Chapter 3
Effect of Application Techniques

As well as design, application technique of screw is also important for pullout strength. Surgeons should avoid application techniques which decrease the pullout strength. Many researches had already investigated tapping, hubbing, fixation techniques and insertional conditions of pedicle screws to increase the holding strength [6, 7, 19].

3.1 Effect of Tapping

Tapping the pedicle screw decrease the pullout strength because of micro cracks caused on the insertion path of pedicle screw [8]. For instance, Chatzistergos et al. [7] compared pullout strengths of tapped, untapped screws and screws used for tapping to understand the effects of tapping on polyurethane blocks demonstrating the osteoporotic bone. Tapped holes were drilled in different sizes, either threaded or cylindrical to understand the effect of pilot hole and tapping. Increasing the outer diameter of threaded hole decreased the pullout strength for tapped screws. Tapping with a tap tool or with a smaller sized screw gave similar mechanical results. Holding strength of the self-tapping screws did not differ significantly from the tapped screws, which is an unexpected result.

In the same manner, Carmouche et al. [6] investigated three different pilot hole preparation (tapping) technique on human lumbar and thoracic vertebrae. No tapping, tapping with same-size screw and one size smaller screw were used for the tested screws. Tapping decreased the pullout strength on human lumbar vertebra, however it did not affect the strength on thoracic vertebrae.

On the other hand, Helgeson et al. [19] investigated the effect of tapping insertional torque on osteoporotic thoracic human vertebrae. Then the pullout results of two groups (1.5 in-lbs or 2.5 in-lbs) were compared. Pullout strength was significantly higher for the second group (2.5 in-lbs insertional torque). They came to the conclusion that tapping insertional torque had correlation with pedicle screws insertional torque and pullout strength.

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T. Demir and C. Başgül, *The Pullout Performance of Pedicle Screws*,
SpringerBriefs in Computational Mechanics, DOI 10.1007/978-3-319-16601-8_3

3.2 Effect of Hubbing

Pedicle screw can also be inserted deeper into the vertebra than normal depth of insertion, which called counter sinking method (hubbing). For instance, Paik et al. [32] applied monoaxial screws on osteoporotic and normal human cadaveric vertebrae by hubbed (countersinking method) or standard fixation. As a result of this study, hubbing significantly decreased the pullout strength. In the same time, half of the specimens fractured during hubbing procedure. Additionally, the ones which were not fractured externally, founded to have internal fracture.

3.3 Effect of Backing Out the Pedicle Screw

Monoaxial screws are not adjustable as polyaxial pedicle screws. That is the reason, why monoaxial screws must be backed out for the rod-screw placement. During backing out procedure pullout strength of pedicle screw must be preserved [1, 2, 9, 11, 29].

To observe backing out effect, Abshire et al. [1] divided the test groups of screws into three groups according to their insertion conditions; fully inserted, backed out 180° and backed out 360°. As a result of this study, there were no differences in mechanical properties of either conical or cylindrical cored screws when they were backed out 180° or 360°.

On the other hand, Lill et al. [29] drew attention to a significant difference on pullout strength after backing out of cylindrical and conical pedicle screws. Cylindrical and conical cored pedicle screw were tested when were fully inserted and backed out 180° on calf vertebrae (BMD measured) for the tests. The pullout tests were done either directly or after cyclic loading. When screws were backed out 180° cylindrical cored screws showed significantly higher pullout strength than conical cored screws. That indicated backing out is more dangerous for the conical screws than cylindrical screws.

Moreover, Amaritsakul et al. [2] investigated the effect of backing out on eight different screw designs (seven conventional designs and one novel design). Those screws were inserted on synthetic foams and backed out 360° after insertion, then pulled out. Conical cored screw designs showed higher pullout strength than the other screw designs. However they were less durable to backing out process. On the other hand, dual inner core screw and double dual core screw showed higher stability both before and after backing out.

Backing out for intra operative adjustment is also an important process when screws are needed to be augmented for osteoporotic patients. From this point of view, Cho et al. [20] tested pedicle screws augmented either PMMA or Calcium Phosphate (CP) to understand the backing out a pedicle screw with cement augmentation on human cadaveric vertebrae. As a result, pedicle screw augmented both PMMA or CP could be comfortably removed. However bone growth for CP augmentation must be taken into account in long terms. In the same manner, Chen et al. [9] also tested the screws augmented with PMMA either before perforation or after insertion. The screws were pulled out either after full insertion or after 360° back-out. They also concluded that there was no loss of fixation strength for all cases in this study when pedicle screws were backed out 360°.

3.4 Fixation Techniques

The structure of vertebra had been already researched many times to increase the pullout strength of pedicle screws. A pedicle provides approximately 60 % of the pullout strength [20]. The pedicle and the vertebral body have different bone mineral densities on different areas. Because of this differential density, the varied insertion directions of pedicle screw had been investigated [3, 14, 16, 36].

Firstly, Zindrick et al. [40] investigated different insertional depths by inserting the pedicle screws with various designs into the lumbosacral cadaveric vertebrae. Then pullout and cyclic loading tests were performed for the inserted PS. As a result, pedicle screws which were inserted deeper were more durable to the cyclic testing.

From a different point of view, Crawford et al. [12] investigated different trajectories for pedicle screw by changing the degree of trajectory angle on human cadaveric vertebrae. Angle of trajectory were changed either 10°, 20°, 30° medially or 10°, 20°, 30° laterally. Although 10° medially trajectored screws showed the highest pullout strength, there were no significant differences between pullout values of straight ahead and inward trajectored pedicle screws. Additionally, cortical wall is more prone to get broken for laterally applications than medially applications.

Santoni et al. [34] also showed the sensibility of cortical wall by comparing the traditional medially directed trajectory with cortical bone trajectory on human cadaveric lumbar spines. Pullout, stiffness, failure moment were recorded. New cortical trajectory's pullout strength was 30 % higher than cortical trajectory, however 20 % of new cortical trajectored screws caused wall breach.

Furthermore, Kilinçer et al. [23] conducted a research to investigate the effect of angle between two pedicle screws in a vertebra. 60° screw angle, 60° screw angle with laminectomy and 90° screw angle were prepared as test conditions on calf vertebrae. Then, peak pullout loads were compared. Figure 3.1 depicts the applications of the angle between two pedicle screws on a single vertebra. Mean peak loads of those 3 systems did not differ significantly from each other. Laminectomy had also no effect on pullout strength.

Additionally, Lehman et al. [27] investigated two different insertion techniques by straight forward and anatomic trajectories of pedicle screws. As a result, straight forward trajectory achieved 39 % higher maximum insertional torque and 27 % higher pullout strength than anatomic trajectory.

Moreover, Fürderer et al. [17] compared transpedicular, trans-transverse and supratransverse fixation techniques as different fixation techniques on osteoporotic

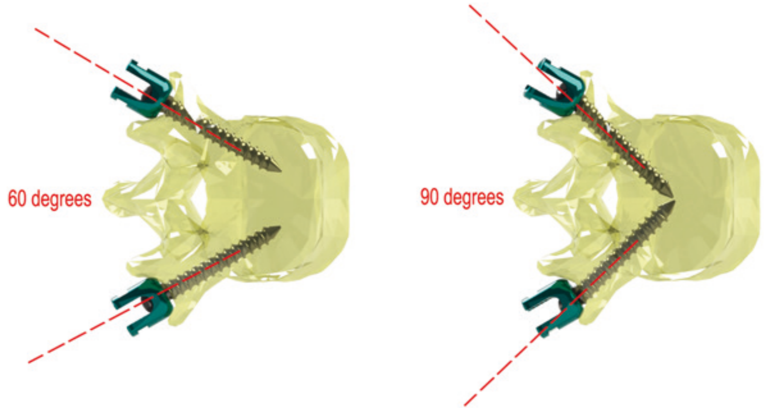

Fig. 3.1 Different angles between two pedicle screws inserted in a vertebra

human cadaveric vertebrae. Pullout strength of pedicle screw for each fixation techniques was recorded. Although transpedicular fixation provided higher pullout strength than trans-transverse and supratransverse techniques, there was no significant difference between these three application types.

Besides, White et al. [37] also compared the transpedicular and extrapedicular fixation techniques. Failure load and stiffness values of the screws were recorded. The screw stability for pedicle screws fixed with transpedicular method was significantly higher than extrapedicular fixed screws for both loads.

Contrary to stability increment by pedicle, Yüksel et al. [38] investigated extrapedicular and intrapedicular fixation techniques and the possible usage of extrapedicular fixation technique as revision surgery method. Pedicle screws were inserted either intrapedicular or extrapedicular on human cadaveric vertebrae and then pulled out. The intrapedicular fixed sides were then inserted this time with extrapedicular fixation technique. As a result, extrapedicular fixed screws could be used as a revision technique of failed intrapedicular fixation.

3.4.1 Misplacement

It is difficult to place the pedicle screw into the pedicle always in the right position. Due to the deformity and the position of vertebrae misplacement can occur. Not only it is dangerous when misplacing a pedicle screw, but also the pullout strength decreases. Medial, lateral and normal perforations are shown in Fig. 3.2.

To analyze the loss of pullout strength while misplacement of the pedicle screw, four types of probable misplacement positions were compared in Brasiliense et al.'s study [5]; standard pedicle screw, pedicle screw with medial cortical perforation, pedicle screw with lateral cortical perforation and "airball" screw (a screw which totally misses the body of the vertebrae). Medially misplaced pedicle

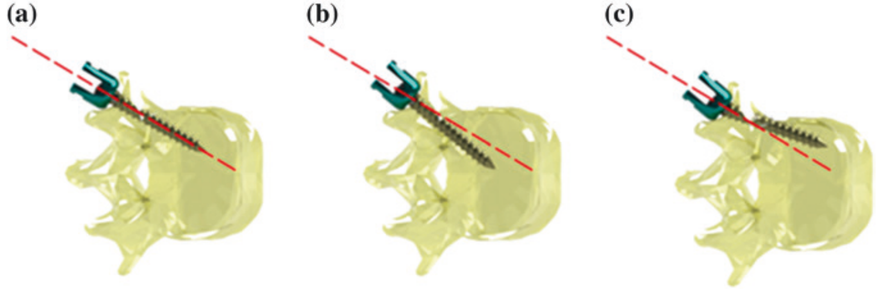

Fig. 3.2 Normal (**a**), Medial (**b**) and Lateral (**c**). Perforation of pedicle screw

screws showed significantly higher and laterally misplaced screws showed significantly lower pullout strength than well-placed pedicle screws. Additionally loss of pullout strength of "airball" screw was observed.

Additionally, to decrease the cortical perforation and root damage (misplacement effects) new designed novel partially non-threaded pedicle screw were tested for pullout strength in Kwan et al.'s study [25]. This novel screw decreased the medial perforation and nerve damage. Also pullout strength of novel screw was not significantly less than normal PS.

3.5 Effect of Insertional Temperature

Insertional temperature is important for the screw stability because of the micro expansion of the pedicle screw after insertion [35]. To understand the effect of different insertional temperatures on pullout strength, pedicle screws were inserted to calf vertebrae on four different temperatures (−100, −35, +4, +24). Then the pedicle screws were pulled out at room temperature. The highest pullout strength on screws that are placed was observed at + 4 °C. In addition to that, the more difference between bone and screw temperature could cause more cracking on bone-screw interface.

3.6 Effect of Insertional Torque

Insertional torque was generally founded to be correlated with the pullout strength and studied by several researchers [1, 21, 26, 29, 35].

For instance, Zdeblick et al. [39] investigated the correlation between pullout and insertional torque in 1993. Insertional torque and pullout strength were tested on human cadaveric vertebrae. As a result, positive correlation was found between insertional torque and pullout strength.

Moreover, Inceoglu et al. [22] tested three types of pedicle screw on calf lumbar spine. Insertional torque, peak torque, pullout and stiffness were recorded.

Contrary to other studies, there was no significant correlation between pullout strength and insertion torque for Xia screws. Because of the Xia screw's design (progressive pitch and thread shape), it showed higher insertional torque and lower pullout strength. In the same viewpoint Mummaneni et al. [31] also showed that there was not a correlation between pullout strength and insertional torque for dual lead PS.

3.7 Effect of Revision

For certain cases such as surgical reasons, implant failures and metal fatigue of stabilization system, revision can be needed [30]. Revision surgeries are challenging for surgeons because the loss of vertebral bone tissues from first insertion. Expandable and cannulated screws with cement augmentation could be solutions for the revision surgeries [10, 15, 18, 28, 33, 38].

For instance, Bostan et al. [4] compared expandable pedicle screws and pedicle screws with PMMA augmentation used for revision surgeries according to their pullout strength. Before and after revision pullout strengths were significantly different for both groups. As a result, both techniques showed higher pullout stability than first insertion as a revision technique.

Moreover, as revision techniques, the pullout strength of pedicle screw either with anatomic trajectored or augmented with Calcium sulfate were compared by Derincek et al. [14]. Anatomic trajectory for revision decreased the maximum insertional torque and pullout strength than straight forward trajectory. On the other hand, cement augmented group increased the pullout strength by comparison to control group. As a result of this study, cement augmentation could be a better solution for revision operations with pedicle screws.

Furthermore, Defino et al. [13] compared dual and cylindrical cored pedicle screws after repeated insertion to understand the stability of these two different screws. The screws were pulled out after first, second and third insertion. The pullout strength difference between after first and third insertion of dual cored screws was 30 %. Similarly, this decrement was 42.3 % for cylindrical cored screws. As a result, dual cored pedicle screw could be a better solution according to its promising pullout result.

Finally, Klein et al. [24] designed partially threaded (no threads in pedicular region) and half-partially threaded pedicle screws to decrease the nerve root damage in revision operations. Those screws and control group (completely threaded) were then subjected to pullout and fatigue tests. Half partially pedicle screws could achieve 80 % of standard screws pullout strength. So that, half partially threaded screw might be a solution without damaging the nerve roots. On the other hand, this new designed screw might be dangerous for the osteoporotic cases due to the less FOA.

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