# THE COMPARISON OF PULL-OUT STRENGTHS OF THE PEDICLE HOOKS OF DIFFERENT SPINAL INSTRUMENTATION SYSTEMS ON HUMAN CADAVER SPINES

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***ABSTRACT :***

*Failure of the bone-metal interface in posterior spinal instrumentation systems is still a problem in spinal surgery. The posterior pull-out of the upper hooks with or without loss of correction is a relatively common problem postoperatively. We have performed a serial of experiments on the human cadaver thoracolumbar spines for clarifying the reasons of the upper hook pull-out phenomena. In these tests, we compared the anatomical pedicle hooks with the non-anatomical pedicle hooks concerning the posterior pull-out strength with Instron Universal Test Machine. Finally, we were able to decide that contact surface width and depth of the hook blade are important factors for the posterior pull-out strength. Because of the contact surface area of the anatomical pedicle hooks are greater than that of nonanatomical pedicle hooks, maximum load to failure of the anotomical hooks is also higher. Except from the effect of the contact surface area of the pedicle hooks on the pull-out strength, rod contouring, careful technique of the hook site preparation and insertion, preoperative evaluation of the patient and accurate selection of the fusion levels, avoidance from the overdistraction intraoperatively, usage of claw construct and supporting the upper hooks with sublaminar wiring are also effective against the postoperative failure of the upper hooks.*

***Key words:*** *biomechanics, pedicle hook, pull out strength*

## INTRODUCTION

Various types of instrumentation systems are available in spinal surgery and their numbers are increasing continuously. With new contributions to the knowledge of biomechanics of the spine, the effects of the implant systems on fusion and their stability characteristics are becoming more clear.

Although the frequency of postoperatively encountered implant failures is decreased in contemporary instruments, many problems regarding the bone-metal contact surface are still waiting to be solved. The ability of the instrument to embrace the spine and degree of the stability should be well-known in order to get a good and suitable fixation in the thoracic spine. The posterior pull-out strength of the anchors of the thoracal spinal implants has been subject to many publications (1, 2, 4, 6, 7, 10, 12).

The aim of our study is to highlight the upper hook pull-out phenomena often seen postoperatively by investigating the pull-out strength of the pedicle hooks which are commonly used in posterior spinal systems and determine the factors effecting it.

## MATERIAL AND METHODS

The pedicle hooks as the subject of our work, are indispensable parts of daily used universal spinal instruments. They establish the stability by gripping the pedicles and laminae of the vertebra. In our experiment, we tested the posterior pull-out strength of the pedicle hooks of three different posterior spinal instruments. The pedicle hooks we used in our experiment were:

1. CD pedicle hook
2. TSRH pedicle hook
3. Alıcı pedicle hook

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Of these, Alıcı pedicle hook is an anatomical pedicle hook where CD and TSRH pedicle hooks are non-anatomical. As known, lamina and facet excision is not needed when applying the anatomical hooks, however is needed in the non-anatomical hooks.

In our study, four human thoracolumbar vertebrae was used. The segments between T2-S1 were taken with four centimeters of costae on each side. The vertebrae were kept in the formaldehyde solution until the experiment was performed. Two of the cadavers were male and two of them were female between the ages of 30 and 65 with a mean age of 44.

No primary or metastatic bone tumour, or severe osteoporosis was detected in the radiographic examination of the vertebrae before the experiments.

As T1 vertebra is not included in many instruments, it was not used in our experiment. T11 and T12 vertebraes were not used either, as they are not convenient for applying pedicle hooks. All of the muscles and soft tissues were stripped off and the vertebrae were put forward with the discs and ligaments. The posterior elements were deperiosted for the experiment.

Before the experiment, the vertebrae were not examined for their bone mineral density (BMD). Although there is a close relationship between BMD and pull-out strength of transpedicular screws and wires used for the spinous processes, no relationship was observed between BMD and the load needed to pull-out laminar hooks (2). However, for eliminating the osteoporosis affect, pull-out tests were performed by applying different hooks to either sides of the same vertebra (Fig. 2).

While anatomical hooks were inserted directly to the pedicle without excising the inferior facet, the non-anatomical hooks were inserted after facet excision. After applying the hooks in this manner, the instrumentation was completed by applying screw or supralaminar hook distally and kyphotically contoured rod in-between. Then, convenient apparatus was made to apply the hooks to be tested to the Instron machine. All the experiments were performed by Instron 1195 Universal Test Machine at the Faculty of Chemistry and Metallurgy of İstanbul Technical University. The direction of pull of every hook were arranged posteriorly by being perpendicular to the vertebral axis after fixing the two different sides into the jaws of the Instron (Fig. 3).

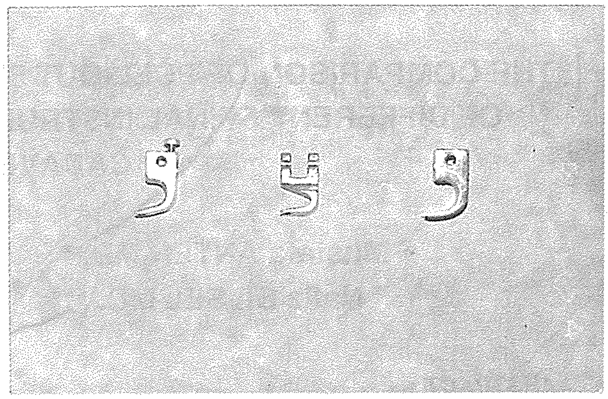

**Figure 1.** The pedicle hooks used in the experiment: CD, TSRH and Alıcı pedicle hooks from left to right.

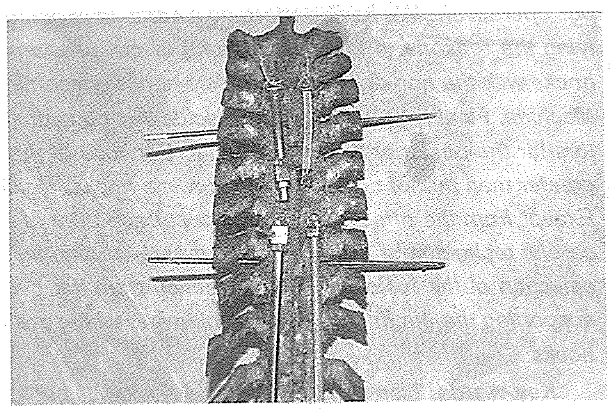

**Figure 2.** Prepared vertebral column segment for the experiment.

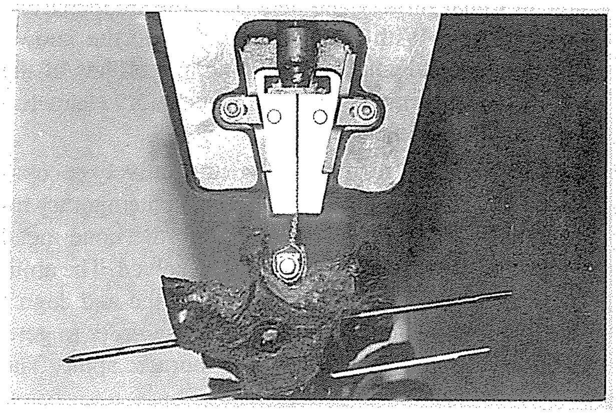

**Figure 3.** Application of Instron Test Machine.

The loading was performed with a speed of 2 mm/min. The pull out strengths of the hooks were found as the result of experiments. For each experiment a different load-displacement curve was obtained. At the end of every try, maximum load value on loading was found from the graphs and meanwhile the energy absorved by the system was determined by calculating the area under the curves.

## RESULTS

Bone contact surface area of the three types of pedicular hooks has been measured before the experiments (Table 1). Trial numbers for each hook type were 7,5,5 for CD, TSRH, Alıcı respectively. Pull-out strength values were determined for the hooks as shown in Table 2. As shown on the table, the pull-out strength of Alıcı anatomical hook is higher compared with the other two non-anatomical hooks. Trial numbers in our experiment could not reach a sufficient level to give more significant results due to the restricted number of cadavers available.

**Table 1.** Surface areas of the blades of different hook types.

| Hook type | The surface area of the hook blade (cm sq.) |
|---|---|
| Cd pedicle hook | 0.762 |
| TSRH pedicle hook | 0.813 |
| Alıcı pedicle hook | 1.246 |

Fracture types encountered during experiments are grouped in Table 3. According to the fracture types seen on Table 3, CD and TSRH hooks caused failure usually due to vertical fractures of the laminae or lateral pull out without fracture. With both hooks, there were two separations of costotransversal joints each. Fractures of Alıcı anatomical hook involve the pedicle with or without fractures of the vertical laminae. Lateral pull-out without fracture or separation of costotransversal joints had not been observed with any Alıcı hooks.

In our opinion, the reason for the frequent fractures of pedicle seen with Alıcı hooks is related to the greater contact surface area of the blades of these hooks and their high gripping capacity to the pedicle. Lateral hook dislocation without fracture has not been observed with Alıcı hooks in our trials. This also may be an indicator of the hook's sufficient rotational stability. Trials done with CD and TSRH pedicle hooks have revealed frequent lateral dislocations of the hook without fracture and costotransversal joint separation. We believe that the main reasons for this is the reduction of contact surface area with inferior facet resection and inability of the hook blade in grabbing the pedicle fully. We think that

**Table 2.** Pull-out strength value of different hook types. The level of the hook applied vertebra for every trial can be seen within parentheses.

| | Pull-out strength values (Kg) of different hook types | | |
|---|---|---|---|
| Trial no. | CD | ALICI | TSRH |
| Trial 1 | 25 (T5) | 84 (T10) | 17.5 (T3) |
| Trial 2 | 23 (T6) | 34 (T5) | 40 (T7) |
| Trial 3 | 48 (T8) | 76 (T3) | 15 (T4) |
| Trial 4 | 25 (T3) | 98 (T7) | 17.5 (T5) |
| Trial 5 | 18 (T7) | 52.5 (T10) | 40 (T9) |
| Trial 6 | 42 (T3) | – | – |
| Trial 7 | 76.5 (T7) | – | – |
| Mean value (Kg) | 37 | 69 | 26 |

**Table 3.** Observed fracture types for different hook types.

| Hook type | CD | ALICI | TSRH |
|---|---|---|---|
| Vertical fracture of the laminae | 4 | 3 | 2 |
| Pedicle fracture | – | 4 | – |
| Costotransversal joint separation | 2 | – | 2 |
| No fracture | 3 | – | 3 |

the faulty lateralisation of the hook might be the reason for one of these pull-outs in our trial.

Different pull-out forces were obtained with the same pedicle hook in pull out trials carried out at different levels of the same spine. This shows that the spine might have microstrictural differences in different anatomical positions. In anatomical pedicle hooks the fractures usually involving pedicles might be explained by greater contact surface area and better grabbing of the pedicle. The forces affecting the hook are shared by the pedicle and the laminae; thus, increasing the pull-out strength. No costotransversal joint separation has been seen in pull out tests done with anatomical hooks; this shows the primary contact is on the pedicle. There is also a greater contact area since facet resection is not carried out with anatomical hooks.

## DISCUSSION

Spinal instrumentation systems serve two important purposes:

1- To correct deformity

2- To carry and balance forces which affect the spine until fusion is achieved.

The ability of the spinal instrumentations in correcting scoliosis and kyphosis can be defined according to the measurement of two components of the system:

1- Load to failure

2- Stiffness (Defense to deformation)

The load to failure is the load value which causes mechanical insufficiency at the implanted components of the instrumented spine or at the junction of bone-metal interface. We have investigated the potential insufficiency of pedicle hooks at the junction of bone-metal interface under posterior pull-out forces. Under these circumstances we tried to determine the load to failure. We applied pull-out forces on 3 different pedicle hooks in order to determine the strength of them. According to our results anatomical pedicle hooks grab the spine better, and insufficiency during postoperative period is lesser. The greater surface area and length of the hook blade leading a better grabbing of the pedicle are the main factors which determines the better stability of anatomical pedicle hooks. Also placement of the anatomical hook without the need of inferior facet resection increases the stability of the hook by widening the contact surface area. The strength of the hooks of the thoracic implants against pull out has been discussed in different views in the literature (1, 2, 4, 6, 7, 10, 12).

A loosening or discontinuation in the bone-hook-rod integrity causes the loss of correction or extensive segmental motion, thus causing insufficiency of fusion as known.

The role of bone mineral density on the stability of thoracic implants has not been fully understood yet. One study has shown that spinous process wires and transpedicular screws are more dependent on bone mineral density while laminal hooks were minimally effected from osteoporosis and their stability in osteoporotic spine is better than the others (2). We tried to eliminate osteoporosis factor by placing different types of hooks on either sides of the same vertebra.

In another study evaluating the stability of different distraction hooks, it has been found that bifid hooks were more stable and prevention of the hook pull-out by fracture of the lamina could be achieved with bifid hooks (7). Bifid hooks grab pedicle and provide load sharing between lamina and pedicle, increase the value of hook pull-out strength, as also shown in our study. We found out different pull-out strength values for the same pedicle hook in the same vertebra at different levels. Freedman has also drawn attention to the fact that different vertebrae and the same vertebra at different levels have different load bearing capacities (2, 12).

Hook pull-out phenomenon that we have studied experimentally, can be seen clinically with or without loss of reduction or correction in posterior spinal systems and is one of the most frequent complications (3, 4). There are three main reasons for the failure of the upper hook.

1- Hook dislodgement

2- Hook - rod disengagement

3- Failure due to laminal fracture

Here, we will not discuss the hook-rod disengagement, i.e. slip of the rod from the hook, since it is caused by a different mechanism and is rarely seen in the rigid systems of today.

**Hook dislodgement**

Many upper hooks, especially in the distraction systems, pull out under the lamina (8, 9, 11). The initial mechanism of the hook pull-out is the flexion and rotation of spine in fracture and scoliosis test models. Rotation beginning with the flexion of the spine increases interlaminary distance; thus more tilting to flexion is seen. Hook pull-out phenomenon is related to 3 factors.

1- Rigidity of fixation: Since straight Harrington rodes allow a greater degree of flexion and rotation of the spine, hook pull out is frequent. Conveyance of all the weight through one proximal hook, like in Harrington system, is another cause of inadequacy. Addition of sleeves (cylindrical elements) to the rod and giving the rod a kyphotic contour and fixation with segmental wires; adding multiple hooks which control extensive flexion and rotation; adding the upper hook a claw with a transverse or laminar hook prevent hook pull-out (4,5,6,10). Two level pediculotransverse claw (double level construction) is superior to one level claw when compared for hook pull-out phenomenon (10). Two level laminolaminar claw is significantly stronger than two level pediculotransversal claw (6).

2- Hook Design: Jacobs has designed a hook with a special type of lock which prevents hook pull-out. These L-shaped anatomic hooks contact with the lamina more closely compared with standard C-shaped hooks, thus providing prevention of laminar tilt and resorption seen in Harrington hooks.

Most of the standard pedicle hooks are non-anatomical as known. Inferior facet resection is needed for placement. This process reduces the contact surface and also makes an angle of 90 degrees between the osteotomies establishing a point of maximum stress which facilitates fracture. Also, we have found out that non-anatomical hooks do not grab the pedicle fully despite facet resection. Since Alıcı anatomical hook grabs the pedicle directly, pull out strength has been the greatest and most of the fractures were in the pedicle area. None of the anatomical hooks has shown a failure like lateral hook pull out without fracture; where this phenomenon was a frequent complication of non anatomical hooks. This also is an indicator of stability problem due to contact deficiency. Since the intraoperative stability of non-anatomical hooks are not satisfactory, it is essential to check and load (distraction) them for contact while the system is being set up.

3- Erroneous surgical technique: We have found out that the most frequent fault is the placement of the hook laterally. This reduces the contact area dramatically. Hook pull-out is also seen in instances where too much inferior facet has been resected, hook is not placed bicortically, thoracic kyphosis is not given to the rod, screws of the set are tightened without suitable load bearing on the hook, too much intraoperative distraction has been made, the claw is not used, too much decortication has been carried out.

## CONCLUSION

According to our experiences and search of the literature, prevention of the failure of the upper hook during postoperative period depends on the following points.

1- Patients to be instrumented must be evaluated with X-rays for determining the fusion area and levels of instrumentation. This is particularly important in kyphotic patients. Proximal hook application to T2 level, if possible, provides an additional stability (1).

2- Proximal hook should be chosen as an anatomical pedicle hook if possible.

3- The hook application area with non-anatomical hooks must be prepared properly without extensive lamina and facet resection.

4- Convenient kyphotic contour must be given to the rod.

5- After the instrumentation has been completed, it must be made sure that the hook is in optimal position before the set screws of upper hook are tightened. If the hook are tightened. If the hook is placed laterall, it must be corrected and the set screws must be tightened after loading.

6- Addition of pediculotransverse or pediculolaminar claw and usage of sublaminar wire support to support the proximal pedicular hook increases the duration of the system against pull-out forces. Two level claw and DTT usage provides better stability.

7- Extensive forces must be avoided intraoperatively and distraction must be done gradually.

8- The transportation of the patient to his bed must be carried out cautiously after the operation and if there is any doubt about the quality of fixation or the patient is osteoporotic, the patient must be supported with a brace.

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