How and When to Use Hooks to Improve Deformity Correction

Jonathon M. Lentz, DO[1]; Frederick Mun, BS, BA[1]; Krishna V. Suresh, BS[1]; Mari L. Groves, MD[2]; Paul D. Sponseller, MD, MBA[1]

[1]Department of Orthopaedic Surgery, Johns Hopkins University Hospital, Baltimore, MD; [2]Department of Neurological Surgery, Johns Hopkins University Hospital, Baltimore, MD

Abstract:
Hooks can play an important role in helping to achieve fixation during posterior spinal fusion (PSF) in patients with spinal deformity. This article reviews the different types of hooks used in PSF, advantages and disadvantages, indications, and multiple surgical techniques for insertion based on hook type.

Key Concepts:
- There are two types of down-going hooks: transverse process hooks and supralaminar hooks. There are also two types of up-going hooks: pedicle hooks, which can be seated laterally in the thoracic spine, and sublaminar hooks, which are more central.
- Characteristic advantages of hooks are excellent cortical purchase for compression and distraction. Disadvantages of hooks include less three-dimensional control.
- Indications for hook use include creating an adaptable upper transition, and an option for vertebrae with poorly developed or weakened pedicles.
- Surgical techniques for hook insertion are specific for each type.

Introduction

Posterior spinal fusion (PSF) is a routinely performed procedure to correct spinal deformity. Various implant systems have evolved over time including Harrington's hook-rod system, sublaminar steel wires with L-shaped rods, and Cotrel-Dubousset (CD) instrumentation.[1,2,3,4] In the 1990s, the development of dual-rod pedicle screw constructs revolutionized scoliosis surgery, allowing for significant 3D correction of deformity, while providing improved biomechanical fixation strength.[5,6]

Though pedicle screws have increased resistance to dorsal pull-out strength compared to hooks alone, strategic use of hooks within pedicle screw constructs can play a key role in supplementing deformity correction.[7,8,9] Hooks can resist pullout if pedicle screws are plowed or weakened and can augment fixation where type C or D pedicles are encountered.[10] Furthermore, hooks provide several characteristic advantages when used within pedicle screw constructs, including preservation of the vertebral cortex and prevention of stress risers.[10,11,12]

While spinal deformity correction has been improved upon by the use of pedicle screws, hooks remain a valuable asset for augmenting modern instrumentation constructs. A review of the indications, advantages, disadvantages, and applications of hooks in modern spinal deformity surgery has not appeared in the literature. The purpose of this technical note is to present how hooks may assist modern spine surgeons in deformity correction and describe safe and effective techniques to insert different types of spinal hooks. Please refer to the related technique video, *How and When to Use Hooks in Deformity Correction*, accompanying this paper and available on POSNAcademy.

Description of the Method

Types of Hooks

Hook nomenclature can be confusing—fundamentally these implants consist of a tulip that engages the rod, and the "hook" is varied according to the depth and shape of the throat and the shoe which can be narrow, wide, bifurcated, or offset (Figure 1).

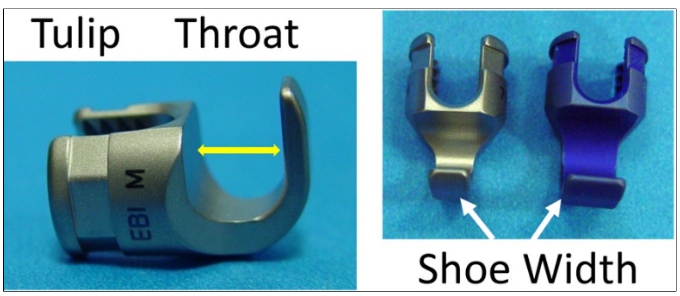

Figure 1. *A standard hook should be considered according to some general measures. The throat height should match the thickness of the bone it hooks to. While an implant with a broad throat height (yellow arrow) can be hooked onto a thin lamina, the excessive throat height could unnecessarily project the shoe into the spinal canal. The shoe of the hook can be narrow which makes placement easier, yet a wider shoe engages more bone and is less resistant to bony failure.*

One can further describe hooks according to the *direction* for which they are placed; hooks directed cephalad are considered "up-going," and those directed caudad are considered "down-going." Finally, hooks are classified according to where they are placed. Pedicle hooks are always bifurcated at the shoe and are always placed up-going in the thoracic spine usually from T1 to T10 (Figure 2). Pedicle hooks engage the inferior pedicle in the

Figure 2. *Pedicle Hook: Pedicle hooks are easy to identify as the shoe is bifurcated and is designed to capture the inferior pedicle when placed up-going in the thoracic facet joint.*

residual facet joint. They are commonly used in the thoracic spine which has narrower pedicle diameters.[13]

Lamina hooks are not bifurcated—an infralaminar hook is placed "up-going" on the inferior edge of any lamina (thoracic or lumbar), and a supralaminar hook is placed "down-going" on the superior edge of any lamina. Lamina hooks can also be placed down-going on the superior edge of the transverse process in the thoracic spine from T2 to T10; when a laminar hook is placed in such a way, it is called a "transverse process hook" (Figures 3 and 4).

Technique: Pedicle Hook (Up-going)

The cortical surface of the posterior elements is completely exposed out to the tip of the transverse processes. The inferior facet joint capsule is buried and cannot directly be visualized. A portion of the inferior articular process (IAP) is removed using an osteotome or bone scalpel rather than rongeur or high-speed burr. This will allow for a "square" cut for the pedicle hook to sit against. This also prevents lateral migration as pressure is directed cranially against the hook. This osteotomy is achieved using two cuts in an "L" shape with a 3/8" straight osteotome. The vertical cut is made at the junction of the IAP and the lamina. The osteotome is advanced from caudal to cranial ending at the level of an imaginary line drawn across the inferior aspect of the transverse process. The cut is oriented perpendicularly to this imaginary line. The depth of the osteotome should be angled slightly laterally and carefully observed to ensure that it is not entering the canal—this is generally less than half the width of this osteotome (or 3/16"). The transverse cut is made just inferior and parallel to the

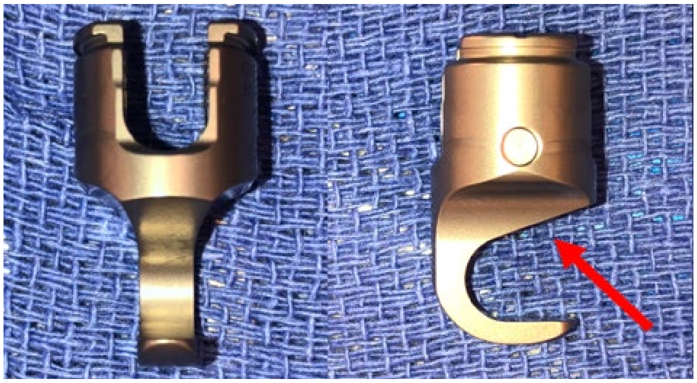

Figure 3. *Supralaminar (reduced distance) Hook: Notice that the slope of the throat (arrow) matches the "shingled" alignment of the lamina and when fully engaged, limits shoe intrusion into the canal. Also notice the narrow medio-lateral dimension of the shoe. This is intended to minimize canal intrusion during insertion. Yet, the fixation is still adequately strong because of the thick supra-laminar cortex.*

Figure 4. *Transverse Process Hook and Standard Up-going (Infralaminar) Hook: This hook may be interchangeably used as a transverse process hook when placed down-going on a thoracic transverse process and can be reversed as a standard up-going hook when placed on a thoracic or lumbar lamina. Notice the different throat shape compared to the reduced-distance hook as well as the greater width of the throat.*

transverse process (along the aforementioned imaginary line). It begins at the cranial edge of the initial cut and extends out to the lateral border of the IAP. Care is taken to aim the osteotome away from the canal to avoid inadvertent plunging. Once the cut is complete, there will be an audible pitch change and visible motion at the IAP. A gentle twisting motion of the osteotome at this point allows easy removal of the IAP. If the resection is performed properly, the cartilage of the superior articular process is exposed. If there is bone overlying from an

Figure 5. *Offset Hook: The offset hook is a laminar hook that can be placed down-going or up-going. The offset orientation allows the tulip to be positioned lateral to the hook which attaches to the medial lamina. The laterally positioned tulip remains colinear with the tulip of an adjacently placed pedicle screw.*

incomplete osteotomy, a curette can be used to easily complete the resection. This sequence will allow the hook to be inserted without obstruction. A pedicle seeker is then placed in the osteotomy site aiming cranially. The cartilaginous surface of the superior articular process (SAP) guides the pedicle seeker. It is important that this instrument is placed beneath the ventral cortex of the resected IAP rather into the cancellous bone. A mallet is used to gently advance the pedicle seeker. This maneuver creates a path for the pedicle hook. A pedicle hook inserter is then used to place the anchor. There is an audible pitch change noted once the hook contacts the pedicle above. There should be a tight fit of the pedicle hook around the bone and the tip of the hook should rest on the pedicle above. With the inserter still on, the hook is wiggled to check for motion. An appropriately sized hook will have a snug fit with little motion. At this point, the caudal vertebrae pedicle screw can be inserted into the prepared tract. This screw and the hook sit quite close to each other. A distractor can be used to seat the hook and ensure that it has good bony apposition while pushing up against the pedicle. Once the desired tension on the hook is achieved, the set screw is tightened over the rod to hold the hook in place (Figure 6).

Technique: Transverse Process Hook (Down-going)

The cortical surface of the posterior elements is completely exposed out to the tip of the transverse processes with sub-periosteal dissection. The cranial facet joint should not be exposed if this hook is being used as the

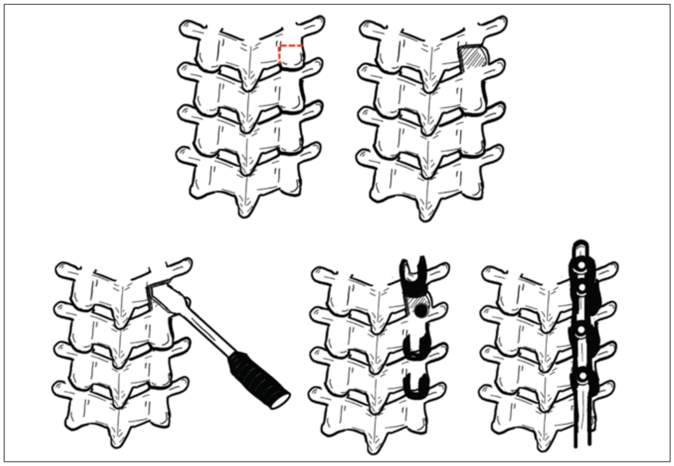

Figure 6. Pedicle Hook Technique: osteotomy, pedicle seeker, hook insertion, rod placement. The amount of bone to be removed from the IAP is outlined in red. Once the IAP is removed, the SAP from the lower vertebra is exposed (top right). Key tip: One can burr the cartilage from the SAP which can facilitate placement of the pedicle hook. A pedicle seeker can be used to identify the pedicle (bottom left). Important safety tip: Great care is needed to find the pedicle with this instrument. If not placed appropriately, it can be driven into the spinal cord. The final construct consists of three pedicle screws with a superior pedicle hook.*

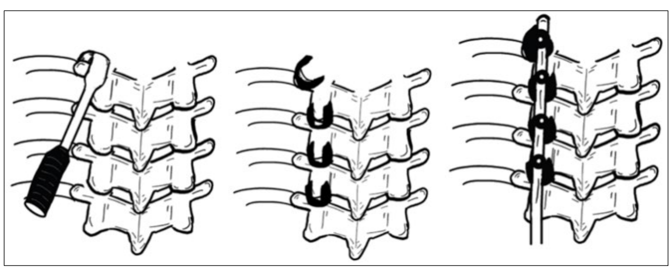

Figure 7. Transverse Process Hook Technique: lamina seeker, hook insertion, rod placement. The lamina seeker is used to develop the space between the transverse process (TP) and the underlying rib head. The TP hook will be the superior implant with three pedicle screws below.*

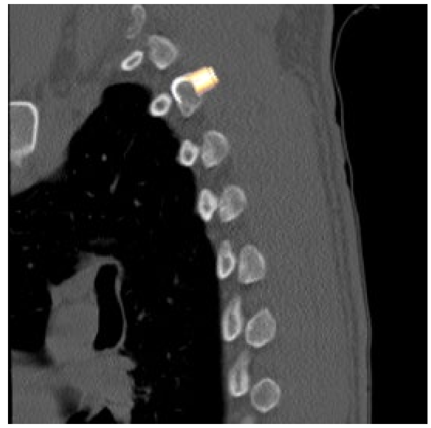

Figure 8. CT scan demonstrating relevant features of lamina and costovertebral space in thoracic spine. Orientation and placement of a hypothetical transverse process hook into the costovertebral space is shown.*

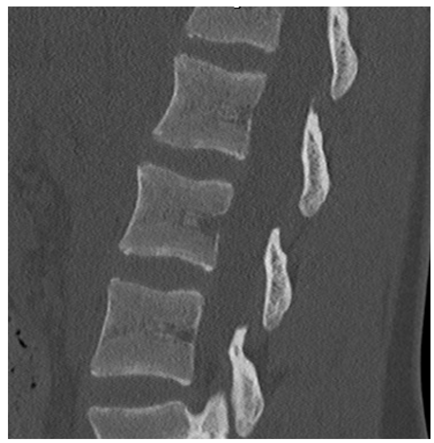

Figure 9. CT scan demonstrating relevant features of the laminae in lumbar spine. Note that they are stacked and inclined inward at the cranial edge. Also note that they are narrow on the cranial edge and wide on the caudal edge. Notice the dense cortical bone at the upper edge.*

upper instrumented vertebra (UIV) anchor. The lamina seeker is used to create a path for the transverse process (TP) hook. The tip of this instrument is placed on the TP starting just lateral to the cranial facet joint. The instrument is advanced cranially over the superior edge of the TP. Gentle ventral and superior pressure will allow the tip of the lamina seeker to bluntly dissect the space between the TP and its corresponding rib head at the costovertebral junction. Once in this space, the lamina seeker can be pulled caudally to allow the curved surface to lie against the superior aspect of the TP. Care is taken to maintain contact with bone throughout the maneuver to avoid cutting into and weakening the cortex of the TP. This technique is repeated with the TP hook. An appropriately sized hook will have a snug fit around the TP. There should be no space between the bone and the hook (Figure 7). The TP hook has a slightly lateral position as compared with pedicle screws. Positioning of the hook in relation to the costo-transverse space is shown in Figure 8. There is no need to contour the rod differently to accommodate this difference. Because of the slight upward flare of the TP, the well-positioned hook faces slightly medially. The medial angulation of the hook head allows the rod to seamlessly dock into the hook. A compressor can be used to seat the hook and ensure that it has good bony apposition. Once the desired tension on the hook is achieved, the set-screw is tightened over the rod to hold the hook in place. Contour the rod with in-situ sagittal benders or prior to rod placement so that its tip is curved ventrally.

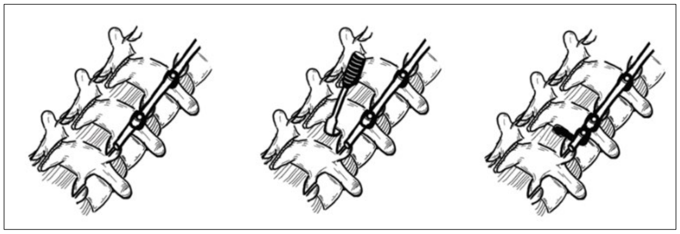

Figure 10. *Up-going (Infralaminar) Hook Technique: lamina seeker, hook insertion, rod placement. In this instance, supplemental hook fixation is used after the rod has been fixed. A laminar seeker creates a path for an offset hook which aligns with rod.*

Technique: Infralaminar Up-going Hook

These hooks are easier to insert than supralaminar hooks since the caudal end of the lamina is inclined outward. The caudal part of the lamina is typically wider than the superior portion (Figure 9).

The cortical surface of the lamina is exposed with sub-periosteal dissection. A lamina seeker is used to enter the inter-laminar space between the undersurface of the lamina and the ligamentum flavum. The lamina seeker is curved to match the shape of the hook that will be inserted. The tip of this instrument is placed at the caudal dorsal surface of the lamina. The tip is used to dissect the ligamentum from the bony surface (Figure 10). The tip should remain on bone at all times to avoid plunging into the inter-laminar space. Once a path has been created, the lamina hook is inserted using the same method. Choose the widest hook possible in order to distribute load. The hook should have a snug fit around the lamina with no space between the bone and hook so that it cannot intrude farther into the spinal canal. If there is space, the hook should be exchanged for a hook with narrow throat. To check the hook integrity, the surgeon can pull up on the hook using the inserter; an appropriately sized and positioned hook will pull the vertebra up with this maneuver. There are two designs of infralaminar hooks: standard and offset. The offset design allows the hook to line up with the pedicle screws in the construct. This eliminates the need for rod-to-rod configurations. A compressor can be used to seat the hook and ensure that it has good bony apposition. Once the desired tension on the hook is achieved, the set screw is tightened over the rod to hold the hook in place.

Technique: Supralaminar Down-going Hook

The insertion of this type of hook is the most challenging of all hook types because the laminae are like shingles with their upper edges inclined or even buried beneath the level below. Not only are the laminae slightly sloped toward the spinal canal but the ligamentum flavum inserts on the undersurface—away from the surgeon's view. This is most pronounced in the T2-T10 region (Figure 11).

Figure 11. *CT scan demonstrating relevant features of laminae in thoracic spine. Note that compared to the lumbar spine, the laminae are "shingled" and overlap such that the top of each lamina is buried under the one above. This is especially pronounced between T2 and T10, below which they become more sagittally oriented.*

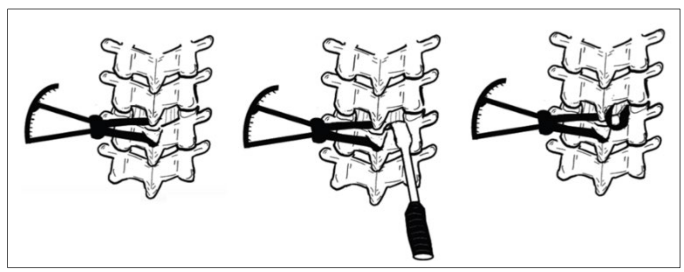

Figure 12. *Down-going (Supralaminar) Hook Technique: lamina spreader, lamina seeker, and hook insertion.*

The cortical surface of the posterior elements is exposed with sub-periosteal dissection to the cranial edge of the lamina. If needed, a lamina spreader can be useful to temporarily gap the inter-laminar space and facilitate hook placement (Figure 12). A curette or lamina seeker is initially used to create the path for the hook. The tip of the instrument is placed on the lamina. It is helpful to begin with the tip facing 90 degrees medially. The tip is advanced toward the cranial edge of the lamina. Care is taken to remain on bone at all times to avoid inadvertent plunging into the canal. Once the tip has passed over the cranial edge, the handle can be rotated to bluntly dissect the ligamentum flavum from the ventral surface of the lamina. This maneuver also brings the tip of the lamina seeker onto the ventral lamina. This process is repeated with the hook on a hook inserter. A "reduced distance" hook is often preferable as it has a shape which matches the "shingling" and provides a tight fit around the lamina. This avoids unnecessary bulk within the canal. When properly placed, the hook will have tight interference fit with little motion. The hook body will face slightly laterally due to the inclination of the lamina.

Comparison to Other Methods

Advantages and Disadvantages of Hooks

Hooks provide several distinct advantages, including preservation of the cortex. Also, pedicle screws at the UIV may occasionally produce paired stress-risers which can cause proximal junctional failure (PJF)—hooks avoid this. Hooks, when utilized with pedicle screws, can provide greater resistance to failure in response to cranial and caudal forces without affecting normal motion segments.[10,11,12] Hooks have less rigid control of upper and lower instrumented vertebrae (UIV and LIV) which allows for the spine to adjust and form a harmonious transition between adjacent segments. Supralaminar and infralaminar hooks are especially strong due to the high surface area contact between the hook and lamina.[10] Furthermore, several biomechanical studies have shown that the dense cortical bone of the lamina contributes to supralaminar and infralaminar hook stability.[7] They can help to counteract dorsally directed, craniocaudal and mediolateral forces on the walls of the pedicle during surgical correction.[7,8,14,15] Finally, pedicle screws are significantly more expensive than hooks.[16]

Hooks also have some disadvantages, including lack of three-dimensional and rotational control. Application of force in only one direction requires that multiple segments be included to achieve fixation.[17] Furthermore, hooks do not "sit still" and align linearly on a rod as effectively as screws and need to be held in order to stay in place. Also, due to the "shoe" of the hook in the canal, there is a small risk for neurologic injury.[10,12,18]

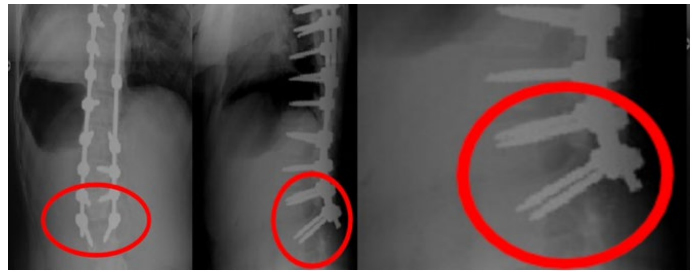

Figure 13. *Sagittal and coronal radiographs of bilateral pedicle screw plowing at the lowest instrumented vertebrae (L3).*

Indications for Hook Use

Several biomechanical studies have demonstrated that repeated craniocaudal and mediolateral forces can lead to "plowing" or pedicle screw movement in bone.[10,12,15] In general, hooks can resist pullout in a segment where pedicle screws have plowed. An example of loss of correction from pedicle screw plowing is shown in Figure 13. Particularly, hooks can augment type C and D pedicles, which have greater instability and difficulty when inserting.[11]

Hooks have significant advantages in several pathologies. For example, hooks have higher pullout resistance compared to pedicle screws in osteoporotic bone.[19] Patients with secondary scoliosis due to Marfan syndrome or Loeys-Dietz syndrome have shown success with correction by pedicle-hook hybrid instrumentation.[20,21,22] Hooks are also especially effective in patients with large curves, particularly proximal thoracic curves and plowed UIV or LIV pedicle screws.[10,11,23] In fact, using hooks allows for a "soft landing" when used in the UIV, which can decrease the risk of PJK. The goal of this technique is to create a gradual transition from instrumented spinal segments to the native spine at the proximal end of the construct. This can decrease the amount of stress at the junction, minimizing risk of PJK. The UIV is exposed leaving the cranial facet joint capsules intact. One or more supralaminar, infralaminar, pedicle, or transverse process hooks can be used to extend the construct proximally on the unilateral side, which can subsequently decrease junctional stresses.[24]

Senior Author's Preferred Use

I prefer to use hooks at the UIV in idiopathic and non-idiopathic deformity (except for some Lenke 5 curves). This limits the amount of soft tissue dissection compared to the straight-ahead direction if screws were used at this level. I use a pedicle hook on the concavity and a transverse process hook on the convexity (Figure 14). On rare instances where a transverse process hook is not feasible, a supralaminar hook may be used. In Scheuermann kyphosis, two transverse process hooks are used at the UIV (Figure 15).

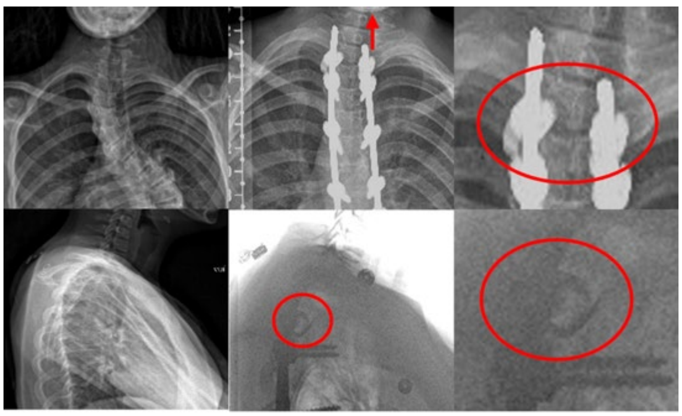

Figure 14. *Pre- and post-operative sagittal and coronal radiographs of a pedicle hook at the concavity and transverse process hook on the convexity of the curve in a patient with adolescent idiopathic scoliosis (upward arrow on concavity showing where hook is pushing up).*

I also use offset infralaminar hooks as a back-up at the LIV when the pedicle screw appears weakened by the corrective forces (Figure 16). This happens most often at the convexity when forces are directed cranially at the LIV. In other words, the LIV is augmented with an extra anchor.

In Early Onset Scoliosis (EOS), I use hooks as a third rod in hemivertebra resections to provide additional cortical purchase and relieve stress from the immature pedicles as described by Hedequist et al. (Figure 17).[25] Finally, I use hooks at the upper foundation in many growing rod constructs when the pedicles are narrow. A combination of a down-going hook with an up-going hook one level caudal—known as a "claw" construct—provides a durable foundation (Figure 18).

Figure 15. *Sagittal and coronal radiographs of two transverse process hooks used at the upper instrumented vertebrae in a patient with Scheuermann kyphosis.*

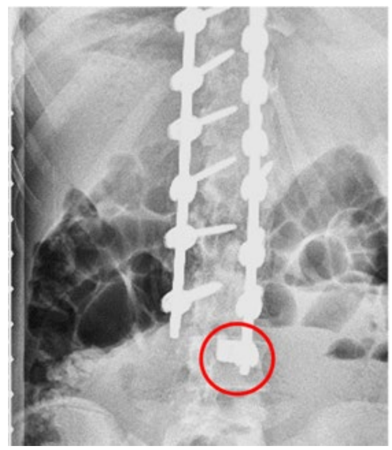

Figure 16. *An offset lamina hook is added at the same level as a pedicle screw which is thought to be at risk for plowing.*

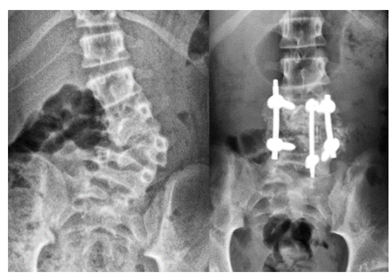

Figure 17. *In this low lumbar hemivertebra resection it was important to save levels so the pedicle screws were augmented with two hooks on a third rod.*

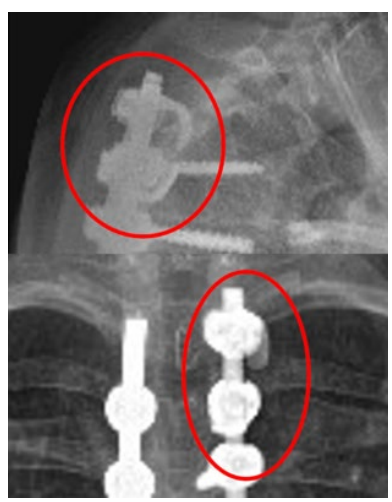

Figure 18. *A combination of a down-going hook with an up-going hook one level caudal—known as a "claw" construct—provides a durable foundation in growing rod constructs when the pedicles are narrow.*

Summary

Hooks continue to play an integral role in correcting spinal deformity. Use of hooks as an adjunct to pedicle screw constructs can help to achieve stability and is especially advantageous in several pathologies. Thus, the modern spine surgeon can benefit from understanding the types of hooks, advantages, disadvantages, indications, and surgical techniques for insertion.

Additional Links

- AO *Surgery Reference–Hook Insertion*: https://surgeryreference.aofoundation.org/spine/deformities/adolescent-idiopathic-scoliosis/basic-technique/hook-insertion
- Chiba M, McLain RF, Yerby SA, Moseley TA, Smith TS, Benson DR. *Short-segment Pedicle Instrumentation. Biomechanical Analysis of Supplemental Hook Fixation*. *Spine (Phila Pa 1976)*. 1996;21(3):288-294. doi:10.1097/00007632-199602010-00006

References

1. Harrington PR. Treatment of scoliosis. Correction and internal fixation by spine instrumentation. *J Bone Joint Surg Am*. 1962;44-A:591-610.

2. Luque ER. Segmental spinal instrumentation for correction of scoliosis. *Clin Orthop Relat Res*. 1982;(163):192-198.

3. Cotrel Y, Dubousset J, Guillaumat M. New universal instrumentation in spinal surgery. *Clin Orthop Relat Res*. 1988;227:10-23.

4. Hasler CC. A brief overview of 100 years of history of surgical treatment for adolescent idiopathic scoliosis. *J Child Orthop*. 2013;7(1):57-62. doi:10.1007/s11832-012-0466-3.

5. Roy-Camille R, Roy-Camille M, Demeulenaere C. Ostéosynthèse du rachis dorsal, lombaire et lombo-sacré par plaques métalliques vissées dans les pédicules vertébraux et les apophyses articulaires [Osteosynthesis of dorsal, lumbar, and lumbosacral spine with metallic plates screwed into vertebral pedicles and articular apophyses]. *Presse Med*. 1970;78(32):1447-1448.

6. Suk SI, Kim JH, Kim SS, et al. Pedicle screw instrumentation in adolescent idiopathic scoliosis (AIS). *Eur Spine J*. 2012;21(1):13-22. doi:10.1007/s00586-011-1986-0.

7. Baluch DA, Patel AA, Lullo B, et al. Effect of physiological loads on cortical and traditional pedicle screw fixation. *Spine (Phila Pa 1976)*. 2014;39(22):E1297-E1302. doi:10.1097/BRS.0000000000000553.

8. Benson CD, Lansford T, Cotton J, et al. Biomechanical Analysis of Cement Augmentation Techniques on Pedicle Screw Fixation in Osteopenic Bone: A Cadaveric Study. *Spine Deform*. 2014;2(1):28-33. doi:10.1016/j.jspd.2013.10.002.

9. Kwak DS, Shin JH, Cho HJ, et al. Fixation Strength of Pedicle and Cortical Lumbar Vertebral Screws after Laminectomy: A Cadaver Study. *J Neurol Surg A Cent Eur Neurosurg*. 2018;79(4):273-278. doi:10.1055/s-0038-1639333.

10. Watanabe K, Lenke LG, Matsumoto M, et al. A novel pedicle channel classification describing osseous anatomy: how many thoracic scoliotic pedicles have cancellous channels?. *Spine (Phila Pa 1976)*. 2010;35(20):1836-1842. doi:10.1097/BRS.0b013e3181d3cfde.

11. Murakami H, Tsai KJ, Attallah-Wasif ES, et al. A biomechanical assessment of infra-laminar hooks as an alternative to supra-laminar hooks in thoracolumbar fixation. *Spine (Phila Pa 1976)*. 2006;31(9):967-971. doi:10.1097/01.brs.0000214932.49027.6a.

12. Chiba M, McLain RF, Yerby SA, et al. Short-segment pedicle instrumentation. Biomechanical analysis of supplemental hook fixation. *Spine (Phila Pa 1976)*. 1996;21(3):288-294. doi:10.1097/00007632-199602010-00006.

13. Kim HJ, de Kleuver M, Luk K et al. “AO Surgery Hook Insertion.” AO Surgery Reference, surgeryreference.aofoundation.org/spine/deformities/adolescent-idiopathic-scoliosis/basic-technique/hook-insertion.

14. Wray S, Mimran R, Vadapalli S, et al. Pedicle screw placement in the lumbar spine: effect of trajectory and

screw design on acute biomechanical purchase. *J Neurosurg Spine*. 2015;22(5):503-510. doi:10.3171/2014.10.SPINE14205.

15. Bianco RJ, Arnoux PJ, Wagnac E, et al. Minimizing Pedicle Screw Pullout Risks: A Detailed Biomechanical Analysis of Screw Design and Placement. *Clin Spine Surg*. 2017;30(3):E226-E232. doi:10.1097/BSD.0000000000000151.

16. Jaquith BP, Chase A, Flinn P, et al. Screws versus hooks: implant cost and deformity correction in adolescent idiopathic scoliosis. *J Child Orthop*. 2012;6(2):137-143. doi:10.1007/s11832-012-0400-8.

17. Liljenqvist U, Hackenberg L, Link T, et al. Pullout strength of pedicle screws versus pedicle and laminar hooks in the thoracic spine. *Acta Orthop Belg*. 2001;67(2):157-163.

18. Fagerström T, Hedlund R, Bancel P, et al. Laminar hook instrumentation in the cervical spine. An experimental study on the relation of hooks to the spinal cord. *Eur Spine J*. 2001;10(4):340-344. doi:10.1007/s005860100251.

19. Hasegawa K, Takahashi HE, Uchiyama S, et al. An experimental study of a combination method using a pedicle screw and laminar hook for the osteoporotic spine. *Spine (Phila Pa 1976)*. 1997;22(9):958-963. doi:10.1097/00007632-199705010-00004.

20. Demetracopoulos CA, Sponseller PD. Spinal deformities in Marfan syndrome. *Orthop Clin North Am*. 2007;38(4):563-vii. doi:10.1016/j.ocl.2007.04.003.

21. Gjolaj JP, Sponseller PD, Shah SA, et al. Spinal deformity correction in Marfan syndrome versus adolescent idiopathic scoliosis: learning from the differences. *Spine (Phila Pa 1976)*. 2012;37(18):1558-1565. doi:10.1097/BRS.0b013e3182541af3.

22. Bressner JA, MacCarrick GL, Dietz HC, et al. Management of Scoliosis in Patients with Loeys-Dietz Syndrome. *J Pediatr Orthop*. 2017;37(8):e492-e499. doi:10.1097/BPO.0000000000000833.

23. Di Silvestre M, Bakaloudis G, Lolli F, et al. Posterior fusion only for thoracic adolescent idiopathic scoliosis of more than 80 degrees: pedicle screws versus hybrid instrumentation. *Eur Spine J*. 2008;17(10):1336-1349. doi:10.1007/s00586-008-0731-9.

24. Cazzulino A, Gandhi R, Woodard T, et al. Soft Landing technique as a possible prevention strategy for proximal junctional failure following adult spinal deformity surgery. *J Spine Surg*. 2021;7(1):26-36. doi:10.21037/jss-20-622.

25. Hedequist D, Emans J, Proctor M. Three rod technique facilitates hemivertebra wedge excision in young children through a posterior only approach. *Spine (Phila Pa 1976)*. 2009;34(6):E225-E229. doi:10.1097/BRS.0b013e3181997029.