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The Stiffness Comparison of Four-Screw versus Six-Screw Short Segment Pedicle Posterior Stabilization Instrumentation in Cyclic Axial Compression

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Abstract

Background: Thoracolumbar burst fracture required to conduct short segment posterior stabilization as the operative therapy. The short segment fixation (above and under fracture level (four-screw pedicle)) encounters loss of correction and failure including progressive kyphosis, screw pedicles and rods that are bent or fractured. Rod around fracture site receives bigger loads than other parts due to its function as cantilever. To overcome this, it uses short-segment posterior stabilization instrumentation in which pedicle screw is installed above, under, and on fracture site level (six-screw pedicle) to increase stiffness.

Objective: To analyze the comparison stiffness of four-screw versus six-crew short segment pedicle posterior stabilization instrumentation in cyclic axial compression.

Method: This study used in vitro mechanical test in simulation of vertebrae from UHMWPE (Ultra High Molecular Weight Polyethilene) that was fixated with four-screw and six-screw pedicle. Each construction is given cyclic axial compression. Afterwards, the stiffness of each construction was measured.

Results: Six-screw short segment pedicle posterior vertebrae stabilization instrumentation had higher stiffness of 43.38% than four-screw short segment pedicle posterior vertebrae stabilization instrumentation in cyclic axial compression. There was a significant difference in both groups ($p<0.05$)

Conclusion: Six-screw short segment pedicle posterior vertebrae stabilization instrumentation was better than four-screw short segment pedicle posterior vertebrae stabilization instrumentation in cyclic axial compression.

Keywords: *In vitro mechanical test,thoracolumbar burst fracture, six-screw short segment pedicle, four-screw short segment pedicle, cyclic axial compression, stiffness*

Introduction

In Indonesia, the case of spinal cord injury has commonly occurred. Spine fracture therapy can be performed either operatively or nonoperatively. The goal of spinal fracture therapy is to restore stability, reduce pain and correct deformity. The variety of therapy instrumentations that are currently used are SRSSI, PSP, and PSR (Pedicle Screw and Rod). Fixation with transpedicle screw is often used as a spinal instrumentation for the stabilization and correction of deformity caused by trauma, degenerative processes, tumors, and congenital abnormalities(1, 2). The pedicle screw system can provide instability treatment because of a burst fracture or tumor resection in the thoracolumbar(3).

In the previous study on the short segment of four-screw pedicle, there was a change in kifotic angle post op of 2.0625 to 5.312 after 6 months, whereas in the short segment of six-screw pedicle, there was a change in kifotic angle post op of 1.000 to 1.333 after 6 months (4). The short segment fixation (above and under fracture level (four-screw pedicle)) encounters loss of correction and failure including progressive kyphosis, screw pedicles and rods that are bent or fractured. In this case, if the construction is mounted a pedicle screw on the fracture site, it will overcome the problems (5). Several studies reported a 25% failure on lumbar or thoracolumbar fractures treated with instrumentation with short-segment pedicle screw(6). This is due to the short segment caused by the occurrence of axial instability that reflects the anterior and medial mechanical incompetence.

Several biomechanical studies are aimed to indicate the character of the spine in a physiological (non-injury) state, which includes a stiffness test or flexibility. The results of the study are described in the load displacement curve. Clinically, this series of instrumentation requires in vitro testing either in a plugged in synthetic material or cadaveric spine. The results of this biomechanical test provide information on tool stiffness, fatigue life and failure mechanisms to improve the instrumentation [7].

The researchers are intended to compare the stiffness by assigning a load to a cyclic axial compression force between the construction of four screw short-segment pedicles with six screw short segment pedicles on a vertebral simulation using polyethylene material.

Method

This research is an in vitro biomechanical test with true experimental. This method used Post test only control design, which distinguished two types of short-segment pedicle construction mounted on polyethylene (UHMWPE) material that resembles human spine with unstable fracture or (anterior and medial damage) and cyclic axial compression load. The first construction used four pedicle screw (pedicle screw mounted above and below fracture level) while the other type of construction used six pedicle screw (pedicle screw mounted above, below fracture level and fracture level).

The tool used was material testing machine servohidraulic type Schenck, 1990, made in Germany. Biomechanical tests on the vertebral simulation of polyethylene material was performed to compare the stiffness of a six-screw pedicle short-segment construction with four-screw pedicle short-segment construction in cyclic axial compression. The specimens were subjected to repeated loading on the top and downward direction in the sinusoidal function with cross head displacement of ± 1 mm. The frequency of displacement was 2 Hz in sinusoidal wave. The magnitude of this displacement was determined based on previous studies showing that displacement of 1 mm provided a load to the pedicle screw equivalent to the load received during walking [8]. The amount of load received is calculated; thus, the load displacement curve can be obtained to calculate the stiffness coefficient.

The measurement of the slope stiffness of the load displacement curve was carried out in the range of 10-90% from the 1000 cycles. It was intended to remove the pre-stress conditions received during insertion or tightening of the screw [8]. This measurement was conducted four times; thus, each specimen has a total of 3000 cycles to recognize changes in the entire cycle. This test used a servohydraulic testing machine (ESH) composed of displacement transducer and compressive load-cell. The data collection of load displacement was conducted through analog to digital interface. Three groups of data obtained were time (s), displacement (mm), and load (N).

Two holes were made on polyethylene on the posterior side with 40 mm distances. Both holes had the same distance from the bottom surface of the block, which was 9 mm. The direction of the screw hole was perpendicular to the cut posterior surface; thus, it angles 15° anteromedial. Both holes were tapered 6.0 and mounted two monoaxial pedicle screw in each polyethylene block. The screw had 35 mm long from 316L stainless steel made by PT Marthys Indonesia. This study used two types construction: the first construction used two blocks of polyethylene by spacing between two blocks and the second construction used three blocks of polyethylene. Once tested, the polyethylene specimen can be reused only if visual inspection was not cracked, ebris due to the usage, or permanent shaping. Furthermore, the reduced torque strength can cause the polyethylene cannot be used.

Screw pedicle used had a head structure that can accommodate longitudinal rod, perform closure mechanism, and deformity correction. Closure mechanism is an important part because it has an effect on the rigidity of a construction. To see the actual strength of the construction, a scenario condition was created, in which the construction must support axial compression loads on both polyethylene blocks above and below. The statistical analysis was conducted by using ANOVA (Analysis of Variance) with $p < 0.05$ as the degree of significance. This study compared the stiffness between devices as well as between cycles; therefore, it was not possible to use t test.

Results

Based on the statistical test descriptively, the highest average stiffness of 6 screw pedicle after giving axial compression style of 500 N was 528.75±32.50 N/mm in initial cycle (cycle 0). On the other hand, the lowest stiffness value in 3000 cycle was 431.25±37.50 N/mm. In the results of axial compression of 900 N, the highest stiffness in initial cycle was 356.25±71.80 while the lowest stiffness in cycle 3000 was 137.50±43.30 N/mm. The highest average stiffness of 4 screw pedicle after giving axial compression style of 500 N was 276.25±16.52 N/mm in initial cycle (cycle 0). On the other hand, the lowest stiffness value in 3000 cycle was 243.75±23.93 N/mm. In the results of axial compression of 900 N, the highest stiffness in initial cycle was 175±95.74 while the lowest stiffness in cycle 3000 was 87.50±25.0 N/mm.

Table 1. The multi-cyclic stiffness post compression force in pedicle screw installation

Treatment	Sample	Compression 500N				Compression 900N			
		Cycle 0 (N/mm)	Cycle 1000 (N/mm)	Cycle 2000 (N/mm)	Cycle 3000 (N/mm)	Cycle 0 (N/mm)	Cycle 1000 (N/mm)	Cycle 2000 (N/mm)	Cycle 3000 (N/mm)
6 pedicle screw	1	525.0	475.0	450.0	475.0	375.0	350.0	250.0	100.0
	2	515.0	485.0	475.0	450.0	400.0	225.0	200.0	175.0
	3	500.0	435.0	400.0	400.0	400.0	150.0	100.0	100.0
	4	575.0	450.0	410.0	400.0	250.0	175.0	150.0	175.0
4 pedicle screw	1	285.0	275.0	260.0	225.0	300.0	200.0	200.0	125.0
	2	295.0	285.5	275.5	260.0	100.0	75.0	75.0	75.0
	3	275.0	265.0	250.0	225.0	100.0	175.0	100.0	75.0
	4	300.0	270.0	250.0	250.0	200.0	175.0	100.0	75.0

The analytical statistic used Independent t-test. Mann-Whitney was performed to measure the average stiffness after giving the axial compression 500 N and 900 N in 6 screw pedicles and 4 screw pedicles. It was also repeated ANOVA test to understand the stiffness change along with cycle change (1000, 2000, dan 3000 N/mm) in both ways of installations.

Table 2. The comparison of stiffness mean in 6 pedicle screw and 4 pedicle screw (independent t-test)

Compression	Pedicle screw treatment	Stiffness mean (N/mm)	Difference percentage (%)	(p)
The comparison of stiffness mean in 6 pedicle screw and 4 pedicle screw post compression 500 N and 900 N (independent t-test)				
500 N	6 screw	463.75 ± 49.91	43.38	0.001
	4 screw	262.56 ± 19.11		
900 N	6 screw	223.44 ± 67.15	39.85	0.008
	4 screw	134.38 ± 66.38		
The comparison of stiffness mean each cycle in 6 pedicle screw and 4 pedicle screw post compression 500 N (independent t-test)				
0	6 screw	528.75 ± 32. 50	47.75	0.001a
	4 screw	276.25 ± 16. 52		
1000	6 screw	461.25 ± 22. 86	42.52	0.029b
	4 screw	265.12 ± 10. 95		
2000	6 screw	433.75 ± 37. 50	38.87	0.001a
	4 screw	265.12 ± 10. 95		
3000	6 screw	431.25 ± 37. 50	43.38	0.001a
	4 screw	243.75 ± 23. 93		
The comparison of stiffness mean each cycle in 6 pedicle screw and 4 pedicle screw post compression 900 N (independent t-test)				
0	6 screw	356.25 ± 71. 80	50.88	0.023
	4 screw	185 ± 95. 74		
1000	6 screw	225 ± 88. 97	30.56	0.238
	4 screw	156.25 ± 55. 43		
2000	6 screw	175 ± 64. 54	32.14	0.234
	4 screw	118.75 ± 55. 43		
3000	6 screw	137.50 ± 43. 30	36.36	0.104
	4 screw	87.5 ± 25. 00		

* Homogeneity test was performed using Levene test

a Analytical test using independent t-test parametric test

b Analytical test using non-parametric test Mann-Whitney test

It has been revealed that the average stiffness of 6 screw pedicles was higher than 4 screw pedicles with the percentage of 43.38% post compression of 500 N and 39.85% post compression of 900 N. It was a significant difference ($p<0.05$). The stiffness in 6 screw pedicles post giving axial compression of 500 N was higher than 4 screw pedicles of each cycle with the initial cycle percentage of (47.75%) and it was considered significant ($p<0.05$). The stiffness in 6 screw pedicles post giving axial compression of 900 N was higher than 4 screw pedicles of each cycle in the initial cycle and it was considered significant ($p<0.05$). However, there was no significant difference in other cycles ($p>0.05$).

The average stiffness of 6 screw pedicles had tendency to decrease along with increased cycle yet it was not considered significant ($p>0.05$). The post hoc test of 4 screw pedicles showed that there was significant decreased stiffness from cycle 0 to 1000, as well as from cycle 1000 to 2000 ($p<0.05$). However, there was an insignificant decrease of average stiffness in cycle 2000 to 3000 ($p>0.05$). In general, there was decreased stiffness along with insignificant increased cycle with axial compression of 500 N in 3-level pedicle screw ($p>0.05$). In addition, there was a decreased stiffness along with insignificant increased cycle in 4 pedicle screws ($p>0.05$). Based on post hoc test in 4 pedicle screws, there was no statistically significant average stiffness in each cycle change ($p>0.05$). It can be concluded that there was no significant decreased stiffness along with increased cycle with axial compression of 500 N in 4 pedicle screws ($p>0.05$).

The average stiffness of 6 screw pedicle showed a tendency to encounter insignificant decreased along with increased cycle ($p>0.05$). Based on post hoc test in 6 pedicle screws, there was no statistically significant average stiffness in each cycle change ($p>0.05$). It can be concluded that there was no significant decreased stiffness along with increased cycle with axial compression of 900 N in 6 pedicle screws ($p>0.05$).

The average stiffness of 4 screw pedicle showed a tendency to encounter insignificant decreased along with increased cycle ($p>0.05$). Based on post hoc test in 4 pedicle screws, there was no statistically significant average stiffness in each cycle change ($p>0.05$). It can be concluded that there was no significant decreased stiffness along with increased cycle with axial compression of 900 N in 4 pedicle screws ($p>0.05$).

Discussion

To ensure the ability of instrumentation construction as a fixation of the spine, the implant construction must have genuine stiffness. Therefore, the stiffness should be measured to support and stabilize the spine until bone healing occurs in an instrumentation construction . Basically, the instrumentation construction has varying stiffness due to the difference in load and the amount of cyclic received. It is due to the interspecimen slippage and microcrack in the implantable material. By using UHMWPE as a consistent fixation medium with the right size, the depth and placement of the implants can be made constantly [9].

This study protocol is a consistent and logical technique for the posterior spinal instrumentation biomechanical test. This method also provides evaluation base and biomechanical comparison of both constructions. In implant construction, the construction material and types affect the stiffness from the implant construction (10). Theoretically, the posterior stabilization of the short segment of six screw pedicles can increase the resistance and stabilization of the spine (13). In this study, in addition to the stiffness between the two constructions, we also observed the change of stiffness between cycles, so it can be found how strong the construction after being given increased cyclic axial compression cycle. This is in accordance with studies stating that the stiffness of an implant will vary according to the size of the load cycle received as a result of the intraspicemen slippage and microcrack occurring in the implant material (10, 12).

In this study, there was no broken construction on screw pedals and rods when the device was given cyclic axial load or upon inspection after the tool was removed. From the results of research using synthetic spine of UHMWPE material, it is found how big the difference of stiffness in both constructions is. The use of UHMWPE has the advantage of being a stable specimen in a research because it can be reduced to biological deterioration; therefore, it can be used as a consideration for deciding which type of construction will be used to deal with cases of spinal trauma. However, the value obtained does not mean exactly the same as if it is implemented on the patient directly. In the use to the patient, it still must be considered because there are many biological factors such as the age of patients, osteoporosis, the patient's nutrition, postoperative rehabilitation of the patient or the presence of comorbid diseases such as malignancy, and infection.

Conclusion

The six-screw short segment pedicle posterior vertebrae stabilization instrumentation was better than four-screw short segment pedicle posterior vertebrae stabilization instrumentation in cyclic axial compression.

Ethical Clearance: This study received an ethical test from Dr. Soetomo General Hospital and faculty of medicine Universitas Airlangga.

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Conflict of Interest: There was no conflict of interest from this study.

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