Transfacet Technology: An Alternative to Pedicle Screw Fixation with Interbody Techniques

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ABSTRACT
Currently transpedicular fixation remains more popular than other methods of lumbar posterior fusion. Despite the rise of its popularity, the efficacy safety of this technique has remained in question. Facet fixation is an alternative for primary fusion or as an augmentation to an interbody fusion and is associated with decreased cost, smaller incisions, and less morbidity. True transfacet and translaminar techniques are both fusion methods that achieve stabilization through facet engagement. Recent biomechanical data support both transfacet techniques as an alternative option for posterior fusion following short segment interbody spacer placement.

KEY WORDS: MISS, transfacet screw

Lumbar fusion was developed to treat spinal instability, which may arise from a variety of disorders including trauma, neoplasms, degenerative disc disease, or iatrogenic causes. Early fixation was met with little success. However by the 1980s, pedicle screw placement became the gold standard for achieving stabilization (12).

Today, transpedicular fixation remains more popular than other methods of lumbar posterior fusion. Despite the rise of its popularity, the morbidity and safety of this technique has remained in question (1,12). For example, transpedicular screw placement requires excessive muscle dissection resulting in damage to paraspinal muscle leading to functional loss of muscle along with increased infection and volume of devitalized tissue (5,10,12-14,19,26,30-32). Furthermore, many studies have reported screw malposition and breakage in addition to sub-optimal fixation from transpedicular screw placement, increasing risk of neurological and vascular injury (1,5,10,12-14,19,26,30-32). There is also concern for a high rate of device-related osteoporosis due to the rigid fusion achieved with pedicle screws (8,9,21,22). Lastly, the most cephalad screw or rod in the construct may mechanically compromise the adjacent facet (8). Due to these reasons, some surgeons have sought less invasive and equally efficacious techniques.

Facet fixation is an alternative for primary fusion or as an augmentation to an interbody fusion and may be used as a salvage technique when fractured or small pedicles are encountered (9) (Figure 1). The posterior elements including the lamina must be left partially intact to place facet screws. Specifically, when more than 50% of the facet has already been resected, the transfacet technique is not recommended (9).

HISTORY OF TRANSFACET FIXATION

In 1948, King originally described transfacet fusion utilizing short screws across the ipsilateral facet joint (6). Boucher later modified this technique in 1959 with the addition of longer screws directed towards the pedicle for added fixation (4,6). Several decades later, Magerl developed the translaminar technique, which is a variant of the true transfacet method. In this technique, the screw enters from the contralateral lamina, transverses its whole length, and passes through the ipsilateral facet joint. The use of transfacet fixation has seen a rise recently due to its use for posterior fusion with anterior lumbar interbody fusion (ALIF) (4,9,25). Still, there remains a stigma related to using transfacet techniques that may come from a perceived notion of incomplete fixation when traversing the joint for fusion (1).
Figure 1: Three fixation techniques. A) Translaminar facet screw fixation (contralateral facet fixation from the site of insertion). B) Transfacet pedicle screw fixation (ipsilateral facet fixation from the site of insertion). C) Traditional pedicle screw fixation. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2014. All Rights Reserved).
Although both transfacet methods are associated with decreased cost, smaller incisions, and are technically less demanding, translaminar fixation has remained the more popular of the transfacet techniques (4,12). It should be noted, the translaminar method requires a larger surgical field for insertion and has a higher risk of neurological injury due to its long passage through the lamina compared to transfacet method (12). For example, translaminar screw placement has been associated with a 10% incidence of laminar wall violation and imperfect screw position (25). Still, these risks are comparably less than transpedicular screw placement (8,27).

**FACET STABILIZATION**

The facet joints are diarthrodial joints and are the only true articulations in the lumbosacral spine (8). Lumbar facets are oriented in the sagittal plane which increases their ability to resist translation or flexion (3). Furthermore, there is great variation in the angle from midline of the facets, which increases form L1-L5 (3). Both the facet capsule and spatial orientation of its articular surface play a role in guiding spinal motion. In flexion, the distances between the articular surfaces of the joint widen and as the posterior ligaments are stretched movement is limited. In contrast, with extension the distance between the articular surfaces decreases, which increases the compressive load and limits rotation (Figure 2). Specifically, during extension the superior facet of the lower vertebra blocks the inferior facet of the upper vertebra, which further inhibits extension (17,23). The facet joints of the lumbar spine only support axial loads while in extension (3). For these reasons, facets in extension are more stable. Given the above, directly fixating through the facet joints appears logical for stabilization of the spine (8).

Additionally, after interbody spacer placement, there is a diminished ability to resist extension not only due to the loss of the anterior longitudinal ligament and anterior annulus but also secondary to facet joint distraction (17). The same is true for lateral bending, where facet joints resist motion in combination with the intertransverse ligament and lateral annulus (17). Following interbody spacer placement fixating through the facets becomes especially important in stabilizing segmental intervertebral motion and enhances the interbody fusion rate by maintain tight graft compression.

**BIOMECHANICS OF FAILURE** (3)

Failure of posterior fixation devices, including both transfacet and pedicle screw fixation, occurs secondary to failure of either the implant, bone at the implant-bone interface, or component-component juncture. In order to prevent failure of spinal fixation devices, four types of biomechanical testing may be undertaken: 1) strength, 2) fatigue, 3) stability, and 4) mathematical testing.
First, stress to failure testing can generate a load-deformation curve of posterior spinal instrumentation devices by gradually adding a load until the implant fails. Strength of a rod or screw is directly proportional to the diameter of the rod or inner core of the screw to the 3rd power. Strength correlates to the magnitude of the load and deformation at the time of failure. Stiffness may also be calculated from this data and is equal to the slope of the load-deformation curve. Similarly to strength, stiffness is proportional to the diameter of the rod or core of the diameter of the screw to the 4th power. Therefore, as the diameter of the inner core of the screw or rod increases, the stiffness increased more rapidly than the strength, and the stiffness is higher in rods and screws with a larger diameter.

Once strength and stiffness of a construct have been established, fatigue testing must be undertaken. Fatigue testing assesses the ability of posterior instrumentation to withstand repetitive submaximal loads. The implant undergoes cycles of testing until it fails or until a predetermined number of cycles have been reached without failure. With cyclic testing the fatigue life of the implant can be determined. Moreover, fatigue testing models the clinical scenario the best.

Additionally, stability testing can be used to determine the stiffness and flexibility of the implant, and mathematical testing using finite element model may be used to test posterior instrumentation devices as well. As above, displacing the construct and measuring the load and moment arm determine stiffness. Whereas flexibility is calculated after a load or moment arm is applied and the displacement is measured. Finite element models divide anatomical structures into multiple elements and tests stresses after applying preset loads to elements. The more elements and complexity to a model the more likely it is to be clinically accurate. Assumptions must be made and simplified in these models, which makes the validity difficult to determine.

Lastly, implant failures occur at points of maximum stress (3). Both diameter of screws and rods utilized affect not only the stiffness and strength as stated above but also the stress of an implant. Stress is a function of the bending moment as well as applied strength and moment arm. Stress (θ) is defined by the equation θ= M (bending moment)/Z (elastic modulus) or force per unit area applied to a structure. As described in Figure 3, if a screw with a constant inner diameter is attached to a plate with a fixed moment arm, the bending moment increases linearly as a load is applied along the screw to its tip. The highest stress is therefore at the junction of the plate and the screw tip and that is more likely where failure is to occur.

**BIOMECHANICAL EVIDENCE**

Biomechanical studies have supported the use of transfacet and translaminar screw fixation for providing adequate stiffness and immobilization of the lumbar spine after interbody spacer placement (8,12,16). More recent studies have compared these transfacet fusion techniques to traditional pedicle screw fixation and have found similar clinical and radiographical outcomes (4,24).

**Transfacet Fixation**

The earliest most comprehensive study evaluating transfacet fixation was by Panjabi et al in 1991 (24). This study used an in vitro acute instability model at the L5-S1 level in human cadavers and rendered them unstable by transection of the posterior ligaments and drilling transverse holes through the intravertebral discs. They compared 5 pedicle screw fixation systems with facet screw fixation under flexion, extension, lateral bending and axial torque. For each load type, average load-displacement curves and average stiffness were calculated. In flexion, transfacet fixation provided equivalent stiffness to pedicle screw placement, which was three times greater than intact in both instances. Although in lateral bending transfacet fusion provided excellent stability it was less than some of the pedicle screw devices. During torque, facet fixation was on average stiffer than other pedicle screw methods and was two times the intact stiffness. In extension, however, facet screw fixation proved the least stiff, which was half of pedicle screw fusion but equal to intact spine stiffness. Overall, facet screw fixation is stable in axial rotation but in other loading types its stability tended to be lower than other pedicle screw devices.

In 1996, Volkman further studied transfacet screws after the insertion of laterally placed threaded cages (28). They found that transfacet screws increased motion segment stiffness in all modes compared to cage alone. This study gave support for the use of transfacet fixation for stabilizing posterior segments following interbody placement.

A more recent biomechanical study by Ferrara et al demonstrated bilateral facet fixation had had equivalent biomechanical performance to standard pedicle screw fixation with repeat cycling of motion segments (12). Human cadaveric spines were used in vitro to test flexion,
extension, lateral bending, and rotation; intact discs were compared to transforaminal interbody fusion (TLIF) after transfacet fixation and intact discs were compared to TLIF after posterior spinal fusion with pedicle screws. No significant differences were found between pedicle screw and transfacet fusion in all loading modes except flexion, where transfacet fixation was significantly stiffer than pedicle screw placement. Using non-destructive cycling of approximately 200 cycles demonstrated that facet engagement does provide stability that is equivalent to pedicle screw placement.

Furthermore, percutaneous placement of transfacet fixation was compared to pedicle screw fixation following L4-5 anterior lumbar interbody fusion (ALIF) and found no difference in screw stiffness for any direction (including flexion, extension, lateral bending, and torsion) in cyclic testing (20). There was also comparable anterior column loading between posterior fixation systems during physiologic testing with and without anterior interbody placement.

Agarwala et al further compared facet screw and pedicle screw fixation with and without ALIF at L4-5 in a cadaveric model (1). Authors showed both techniques reduced motion in flexion, extension, lateral bending, and axial rotation below intact levels. In primary fusion without ALIF, transfacet fixation reduced motion more than pedicle screw fixation but only in flexion and extension. After ALIF, posterior fusion with pedicle screws reduced motion more than transfacet fixation in all loading modes but not to a statistically significant level. Their results are similar to Ferrara et al that transfacet fixation is equivalent to pedicle screw placement following interbody spacer placement in all loading modes.

Translaminar Fixation

The first biomechanical studying evaluating translaminar fixation was by Kornblatt et al and compared translaminar facet joint screws to other posterior fixation techniques to normal spine with and without posterior ligaments (18). They found fixation with facet joint screws statistically decreases pseudoarthrosis. Also, there was increased stiffness in static loading tests.

Under cyclic testing, Heggeness and Esses showed translaminar facet screws were able to maintain stiffness after 5000 cycles in cadaveric spines (15). Additionally, in their series of 35 patients, they found no pseudoarthrosis or iatrogenic neurologic injury.
As above, in the early 1990s, high fusion rates and clinical success were reported with translaminar fixation (8). In 1998, Deguchi used a sheep model to compare range of motion, neutral zones, linear elastic zone stiffness, and total energy absorption during load-unload cycles between transverse and pedicle screw fixation. They found statistically similar performance in flexion and extension between fixation devices.

In a retrospective review, operative time and blood loss were significantly lower with translaminar screw placement compared to pedicle screw placement (4). Pseudoarthrosis and rate of reoperation also favored translaminar fixation. Specifically, rate of reoperation was 4.7% in translaminar screw placement, which was statistically lower than the 37.5% in the pedicle screw group. In a prospective study, however comparing long-term outcomes between translaminar and pedicle screw fixation, an increased risk of reoperation for nonunion was found among the translaminar group (27).

In the 77 patients analyzed, nonunion was noted in 7 of the 40 translaminar patients compared to 1 in 27 in the pedicle fixation group.

Finally, transverse fixation has been evaluated following interbody spacer placement. Transverse fixation was compared to both unilateral and bilateral pedicle screw constructs following interbody spacer implant in a 360-degree arthrodesis model in cadavers (7). Each method decreased range of motion in torsion, flexion, extension, and lateral bending compared to intact state. Transverse fusion was found to be equivalent to bilateral pedicle screw placement in all modes and was superior in flexion and extension but not to a statistically significant level.

**Transverse Versus Translaminar Fixation**

Transverse and translaminar fusion have been directly compared in several biomechanical studies. In 2004, Beaubien et al compared pedicle screw placement to both translaminar and transverse fixation following ALIF in a cadaveric model in the immediate postoperative state (2). They found that all posterior fusion techniques significantly reduced mean neutral zone and range of motion in most loading conditions compared with ALIF alone for a single motion segment. Furthermore, there was no significant difference between methods in lateral bending, flexion, extension and axial torsion. There was a trend for higher range of motions in facet screws in lateral bending and flexion-extension compared to both translaminar and pedicle screw methods of fusion.

Similarly, Kim et al compared pedicle, transverse, and translaminar screw placement following ALIF in non-destructive short-term testing, and authors found transverse was slightly inferior to translaminar screw fixation in all loading modes but the difference was not statistically significant (17). Pedicle screw fusion was superior to transverse fixation in lateral bending but was equivalent in other loading modes.

A new facet interference screw was directly compared to both transverse and pedicle screw fixation in 2005 by Kandziora et al. (16). They found that the addition of any posterior fusion following 1-level ALIF increased stiffness in all loading modes. No significant difference was found in directly comparing the facet interference screw to translaminar screw placement following ALIF. However, the bilateral pedicle screws showed statistically significant increased stiffness in flexion and rotation compared to facet techniques.

Finally, two current studies have evaluated transverse screw fixation following 2-level ALIF (11,29). In 2010, Chang-Yau Fan et al used a three-dimensional finite element models to evaluate five types of fusion following 2-level ALIF at L3-4 and L4-5 under six loading conditions (11). They found that the three-level pedicle screw and rod provided the best stability as compared to two-level transverse screw and two-level translaminar screw. Similarly by Wang et al, using fresh cadaver spines a 2-level ALIF model was studied comparing pedicle screw placement to both transverse and transverse screw placement (29). Mean stiffness was found to be comparable in axial rotation. In lateral bending and flexion, pedicle screw and rod fusion had higher stiffness reaching statistical significance. Specifically, in flexion, the least stiff construct was the transverse screw construct.

**DISCUSSION**

In the past, transverse fixation techniques have been thought to perform inferiorly in biomechanical evaluation compared to pedicle screw fusion. Moreover, transpedicular screw placement has remained the most popular posterior fixation technique following interbody spacer placement in the lumbar spine despite many associated co-morbidities.

Overall, the biomechanical evidence for transverse screw placement is heterogeneous in both methods and conclusions, and there is research bias in many study designs as well. For example, some researchers have used cadaver spines whereas others have used finite element models or calf.
spines. Also, screw diameter and length was not standard between studies and sometimes omitted from results. As discussed above, screw diameter and length have a significant affect on the stability of constructs.

Additionally, cyclic or fatigue testing most closely represents the forces implants are subjected to in the real life clinical scenario. Only 3 of the many studies discussed above evaluated transfacet and pedicle screw fixation devices under repetitive testing (12,15,20). They all found transfacet fixation performed favorably under cyclic testing. Still, in the cadaveric model fatigue testing degrades the specimen and no physiologic remodeling is able to occur (12). This may result in spinal segment failure, which may be preceded by a stiffened state due to compressed fragments from microfractures (12).

Ideal stiffness of posterior fusion devices is unknown and may not be predictive of the ability of solid arthrodesis to form (12). Both pedicle screw and transfacet fixation techniques increase stiffness compared to the intact state and in some cases pedicle screw fusion may be more rigid but it is not known whether this increased rigidity is advantageous or harmful. Following initial posterior fixation after interbody spacer implantation, the fusion mass has no strength so the implant must bear the load and be rigid in order for early fusion mass to form otherwise the graft will be absorbed (8). As the fusion mass gains strength and bears more load, it is ideal to have a less rigid fixation device. If the implant has too much rigidity, pseudoarthrosis at adjacent levels may form and the graft may be absorbed.

The biomechanical data support both transfacet techniques as an option for posterior fusion following short segment interbody spacer placement. Both methods can be used percutaneously or open and are associated with less morbidity than posterior pedicle screw fixation. Furthermore, the costs of transfacet screws are significantly less than pedicle screws at most hospitals, which is becoming increasingly important with the changing face of healthcare. However, there is limited repetitious short and long term testing of these devices following interbody spacer fixation. Further studies should be pursued to establish biomechanical equivalence.

REFERENCES


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