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The manuscript by Hedequist, Larson and Erickson, which also includes a video of the surgical technique, is a great overview of where we are today with surgical navigation and robotics when placing pedicle screws in pediatric spinal deformity. The premise behind this writing is that these technologies can improve the accuracy of placing pedicle

screws in deformity patients, presumably avoiding complications from misplacement and avoiding reoperation, saving time, limiting blood loss, and best of all, leading to better surgical outcomes. The manuscript and video beautifully outline the technique of both navigation alone, as well as the use of robotic screw placement. Dr. Hedequist nicely demonstrates the surgical technique in the video using patient surgical footage, in addition to screw placement in a sawbone model. He reviews the specific details which make this technique successful in the hands of those who use it. The manuscript outlines three concepts of navigation/robotics: 1. screw accuracy is improved; 2. preop planning is possible, screw trajectory guidance occurs, and all instruments can be navigated; 3. the technology needs further study to determine the benefits/risks of routine use. Let's analyze each of these.

The notion that navigation/robotics will improve accuracy is certainly logical as machines are more accurate than humans, and most spine studies agree with this conclusion.¹⁻⁵ Screw accuracy is certainly critical for the safe and effective use of pedicle screws, but questions remain as to the degree to which this accuracy

is improved. We are reporting at the upcoming 2020 POSNA meeting a 16-year experience placing 20,983 pedicle screws (16,125 thoracic, 4,858 lumbar) without navigation in 1,667 AIS patients with a 0.72% of revision due to screw malposition without neurologic deficits or other adverse sequelae.⁶ Similarly, a large multicenter study of 1,435 AIS patients in which screws were most likely placed without navigation, reports a revision rate for screw misplacement of 0.6%⁷, and both studies compare favorably to those using navigation. We can learn from these studies to improve the overall accuracy without the need for navigation by limiting screw placement in the high-risk areas (proximal thoracic spine and the concavity), “dosing” the screw density to the severity of the deformity, and critically analyzing the intraoperative fluoroscopy images or CT scans to ensure safe placement prior to exiting the operating room. Finally, it may be that more straightforward diagnoses like AIS are done without navigation/robotic surgery, while the more complex, larger deformities and revision surgeries are best suited for navigation. The argument against this is the need for repetition to ensure the team is familiar and facile with the technology.

The second point of the preoperative planning feature of these navigation systems is important and allows for one to choose the diameter and length of the screws which provides an opportunity to have the implants ready, limiting time and space in the operating room. Limiting time in the operating room is an important feature to decreasing cost since it is one of the two main drivers of surgical costs in AIS surgery, with the other being implant costs.^{8,9} It should be remembered that preoperative or intraoperative CT imaging is not necessary to carefully plan surgery as plain radiographs can be measured and used as a guide together with previous experience to selecting the most common screw sizes that might be used for each pedicle. However, it does not provide the ability to identify the exact size or trajectory for each screw afforded by the navigation

technology. Other important variables are important to take into consideration when deciding to move forward with these technologies and include the significant up-front cost, including the need for multiple units at a large busy center, the size and bulk of the imaging modalities and the robotic arm, and finally, the radiation exposure to the patient and surgical/anesthesia team since some form of a 3D fluoroscopy or CT scan is necessary. The significant cost of the technology can be justified if revision surgery can be decreased and surgical time can be significantly diminished. However, neither of these parameters has been fully studied as most studies are limited by their retrospective design and incomplete postoperative advanced imaging of all of the patients. The cost for the 3D fluoroscopy units (Siemens Orbic 3D, Ziehm RFD 3D, Siemens CIOS spin) are in the \$350-500k range, the O-arm is closer to \$ 900k, with the true intraop CT scanners (Mobius Airo and Samsung BodyTom) generally over \$1 million.¹⁰ The navigation systems are an additional cost between \$300-700k, with significant additional costs (>\$1 million) for the two additional robotic arms that are available (MazorX and Globus Excelsius). Although there is greater radiation when placing pedicle screws with navigation¹¹, the ability to adjust to a “pediatric” mean radiation setting (1.17mSV) can decrease the dose up to 10x the defaults on the system and limits the difference between the navigation and fluoroscopy technique.¹² Hedequist et al. nicely review the issues around the increased radiation and provides a balanced discussion on the topic with key steps to limit exposure to the team with protective shields during imaging.

The third point is something we can all agree on. Further research is needed to continue to understand the benefits and risks of these technologies to more effectively manage the patients we are all privileged to treat. There is no question the technology will improve over time, especially with the important features like accuracy, the size of the units, and hopefully the cost. The paper by Hedequist, Larson and Erickson reviewed the important aspects of this topic. I found that the technique section, together with the video, provided critical tips to optimize

the technology and should be read and viewed by anyone beginning to use these platforms.

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