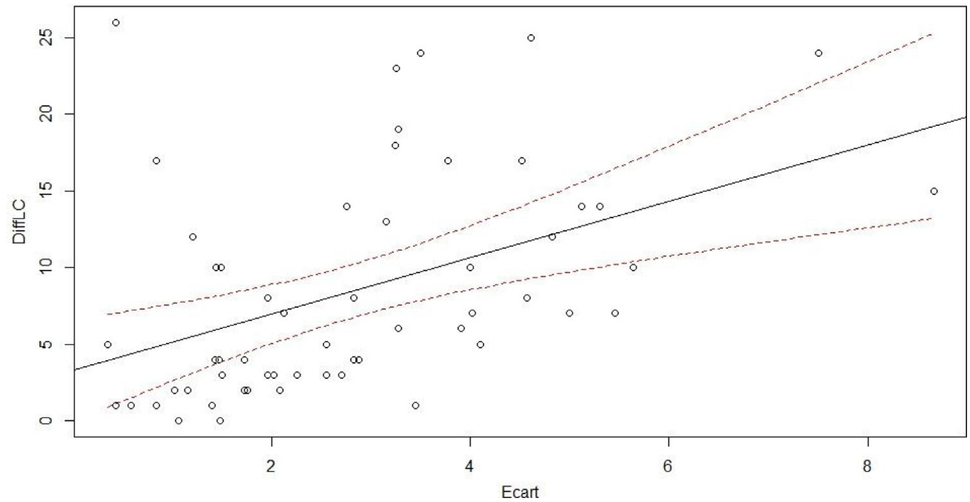

Fig. 5. DiffL depending of EcarT.

Table 2
Multivariate regression model with DiffL as dependent variable and lambdaMA,TetaMA, EcarT as explanatory variables.

Variables Model R^2 = 0,37	Coefficient [CI95%]	*p*-value
Intercept	40.1 [7.88;72.27]	0.02
TetaMA	−0.46 [−0.82;−0.09]	0.01
LambdaMA	0.71 [0.11;1.31]	0.02
EcarT	1.16 [0.31;−1.99]	0.008

We integrated these three indices in a multivariate regression model summarized in Table 2, to create the MAI index. ThetaMA, LambdaMA and EcarT are used as explanatory variables while the dependent variable is the DiffL. We get the following index:

$$MAI = 40.1 - 0.46 \times ThetaMA + 0.71 \times LambdaMA + 1.16 \times EcarT$$

ROC curves associated with the predictive power of L/C difference greater than 5°, using the MAI index can be found in Fig. 6.

MAI index gives an improvement on the prognostic of the severity of the diffL. MAI index yields to an AUC of 0.84 [0.75, 0.93] for predicting a diffL greater than 5°. The estimated diagnosis cut point of the MAI index for predicting a diffL greater than 5 is 6.

4. Discussion

This study highlights three radiologic parameters involved in the mismatch between lordosis of the fused segment and rod bending: ThetaMA, LambdaMA and regular distance between posterior wall and rod (EcarT).

These radiological parameters highlight two major technical points:

- The importance of good positioning of the screws. First is to put the screw parallel to superior endplate, but the most important is to put the screws with a homogeneous depth.
- A bad use of new technologies: polyaxial screws. These screws allow an easier positioning of the rod but as a side effect it allows also to position the rod on a badly implanted screw. The use of polyaxial screws allows a wide mismatch between rod-contouring and lordosis of the fused segment. Patients had a mismatch higher than 25° between the rod lordosis and the actual vertebral lordosis. That shows that contouring the rod is not enough to restore planned lordosis.

Forty nine percent of the patients in our study didn't present a mismatch (less than 5°) despite the use of polyaxial screws, with or without interbody devices. It also shows that it is still possible to use polyaxial screws if they are well positioned and if the good bone osteotomy is made avoiding mismatch.

The lambda MA and the ecarT highlight the link between the instrumentation and the spine, those two parameters depend on how the surgeon implants the screw. Whereas the thetaMA is the reflect of the poly axiality and highlight the link between the rod and the screw body.

Several surgical techniques play a part in restoring the planned lordosis and in fact, influence the thetaMA: anterior approach combined with posterior [9], osteotomies [10], interbody devices [11], screw compression/distraction [12], mono-axial screws4, in situ rod contouring. We can illustrate it with the case Fig. 7. If we apply the three parameters we highlighted, we obtain the same lordosis on the spine we have on the rod but to do so, a substantial rotation is needed on the vertebral boy which means a softening of the spine is needed (operative position [13], release, osteotomy, facetectomie, discectomy). We can then notice the important height and angle between vertebral bodies. The use of compression and interbody cage could be discussed.

The MAI index permits us to add some value to our three factors, that put together can create an index with a great AUC. It will allow validating surgical techniques, by highlighting their ability to avoid mismatch between rod bending and lumbar lordosis.

The aim of the study is not to show any superiority of mono vs polyaxial screws nor to give the only way arthrodesis should be realised, but it gives a better understanding of the link between screw positioning, rod contouring, osteotomies and sagittal curves.

This preliminary study begins a longer work. We have now to study longer constructs, conduct a large-scale and multicentric study, include in the model some other variables that might improve its accuracy, validate the MAI and not to focus on lumbar area.

This immediate post-operative X-ray study did not permit us to have clinical results. The clinical and radiological follow-up is still going on to know if patients without mismatch have better clinical results (health-related quality of life scores). It will also permit to know if the mismatch is linked to a higher rate of adjacent segment disease or adjacent segment degeneration.

The study was monocentric, x-rays were read by a single examiner, the surgical technique was not unique, there was no comparison with preoperative lordosis and the repeatability of the

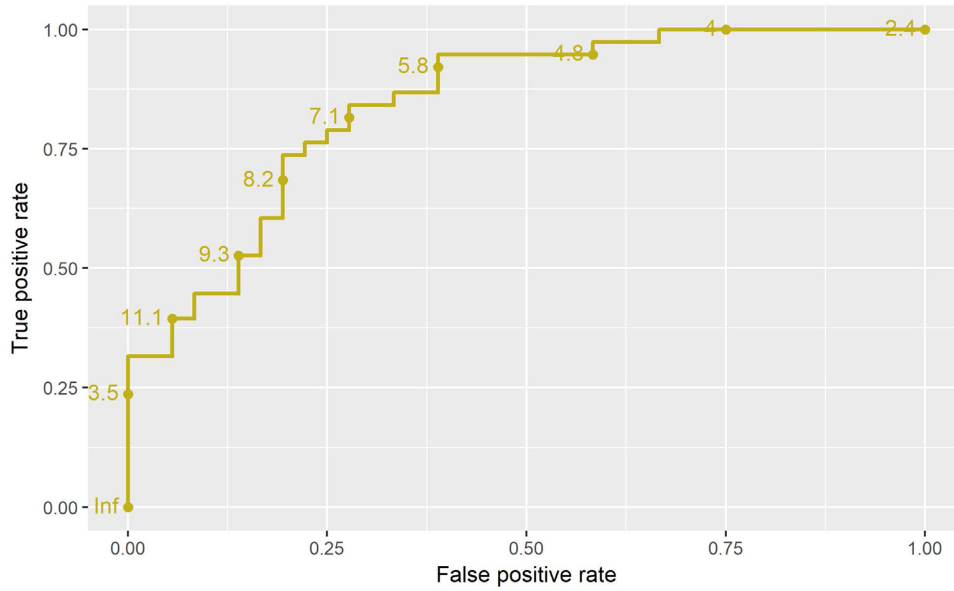

Fig. 6. ROC curve of MAI for the prognostic of a DiffL greater than 5 (AUC = 0.84).

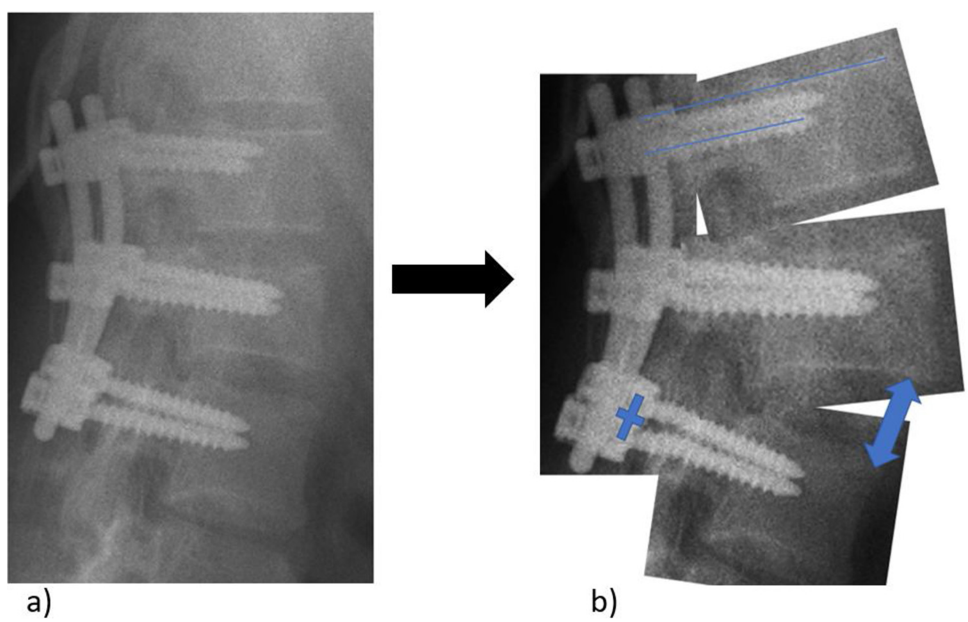

Fig. 7. Illustration case with a wide mismatch in a) and a proper TetaMA, lambraMA, EcarT, to obtain a perfect match in b).

measure is yet to be proven. All these factors decrease the power of the study.

The principle of polyaxial screw is a mobility between the screw's head and the screw's body, which allows a variation of Theta MA. The very principle of poly axial screw with mobility between the head and the body screw permit to have a variable theta MA. And it may initially lead surgeon to think that it is the only reason for this mismatch. We showed in our study that ploy axiality (thetaMA) is indeed playing a role in this mismatch but that there are also two other factors (lambda MA and ecarT) that need to be taken into account in the analysis of the mismatch. Those two last factors explain the possibility of mismatch using mono axial. Because some surgeon could think that the solution to have a perfect match is the exclusive use of mono-axial screws. But it would be a mistake. Mono axial screws would first need to be well positioned. Only then we would obtain a 90° thetaMA, 0° of lambdaMA and a very low EcarT and by the way a match between rod bending and lumbar lordosis. But osteotomies would be needed, a very small approximation in screw positioning would be tolerated, and above all, the rode shouldn't be used to help the correction. This technique using the mono-axiality of the screws is often used in paediatric surgery [14] and in traumatology [15,16] with young patients, but it is difficult to use in adult degenerative spine due to an important stiffness of the spine and a poor bone quality [17] (pull-out). In spinal deformity, because of the release and osteotomies, the lordosis in spine must be superior to the one in the rod to avoid too much rod contouring in a locate area. The contouring process affects the fatigue resistance of spinal rods, and ultimately, the mechanical integrity and fatigue resistance of the entire spinal construct [18].

One of the solutions could be the use of mixed construct with mono and polyaxial screws, associated with facetectomies and compression on the screws.

5. Conclusion

Our study is the first on the link between rod contouring and lumbar lordosis. It questions our habits about rod bending. It has highlighted 3 radiologic factors that explain the mismatch between lordosis of the rod and lordosis of the instrumented segment with polyaxial screws. LambdaMA and EcarT which depend on how the surgeon implants the screws and ThetaMA that is depending on the surgical technique.

Despite a perfectly contoured rod, a good positioning of the screws and the good bone osteotomy is mandatory to have a lumbar lordosis similar to rod lordosis. If the three criteria highlighted here are respected, it is possible to have a perfect match between spine lordosis and rod lordosis, even with polyaxial screws.

Disclosure of interest

No funds were received in support of this work. No benefits in any forms have been or will be received from a commercial party related directly to the subject of this manuscript.

The authors declare that they have no competing interest.

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Authors' contribution

All authors worked on the conception and design of the study.

Moufid, Cloché, Ghailane, Ounajim and Gille worked on the acquisition and data.

Moufid,Ounajim Vendeuvre and Gille worked on the analysis and interpretation of the data.

Moufid, Cloché, Ghailane, Vendeuvre and Gille worked on the drafting of the manuscript.

All the authors made a critical revision of the manuscript for important initellectual content.

Moufid and Ounajim made the statistical analysis.

Vendeuvre and Gille gived administrative, technical or material support for the study.

Moufid, Cloché, Ghailane, Vendeuvre and Gille were active for the supervision of the work.

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