The Effect of Repetitive Insertion and Pullout of Spinal Screws on Pullout Resistance : A Biomechanical Study

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= Abstract =

척추 수술에 사용되는 나사못의 반복 삽입과 인출이 인장항력에 미치는 영향 : 생체 역학적 연구

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Object : The clinical uses of screws are increasing with broader applications in spinal disorders. When screws are inserted repeatedly to achieve optimal position, tips of screw pitch may become damaged during insertion even though there are significant differences in the moduli of elasticity between bone and titanium. The effect of repeated screw insertion on pullout resistance was investigated.

Methods : Three different titanium screws(cortical lateral mass screw, cancellous lateral mass screw and cervical vertebral body screw) were inserted into the synthetic cancellous material and then extracted axially at a rate of 2.4mm/min using Instron(Model TT-D, Canton, MA). Each set of screws was inserted and pulled out three times. There were six screws in each group. The insertional torque was measured with a torque wrench during insertion. Pullout strength was recorded with a digital oscilloscope.

Results : The mean pullout force measurements for the cortical lateral mass screws(185.66N±42.60, 167.10N±27.01 and 162.52 N±23.83 for first, second and third pullout respectively : p=0.03) and the cervical vertebral body screws(386.0N±24.1, 360.2N±17.5 and 330.9N±16.7 : p=0.0024) showed consecutive decrease in pullout resistance after each pullout, whereas the cancellous lateral mass screws did not(194.00N±36.47, 219.24N±26.58 and 199.49N(36.63 : p=0.24). The SEM after insertion and pullout three times showed a blunting in the tip of the screw pitch and a smearing of the screw surface.

Conclusions : Repetitive screw insertion and pullout resulted in the decrease of pullout resistance in certain screws possibly caused by blunting the screw tip. This means screw tips suffer deformations during either repeated insertion or pullout. Thus, the screws that have been inserted should not be used for the final construct.

KEY WORDS : Biomechanical · Pullout · Repetitive · Screw.

Introduction

Spinal stabilization and spinal fusion have been used to treat a variety of spinal problems. King11 was the first who used spinal instrumentation involving screw fixation of vertebral bone in 1944. Roy-Camille[22] pioneered the use of plates with intrapedicular screws to enhance the internal stabilization technique in 1961. Since then, screws are used clinically with increasing frequency and with increasingly broader applications. The deep knowledge of screw anatomy, screw interactions with bone, and screw biomechanics is mandatory for effective and safer use of screws.

Factors that may affect pullout resistance of screws have been widely investigated[4-9)10)12)15)16)23)24)]. The main determinants of screw pullout resistance are bone density, screw diameter, thread depth, extent of cortical purchase, depth of screw penetration, and thread design[13-15)].

The injury to a spinal implant during operation can result in metal failure[1)]. During spinal instrumentation, operators insert and remove screws for optimal position. Sometimes operators reuse screws for final construct after repeated insertion. Even though there are significant differences in moduli of elasticity between bone and steel, screw tips may suffer injury during insertion. However, the effect of repetitive use of spinal screws on the screw pullout resistance has not been investigated. The goal of this study is to quantify the effect of repetitive insertion of spinal screws on screw pullout resistance.

Materials and Methods

Uniform, rectangular blocks of synthetic cancellous material with a medium porosity and 0.24gm/cc of compressive performance (25×25×50mm) were used (General plastics Manufacturing Co., Tacoma, WA).

All screws were placed centrally. The pilot holes were prepared using a vertical drill press to maintain consistent placement of the screw in a perpendicular orientation to the test medium. The length of the pilot hole was 80% percent of the screw penetration of test material.

Three different screws were tested : Six cancellous lateral mass screws (14mm overall length, 4mm outer diameter, 2,8mm core diameter and 1.65mm pitch length : DePuy-Acromed, Raynham, MA) were placed 10mm into the test material. Six cortical lateral mass screws (14mm overall length, 3.5 outer diameter, 2.0mm core diameter and a 0.50 mm pitch length: DePuy-Acromed, Raynham, MA) were placed 10mm into the test material. Six cervical vertebral body screws (expandable screw with conical core diameter, 14 mm overall length, 4.0mm outer diameter and a 0.18mm pitch length : DOC ventral cervical stabilization system, DePuy-Acromed, Raynham, MA) were placed 12mm into the test material using platform. A commercially available torque screwdriver (0.1 - 12 in.-pd., Snap-On Inc., Kenosha, WI) was used to measure the insertional torque of the screw. The torque screwdriver was modified using an attachment to fit the head of the screws. The applied torque was measured as the screw advanced into the test material. In all cases maximum torque was observed and recorded when the designated depth of insertion for each screw type was obtained.

1. Pullout testing

Bone blocks were secured onto the base plate of the testing apparatus (Instron Model TT-D, Canton, MA) with a load capacity ±5kN (Fig. 1). After clamping the upper fixture to the machine and gripping the head of the screw, the screws were axially extracted from the host material at a constant speed of 2.5mm/min. Each set of screws was pulled out three times. The force and time history of each screw extraction is digitally recorded using a digital oscilloscope (LeCroy 9304C, Switzerland). From this data, the maximum value of the applied tensile force was determined and defined as the screw pullout resistance.

All screws were examined with SEM (Scanning Electron Microscope) three times prior to and after pullout. The screw pullout resistance and insertional torque for each study were then compared. The statistical analysis comprised an

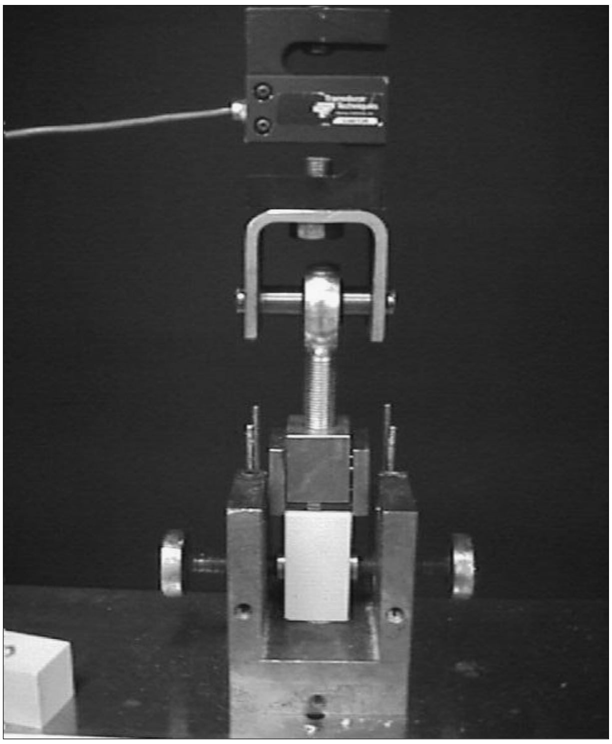


Fig. 1. The photograph showing the test in progress.

ANOVA test. The results were confirmed with using a two-sided paired t-test. A level of 95% was considered to be statistically significant.

Results

1. Insertional torque and pullout resistance

The insertional torque measurements for cancellous lateral mass screws, cortical lateral mass screws, and cervical vertebral body screws are presented in (Table 1). The pullout resistances are presented in (Table 2).

1) The mean insertion torque measurements for cancellous lateral mass screws were 1.42in-lb (±0.13), 1.50in-lb (±0.14) and 1.42in-lb (±0.13) for first, second and third studies respectively. The mean pullout resistance values were 194.00N (±36.47), 219.24N (±26.58) and 199.49N (±36.63) for first, second and third studies respectively.

2) The mean insertion torque measurements for cortical lateral mass screws were 1.04in-lb (±0.19), 0.92in-lb (±0.13) and 1.08in-lb (±0.13) for first, second and third studies respectively. The mean pullout resistance values were 185.66N (±42.60), 167.10N (±27.01) and 162.52N (±23.83) for first, second and third studies respectively.

3) The mean insertional torque measurements for cervical vertebral body screws were 5.71in-lb (±0.45), 5.75in-lb (±0.43) and 5.58in-lb (±0.27) for first, second and third studies respectively. The mean pullout resistance values were 386.0N (±24.1), 360.2N (±17.5) and 330.9N (±16.7) for first, second and third studies respectively.

In the analysis of the results in pullout study, the cortical lateral mass screw and cervical vertebral body screws showed consecutive decrease in pullout resistance. ANOVA test showed a statistically significant decrease between all studies in cervical vertebral body screws and second and third study in cortical lateral mass screws.

The amount of pullout resistance decrease was greater in anterior cervical vertebral body screws in which the insertion torque was greater than the other screws.

2. SEM study

The post pullout SEM of the screws shows definitive blunting and dent on the screw pitch tips in the low power scan and smearing of screw surface in the high power scan after inserting three times when compared to the original contour (Fig. 2).

Discussion

1. Pullout resistance of screw

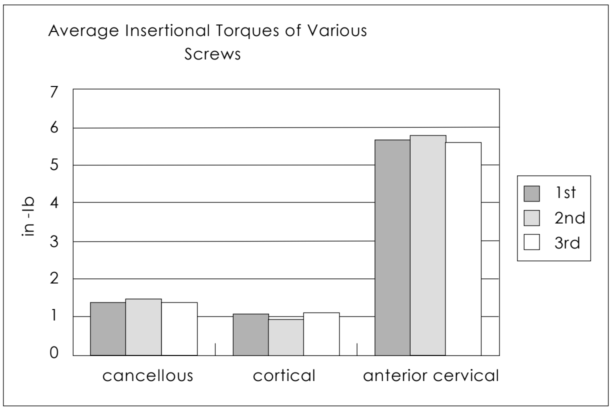
A variety of factors influence the pullout resistance of screw : (1) screw design[15)20)] (e.g., major screw diameter, thread depth, thread design) (2) the structural characteristics of bone (e.g., bone mineral density, pedicle diameter)[2)3)6)7)17)18)] (3) screw fit to bone2 (e.g., depth of screw placement, opposite cortical purchase, extent of cortical purchase),

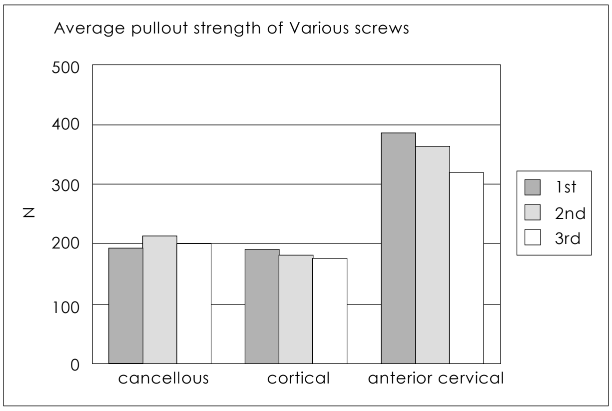
Table 1. The mean insertional torque of various screws

Pullout	#1	#2	#3
Cancellous Screws	1.42±0.13	1.50±0.14	1.42±0.13
Cortical Screws	1.04±0.19	0.92±0.13	1.08±0.13
Ant. Cervical Screws	5.71±0.45	5.75±0.43	5.58±0.27

Table 2. The mean pullout force of various screws

Pullout	#1	#2	#3
Cancellous Screws	194.0±36.5	219.2±26.6	199.5±36.6
Cortical Screws	185.7±42.6	167.1±27.0	162.5±23.8
Ant. Cervical Screws	386.0±24.1	360.2±17.5	330.9±16.7





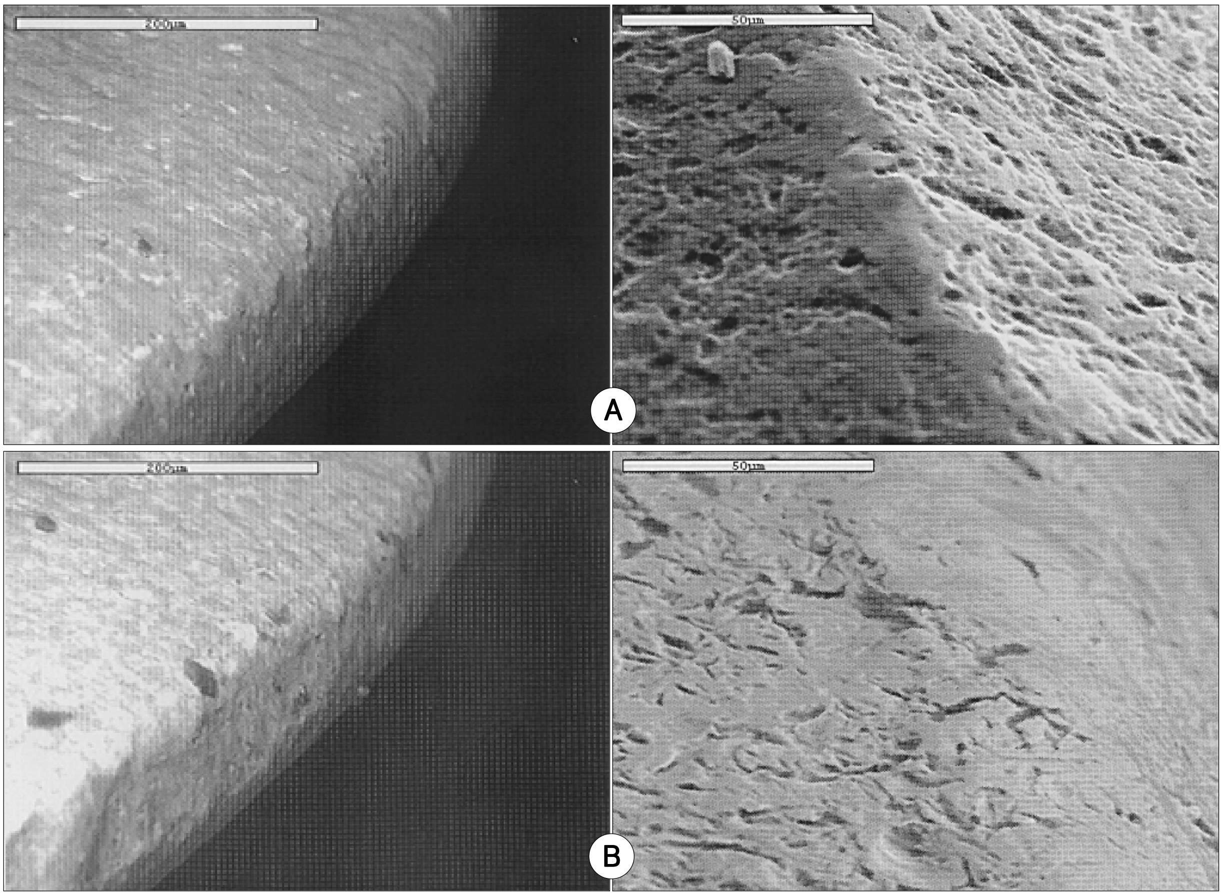


Fig. 2. Electronic microscopic scans before(A) and after(B) pullout. Post-pullout scan demonstrating a definite blunting and dent in the screw pitch tip in the low power scan(left) and a smearing of surface in the high power scan(right).

(4) technique of insertion[4)5)9)12)13)17)](e.g., hole preparation, augmentation of screw stability with adjuvant materials).

Screw diameter, thread depth, extent of cortical purchase, depth of screw penetration and thread design have been known as the main determinants of screw pullout resistance.

There were many efforts to increase the pullout resistance[8)16)].

2. Deformation in a spinal implant.

A spinal implant can be damaged during preparation for implantation1. Those are stress riser and notching. Besides these, minor changes in an implant contour may reduce resistance. Resistance to implant injury or deformation depends on several factors: (1) implant composition, (2) implant morphology, and (3) material treatment.

3. Possible Causes of decreased pullout strength after repetitive insertion and pullout

Our SEM study showed blunting of the screw tips after repeated insertion and pullout. The tip of the screw pitch would be blunted either by compressive force against the artificial bone during insertion or shearing force across the tip during pullout. The authors think that repeated insertion rather than pullout caused the blunting that eventually leaded to the decrease in pullout resistance: (1) The SEM image of the tip implies that the tips of screw pitch were compressed rather than bent over. (2) The compressive force along the pitch can cause depression in the screw tips but the bending force across the screw pitch can't possibly modify the contour of screw tip because the elasticity modulus of synthetic bone is much smaller than that of titanium. (3) Furthermore, the amount of decrease in pullout resistance was greater in screws in which the insertion torque was greater. The pilot hole diameter of cervical vertebral screw was smaller in comparison to outer screw diameter than other screws. The greater the insertional torque measured, the greater occurrence of deformation in screw pitch tips.

4. Insertional Torque and pullout strength

Kwok et al[15)] investigated the relationship between insertional torque and pullout strength. They found there is statistically significant correlation between insertion torque and pullout strength in some screws while not in others. They concluded that insertional torque is not a reliable predictor of pullout strength.

However, this study showed that the decrease in pullout resistance was greater in screws with greater insertional torque. It can be assumed that there are still tight contacts between bone and screw though some of the screw pitches may become blunt at the first insertion. So there would be little difference in pullout resistance whether the insertional torque was high or low at the first insertion. But the pullout strength decreases after repeated insertions by blunting the screw tips.

Conclusion

Repetitive screw insertion results in the decrease of pullout strength in certain screws by blunting the screw tips. The SEM showed that screw tips are damaged during repeated insertions. Thus, the screw that have been inserted several times should not be used for the final construct.

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= 국문초록 =

목　적 : 최근 척추 수술에 나사못을 사용하는 빈도와 범위가 넓어 지고 있는데 때로 수술 중 한번 삽입하였던 나사못을 다시 사용하는 경우가 있다. 인체 골과 타이타늄의 탄성계수가 크게 차이 나지만 반복 삽입 과정에서 나사못의 이가 손상될 가능성이 있다. 저자들은 나사못의 반복 삽입이 나사못의 인출 저항에 미치는 영향을 조사하였다.

방　법 : 각각 6개의 세가지 다른 종류 cortical lateral mass screw, cancellous lateral mass screw and cervical vertebral body screw의 나사못을 시험하였다. 나사못을 인체의 골과 비슷한 밀도의 인공합성골에 삽입하였으며 삽입 중 삽입력을 측정하였고 그 후 Instron(Model TT - D, Canton, MA)을 이용하여 2.4mm의 속도로 인출하여 인장항력을 digital oscilloscope에 기록하였다. 위의 과정을 3회 반복하여 기록한 뒤 나사못을 광학 현미경으로 확대하여 관찰하였다.

결　과 : cortical lateral mass screws의 평균 인장항력(1회인장 시험185.66N±42.60, 2회 인장시험 167.10N±27.01, 3회인장 시험 162.52N±23.83 : p=0.03)과 cervical vertebral body screws (386.0N±24.1, 360.2N ±17.5 and 330.9N±16.7 : p=0.0024)은 반복하여 삽입, 인장 검사 할 때 마다 감소하였으나 cancellous lateral mass screws의 평균 인장항력(194.00N±36.47, 219.24N±26.58 and 199.49N±36.63 : p=0.24)은 감소하지 않았다. 전자현미경 소견에서 나사이의 끝이 무디어지고 표면이 문드러진 것을 관찰할 수 있었다.

결　론 : 일부 나사못을 반복하여 삽입한 후 나사못의 인장항력이 감소되었으므로 수술중 여러번 삽입하였던 나사못은 최종 구조물에 사용되지 않아야 한다.

중심 단어 : 생체역학 · 인장항력 · 반복 · 스크류.