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SALVAGE OF FAILED SACRAL PEDICLE SCREW: BIOMECHANICAL COMPARISON OF ALA SCREW, BIGGER PEDICLE SCREW, POLYMETHYLMETHACRYLATE AUGMENTED PEDICLE SCREW

YETMEZLİK GELİŞEN SAKRAL VİDALARIN KURTARILMASI: ALA VİDALARI, BÜYÜK PEDİKÜL VİDALARI VE POLİMETİLMETAKRİLAT İLE GÜÇLENDİRİLMİŞ PEDİKÜL VİDALARININ BİYOMEKANİK OLARAK KARŞILAŞTIRILMASI

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SUMMARY:

Background Data: *Salvage procedures are needed to restore the stability of lumbosacral arthrodesis when pedicle screw fixation in the sacrum fails.*

Purpose: *The aim of this study is to determine biomechanical differences ala, polymethylmethacrylate (PMMA) augmented and larger pedicle screws as salvage techniques for failed primary sacral pedicle screw.*

Material and Methods: *Primary pedicle screws were inserted to 21 fresh frozen calf's first sacral vertebra (S1) pedicle bicorticaly. The screws were pulled out in a random order at 5mm/min Materials Testing Machine. The pull-out strengths (POS) were measured. Afterwards, these pedicle screws were randomly assigned to be replaced by PMMA augmented screws (group 1), larger screws (group 2) and ala screws (group 3) as a revision technique. Finally, POS of the revision screws were recorded.*

Results: *The mean POS of all primary screws was 1981 N/m^2. Group 1: The mean POS of primary screws was 1650 N/m^2. After PMMA augmentation, mean POS was 1295 N/m^2 (p=0,139). The mean POS ratio (primary POS/revision POS) was 1.54±0,24. Group 2: The mean POS of primary screws was 2046 N/m^2. After larger screw replacement, mean POS was 1320 N/m^2 (p=0,007). The mean POS ratio was 1.84±0,22. Group 3: The mean POS of primary screws was 2247 N/m^2. After ala screw insertion, mean POS was 1290 N/m^2 (p=0,011). The mean POS ratio was 2.98±0,91. There was no statistical differences between POS (p=0,381) and POS ratio (p=0,185) of revision pedicle screws.*

Conclusion: *PMMA augmentation achieved close POS to that of the primary screw so it can be concluded that it is a stronger revision technique compare to the larger or ala screws. On the other hand, there were no statistical differences between revision screws based on POS and POS ratio.*

Key Words: *Biomechanics, Sacrum, Pedicle screw, Revision*

Level of Evidence: *Experimental study, Level I*

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ÖZET:

Geçmiş Bilgiler: *Sakral pedikül vida fiksasyonunun başarısızlığı durumunda, lumbosakral artrodezin stabilitesinin restorasyonu için kurtarma yöntemlerine ihtiyaç duyulur.*

Amaç: *Bu çalışmanın amacı; başarısız primer sakral pedikül vidasını kurtarma amacıyla kullanılan; ala vidası, polimetilmetakrilat (PMMA) destekli vida ve büyük vidanın biomekanik farklılığını saptamaktır.*

Materyal ve Metod: *21 taze donmuş dana omurga 1. sakral vertebrasına, primer pedikül vidaları çift korteks tutacak şekilde yerleştirildi. Primer vidalar randomize olarak Materyal Test Makinesi ile 5 mm/dk hızda aksiyel yönde çekildi ve çekme güçleri ölçüldü. Takiben bu vidalar randomize olarak, PMMA destekli vida (grup 1), büyük vida (grup 2) ve ala vidası (grup 3) yöntemi ile revize edildi. Son olarak revizyon vidalarının çekme güçleri ölçüldü.*

Sonuçlar: *Primer vidaların ortalama çekme gücü 1981 N/m^2 idi. Grup 1: Primer vidaların ortalama çekme gücü 1650 N/m^2. PMMA destekleme sonrası ortalama çekme gücü 1295 N/m^2 olarak saptandı (p=0,139). Ortalama çekme gücü oranı (primer/ revizyon) 1.54±0,24 idi. Grup 2: Primer vidaların ortalama çekme gücü 2046 N/m^2 idi. Büyük vida uygulama sonrası ortalama çekme gücü 1320 N/m^2 olarak saptandı (p=0,007). Ortalama çekme gücü oranı (primer/ revizyon) 1.84±0,22. idi. Grup 3: Primer vidaların ortalama çekme gücü 2247 N/m2 idi. Ala vida uygulama sonrası ortalama çekme gücü 1290 N/m^2 olarak saptandı (p=0,011). Ortalama çekme gücü oranı 2.98±0,91 idi. Gruplar arasında çekme gücü (p=0,381) ve çekme gücü oranları (p=0,185) arasında istatistiksel olarak anlamlı bir fark bulunamadı.*

Tartışma: *PMMA destekli vida, primer vida çekme gücüne en yakın çekme gücünü elde ettiği için büyük ve ala vidalarına göre daha güçlü olduğu söylenebilir. Ancak revizyon vidalarının çekme gücü ve çekme gücü oranları arasında istatistiksel fark saptanmamıştır.*

Anahtar Kelimeler: *Biyomekanik, sakrum, pedikül vidası, revizyon.*

Kanıt Düzeyi: *Deneysel çalışma, Düzey I*

INTRODUCTION:

Pedicle screw fixation has been used for scoliosis [23,27-28], kyphotic deformities [4,24,32], tumors [3,9], degenerative disease [8,26] and infection [22]. The advantages of pedicle screw fixation are dependent upon its ability to retain bony purchase until the fusion mass is stable.

Sacral fixation failure due to osteopenia, poor general health, advanced age, decreased muscle tone, and neurologic or muscular impairment are still clinical problems for patients who have been operated for the following indications: fusion across the lumbosacral joint due to neuromuscular scoliosis with pelvic obliquity, scoliosis with associated degeneration of the lumbosacral spine, painful spondylolisthesis, and progressive lumbar deformity below a spine previously instrumented for scoliosis.

At the lumbosacral junction, osteoporotic bone, lumbosacral overloading and increased motion can negatively effect the fusion. Recognized complications after lumbosacral fusion are screw pullout or breakage, misalignment, loss of correction and pseudoarthrosis. Allen and Fergusen reported 9 % - 40 % pseudarthrosis rates at the lumbosacral junction, depending on the technique employed [3], and Boachie- Adjei et al reported a 23 % pseudarthrosis rate with the Luque-Galveston technique [2]. On the other hand, Devlin et al reported 12 of 27 (44 %) patients who underwent reconstruction for adult scoliosis using CD instrumentation to the sacrum had sacral screw failure by pull-out; one patient had sacral screw breakage [6]. In the series by Kuklo et al evaluation lumbosacral fusions for high-grade spondylolisthesis using bilateral S1 and iliac screws a 14 % pseuoarthrosis rate was demonstrated [13].

There are many ways to salvage pedicle screws such as using larger and/or longer size pedicle screws, augmenting failed screw holes or inserting the pedicle screws in a different trajectory [14-15,17-21,25,30-31,34]. The removal and replacement of a screw in a revision procedure substantially decreases its mechanical stability. To our knowledge, no biomechanical comparison between ala, larger and PMMA augmented pedicle screws as a salvage technique in sacrum has been reported.

MATERIAL AND METHODS:

Twenty-one calf sacral vertebras were harvested and stored at –20°C. The bone mineral density (BMD) of each vertebra was determined by using dual energy X-ray absorbsiometry. Before use, the specimens were thawed for 24 hours at room temperature, and cleaned of all soft tissues after fully thawed. Mechanic tests were performed in 2 stages.

Stage 1: Primary Screws Pullout Test

Primary Pedicle Screws:

6.5 mm polyaxial pedicle screws (XIA Spinal sistem, Stryker, NJ, USA) were inserted to S1 (first sacral vertebra) pedicle bicortically. The entry point for the S1 pedicle was located at the intersection of the vertical line tangential to the lateral border of the superior articular process and the horizontal line tangential to its inferior border. Pedicle finder was directed 30° converges towards the midline and 15° cranially to aim towards the anterior corner of the promontorium and than a 5.5 mm tap was applied to the pedicle hole. After tapping, the pedicle hole was checked with a probe and an adequately sized pedicle screw was inserted. Following screw insertion, each sacrum was embedded in cement (AMBEROK Model Stone) with the anterior cortex facing down.

Once the cement set, each potted specimen was mounted on the base of an Instron Materials Testing Machine (United Kingdom) and pedicle screws were pulled out in a random order at 5 mm/min. The load-displacement curve was recorded and the pull-out strength (POS) was measured.

Stage 2: Revision Screws Pull-out Test

A random number generator was used to determine which of the three revision techniques would be used to instrument each pedicle side. Seven screws were used for each revision technique.

Group 1 (PMMA augmented screws):

After primary screws pullout test, 2 cc PMMA (Simplex P, Howmedica, Mahwah, NJ) was injected without pressurizing the screw holes. After PMAA injection, 6.5 mm polyaxial pedicle screws, which were the same size with the primary screw, was inserted.

Group 2 (Larger Pedicle Screws):

7.5 mm polyaxial pedicle screws were inserted. This revision screw was not longer than the primary screw which was inserted bicortically before.

Group 3 (Ala Screws):

Using the same entry point, Ala screw was inserted to ala unicortically, angled 45° cranially and 20° laterally which parallel to sacroiliac joint.

The revision pedicle screws were tested at the same loading rate as in the first stage; at 5 mm/min. The load-displacement curve was recorded and the POS of each revision screw was measured.

Statistical Methods:

All comparisons were made at a statistical significance level of 0.05 or 95 % confidence. Bone mineral densities of specimens were compared using paired t-test analysis. Each primary and revision technique pullout strength was compared using a paired t-test. Revision screw pullout strengths were compared using one-way ANOVA test. The POS ratios between the revision techniques (primary / pmma augmented vs. primary /larger vs. primary / ala) were compared using one-way ANOVA. All statistical analyses were performed using SPSS, version 10.0 (Chicago, IL).

RESULTS:

The mean bone mineral density of the specimens was 1.25 g/cm^3. There was no statistical difference between the bone mineral density of the specimens ($p>0.05$). The mean POS of all primary pedicle screws was 1981 N/m^2.

Group 1:

The mean POS of primary pedicle screws was 1650 N/m^2. After PMMA augmentation, mean POS was 1295 N/m^2 ($p=0.139$). The mean POS ratio was 1.54 ± 0.24 (Table-1).

Group 2:

The mean POS of primary pedicle screws was 2046 N/m^2. After larger screw replacement, mean POS was 1320 N/m^2 (p=0,007). The mean POS ratio was 1.84 ± 0.22 (Table-1).

Group 3:

The mean POS of primary pedicle screws was 2247 N/m^2. After Ala screw insertion, mean POS was 1290 N/m^2 ($p= 0.011$). The mean POS ratio was 2.98 ± 0.91 (Table-1).

There was no statistical differences between POS ($p= 0.381$) and POS ratio ($p= 0.185$) of revision pedicle screws

Table - 1. Summary of Biomechanical Test Results

Cadaver	Group1 Primary/pmma* POS** (N/m²)	Group1 POS** ratio	Gorup2 Primary/Larger POS** (N/m²)	Group 2 POS** ratio	Group3 Primary/Ala POS** (N/m²)	Group 3 POS** ratio
1	1862/929	2.004	2031/800	2.538	3586/1583	2.265
2	1250/1287	0.971	1740/690	2.521	1686/401	4.207
3	1415/780	1.814	1210/650	1.861	1260/1114	1.131
4	1808/720	2.511	2775/2549	1.088	1490/450	3.31
5	817/475	1.72	2687/2428	1.106	3982/3262	1.220
6	1688/1907	0.885	1454/725	2.005	2088/2012	1.037
7	2713/2973	0.912	2430/1400	1.735	1639/213	7.694
mean	1650/1295	1,54±0,24	2046/1320	1.84±0,22	2247/1290	2.98±0,91

pmma*: polymethylmethacrylate, **POS**:** pull-out strength

DISCUSSION:

Transpedicular screw is the best surgical fixation technique for treatment of spinal disorders. Pedicle screw fixation provides short and rigid segmental stabilization, even in the absence of intact posterior elements. The resistance of pedicle screws to axial and tangential loading is significantly higher than that of pedicle and laminar hooks [(10)].

In English literature; there are studies showing that PMMA augmentation achieves the best mechanical strength for both primary and revision pedicle screws [(20,25,31)]. We also found similar test results with PMMA augmented revision screws. With regards to these results, it is possible to say that PMMA augmented pedicle screws achieved the closest POS to primary pedicle screws POS, compared to primary pedicle screw. Ngu et al compared expandable, and cement augmented pedicle screws as revision techniques and found significantly greater pullout strength than their respective initial standard pedicle screws. Derincek et al has also shown greater POS with PMMA augmented pedicle screw compared to the initial pedicle screw in osteoporotic thoracic bone [(5)]. Polymethylmethacrylate has long been used for augmenting pedicle screws in revision procedures. However, PMMA is an exothermic polymer, which may cause bone necrosis, toxin release and/or neural injury [(12,29)]. The alternative augmentation material is the calcium sulfate/phospate bone graft, which has a higher potential for biologic incorporation and nonexothermic, in-situ setting graft causes no thermal injury to the bone or the nerves. Such bioresorbable property is especially beneficial for revision surgeries [(5,11)].

The effects of using bigger or longer screws to salvage failed pedicles have been studied [(21,31)]. Zindrick et al [(34)] performed axial pull-out and cyclic loading tests, using multiple screw designs inserted into various depths of fresh human lumbosacral vertebra. They found that large diameter and fully-threaded screws inserted deep enough to engage the anterior vertebral cortex resulted in the most secure fixation. On the other hand, Polly et al [21] showed that increasing the diameter causes increased insertional torque, but increasing the length of the screw does not. In clinical application, salvaging a previously violated pedicle with a longer or larger screw might not be safe due to the anatomic size, amount of the pedicle violation and proximity to the spinal cord. In our study we used wider but no longer sacral pedicle screws for revision because the primary pedicle screw had been already inserted bicortically and after larger screw insertion POS was decreased 36 % in group 2.

Sacral Ala is the lateral mass of the sacrum. Anterolateral S1 screw placement through the sacral ala has been used alone or in combination with an anteromedially directed screw in the S1 pedicle to enhance pull-out resistance. Although the anatomical safe zone was identified, there is a risk of neurovascular injury particularly when the enhancement of fixation strength requires bicortical purchase. The sacroiliac joint, lumbosacral trunk, internal iliac vein and iliolumbar artery are at risk from laterally-directed S1 screws. Doh and Benzel in an anatomic study using human cadaver, concluded that the previous anatomical safe zone for bicortical S1 screw placement into the sacral ala was not surgically safe, and when lumbosacral fixation surgery is planned, operative techniques other than bicortical screw placement should be considered [7]. In this study ala screws were inserted in a unicortical fashion. Zhu et al demonstrated greater POS of anteromedial directed pedicle screw compared to anterolateral directed (Ala screw) after cyclic loading. They also stated that in a young population, screw orientation (anterolateral or anteromedial) was more important in determining pull-out strength than screw depth (unicortical or bicortical) after fatigue loading, anteromedially directed screws being significantly stronger than laterally placed screws [33]. In group 3, mean POS of primary screw (anteromedial) was greater than the ala screw (anterolateral). On the other hand, Leong et al showed that biomechanicaly; two divergent triangulated screws (anteromedial+anterolateral:Chopin block) to the sacrum was significantly stronger than one-screw fixation (anteromedial) on human cadaveric sacral spine [16]. For revision purpose, greater POS can be achieved with larger + ala screw combination.

In the current study; there was no statistically significant difference between POS of primary and PMMA augmented revision screws in group 1 ($p>0.05$). On the other hand, in group 2 and 3, we achieved statistical differences between primary and revision pedicle screws ($p<0.05$). Biomechanical; PMMA augmentation achieved close POS to that of the primary screw so it can be concluded that it is a stronger revision technique compare to the larger or ala screws. On the other hand, there were no statistical differences between revision screws. Based on POS ratio, even PMAA achieved a small mean value, with no statistical difference between any of the groups. Lumbosacral fusion using pedicle screw has mechanical complications and pseudoarthrosis risk. Both larger and ala screw techniques can be used safely to salvage failed sacral pedicle screw either alone or in combination. A good spine surgeon should be aware of all of the problems and salvage options after using pedicle screws at any level of the vertebra.

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