

Spinal Navigation and Robotics Are More Accurate, More Precise, and More Minimally Invasive

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With any emerging technology there is great anticipation and marketing; however, it is important that spinal surgeons who want cutting edge treatment for their patients understand Everett M. Rogers “Diffusion of Innovations.”¹ He outlined the theoretical participants who adopt innovative technologies—5 Adopter Categories (Figure 1)—innovators (2.5%), early adopters (13.5%), early majority (34%), late majority (34%), and laggards (16%). They are modeled in 5 progressive stages initially influenced by prior conditions yet ultimately directed by peer-to-peer intercommunication—1. Knowledge, 2. Persuasion, 3. Decision, 4. Implementation, and 5. Confirmation. This is usually a bell-shaped diffusion curve, not an S-shaped diffusion curve. Some authors² have already compared the advent of spinal robotics to be as impactful as the industrial revolution and spinal navigation to be similar to the penetration of the cell phone. They are not. There have only been 3 innovations that have deviated from the bell shaped curve and been a S-shaped diffusion curve, demonstrating exponential adoption—the personal computer, the internet, and cell phones.

This Spine Focus issue of the prestigious AO Global Spine Group defined by rigorous peer review process—represents a distillation of only the very best articles. It is such a highly competitive program that frequently many of the invited articles don’t make it and reach final print. Thus these scheduled educational correspondence reset the framework of innovation with the clear intention of spreading and stimulating creativity—which the future will consider several landmark articles that establish the place of spinal navigation and robotics. Currently we are along the bell shaped innovation curve at “the turning point,” Malcom Gladwell’s “tipping point” or “the inflection point”—the space between the early adopters (13.5%) and the early majority (34%). This is described by Geoffrey A. Moore³ as “Crossing the Chasm.” The most critical step in the technology of an innovative life cycle is making the transition between the visionaries (early adopters) and the pragmatists (early majority). It is not predictable to depend on innovators or early adopters because the group is too small and they are too quick to latch

onto the next perceived innovation. Instead it is the early majority that is the decisive recruitment sector—they are a larger group within the target population (34%), they contain key opinion leaders that generate momentum and convey trust given their conservative approach to the remaining most risk adverse cohorts. The challenge is that they are content with the traditional spinal technology they currently use for their patients. Fortunately, they are more dedicated and conscientious once they are convinced to change their practice.

This Focus Issue proves that spinal navigation and robotics has successfully “jumped the chasm.” The complications and early learning curve are acceptable in several different institutional clinical series—Sinkov, La Marca, Kleck, McAfee, etc. Several varied types of navigation have proved to be successful in the following peer-reviewed articles—surface navigation (Qureshi), optoelectronic data interpolation process (Cunningham), 7-D Visible Light grid based (Stewart), calibrated compressed air (Eisermann), and skeletally-based fiducials (Soltanianzadeh and Theodore). Furthermore Coric’s article uses MIS paraspinal surgical approaches for the cervical spine and Kim uses MIS paraspinal approaches MIS for the lumbar spine and also utilizes endoscopic visualization. Other authors have claimed that Spinal navigation and robotics has re-established the standard of care. I would disagree as this is a legal definition and requires a broader multi-state courtroom case-law track record. Instead Coric et al have made cervical navigation and robotics the current state-of-the art. It is not possible to achieve and insert cervical pedicle screws of perfect trajectory, size, and length to the degree demonstrated in Coric’s experience using only freehand techniques. The most

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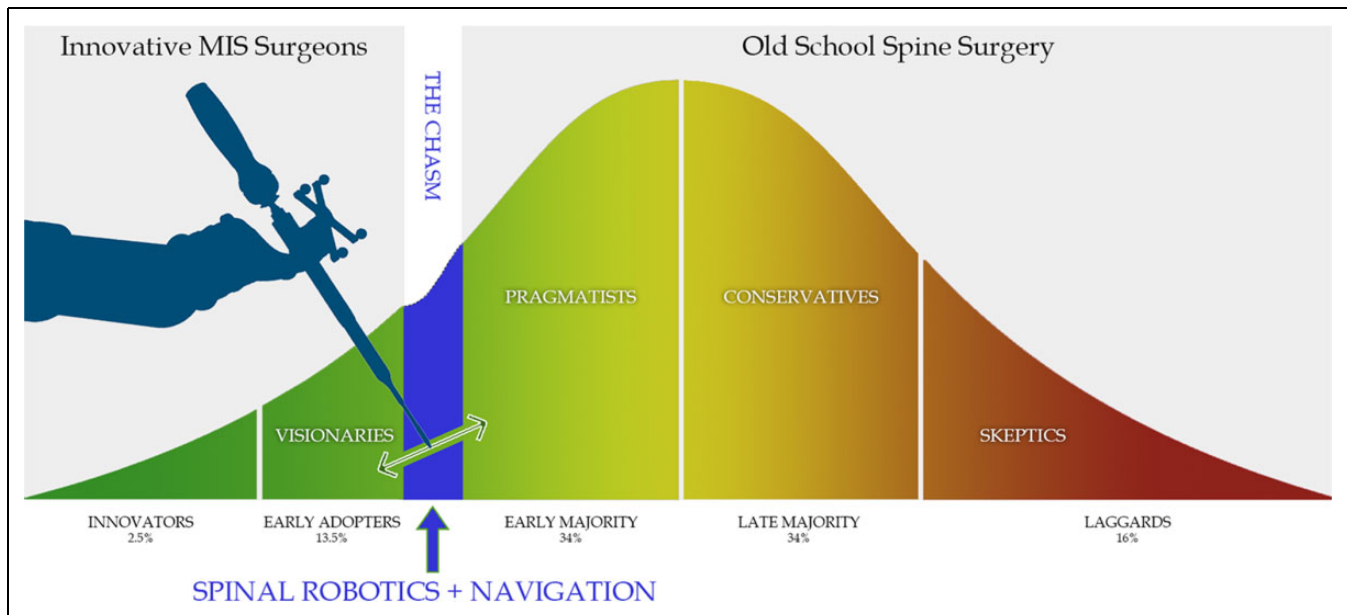


Figure 1. The technology and precision of Spinal Robotics and Navigation are currently at the inflection point along the Innovation Diffusion Curve. The articles in this issue are compelling enough to help Minimally Invasive Surgical (MIS) techniques to Cross the Chasm from the early adopters to the early majority of evidence-based spinal surgeons.

experienced cervical spine freehand pedicle screw experience was published by Abumi. Coric's series is smaller but his incidence of complications is less, and his length of hospitalization was less due to a paraspinal approach which Coric et al and Kim et al show is less invasive to the paraspinal soft tissues.

Another expression of minimal invasiveness is lower radiation exposure. The work of Berven et al is very convincing. If there is any clear cut expression of decreasing imaging and radiation requirements it is the performance of S2AI screws in deformity surgery. Using freehand techniques the surgeon requires AP, lateral, and teardrop fluoroscopic views repeatedly to probe, drill, and insert large pelvic screws, left and right side into the superior acetabular bone. This requires a minimum of 6 views for each side, whereas using navigation, the only imaging is that required for registration. The total radiation exposure to the patient and operative team are dramatically reduced.

The continuation of adoption of navigation and robotics is assured as there is plenty of room for growth and improvement in the next 3 years. Cunningham et al meta-analysis establishes the basic scientific accuracy—0.1 mm translation and 0.1 mm degree in optoelectronic laboratory conditions. This precision falls off in clinical application in the spine to 3 to 4 mm translation and 2 to 3 degrees of rotational accuracy. Total joint navigation and robotics currently lies between these 2 extremes. Total joint robotics does not involve any viscoelastic joints, does not involve a series of 3-joint complexes like the spine, and does not involve a series of chain linkages between the navigated bone and the skeletally anchored reference fiducials.

As predicted the intrinsic computed accuracy of the daVinci urologic robot system is better than spine (1.02 mm) but still

not to the level of Optotrak (0.25 mm).⁴ daVinci systems are in their third generation—it is anticipated that the accuracy of spinal navigation and robotics will demonstrate similar improvements over the same time period with iterative improvements.

There is plenty of room to grow clinically for spinal navigation and robotics. The improvement or current challenges addressed in this Special Focus Issue, including references are multifactorial.

1. The patient's thoracic spine moves under anesthesia with respirations as the chest cavity expands. This decreases the accuracy of placing pedicle screws on the upper convex side of adolescents with scoliotic curves.
2. There needs to be more skeletally-based reference fiducials and they need to be constantly upgraded and closer to the target site (Soltanianzadeh and Theodore).
3. Intervening spinal motion above and below spinal anchors—ie Mazor L3-4 motion when the Hover-T frame spans from the 2 pelvic Steinmann pins (PSIS) to the T12 spinous process (K-wire). The intercolated spinal segments that are bridged are free to move.
4. Need confirmatory additional skeletal reference fiducials to prevent skiving.
5. There should be progressive incorporation of information as each pedicle screw is successfully inserted using AI. For some reason this has not been accomplished or achieved by engineers to this point. The successive introduction of each pedicle screw should be merged into the virtual information—each successive pedicle

screw should add increased accuracy, Artificial Intelligence (AI) learning. Still programs are not sophisticated to do this clinically.

6. The clinical accuracy of robotics and navigation is not solely related to the sophistication of the robot. The resolution of the fluoroscopy used in registration and merging the virtual data intraoperatively is often the gating item. Improvement in intraoperative 3D computed tomography increases the accuracy down toward the ideal levels and decreases the operative time.

Proof of the increased application and “crossing the chasm” is also more convincing just observing the increase in the numbers of cases of the included articles since submission—

Finally, this Special Focus Issue can help establish spinal navigation and robotics as the state of-the-art when one gains the perspective of several prospective randomized multi-institutional MIS trials that have been published since these manuscripts were written. Good et al in their MIS ReFRESH study compared the complications and revision rates from Mazor robotics in 485 patients—374 robotic guidance arm and 111 patients in a fluoroscopy guidance arm from 9 sites. Fluoroscopy time per screw during instrumentation was 3.6 +/- 3.9 seconds with Mazor compared to 17.8 +/- 9 seconds with fluoro-guidance indicating an 80% reduction in intraoperative radiation per screw ($P < .001$). During the first postoperative year robotic guidance led to a 5.8 times lower risk of surgical complications. The use of robotic guidance led to an 11 times lower risk of revision surgery.

It is important to follow the progress of prospective randomized trials such as the MIS-ReFRESH study⁵ as more data is accumulated over longer time intervals. Staartjes et al⁶ pooled 3 randomized controlled trials and Lieber⁷ is following 257 patients in a National Inpatient Sample with matched freehand controls. The key to improving the adoption of spinal robotics and navigation is to continually apply the concepts introduced in these articles in the AO Spine Focus Issue. Gradually the

accuracy should improve, the complications should decrease and the revision rate for all spine surgery should decrease as the early majority of fellowship-trained spinal surgeons gain more peer-reviewed and networked experience.

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