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Original article

Sagittal reduction of spinal deformity: superior versus lateral screw-rod connection

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Abstract

Introduction

Spinal malalignment can greatly impact a patient's quality of life. Various sagittal parameters are used as realignment goals; however, about 50% of patients end up being under-corrected postoperatively.

To improve the correction, prebent rods are available with a radius of curvature corresponding to the patient's "ideal" sagittal alignment. But no studies have been done on how the radius of curvature changes according to the type of connection between the pedicle screws and rods.

The goal of this experimental study was to quantify how much prebent rods flatten based on the method used to connect the screw and rod: top-loading screw vs. dome screw with lateral connector.

Methods

The experiment was done on a material testing system in axial compression on three constructs consisting of two rods secured with top-loading screws and three other constructs consisting of two rods secured with dome screws and lateral connector. The maximum angle of the construct was measured during loading and after removing the load. The primary outcome measure was the mean angle in each construct at each step.

Results

The mean angle of the constructs with top-loading screws when subjected to 500 N load was significantly less than in the constructs with dome screws and lateral connector: 18.6° vs. 24.5° respectively ($p < 0.0003$). The mean angle of the constructs with top-loading screws after removing the load was significantly less than in the constructs with dome screws and lateral connector: 25.7° vs. 32.3° respectively, ($p < 0.0005$).

Conclusion

In vitro, top-loading screws produced significantly greater flattening than dome screws with lateral connector. These findings must be confirmed in vivo. Understanding the behavior of rods as a function of the type of screw connection can be an important factor to minimize the risk of under-correction in the sagittal plane.

Level of evidence: III

Keywords: spine, pedicle screws, rods, sagittal alignment

Introduction

Sagittal spinal malalignment, independent of the cause, is correlated to reduced quality of life [1-2] and is responsible for numerous symptoms that can be grouped into the category of adult spinal deformity. The exact incidence of these deformities is difficult to evaluate, but it may be up to 60% of the population over 65 years of age [3]. Currently, the surgical treatment of these patients, which is based on the intensity of the functional disability, most often consists of performing posterior fusion, potentially supplemented with an osteotomy depending on the amount of correction needed [3-4].

The goal of these surgical procedures is to re-establish the sagittal alignment and the various parameters described in the literature as best possible [5-6]. However, insufficient correction has been found on the radiographs in 50% of patients postoperatively [7]. There

are likely different reasons for this under-correction. One of them is the choice of spinal instrumentation materials, which can influence the correction achieved because the inserted rods flatten out. This flattening can vary depending on which rod is used (diameter, material) but also by the type of connector and method used to reduce the pedicle screws and rod. These data appear to be vital to being able to use the rod as a correction “template” and to ensure that its radius of curvature is not altered intraoperatively during its implantation.

The aim of this work was to study the flattening of prebent rods subjected to axial compression in vitro according to the method used to reduce the screw–rod connection: top-loading screw (tulip screw) vs. dome screw with lateral connector (lateral screw connection). We hypothesized that reduction with a dome screw and lateral connection will limit the rod’s flattening by a traction effect of the spine towards the rods, contrary to reduction with top-loading screw for which the rod is constrained against the spine.

Materials and Methods

Implants used

The implants used in all this study’s trials were provided by Medicrea International® (Rilleux-La-Pape, France). More specifically, the constructs consisted of top-loading polyaxial screws (5.5 mm diameter and 45 mm length) with their nuts (Fig. 1), polyaxial dome screws with their lateral connectors and nuts (Fig. 2) and 5.5 mm-diameter prebent rods made of titanium alloy (Ti6Al4V).

Experimental setup

The rods were secured to a mechanical model consisting of six specially designed high-molecular weight polyethylene blocks (representing the vertebral bodies) that alternated

with five spaces comprising three springs of equal diameter, strength and length (representing the intervertebral discs) (Fig. 3). Screws were implanted into a space between the polyethylene block and the screw heads to prevent potential stress-shielding.

Rod curvature

The curvature of all 12 rods used was the same (36.7°) and corresponded to an average thoracic kyphosis. To ensure that all rods matched, they were curved by the manufacturer before this experiment.

Dynamic tests

The model consisting of alternative blocks and springs (initially straight) was loaded in axial compression in a material testing system. The screws and rods were inserted as recommended by the manufacturer, in the same manner as they are used in vivo: the nuts were placed alternating on the construct's two rods then tightened gradually. The same application method was used for the six tested constructs (Fig. 4). The reduction method for the screw-rod connection was gradual for the screws using a lateral connector and consisted of descending the nut on the threaded extension of the dome screw. Reduction with the top-loading screws was done using a persuader to push the rod into the neck of the screw and while holding the lateral sides of the screw head.

After having locked each screw on the two construct rods, the angle of these rods was measured before any axial compression was applied. Next, a 500 N load was applied. The angle of the rods was measured again. The load was then removed (returned to 0 N) and the angle of the rods measured a third time. Next, the constructs were disassembled, and the rod angles measured outside the construct.

These procedures were done on six constructs involving two rods each:

- Three constructs used two rods fixed with top-loading screws
- Three constructs used two rods fixed with dome screw with lateral connectors.

The primary outcome was the mean angle in each construct at each step. Student's *t* test was used to look for a significant difference between the various configurations tested at a 5% significance threshold.

Results

For each construct, the data consisted of four angles for each rod. The results of the measurements taken on the three constructs using dome screws with lateral connector are summarized in Table 1. The results of the same measurements taken on the three constructs using top-loading screws are summarized in Table 2.

The mean angle for each type of construct was calculated in the different steps of the dynamic testing to compare the two types of screws (Fig. 5). The mean angle of the rods after applying 500 N load was significantly less when the top-loading screws were used (mean 18.7°, min 18.1°; max 19.1°) than when the dome screws with lateral connector were used (mean 24.5°, min 23.1°; max 25.9°) ($p < 0.0003$). The mean angle of the rods after the load was removed was significantly less when the top-loading screws were used (mean 25.7°, min 25.2°; max 26.2°) than when the dome screws with lateral connector were used (mean 32.3°, min 31.8°; max 32.8°) ($p < 0.0005$). At each step of the analysis, the mean angle of the rods using the top-loading screws was significantly less than that of the construct using dome screws with lateral connector (Table 3).

Discussion

Poor sagittal alignment is one of the main causes of pain and disability in adult spinal deformity [1,2,7,8]. Surgical treatment of this imbalance is effective at improving the radiological and functional outcomes; however, a large number of patients end up with insufficient correction postoperatively [7]. The persistence of a sagittal alignment problem, even to a lesser degree, is a known risk factor for nonunion, adjacent segment disease and junctional syndrome [9-10]. In this context of under-correction, which can affect 30% to 40% of operated patients according to various studies, patient-specific instrumentation maybe one of the solutions to minimize the risk of under-correction [11-13].

However, once the prebent rods have been created to match the “ideal” curvature required for sagittal realignment of the patient, we still need to know how they behave once implanted. In a study of the biomechanical properties of the three main types of spinal rods (cobalt-chrome, titanium and stainless steel), Ohrt-Nissen et al. [14] highlighted the importance of knowing the Young’s modulus of the implants since the plastic deformation of the rods during implantation may be responsible for loss of correction due to the low viscoelasticity of the chosen material. According to these authors, using rigid rods helps to improve the sagittal correction, which explains the increasing popularity of large-diameter cobalt-chrome rods.

Thus the “flattening” effect that occurs when assembling the construct must be studied. Our in vitro study appears to provide a logical approach to the behavior of an in vivo construct, with the assembly being done according to the standard surgical procedures and the manufacturer’s recommendations. The 500 N load was chosen based on published biomechanics studies to simulate the stresses to which the construct is subjected in a male of average size when standing [15].

Our study's findings point to a large difference in rod flattening between the two types of screws tested. In fact, we observed that reduction maneuvers on top-loading screws apply the rod against the spine and thus are more restrictive for the radius of curvature. Conversely, the reduction maneuvers for the dome screws with lateral connector bring the screw heads (and the vertebrae in which they are implanted) back towards the rods and thus to limit the stresses on the radius of curvature of the rod.

Performing a reduction on the screw-rod connection using top-loading screws thus leads to significantly more flattening of the rod's initial curvature. This may be cause of under-correction in the sagittal plane due to this permanent flattening (plastic phase of deformation) as evidenced by the angles measured after the load was removed (25.7° vs. 36.7°). Conversely, the reduction using the lateral connection helps to limit the effect of rod flattening and should provide better correction in the sagittal plane.

This difference is also important in terms of rod stiffness. In fact, hardware failure and especially rod breakage and screw pull-out are common complications associated with this type of surgery [16]. While the stresses applied to the rod are large in a construct using top-loading screws and exceed the material's elastic capacity, it would be interesting to compare the stiffness of these two types of constructs in vivo. A 2013 biomechanics study [17] showed the increased risk of pedicle screw pull-out when rod benders are used to secure a fracture fixation rod with top-loading screws, a finding that can be found in agreement with those of our study.

Surgical treatment of spinal deformities continues to be difficult and not well standardized. Various radiological parameters are known to impact the postoperative outcomes [5-6]. One of the main difficulties remains the surgical procedure itself, due to the persistence of various parameters that have still not been mastered, such as the stiffness of

the vertebral column or the exact curvature applied to a rod during manual bending. Thus it may appear logical that using rods with a predefined radius of curvature, based on patient-specific planning, could improve the postoperative correction [11-13]. However, beyond the rod's radius of curvature, the choice of implants and especially the connection type between the screws and rods appears to be important.

Thus, using a lateral connection limits the effect of rod flattening by a lag mechanism of the spine towards the rod, while using top-loading screws increases the flattening effect due to the rod being pushed towards the spine.

These findings about the type of device used can be compared to a previous study by our team where the effect of the type of screw (monoaxial vs. polyaxial) on the correction of idiopathic scoliosis in adolescents was analyzed [18]. It was shown that using polyaxial screws helps to improve the sagittal plane correction to the detriment of the correction in the coronal plane. Thus, choosing the type of screw and screw-rod connection must be integrated into the surgical planning to achieve the best possible sagittal correction, which we know is strongly correlated to quality-of-life scores.

Nevertheless, our study has limitations, such as the small sample size and the in vitro nature, thus our findings must be confirmed in clinical practice. Furthermore, despite significantly less flattening of rods in constructs using lateral screw connections, an approximate 12° variation in angle was observed when the construct was loaded. By extrapolation, we can imagine a similar flattening in vivo. This change in angle is not insignificant and could affect the functional outcomes. If these results are confirmed by an in vivo study with extended follow-up, the radius of curvature of prebent patient-specific rods could be increased when they are manufactured to account for this subsequent flattening.

Conclusion

This study has shown a difference in the flattening and thereby the sagittal plane correction depending on the type of connection chosen between the rods and screws: top-loading screws have a significantly greater flattening effect than dome screws with lateral connector. Surgeons must be aware of this difference, no matter which type of rod is used, so they can be best prepared for the rod's flattening during its use and can take this into account during the preoperative planning. Use of prebent "over-corrected" rods that take into account the expected flattening is one of the ways that spinal instrumentation can be improved.

Conflict of interest:

B Blondel is a consultant for Medicea International, Vexim-Stryker, Implanet, and an Associate Editor for OTSR and Advances in Orthopedics

S Fuentes is a consultant for Medicea International, Vexim-Stryker, Medtronic

P Tropiano is a consultant for Depuy-Synthes, FH Orthopedics

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Author Contributions

- Solène Prost, Sébastien Pesenti, Kaissar Farah and Benjamin Blondel wrote the manuscript
- Stéphane Fuentes and Patrick Tropiano reviewed and corrected the manuscript

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Table 1: Angles measured on the rods within constructs made with dome screws and lateral connector (For each construct, the values show correspond to the left rod T1 and right rod T2).

	1st construct	2nd construct	3rd construct
	T1 /T2	T1 /T2	T1 /T2
Initial angle	36.7°		
Angle after locking the rod	24°/25°	24°/23°	22°/26°
Angle after applying 500 N load	24°/25°	25°/25°	22°/26°
Angle after removing load (0 N)	23°/25°	23°/22°	19°/24°
Angle after removing construct	32°/33°	32°/33°	32°/32°

Table 2: Angles measured on the rods within constructs made with top-loading screws (For each construct, the values show correspond to the left rod T1 and right rod T2).

	1st construct	2nd construct	3rd construct
	T1 /T2	T1 /T2	T1 /T2
Initial angle	36.7°		
Angle after locking the rod	19°/19°	18°/19°	19°/18°
Angle after applying 500 N load	18/19°	19°/19°	19/18°
Angle after removing load (0 N)	16°/16°	15°/16°	16°/15°
Angle after removing construct	25°/26°	26°/26°	26°/25°

Table 3: Comparison of the mean rod angles by type of construct

	Top-loading screw	Dome screw with lateral connector	<i>P value</i>
Initial angle	36.7°		
Angle after locking the rod	18.7° [18.2°-19.2°]	24.0° [22.6°-25.4°]	< 0.0007
Angle after applying 500 N load	18.6° [18.1°- 19.1°]	24.5° [23.1°-25.9°]	< 0.0003
Angle after removing load (0 N)	15.7° [15.2°-16.2°]	22.7° [20.6°-24.8°]	< 0.0006
Angle after removing construct	25.7° [25.2°-26.2°]	32.5° [31.8°-33°]	< 0.0005

Figure legends

Figure 1: Example of top-loading screw

Figure 2: Example of dome screw with lateral connector

Figure 3: Diagram of the construct used: highly cross-linked polyethylene (PE) blocks represent the vertebral bodies in which screws were inserted; the springs represent the intervertebral discs, with the entire unit simulating the spine being instrumented.

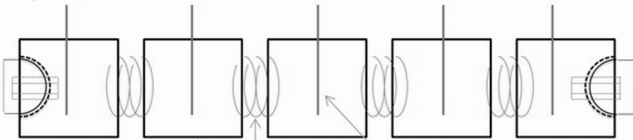
Figure 4: Loading of a construct with dome screws and lateral connector

Figure 5: Mean angle for each type of construct





Tige cintrée



Bloc PE

Ressort

Vis à tester

