ACTA
ORTHOPAEDICA
et
TRAUMATOLOGICA
TURCICA

Author's translation
Acta Orthop Traumatol Turc 2006;40(1):72-81

Comparison of the pull-out strengths of three different screws in pedicular screw revisions: a biomechanical study

Pediküler vida revizyonlarında üç farklı tip vidanın sıyırma kuvvetlerinin karşılaştırılması: Biyomekanik çalışma

Irfan ESENKAYA,[1] Yurdaer DENIZHAN,[1] Mehmet Akif KAYGUSUZ,[1] Mehmet YETMEZ,[2] Mehmet Halidun KELESTEMUR[3]

[1]Inonu University, School of Medicine, Department of Orthopaedics and Traumatology; [2]METU, Engineering Faculty, Engineering Sciences Department; [3]Firat University, Engineering Faculty, Department of Metallurgy Engineering

Amaç: Pediküler vida revizyon cerrahisinde üç farklı tipte pediküler vida tasarımının aksiyel sıyırma kuvvetini nasıl etkilediği araştırıldı.

Çalışma planı: Çalışmada dana lomber vertebralarından iki ayrı deney grubu oluşturuldu. Vertebraların her bir pedikülüne (tepleme uyguladıktan sonra veya tepleme uygulamadan) 6.5 mm dış çaplı Alıcı pediküler vidalar uygulandı. Vidalara aksiyel sıyırma (pull-out) testi uygulanarak pedikül yetersizliği geliştirildi. Tüm vertebraların sol pediküllerine 7 mm dış çaplı Alıcı tipi pediküler vida uygulandı. Sağ pediküllere ise, bir deney grubunda birinci tipte, diğer deney grubunda ikinci tipte uç kısımları genişleyebilen pediküler vida uygulandı. Aksiyel sıyırma testi her iki grupta tekrar edildi ve elde edilen sonuçlarla 6.5 mm Alıcı vidalarla ölçülen sıyırma kuvvetleri karşılaştırıldı.

Sonuçlar: Birinci deney grubunda, 7 mm'lik Alıcı tipi revizyon vidalarıyla başlangıçtaki sıyırma kuvvetinin %65'i, birinci tip uç kısımları genişleyebilen pediküler vidalarla da %64'ü elde edildi. İkinci deney grubunda ise 7 mm'lik Alıcı tipi revizyon vidalarıyla başlangıçtaki sıyırma kuvvetinin %70'i, ikinci tip uç kısımları genişleyebilen pediküler vidalarla da %68.5'i elde edildi. Vida giriş yerinin teplenmesi, teplenme uygulanmayan grupla karşılaştırıldığında, sıyırma kuvvetinde ortalama %13'lük bir azalmaya neden oldu.

Çıkarımlar: Pediküler vidaların revizyonunda, vida çapında sadece 0.5 mm'lik bir artışla yeterli vida-kemik ara yüzey kuvveti ve pedikül doluluğu elde edilemedi. Genişleyebilen pediküler vida kullanımıyla da yeterli pediküler vida stabilitesi sağlanamadı.

Anahtar sözcükler: Biyomekanik; kemik vidası/yan etki; vertebral hastalıklar/cerrahi; vertebra/cerrahi.

Objectives: We investigated the possible effects of three pedicular screws on axial pull-out strength in pedicular revision surgery.

Methods: Two study groups were formed from calf lumbar vertebrae. Initially, Alıcı pedicular screws with an outer diameter of 6.5 mm were applied (with our without tapping) to all the pedicles. All the pedicles were subjected to axial pull-out testing to induce pedicular insufficiency. Then, Alıcı pedicular screws with an outer diameter of 7 mm were applied to the left pedicles. The right pedicles in the two study groups were assigned to receive two different types of pedicular screws with an expandable (enlargeable) end, respectively. Axial pull-out testing was repeated in both groups and the results were compared with the initial pull-out strength values.

Results: In the first group, 65% and 64% of the initial pull-out strengths were obtained with 7-mm Alıcı pedicular screws and with expandable pedicular screws, for the left and right pedicles, respectively. The corresponding pull-out strengths in the other study group were 70% and 68.5% of the initial values, respectively. Tapping of the screw hole entrance resulted in a mean decrease of 13% in the pull-out strength compared to screw applications without tapping.

Conclusion: Pedicular screw revisions using a 0.5 mm greater screw in diameter did not provide adequate screw-bone inter-face strength and pedicle filling. Similarly, expandable pedicular screws did not contribute to screw stability.

Key words: Biomechanics; bone screws/adverse effects; spinal diseases/surgery; spine/surgery.

Correspondence to: Dr. İrfan Esenkaya. Inonu University, School of Medicine, Department of Orthopaedics and Traumatology, Malatya-TURKEY, Phone:+90 422 - 341 06 60 / 5102 Fax: +90 422 - 325 82 83 e-mail: iesenkaya@hotmail.com

Received: 31.03.2005 **Accepted:** 19.09.2005

The use of transpedicular screw fixation is commonly used in various diseases of vertebral column because of their advantages.[1-9] However, when or after performing pedicle screws some complications like screw malpositions, spinal injuries, retroperitoneal organ injuries, infections, screw breakages and screw pull-out may occur.[2,3,7,8,10-12]

Various methods defined to increase the screw fixation strength in bone quality deficiency. These include larger diameter screw or longer screw use, augmentation the deficient hole by bone graft or bone cement (polymethylmethacrylate) and inserting the screw to a new pilot hole.[6,13-15] There are important anatomical limitations in application of pedicle screws. Using a larger (bigger) diameter screw can cause pedicle fractures. Especially if the fracture occurs by forcing the medial and inferior walls of the pedicle then it may cause neural injuries. By a longer screw use after the penetration of anterior vertebral cortex, vascular and visceral injuries may occur.[6,16,17] The risk of deficient hole augmentation by the use of polymethylmethacrylate (PMMA, bone cement) is the neurologic injury as a result of direct compression or thermal effects.[6,15] Because of these, there are studies on alternative screw designs to increase the pedicle screw fixation strength to use in pedicle screw revision surgery of the osteoporotic patients with low bone mineral density.[1,18-21] In expandable tipped pedicle screws, the tip of the screw is expanded in four wings and this provides more bone contact thus increases the fixation strength. And because the major (external, outer) diameter of the posterior part of the screw does not change, there is no change in entrance (pilot hole) diameter of the pedicle too. Thus a possible pedicle fracture related to increased major diameter of the screw is prevented.[1,19]

In this study after applying 6.5 mm in diameter solid pedicle screws to calf vertebrae; we have made a deficiency between the surfaces of screw and bone by pull-out test. Later, we inserted a solid screw which has 0.5 mm larger (bigger) diameter and 2 types of expandable tipped pedicle screws to the same pedicle and we compared the pull-out strengths. We have researched how the larger diameter pedicle screws and expandable screw designs affect the axial pull-out strength in insertion points which became deficient in pedicle screw revisions.

Materials and methods

Four identical types of pedicle screws were used in this biomechanical study which was performed to evaluate the method to be applied when a screw pull-out, which was a complication of pedicle screw application, was faced.

(i) 6.5 mm of major (external, outer) diameter Alıcı pedicle screws (Hipokrat, Turkey), which has a minor (internal, inner) diameter of 4.5 mm, and 45 mm length (Figure 1a).

(ii) 7 mm of major (external, outer) diameter special manufactured Alıcı pedicle screws (Hipokrat, Turkey), which has minor (internal, inner) diameter of 5 mm, and 45 mm length (Figure 1b).

(iii) 7 mm of major (external, outer) diameter first type expandable tipped pedicle screws; which is designed by the first author (TR2001 02296Y, Hipokrat, Turkey).[22] These screws are composed of an external part which has empty inside and an internal part that is inserted to the external part, which is also the pin of the screw, provides the opening of the wings at tip of the external part. The major (external) diameter of cylindrical part which has empty inside is 7 mm, minor (internal, inner) diameter is 6 mm, length is 45 mm, thread depth is 0.5 mm and each thread pitch is 2.5 mm. The outer surface of the external part is threaded and empty inside is smooth. The minor

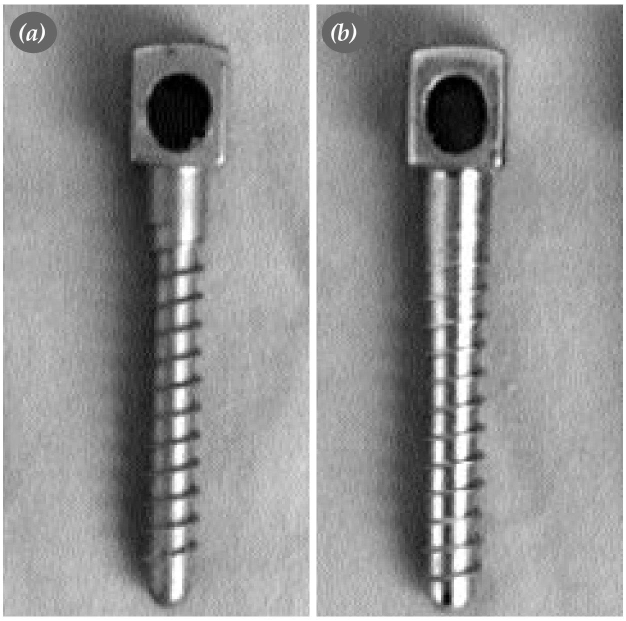

Figure 1. The views of Alıcı pedicle screws **(a)** 6.5 mm, and **(b)** 7 mm in diameter.

diameter of the internal part, which is inserted from the tip of the external part, is 4 mm and has a smooth surface and the diameter of the conical base is 6 mm. The posterior segment of the internal part is threaded to provide locking by the nuts after pull-out. Anterior 1/3 of the screw is separated by four vertical grooves (by two perpendicular grooves) and when the internal screw pin is pulled back four wings concentrically opened in the anterior part. With this system the tip diameter of the screw is increased about 2 mm. Thus by opening of the wings of the screw tip and because the diameter of posterior 2/3 part does not change, a possible pedicle fracture related to the increase in the outer diameter of the screw, is prevented (Figure 2).

(iv) 7 mm of major (external, outer) diameter second type expandable tipped pedicular screws; which is designed by the first author (TR2001 02296Y, Hipokrat, Turkey). These screws are composed of an external cylindrical part which has empty inside and an internal part that is inserted to the external part, which is also the pin of the screw, provides the opening of the wings at tip of the external part. The major diameter of cylindrical part which has empty inside is 7 mm, minor diameter is 6 mm, length is 45 mm, thread depth is 0.5 mm and each thread pitch is 2.5 mm. The outer surface of the external part is threaded and anterior part of empty inside is smooth and posterior part is threaded. The minor diameter of the threaded internal part is 4 mm and the diameter in smooth anterior part is 3 mm. By moving the internal part which is inserted from the posterior segment of the external part, to the tip; the tip of the external part is opened in four wings. With this system the tip diameter of the screw is increased about 2 mm. Thus by opening of the wings of the screw tip and because the diameter of posterior 2/3 part does not change, a possible pedicle fracture related to the increase in the outer diameter of the screw, is prevented (Figure 3).

In our study the vertebra specimens taken from six calves whose average age was 18 months were used. The lumbar regions of the vertebral column were extracted from T_{12}-L_1 and lumbosacral joint and specimens prepared free from their soft tissue. To determine the bone injuries AP and lateral radiographs were taken during preparation of the specimens. Specimens were stored in a deep-freezer at -20 degrees inside a double layered plastic pack till the test day. In the test day we waited for lumbar specimens to deice themselves at room temperature for 8 hours and each specimen was disarticulated from the intervertebral

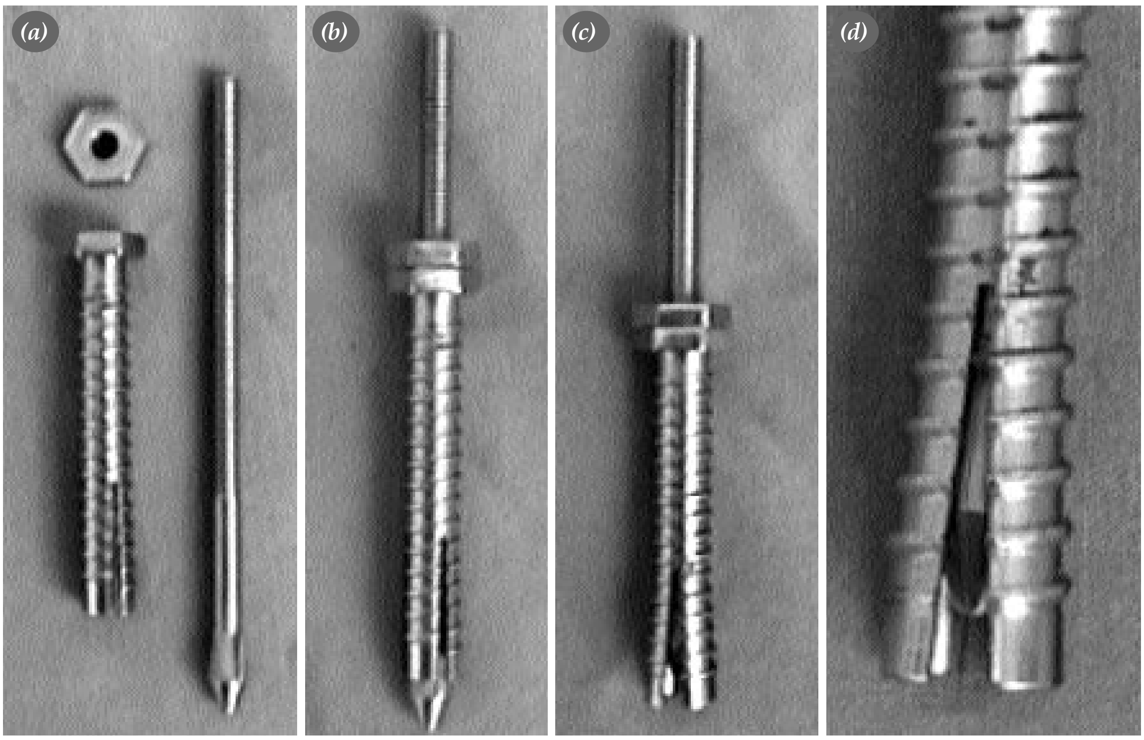

Figure 2. The views of expandable tipped pedicle screws type 1. The views of **(a)** separately (individually three parts), **(b)** composed and **(c, d)** expanded tip when the pin inside is pulled back.

disc space to individual vertebrae. By this way, 36 calf vertebrae were obtained. Two pedicles of each vertebra were drilled by an electrical a 4.5 mm drill from 2 cm inferiorly the superior articular facets through the pedicle axis. Tapping was applied to the half of the thirty-six vertebrae by the use of 6.5 mm tap while the other half was not (Tapping was applied to the vertebrae studied in Middle Eastern Technical University [METU], while the vertebrae in Firat University was not). Initially 6.5x45 mm diameter Alıcı pedicle screws were applied to inside of the two pedicles of each vertebra in end-plate axes and concordant to pedicle axis. We've taken care of the screws not to penetrate the anterior cortex of the vertebrae. Before starting the pull-out test the insertion axes of the screws were controlled by AP and lateral radiographs. The four vertebrae which were not inserted in acceptable axes were extracted from the pull-out test. One of these vertebrae had a penetration to anterior vertebral cortex, and its seen in resting three vertebrae that the screws entered to spinal canal by breaking the inferomedial wall of the pedicle because the insertion axes of the screws were over medial direction. And the rest of our study continued with 32 vertebrae.

In experiments Instron brand test device (Model No: LR50K) was used in METU Engineering Faculty Engineering Sciences Department and Mohr-Federhaff-Losenhausenloss hydraulic universal pull-out device was used in Firat University Engineering Faculty Mechanical Engineering Department. To minimize the calibration errors related to the test devices the experienced technical staffs (fourth and fifth authors) that joined the study, prepared the devices in two different centers. A special edition vise system was used to fixate the vertebrae during experiment. This vise system was fixated tightly to the base of test device by thick screws. Consequently, each vertebra was inserted to this vise system in order. Each pedicle was fixated without preload by putting screw axis and test device piston head in the same direction (The pull-out direction of Instron device and screw axis were parallel) (Figure 4). By using test device to the pedicle screws that inserted to each vertebra, axial pull-out test with 12 mm/min constant velocity was applied. Maximum load achieved during the test was accepted as pull-out force and the load-elongation curves for each vertebra were recorded to computer. The last load was accepted as the maximum load before inadequacy. Inadequacy was defined as an acute decrease in

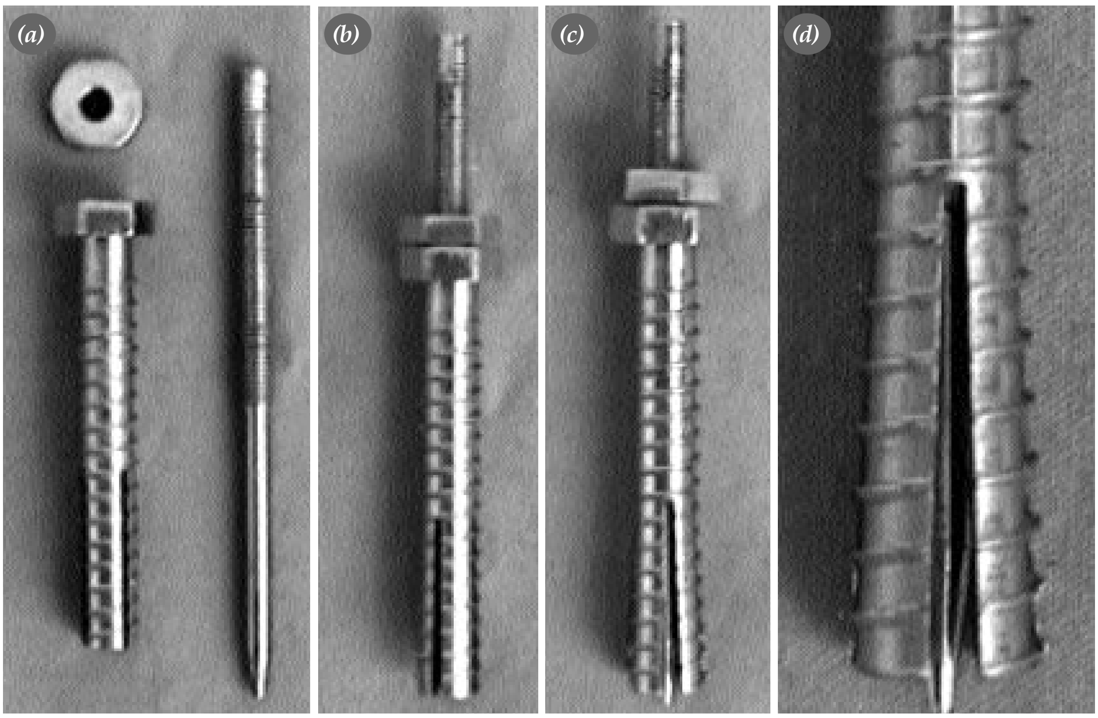

Figure 3. The views of expandable tipped pedicle screws type 2. The views of **(a)** separately (indivually three parts), **(b)** composed and **(c, d)** expanded tip when the pin inside is moved to the tip (to the forward).

pull-out load against continuous axial movement during the test.

Two individual experiment groups were created. Each group was consisting of four subgroups.

Experiment 1: Pull-out tests were performed on the left (group 1) and right (group 3) pedicles of each vertebra by 6.5 mm major diameter Alıcı pedicle screws. 0.5 mm larger 7 mm diameter Alıcı type pedicle screws to left pedicles (group 2) which became inadequate, and type 1 expandable pedicle screws to right pedicles (group 4) which also became inadequate, were applied and results of the pull-out tests were compared.

During this experiment, axial pull-out test was performed on 16 vertebrae. And when performing the tests because the pull-out direction of the device and screw axis was not parallel, pedicle fractures were encountered in two vertebrae and these vertebrae were extracted from the study. So, the results of 14 vertebrae were evaluated. Tapping was applied to six vertebrae that tested in the study, made in METU before Alıcı pedicle screw application.

Experiment 2: Pull-out tests were performed on the left (group 1) and right (group 3) pedicles of each vertebra by 6.5 mm major diameter Alıcı pedicle screws. 0.5 mm larger 7 mm diameter Alıcı type pedicle screws to left pedicles (group 2) which became inadequate, and type 2 expandable pedicle screws to right pedicles (group 4) which also became inadequate, were applied and results of the pull-out tests were compared.

During this experiment, axial pull-out test was performed on 16 vertebrae. And when performing the tests pedicle fractures were encountered in two vertebrae and a corpus fracture encountered in a vertebra, so these vertebrae were extracted from the study. Consequently the results of 13 vertebrae were evaluated. Tapping was applied to eight vertebrae that tested in the study, made in METU before Alıcı pedicle screw application. See the common application of the test in Figure 4.

Statistical evaluation

After the study both experiment groups were evaluated statistically each. Because the datas for both study group determined by counting (non-parametric data), because the subject numbers in both groups were less than 30 and because only two groups were compared in both experiments; Wilcoxon two sample test, which is a non-parametric test, was used. The results were assessed by using the computer program SPSS (Statistical Package for Social Sciences) for Windows 11.01. $p<0.05$ values were accepted as statistically significant. Mean and standard deviation values for all groups were assessed by using SPSS.

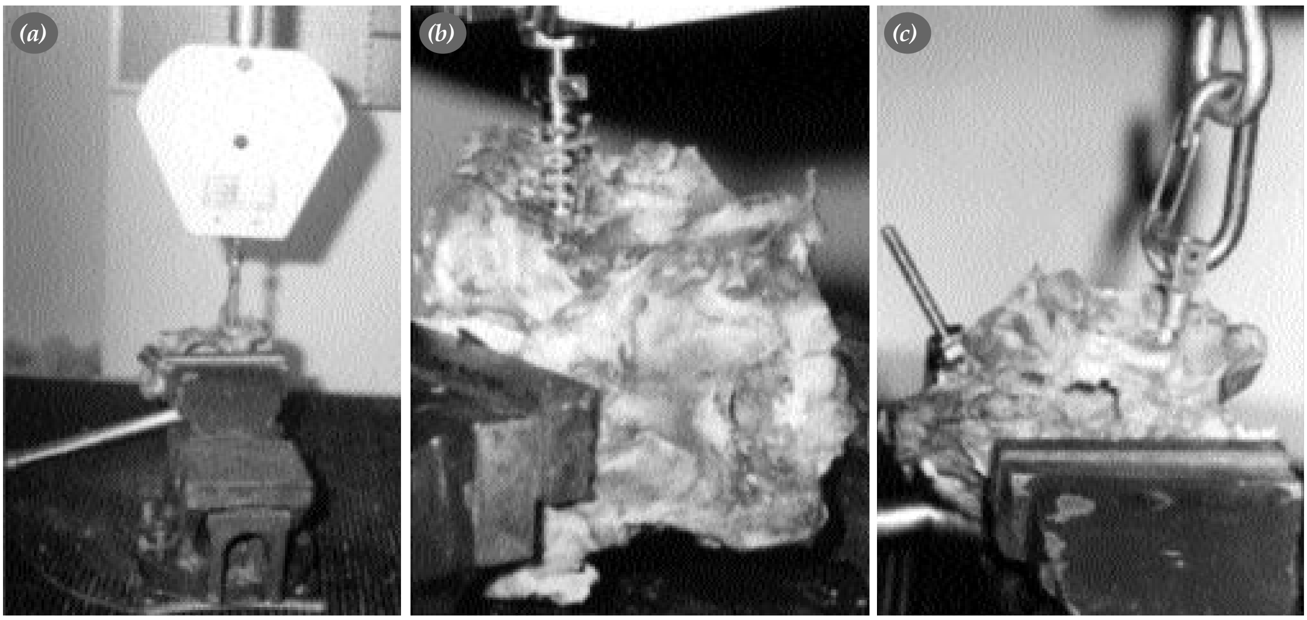

Figure 4. Performing the test. **(a)** vertebra fixated to vise and pull-out device. Application of pull-out tests to **(b)** expandable tipped screw and **(c)** 7 mm Alıcı type screw.

Results

The results of pull-out tests applied to first experiment group are given in Table 1 (first 8 experiments in Firat University, other 6 experiments in METU).

Average pull-out strength was found 2910,9 N in group 1, 1890,8 N in group 2, 2900,2 N in group 3 and 1850,6 N in group 4. When compared to control group (6,5 mm), 7 mm revision screws were only 64.95% of the initial pull-out strength, 7 mm type 1 expandable screws were only 63.8% of the initial pull-out strength. The pull-out strength differences between group 1, group 2, group 3 and group 4 were found statistically significant. (p=0.006 and p=0.002 in order) (Table 1).

No deformation was detected in Alıcı pedicle screws after the pull-out test; however deformation was detected in wing formation of type 1 expandable screws. Its seen that wings were closed and twisted on each other.

The load-elongation graphics of pull-out tests applied to screws in ninth experiment is shown in Figure 5.

The results of pull-out tests applied to experiment group second are shown in Table 2 (first 5 experiments in Firat University, other 8 experiments in METU).

Table 1. Screw pull-out strengths in experiment group 1

Experiment number	Group 1	Group 2	Group 3	Group 4
1	1300	600	3200	1500
2	3800	1200	3000	1100
3	2200	1100	3150	1600
4	3400	2200	1200	400
5	3300	1850	3500	1900
6	2100	2300	2100	2400
7	2700	1650	2200	1200
8	4100	2300	4000	2100
9	4229	1696	2096	2110
10	4937	3574	4568	3978
11	3428	2202	3338	1940
12	1248	1231	1493	1462
13	2186	2418	3070	1638
14	1825	2150	3688	2581
Mean	2910.9	1890.8	2900.2	1850.6
difference	%35.05↓		%36.2↓	
p value	0.006		0.002	

Average pull-out strength was found 3040,9 N in group 1, 2117,2 N in group 2, 3115,8 N in group 3 and 2136,2 N in group 4. When compared to control group (6,5 mm), 7 mm revision screws were only 69,6% of the initial pull-out strength, 7 mm type 2 expandable screws were only 68.5% of the initial pull-out strength. The pull-out strength differences between group 1, group 2, group 3 and group 4 were found statistically significant. (p=0.003 and p=0.006 in order) (Table 2).

Deformations were detected in wing formation of type 2 expandable screws. It's seen that wings were closed and twisted on each other.

The load-elongation graphics of pull-out tests applied to screws in eighth experiment is shown in Figure 6.

Average pull-out strength in vertebrae which we tapped was 2787,3 N however in vertebrae without tapping was 3205,8 N. When the tapped vertebrae and others were compared, its seen that 13,1% decrease in average pull-out strength. And this result was not found significant (p=0.238).

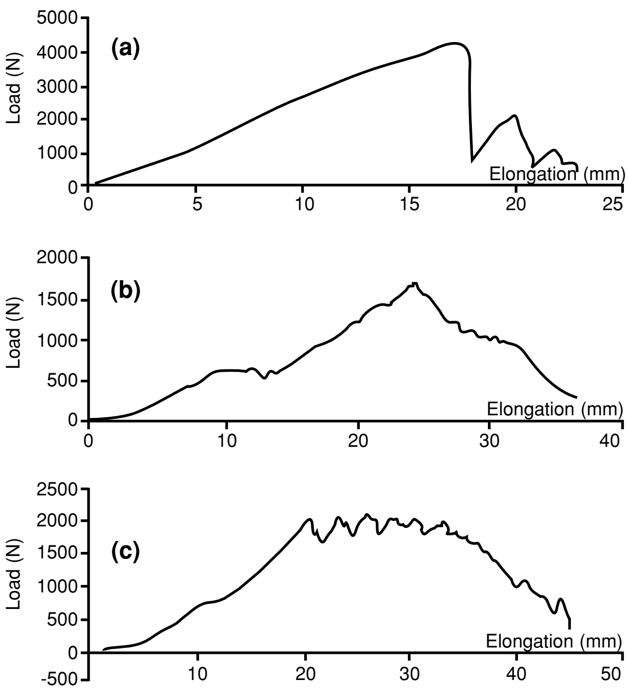

Figure 5. Load-elongation curves of **(a)** 6,5 mm and **(b)** 7 mm Alıcı type pedicle screws and **(c)** expandable pedicle screw type 1.

Table 2. Screw pull-out strengths in experiment group 2.

Experiment number	Group 1	Group 2	Group 3	Group 4
1	3500	2600	3500	1600
2	3500	2800	3700	1800
3	3100	1800	3000	2100
4	5050	2700	4000	1900
5	4050	2500	4700	2100
6	3776	3740	5212	4068
7	2011	1299	3723	3888
8	4871	2417	2953	2432
9	1256	1799	1613	1391
10	1838	1591	2037	2407
11	1465	469	1390	1283
12	2370	1699	1750	538
13	2745	2110	2928	2264
Mean	3040.9	2117.2	3115.8	2136.2
difference	%30.4↓		%31.5↓	
p value	0.003		0.006	

Discussion

There's concordance between the thoracolumbar vertebrae of non-osteoporotic young human and six to eight week old calf vertebrae anatomically and geometrically.[23] Because of this calf and pig vertebrae are used commonly in experimental studies for spinal implants as a test model.[7,22-25]

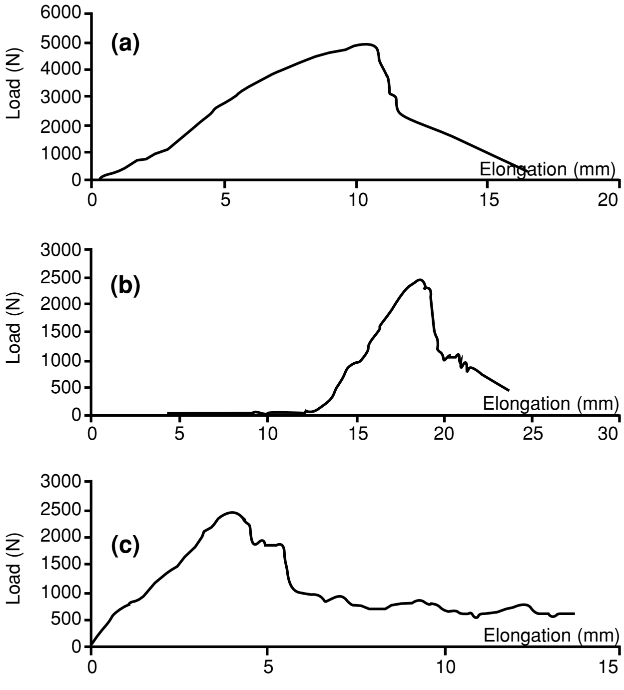

Figure 6. Load-elongation curves of **(a)** 6,5 mm and **(b)** 7 mm Alıcı type pedicle screws and **(c)** expandable pedicle screw type 2.

Dissidences reported about tapping the entrance (pilot) hole for screw which was a factor that effect screw stability. Its recommended not to tap the soft structures like cancellous bone by showing that tapping was resulted by decrease in pull-out resistance.[26] There are studies showing the opposite too. Oktenoglu et al.[27] in a biomechanical study by using synthetic bone blocks, suggested that the preparation of a pilot hole will cause a decrease in the insertional torque (the moment of application) significantly, however not so effective in pull-out resistance. Halvarson et al.[3] found the pull-out forces of the screws inserted to a tapped hole much higher than the ones inserted to a tapped hole in osteoporotic cancellous bone in an in vitro study. In a similar way Sar et al.[24] in a study they performed on calf vertebrae reported that tapping after the preparation of a pilot hole by drill significantly increases the pull-out strength and stability. In our study initially entrance holes are opened by using 4.5 mm drill. Tapping is performed on vertebrae studied in Middle East Technical University; tapping is not performed in Firat University. Average pull-out strength was found 2787 N in tapped vertebrae, 3205 N in untapped vertebrae. This result was not found statistically significant (p=0238) however tapping of screw entrance resulted %13 decrease in pull-out strength. With these findings we believe that tapping of the screw entrance will cause decrease in pull-out strength. Because tapping of the screw hole changes the internal structure of cancellous bone and may result in fracture of trabecular matrix. Thus, a larger space is created between the screw and bone; and less bone will be able to hold the screw. This will cause a decrease in pull-out strength too.

Effects of screw diameter, depth of insertion, concordance between screw and bone structures and surrounding bone tissue on stability is researched in many studies. Zindrick et al.[13] reported that there was no significant difference in stability of the screws they inserted 50% depth of vertebral body and to cortex without passing the anterior cortex; they also reported that the pull-out strength is increased 32% when larger diameter screws passing the cortex are used. Brantley et al.[16] reported that the stability will increase when longer screws are used in high density bones and when the screws fill 70% or more of the pedicle or when a screw that reaches 80% or more depth are used; they also reported that larger diameter screw use in osteoporotic bones do not play a role in increasing the fixation. In regional bone mineral density evaluation, measured by peripheral quantitative computed tomography (pQCT), its shown that the posterior region of vertebral body was significantly denser than its anterior region. As a result there are some authors who think that the deeper insertion will have little effect on fixation stiffness[4] Krag et al.[28] have shown that deeper inserted long screws are not only resistant in pull-out strength along the screw axis and also more resistant to its torsional and flexion strength. In our study we paid attention for not penetrating the anterior cortex. A vertebra which has an anterior penetration is extracted from the study. Screw thread design has also a role in resistance against pull-out strength. Commonly with an increase in screw thread pitch and depth will increase the bone volume between the threads. And it's accepted that this factor increases pull-out strength.[11] In our study when Alıcı type screw and expandable screw are compared Alıcı type screw has more thread pitch and more thread depth. However, when 7 mm Alıcı type screws and expandable pedicular screws which has less thread pitch and thread depth are compared no statistically significant difference is obtained in both experiment groups (Table 1, 2).

When the pedicular screws are extracted in revision surgery, large spaces remain because of the decrease in cancellous bone amount in pedicles and vertebral body. Remaining bone amount is inadequate to provide an adequate screw fixation. This causes resistant pseudoarthrosis for the patient, and predisposing factor for instrumentation deficiency and screw pull-out. In these cases changing the deficient screw with a larger screw sometimes cause adequate fixation.[6,14,24,29,30] Sar et al.[24] reported that in re-application of screws for pulled-out screws, deeper threaded and 1 mm larger diameter screw use is better than cement use. Polly et al.[6] stated that, in pedicular screw revision, when the same screw is inserted after extracting application moment is decreased by 34%, increasing the screw diameter by 2 mm will increase the initial screw application moment by 8.4%. Authors, in pedicular screw revision, recommended 2 mm increase in screw diameter for keeping the screw fixation strength, besides, they reported that increasing the length (5 or 10 mm) will increase the insertional torque (the application moment). Talu et al.[14] in their study of pedicle screw revision, detected 26% loss in the pull-out strength in the group which the same screw is inserted, %15 increase in the group which a longer screw is inserted, %33 increase in the group which a larger screw is inserted, %49 increase in the group which a larger and a longer screw is inserted. Authors, by taking the account of those results, stated that the most important error in pedicle screw revision to be done is inserting a screw in the same length and same width to the hole and a larger and longer pedicular screw will provide adequate stability in an appropriate anatomical position in revisions.[14] McLain et al.[30], in a study they inserted three individually designed large diameter screws for pulled screws detected that when 1 mm larger diameter screw is used the obtained pull-out strength is 62%, 85% and 95% of the initial pull-out strength, and when 2 mm larger diameter screw is used the obtained pull-out strength is 109% and 148% of the initial pull-out strength. In the same way Yerby et al.[29] researched the effects of screw diameter in revision of pedicle screws and showed that in pedicle screw revision use of 7 mm diameter screw for 6 mm pedicle screws which became inadequate provides 73% of the initial pull-out strength. Our findings show similarity with the results which McLain et al.[30] and Yerby et al.[29] explained. 65% of the initial pull-out strength is obtained in with 7 mm revision screws in experiment group 1 and 70% of the initial pull-out strength is obtained in with 7 mm revision screws in experiment group 2. These findings show that in inadequate pedicular screw revisions, only 0.5 mm increase in diameter will not be enough to provide the screw stability.

Cook et al.[1], in a study they performed on human cadaver, compared the pull-out strength of the expandable pedicular screws with self-tapping screws, and showed that the expandable pedicular screws have at about 30% more axial pull-out strength. Expandable pedicle screws have 50% more axial pull-out strength in group with low bone mineral, this ratio was 20% in high bone mineral group. These authors provided a statistically significant increase in pull-out strength in low bone mineral group, whereas they did not detect an important difference in high bone mineral group and stated that expandable pedicle screws have the similar effects with classical pedicle screws in non-osteoporotic bones. As a result, authors showed that expandable pedicle screws provide an important increase in mechanical fixation strength when compared with classical pedicle screws in presence of inadequate bone quality related with osteoporosis and pedicle screw revision.[1,19] Lin et al.[20] have designed a new screw which anchors the cortex to increase the fixation strength in osteoporotic vertebrae. They also reported that because the cortex is the most rigid part, cortex contact is increased by 5 mm by these screws, thus better fixation will be provided. With this new screw system they detected a moderate decrease in fixation strength of normal vertebra, whereas 47% increase in pull-out strength when compared with the classical screws in an osteoporotic bone. Authors thought that the increase of pull-out strength in osteoporotic vertebrae is related to easy penetration of expanded wings to bone tissues. In our study the pull-out strength of first and second type expandable screws were 64% and 68,5% of the initial pull-out strengths in the same order. We think that the cause of why we could not obtain adequate pull-out strength with expandable pedicle screws is related with the specimens that we used as biomechanical test model. Calf vertebrae which have higher bone density than osteoporotic vertebrae are preventing the opening of the wings in the tip of expandable pedicle screw. Besides screw wings which are opened during axial pull-out test are closed because of the strong screw bone surface and this disturbs the mechanical structure of the wings. Thus, opened screw wings cannot penetrate adequately to high mineral density bony structures. Despite the bone mineral density of the test models in Cook et al.[1,19] and Lin et al.[20]'s study was lower than our the test models in our study, the results they established supports our thoughts.

As a result, in pedicle screw revisions only 0,5 mm increase will not provide acquired screw stability. Additionally, adequate stability is not achieved with two individual types of expandable tipped pedicle screws. In our study, tapping of the screw entrance part when compared with un-tapped group is resulted with 13% decrease in pull-out strength.

Acknowledgements

We thank Hipokrat Medical Equipment Production and Marketing Inc. Co., which assisted us at all production levels of the screws that we designed.

References

1. Cook SD, Salkeld SL, Whitecloud TS 3rd, Barbera J. Biomechanical evaluation and preliminary clinical experience with an expansive pedicle screw design. J Spinal Disord 2000;13:230-6.
2. Gaines RW Jr. The use of pedicle-screw internal fixation for the operative treatment of spinal disorders. J Bone Joint Surg [Am] 2000;82:1458-76.
3. Halvorson TL, Kelley LA, Thomas KA, Whitecloud TS 3rd, Cook SD. Effects of bone mineral density on pedicle screw fixation. Spine 1994;19:2415-20.
4. Hirano T, Hasegawa K, Takahashi HE, Uchiyama S, Hara T, Washio T, et al. Structural characteristics of the pedicle and its role in screw stability. Spine 1997;22:2504-9.
5. Okuyama K, Sato K, Abe E, Inaba H, Shimada Y, Murai H. Stability of transpedicle screwing for the osteoporotic spine. An in vitro study of the mechanical stability. Spine 1993;18: 2240-5.
6. Polly DW Jr, Orchowski JR, Ellenbogen RG. Revision pedicle screws. Bigger, longer shims-what is best? Spine 1998; 23:1374-9.
7. Scifert JL, Sairyo K, Goel VK, Grobler LJ, Grosland NM, Spratt KF, et al. Stability analysis of an enhanced load sharing posterior fixation device and its equivalent conventional device in a calf spine model. Spine 1999;24:2206-13.
8. Vaccaro AR, Garfin SR. Internal fixation (pedicle screw fixation) for fusions of the lumbar spine. Spine 1995;20(24 Suppl): 157S-165S.
9. Wu SS, Edwards WT, Yuan HA. Stiffness between different directions of transpedicular screws and vertebra. Clin Biomech 1998;13(1 Suppl 1):S1-S8.
10. Lonstein JE, Denis F, Perra JH, Pinto MR, Smith MD, Winter RB. Complications associated with pedicle screws. J Bone Joint Surg [Am] 1999;81:1519-28.
11. Mummaneni PV, Haddock SM, Liebschner MA, Keaveny TM, Rosenberg WS. Biomechanical evaluation of a double-threaded pedicle screw in elderly vertebrae. J Spinal Disord Tech 2002;15:64-8.
12. Myers BS, Belmont PJ Jr, Richardson WJ, Yu JR, Harper KD, Nightingale RW. The role of imaging and in situ biomechanical testing in assessing pedicle screw pull-out strength. Spine 1996;21:1962-8.
13. Zindrick MR, Wiltse LL, Widell EH, Thomas JC, Holland WR, Field BT, et al. A biomechanical study of intrapeduncular screw fixation in the lumbosacral spine. Clin Orthop Relat Res 1986;(203):99-112.
14. Talu U, Kaya I, Dikici F, Sar C. Pedicle screw salvage: the effect of depth and diameter on pull-out strength: a biomechanical study. [Article in Turkish] Acta Orthop Traumatol Turc 2000;34:300-7.
15. Pfeifer BA, Krag MH, Johnson C. Repair of failed transpedicle screw fixation. A biomechanical study comparing polymethylmethacrylate, milled bone, and matchstick bone reconstruction. Spine 1994;19:350-3.
16. Brantley AG, Mayfield JK, Koeneman JB, Clark KR. The effects of pedicle screw fit. An in vitro study. Spine 1994;19: 1752-8.
17. Krag MH, Van Hal ME, Beynnon BD. Placement of transpedicular vertebral screws close to anterior vertebral cortex. Description of methods. Spine 1989;14:879-83.

18. McKoy BE, An YH. An expandable anchor for fixation in osteoporotic bone. J Orthop Res 2001;19:545-7.
19. Cook SD, Barbera J, Rubi M, Salkeld SL, Whitecloud TS 3rd. Lumbosacral fixation using expandable pedicle screws. an alternative in reoperation and osteoporosis. Spine J 2001; 1:109-14.
20. Lin LC, Chen HH, Sun SP. A biomechanical study of the cortex-anchorage vertebral screw. Clin Biomech 2003;18:S25-32.
21. Rassi-Neto A, Shimano A. Biomechanical properties of expander compared with conventional screws. J Neurosurg 2002;97(3 Suppl):346-9.
22. Esenkaya I, Olcay E, Gulmez T, Vehid H. Biomechanical evaluation of the pull-out strengths of pedicular screws with expandable distal tips. [Article in Turkish]. Acta Orthop Traumatol Turc 2000;34:396-402.
23. Swartz DE, Wittenberg RH, Shea M, White AA 3rd, Hayes WC. Physical and mechanical properties of calf lumbosacral trabecular bone. J Biomech 1991;24:1059-68.
24. Sar C, Kocaoglu M, Kilicoglu O, Domanic U, Hamzaoglu A, Ucisik H. Various techniques of transpedicular screw insertion and their effect on pull-out strength: A biomechanical study. [Article in Turkish]. Acta Orthop Traumatol Turc 1996; 30:175-8.
25. Wittenberg RH, Lee KS, Shea M, White AA 3rd, Hayes WC. Effect of screw diameter, insertion technique, and bone cement augmentation of pedicular screw fixation strength. Clin Orthop Relat Res 1993;(296):278-87.
26. George DC, Krag MH, Johnson CC, Van Hal ME, Haugh LD, Grobler LJ. Hole preparation techniques for transpedicle screws. Effect on pull-out strength from human cadaveric vertebrae. Spine 1991;16:181-4.
27. Oktenoglu BT, Ferrara LA, Andalkar N, Ozer AF, Sarioglu AC, Benzel EC. Effects of hole preparation on screw pullout resistance and insertional torque: a biomechanical study. J Neurosurg 2001;94(1 Suppl):91-6.
28. Krag MH, Weaver DL, Beynnon BD, Haugh LD. Morphometry of the thoracic and lumbar spine related to transpedicular screw placement for surgical spinal fixation. Spine 1988;13:27-32.
29. Yerby SA, Toh E, McLain RF. Revision of failed pedicle screws using hydroxyapatite cement. A biomechanical analysis. Spine 1998;23:1657-61.
30. McLain RF, Fry MF, Moseley TA, Sharkey NA. Lumbar pedicle screw salvage: pullout testing of three different pedicle screw designs. J Spinal Disord 1995;8:62-8.