# Chapter 2
# Effect of Screw Design

Pullout strength of a pedicle screw is significantly correlated with the screw design. To increase the pullout strength of the screw many researches had already been completed. Pedicle screws with radial holes, different core geometries, thread designs, cannulated screws and expandable screws are different pedicle screw designs with different mechanical properties. Figure 1.6 represents the different pedicle screw types and Fig. 2.1 shows the detailed view of pedicle screw to understand mechanical terms better. These pedicle screw designs were reviewed in this section.

## 2.1 Effect of Radial Holes

It is important to increase the interface between bone and pedicle screw. The more interface between screw and bone tissues provide more pullout strength. To increase the interface, radial holes could be an option which allows bone in growth through the holes. The number, sequence, angle between the radial holes had already been investigated [32]. A pedicle screw with radial holes could be seen in Fig. 2.2.

For instance, in Demir et al.'s study [15] geometric features of a pedicle screw such as holes drilled normal to screw axis (radial holes), angle and distance between sequential radial holes had been modified and the effects of those modifications were investigated. The screw with the medium core diameter, containing one hole per two pitches, with 90° angle between sequential holes were achieved the optimum results for both pullout and torsional strength. Its pullout performance was also tested on calf vertebra and achieved 84 % of a normal screws' pullout performance. The pullout strength of this screw had been expected to be higher after the fusion.

As a continuation of this work, Arslan et al. [2] compared the novel pedicle screw (which showed optimum results in Demir et al.'s study [15]) with a classical pedicle screw without radial holes. The pullout strength of this newly designed pedicle screw with radial holes and the classical pedicle screw were obtained for post fusion to understand the effect of radial holes. The newly designed pedicle



T. Demir and C. Başgül, *The Pullout Performance of Pedicle Screws*,
SpringerBriefs in Computational Mechanics, DOI 10.1007/978-3-319-16601-8_2

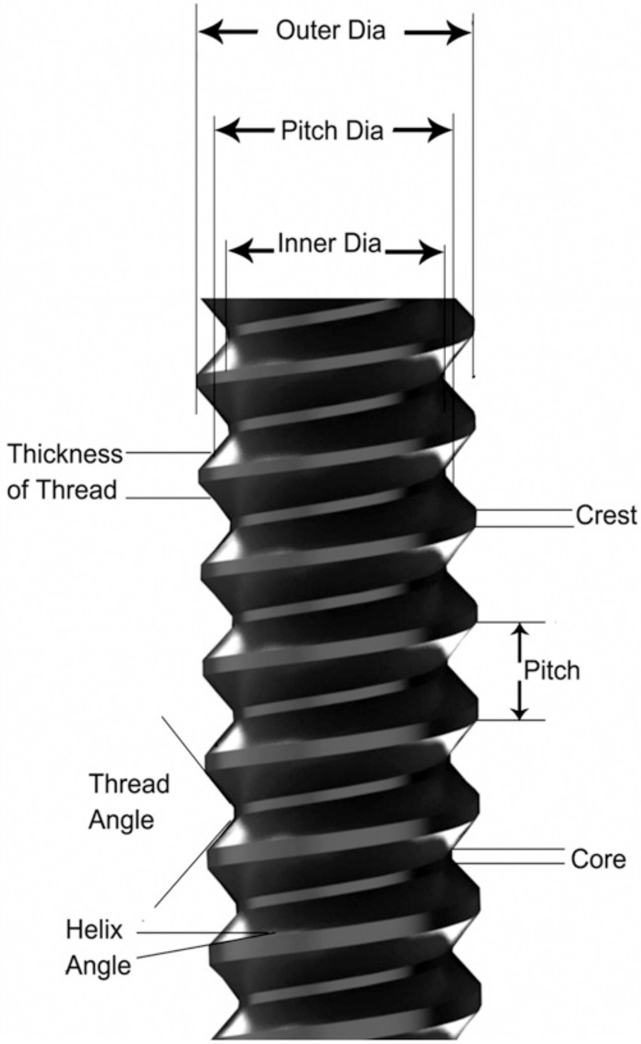


**Fig. 2.1** Detailed view of pedicle screw

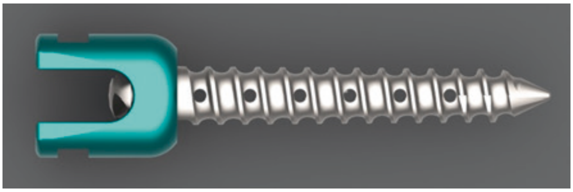

**Fig. 2.2** Pedicle screw with radial holes

screw achieved significantly higher pullout values after fusion for osteoporotic bones (70 %), however it did not prove the same success for healthy bones (10 % increment) and severely osteoporotic bones (9 % decrement).

Another useful study about radial holes was made by Mckoy et al. [30] on osteoporotic human vertebrae. They compared the pullout strengths of CPS with radial holes and normal pedicle screw. Both screws were augmented with Polymethylmethacrylate (PMMA). Radial holes increased the amount of the cement exuded from the cannulated screw, so that the cannulated screw showed 2.78 times higher pullout strength than standard pedicle screw.

In addition to Mckoy et al.'s study [30], Chen et al. [9] also investigated the amount of cement exuded from radial holes and also the importance of exudation point. They tested CPS with radial holes cemented with PMMA on polyurethane foams (density = 0.09 g/cm$^3$) for simulating the severely osteoporotic patient cases. The more radial holes drilled normal to the main axis of the screw, the more amount of cement exuded from the screw which increases the pullout strength. As an expected result, the amount of exuded cement from closer holes to the injection point (proximal side of screw) was much higher than other holes.

In conclusion, radial holes allow osteo-integration for normal pedicle screws, so that the pullout strength increases more than normal PS without radial holes (especially after fusion). However, pullout of a pedicle screw is an early stage problem which occurs before fusion. Therefore, pre-fusion pullout performance of the normal pedicle screw (with radial holes) must be taken into consideration. Besides, radial holes drilled to cannulated screw increase the pullout strength by cement distribution. But, the locations of radial holes are critical for cement leakage risk through the spinal canal.

## 2.2 Core Geometry

The geometry of the pedicle screw's core can be conical, cylindrical or dual. These three types have all different mechanical strengths. The comparisons of those core types were previously researched [4, 7, 8, 10, 19, 20, 22, 27]. Figure 2.3 shows the pedicle screws with different core geometries.

For instance, Abshire et al. [1] compared the conical cored screws and cylindrical cored pedicle screws with the same thread pitch, flank overlap area, thread contour and core diameter for pullout loads and stiffness. Porcine lumbar vertebrae were used to test those screws. Conical cored screws showed better pullout strength than cylindrical cored screws.

Moreover Kwok et al. [25], compared one conical and four different types of cylindrical cored pedicle screws on human vertebrae. Although conical screws showed higher insertion torque, there was no significant difference between the pullouts of those five different pedicle screws. As another result of this study, insertion torque and pullout strengths were not correlated for all of the pedicle screw types.

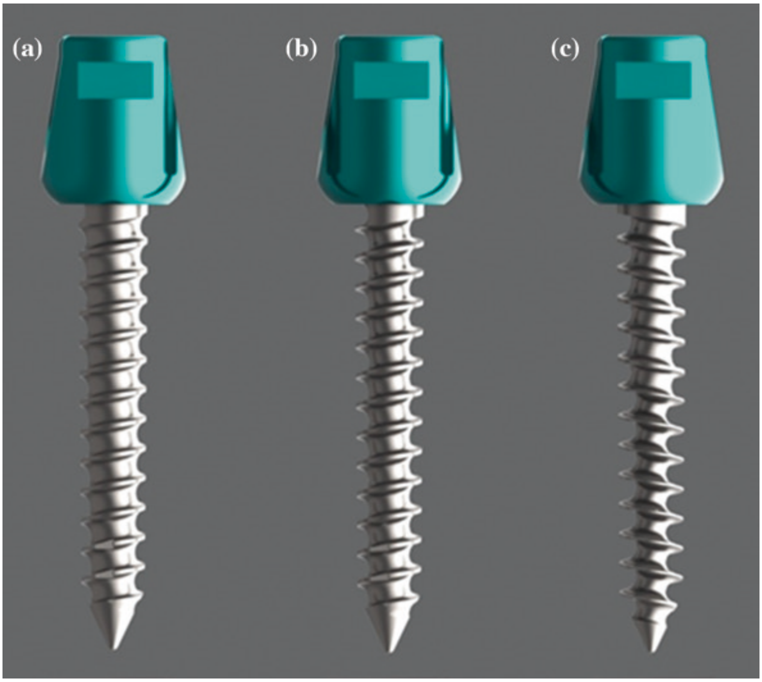


**Fig. 2.3** Core types of pedicle screw. **a** Conical cored PS. **b** Cylindrical cored PS. **c** Dual cored PS

On the other hand, Yaman et al. [39] investigated the pullout strength of a dual cored pedicle screw. Three types of screws (conical cored PS, dual lead PS and dual lead dual cored PS) were tested on ovine vertebrae and synthetic foams. The dual lead dual cored PS showed significantly better pullout strength than the other two screws. Dual cored pedicle screw achieved better performance than conical cored pedicle screw.

Another factor which has an impact on core geometry is core diameter. The difference in core diameter influences the flank overlap area and the bone material volume between core and outer diameter [16]. The higher the core diameter was, the less the bone material volume between core and outer diameter and overlap area were. So increasing the core diameter without increasing the outer diameter decreases the pullout strength [2]. For instance, Wittenberg et al.'s study [36] also showed the significant effect of screw diameter on pullout strength.

Finally, it can be concluded that as in most of the studies conical cored pedicle screws showed better pullout performance than cylindrical pedicle screws. However, further studies also came to the solution that the dual cored PS showed higher pullout strength than conical cored pedicle screw. Apart from that, core diameter is an important factor which increases pullout strength if the outer diameter would be kept constant, otherwise it will decrease the pullout strength.

## 2.3 Thread Design

Thread design of a pedicle screw is another factor that affects the pullout strength [22, 24]. Since, the design of the thread can allow more area between screw threads which called flank overlap area (FOA). As well as FOA, different thread designs such as dual leads can also decrease the operation time which is a vital subject during surgeries. In addition to that, dual lead pedicle screws can provide faster insertion time while maintaining the same pullout strength. More detailed information and researches about these two issues are provided in next two sections.

### *2.3.1 Effect of Flank Overlap Area (FOA)*

As mentioned before the more FOA provides more pullout strength because of higher interface between bone tissue and screw thread.

For instance, Kim et al. [22] investigated different geometric factors (inner diameter, outer diameter and thread shape) of a pedicle screw on three different grades of polyurethane foams. Inner and outer diameter were either conical or cylindrical, thread shape was chosen from V, square and buttress shapes. These different thread geometries are shown in Fig. 2.4. Pedicle screws with V-shaped threads had the highest as pedicle screws with square shaped threads had the lowest pullout strengths. This is an expected result, since V-shaped threads had the highest FOA.

Another study had been made by Krenn et al. [24] to see the effect of FOA with three different pedicle screw designs. Screws were designed indifferent threads, by keeping the length and the outer diameter constant. Those screws were pulled out from polyurethane foam blocks (saw bones) with three different densities. Conical cored, smaller core diameter, larger FOA and moderately small thread pitch provided the best fixation results according to this study.

In conclusion, all those studies showed that FOA is highly correlated with the pullout strength.

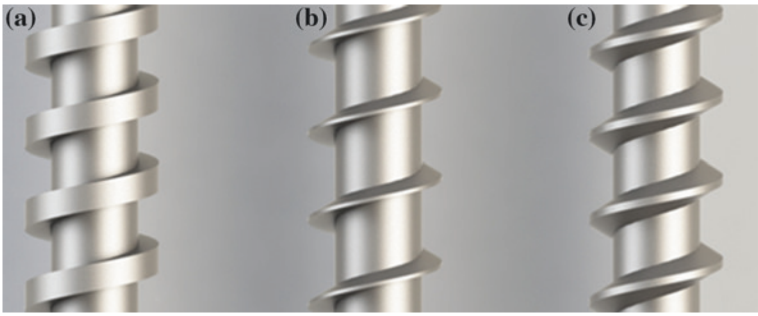


**Fig. 2.4** Different thread designs of pedicle screw. **a** Square shape. **b** Buttress shape. **c** V shape

### 2.3.2 Effect of Dual Leads

Dual lead pedicle screws were designed to decrease the insertion time of the pedicle screws [5, 6, 13, 21, 28, 31]. For instance Brasiliense et al. [5] compared dual threaded pedicle screw with the standard pedicle screw. Lumbar vertebrae and polyurethane blocks (demonstrating osteoporotic and normal bone) were used as test medium. Dual threaded PS showed higher pullout strength on high density foams and lower on low density foams than standard PS. This concludes that dual lead is a better option for healthy bone cases.

Another research had been made by Lill et al. [28] for five different pedicle screws that pulled out from calf and human vertebras before and after cyclic loading. Normal pedicle screws were more sensitive to cyclic loading than dual lead screws. As main result of the study dual lead screws had higher pullout strengths than pedicle screws even after screws backed out. Normally, higher pullout performance of the dual lead PS is not an expected result since core of the screw or flank overlap area is not changing because of the dual lead.

Another opinion about dual lead screws is that they show similar pullout strength with normal PS while having faster insertion time. Chang et al. [6] tested two different dual lead PS (thin crest, thick crest) and standard pedicle screw as control group for osteoporotic incidents. Osteogrip thick and thin crests demonstrated similar pullout strengths with standard pedicle screw; however insertion torques of both crests was higher than standard pedicle screw.

Similarly, Mummaneni et al. [31] compared the pullout strength of dual lead and single lead pedicle screws. The pullout tests were conducted on human vertebrae. However, pullout strengths of those two screws were not significantly different from each other.

Furthermore Jacob et al. [21] also tested single and dual lead screws on human cadaveric vertebrae. They found an insignificant difference on pullout strength of single and dual lead pedicle screws as expected.

As the higher pullout performance of the dual lead PS is defended in some cases, it can be concluded that dual lead PS can provide pullout strength as well as normal PS. The best advantage of the dual lead PS is faster insertion time which is vital for the surgeons.

## 2.4 Cannulated Pedicle Screw

Cannulated pedicle screws are designed for osteoporotic incidents. As bone mineral density diminishes the holding strength of the bone decreases. Cannulated screw with cement augmentation is a viable solution for patients with osteoporosis [3, 11, 14, 33, 40].

For instance, several design parameters on cannulated pedicle screws were investigated in Arslan et al.'s study [3]. CPSs with cement augmentation were tested for pullout strength on polyurethane foams (Grade 10 and 40). For osteoporotic bones CPS with cement augmentation with unilaterally three holes showed the best performance than the other screw designs.

As a future work of this study, Demir et al. [14] investigated the CPSs tested before without augmentation with artificial fusion effect. As a result, cannulated screws without cement augmentation could be a solution for healthy bones according to their promising results. However pullout of a pedicle screw is an early stage problem, so that the results without artificial effect must be considered for this study.

Furthermore, Choma et al. [11] compared non-augmented standard PS, PMMA augmented standard PS, partially cannulated PS augmented with PMMA and fully cannulated PS augmented with PMMA for their pullout strengths and back out torques. Partially cannulated pedicle screw with PMMA demonstrated the highest pullout value between all of those different groups.

On the other hand, Yazu et al. [40] studied the effect of radial holes with cement augmentation in osteoporotic cases. A novel screw with 20 small radial holes was compared with the cannulated pedicle screw by testing the pullout strength. Besides, the novel pedicle screw was augmented with calcium phosphate. The pullout strength of CPS without augmentation was 258 N, while novel pedicle screw with holes was 637 N.

Finally, to increase the effect of augmentation a new designed cannulated screw was tested by Takigawa et al. [33]. This novel screw with PMMA augmentation was compared with a non-augmented normal pedicle screw. The specimens were subjected to axial pullout and cyclic loading tests. Novel pedicle screw significantly increased the pullout strength against the normal pedicle screw for both pullout and cyclic loading test.

As, cannulated pedicle screws with cement augmentation give higher pullout strength than standard pedicle screws, researchers tried to decrease cement leakage probability with different cannulated screw designs, and proved comparable results.

## 2.5 Expandable Pedicle Screw

Expandable pedicle screw is an alternative to cannulated screws also designed for osteoporotic incidents [18, 37]. Expansion mechanism of an expandable pedicle screw can be seen in Fig. 2.5.

For instance, Vishnubhotla et al. [34] compared the expandable pedicle screw with the standard pedicle screw for osteoporotic human cadaveric vertebrae. As a result, ultimate load and energy required to failure which shows pullout stability of a pedicle screw were significantly higher for the EPS.

Furthermore, Wan et al. [35] investigated the histological and mechanical properties of an expandable pedicle screw. They tested EPS and standard pedicle screw (SPS) on sheep lumbar spines. Pullout and cyclic bending tests were performed to measure the screws' stability. EPS proved 59.6 % higher pullout strength then PS. Besides researchers histologically indicated that, new bone tissue were formed more at the center of the EPS, which improves the screw stability after fusion.

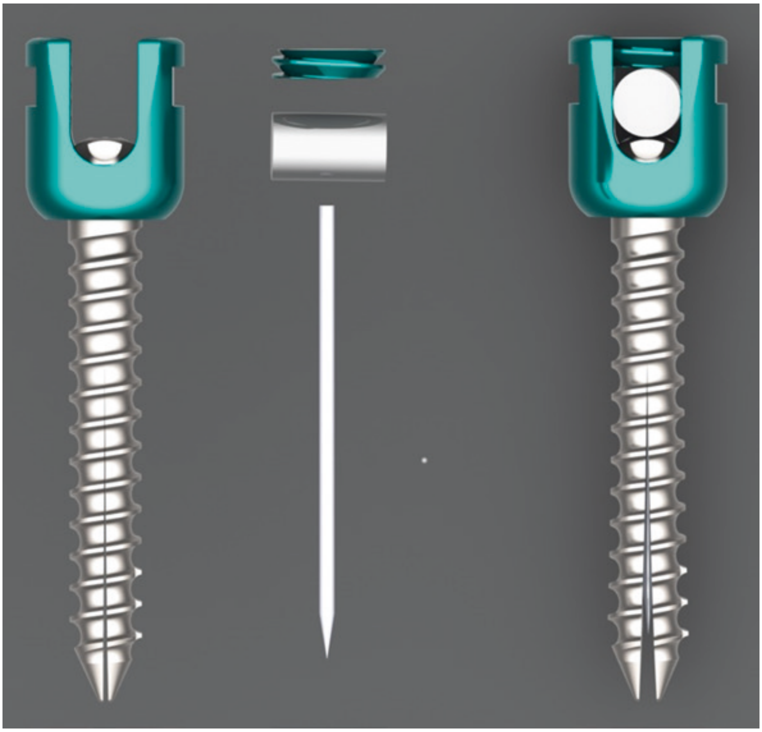

**Fig. 2.5** Expansion mechanism of an expandable screw

Moreover, Liu et al. [29] compared the pullout strengths of EPS, SPS and augmented SPS. EPS increased the pullout strength significantly than SPS. Augmented SPS showed higher pullout strength than EPS, however if cement leakage would be taken into account EPS could still be a good option.

In another study, expandable pedicle screws and 3 different conventional pedicle screws' mechanical performances were tested on osteoporotic calf vertebrae both before and after fusion [26]. Expandable PS's pullout strength was higher than both conical and cylindrical cored conventional PS before and after fusion.

Cook et al. [12] also investigated the effect of expandable pedicle screws on human osteoporotic vertebrae. Expandable pedicle screws were compared with standard pedicle screws. Expandable pedicle screws increased the pullout strength 30 % than standard pedicle screws.

On the other hand, Koller et al. [23] investigated a new distal mechanism added to a standard pedicle screw. Mechanical outcomes were compared with standard pedicle screw. The new designed screws' failure load was one-fifth times of the standard screw. So this new screw could be an intermediate alternative to cement augmented screws in osteoporotic bones.

In some cases even expandable pedicle screws cannot ensure the screw stability such as severely osteoporotic patients. That is why researchers investigated the EPS with cement augmentation [17, 38]. For instance Gao et al. [17] tested conventional and expansive pedicle screws with and without cement augmentation on fresh human cadaver spines for normal, osteopenic, osteoporotic and severely osteoporotic cases. The maximum pullout strength, stiffness and energy absorbed to failure were compared for those tested screws. Not only cement augmented but also non-augmented EPS showed better fixation strengths than conventional PS. None of those four different fixation types were useful for the patients with severely osteoporotic bone quality.

Similarly, Wu et al. [38] researched the effectiveness of pedicle screw and expandable pedicle screw with PMMA augmentation. The test groups were divided into four: Conventional pedicle screws, EPS, cemented Conventional PS and cemented EPS. Pullout strength was recorded for those groups. Also an in vivo study was conducted to compare cemented EPS and cemented conventional PS for total 36 cases. As no screw loosening was observed for cemented EPS, 4 screws (4.2 %) were loosened for cemented conventional PS. For both osteoporotic and severely osteoporotic samples cemented EPS showed the highest pullout values.

Cement augmentation can be risky because of leakage through the spinal canal. In such situations expandable pedicle screws can be more preferable than cannulated pedicle screws. On the other hand, revision of expandable pedicle screw is problematic due to bone in growth through expanded fins of screw. It is hard to obtain screw stability on patients with low bone quality. So that expandable pedicle screws can be also used with cement augmentation to increase the pullout strength.

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The Pullout Performance of Pedicle Screws
Demir, T.; Basgül, C.
2015, XIII, 81 p. 14 illus., 8 illus. in color., Softcover
ISBN: 978-3-319-16600-1