The O-arm revolution in spine surgery

To The Editor: We read with interest the recent article by Ray et al.20 (Ray WZ, Ravindra VM, Schmidt MH, et al: Stereotactic navigation with the O-arm for placement of S-2 alar iliac screws in pelvic lumbar fixation. Technical note. J Neurosurg Spine 18:490–495, May 2013). Most of the major breakthroughs in the history of neurosurgery have been associated with the development and incorporation of new imaging strategies into daily practice. In the 1970s the advent of CT scans (at that time a brand new and innovative imaging technique)9 brought fresh light to a world in which neurosurgeons frequently chose the side of emergent trepanations for acute epidural hematoma evacuation based on a scary combination of neurological examination and personal intuition.17 Also during this period the evaluation of the status of the ventricular system and the presence of intracranial space-occupying lesions was based on a technique involving injection of air into the subarachnoid space, which was referred to by a fancy name composed of the combination of Greek terms (pneumatos, enkephalos, and graphos), probably to hide from the nonspecialists the primitive nature of the procedure that was being performed.9

Similarly, the application of MRI to the study of intracranial lesions brought a whole new therapeutic paradigm in which slow-growing tumors could be detected in much earlier stages, and neuroradiologists embraced the audacious challenge of attempting to preoperatively diagnose the general histological nature of intracranial lesions as ischemic, tumoral, demyelinating, or infectious based on the patient epidemiology and the imaging characteristics revealed by the different MRI sequences.8 Of course, the new generation of MRI modalities (including spectroscopy, perfusion, functional magnetic resonance, and diffusion-weighted and diffusion tensor imaging)9 brought a completely new world of perspectives regarding the diagnosis and follow-up of CNS pathologies.

Nevertheless, despite the fact that such imaging modalities contributed significantly to the improvement of preoperative diagnosis and postoperative follow-up of CNS lesions, a crucial moment toward advancing the quality of the neurosurgical procedures was the actual incorporation of such imaging developments into the operating room setting. In the field of neurooncology, several research studies have already demonstrated the benefits of intraoperative imaging (either with ultrasonography15 or, more markedly, with high-field intraoperative MRI16) as adjuvant techniques that may provide a more accurate evaluation of the extent of tumor resection. Similarly, in vascular neurosurgery, the use of intraoperative angiography11 and, more recently, the developments of indocyanine green videoangiography19 have also substantially contributed to improving the quality of the neurosurgical procedures for intracranial aneurysms and arteriovenous malformations.

However, in spine surgery, besides the adoption of intraoperative fluoroscopy, which for some procedures such as pelvic fixation has become the standard imaging modality, few other similar contributions can be identified. In fact, although intraoperative fluoroscopy currently plays a major role in minimally invasive spine surgery, several studies have demonstrated that placement of pedicle screws based exclusively on anatomical landmarks (the so-called “freehand” technique) can be safely performed during the vast majority of cases that do not involve major deformities, with rates of pedicle violation that are not significantly different from those of procedures in which intraoperative fluoroscopy is employed.15,16

In relation to pelvic fixation, although several studies have demonstrated that the new technique of using sacral-alar iliac screws may present major advantages over the classic iliac wing screws,13,14 the study of Ray et al.20 is the first report in the literature of the benefits of employing intraoperative CT (O-arm) for stereotactic navigation–assisted placement of such type of screws. By providing 3D guidance, as opposed to plain fluoroscopic imaging, the authors have demonstrated that the use of intraoperative CT-guided navigation leads to a very high rate of optimal sacral-alar iliac screw placement (that is, a long, 80–100 mm screw that traverses the sacroiliac joint passing adjacent to the cortical surface located just above the iliac notch).

As noted in Table 1 in their paper, the vast majority of procedures involving pelvic fixation in the study by Ray et al. were long thoracolumbar fusions involving scoliotic deformities or extension of fusion after pseudarthrosis. In our experience, similarly to the authors’ report, the use of the O-arm has brought major changes in the dynamics of such complex spine procedures.

Although the objective data comparing our surgical series before and after the advent of the O-arm is still under final analysis, we have experienced that the use of intraoperative CT-assisted navigation brought substantial changes, both in terms of intraoperative blood loss as well as in the duration of such complex procedures. In fact, before using the O-arm we used to begin such posterior spinal fusions (especially those cases involving a major coronal imbalance) with decompression and multiple osteotomies, so that pedicle screw placement could be performed under direct palpation and visualization of the pedicles. By having the O-arm available, we have changed our surgical routine so that nowadays we perform acquisition of intraoperative CT scans right after exposure of
the bone landmarks in the whole surgical wound. After that, pedicle screws are placed under intraoperative CT-guided navigation, and we finally proceed to the portion of the surgery involving bone decompression and multiple osteotomies, usually the stage that presents the most substantial blood loss due to the extensive exposure of the epidural space and bone resection.

In relation to the scientific literature supporting the benefits of intraoperative CT-guided navigation, previous studies have already demonstrated that the accuracy of pedicle screw placement with the use of O-arm–assisted navigation is higher (99%) than that of the freehand technique (94.1%). Additionally, according to a recent prospective randomized study, the rates of correct screw placement in thoracolumbar instrumentation were also higher with O-arm navigation guidance in comparison with fluoroscopic-guided screw placement. Although another recent study comparing pedicle screw placement with navigation based on either preoperative or intraoperative CT scans did not show major differences in the overall accuracy for pedicle screw placement, it demonstrated that the surgical duration was significantly shorter during procedures using intraoperative CT-guided navigation.

Another major advantage of the use of intraoperative CT-guided navigation is the lower rates of facet joint capsule violation at the superior end of the instrumentation, which has been demonstrated by a recent study, and which may have significant long-term implications regarding the incidence of adjacent-segment disease. Moreover, the use of intraoperative CT-guided navigation appears to be ideal for the placement of screws in alternative trajectories recently proposed as a means of increasing the cortical bone purchase along the screw trajectory, such as the transvertebral pedicle screw (which crosses the intervertebral disc), or the more lateral trajectory in which the screw passes through the cortical bone of the pedicle and vertebral body.

Another area in which initial studies have already demonstrated that the incorporation of O-arm technology may provide major benefits is minimally invasive spine surgery. In fact, the use of intraoperative CT-guided navigation may obviate the need for continuous fluoroscopy (and the consequent high exposure to radiation), one of the main criticisms of minimally invasive spine surgery procedures.

Finally, the availability of the O-arm offers the unique possibility of checking the positioning of the pedicle screws before final closure of the surgical wound, virtually eliminating the necessity of revision surgeries for screws repositioning. Although the accuracy of O-arm navigation–guided screw placement has reached as high as 97.5% in some series, this “final check” CT scan before closure has been demonstrated to lead to repositioning of approximately 1.8% of the screws placed under intraoperative CT-guided navigation. In such study, all these misplaced screws were considered as deserving revision, and would otherwise only be visualized at the postoperative period.

However, there are still some challenges regarding the incorporation of intraoperative CT into the daily routine of spine surgery. The first challenge is the institution of a meticulous routine for protecting the surgical wound and avoiding contamination and infection, which in some early series employing intraoperative CT-guided navigation has reached the alarming rate of 7.5%. Because sterile covering of such a circular system appears very impractical, at our institution we have adopted a protocol that involves covering the surgical wound with multiple layers of folded sterile fields (Fig. 1). Although the final data remains under analysis, in a retrospective comparative overview with our previous experience before the use of the O-arm, the number of infections that could be specifically attributed to the use of the O-arm was negligible.

Another major obstacle to the more widespread implementation of intraoperative CT is the still very high costs associated with its acquisition (approximately $1.5 million), which seems almost prohibitive except for those very high-volume academic institutions. Nevertheless, it is important to remind hospital administrators that the overall costs of such technology must be evaluated in perspective to other available alternatives for intraoperative verification of pedicle screw accuracy. A very interesting cost-effective study to be performed in the future would be to compare, over the course of some few years (probably after around 500 cases), the overall costs of the O-arm—and its associated reduction in terms of operating room time, less revision surgeries, and fewer days of intensive care unit and hospital stay related to the reduced blood loss and overall morbidity—with the alternative of intraoperative neurophysiological monitoring with electromyography, which for legal reasons has been widely used by many groups in every instrumentation case.

In summary, the advent of intraoperative CT and the possibility of its association with navigation systems, avoiding the necessity of the time-consuming repetitive calibration for each single vertebra that is required by the paired-point technique based on preoperative images, renders such new imaging technology as a breakthrough advance in spine surgery that promises to bring major improvements in terms of surgical morbidity and clinical outcomes, especially in more challenging spinal procedures such as those involving complex deformity, spinal trauma, and placement of cervical pedicle screws.

Similar to other neurosurgical subspecialties such as neurosurgical oncology and vascular neurosurgery that have benefited much earlier from the incorporation of intraoperative imaging, it is finally time for spine surgery to experience the advantages associated with real-time intraoperative visualization systems. In relation to the scientific evaluation of the advantages of such technological advances, the study of Ray et al. is very likely only the beginning of many others that are expected to demonstrate that routine spinal techniques such as placement of sacral alar-iliac screws may strongly benefit from the use of intraoperative CT-guided navigation. In fact, after the use of the O-arm we believe that every spine surgeon who has already struggled with major coronal imbalances in complex deformity surgeries will have a strong feeling of relief as expressed by the famous quotation from a blind man, who, according to the Holy Scriptures after being healed by the Messiah, stated the words that later were immortalized in the classic hymn “Amazing Grace” (John Newton, 1827).
“One thing I know: that I once was blind, and now I can see!” (John 9:25).

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Disclosure
The authors report no conflict of interest.

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Response: We appreciate the opportunity to respond to the comments of Drs. Mattei and Fassett. The authors provide a nice historical review of intraoperative imaging and its evolution to current 3D imaging modalities. As discussed by the authors, fluoroscopy has long been the mainstay of intraoperative imaging for thoracolumbar pedicle screw placement and is considered (by most) critical for all minimally invasive spinal procedures. Given the perceived/reported safety of freehand or fluoroscopic pedicle screw placement, the incorporation of more advanced intraoperative navigation has not been adopted into routine practice by most spine surgeons. In addition, as discussed, routine use of intraoperative navigation for pedicle screw placement faces several practical hurdles regarding cost, availability, time, and concerns of infection. Despite these limitations, we agree and believe intraoperative navigation for spine instrumentation is gaining traction.

We agree with Drs. Mattei and Fassett that intraoperative navigation represents a safe and effective technique for pedicle screw placement, particularly when performing instrumentation in revision cases or for challenging anatomy. Furthermore, intraoperative navigation with an optical or magnetic tracking device will reduce radiation exposure to the surgical team and potentially to the patient. We have also found the navigation to be useful for complex thoracolumbar deformity, and after overcoming the initial learning curve, our operative time has also decreased compared with standard fluoroscopy use. In addition to complex thoracolumbar procedures, we have begun to use intraoperative navigation for cervical pedicle screws. In contrast to cervical lateral mass screws, cervical pedicle screws provide dense cortical fixation for complex posterior-only reconstruction and deformity correction. While lateral mass screws can be safely placed through either a freehand or fluoroscopy-assisted method, placing cervical pedicle screws is more technically demanding. Several authors have reported safe placement with fluoroscopy alone, but we believe O-arm navigation holds tremendous potential for more routine cervical pedicle screw placement. Overall, we agree with Drs. Mattei and Fassett and believe spine surgery will enjoy more widespread use of intraoperative navigation and appreciate the authors’ kind comments.

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Epidural fibrosis

To The Editor: We read with interest the article by Liu et al. (Liu L, Sui T, Hong X, et al: Inhibition of epidural fibrosis after microendoscopic discectomy with topical application of mitomycin C: a randomized, controlled, double-blind trial. Clinical article. *J Neurosurg Spine* 18:421–427, May 2013). The authors reported that topical treatment with mitomycin C (MMC) is effective for inhibiting postoperative epidural fibrosis at 3 months after surgery, although clinical benefit was not observed. The authors emphasized that “Mitomycin C has an excellent safety profile with no medically significant adverse events…at lower concentration” (0.5 mg/ml), and MMC “has been used topically in ophthalmological and urological surgery to suppress fibrotic enlargement.” However, complications due to topical use of MMC in ophthalmological areas have been reported, including devastating complications such as severe progressive scleral thinning with or without calcified plaques, necrotizing scleritis, and loss of vision. For example, Kim used MMC eye drops (0.0002 mg/ml) 4 times daily for 2–5 days after regional conjunctivectomy for chronic conjunctival injection. Conjunctival epithelial defects persisted up to 27 months (mean 13.65 months) after the surgery and produced many complications such as thinning of the sclera or avascular necrosis of the sclera in as
many as 92% of the patients.11 Because of the frequent complications, the Korean Ministry of Health and Welfare inspected 1713 people who underwent Kim’s surgery4 and on February 25, 2011, prohibited MMC usage after conjunctivectomy.

Some experimental studies reported reduced epidural fibrosis with MMC use.2,6,11 However, clinical studies did not support the experimental study.1,15 A larger study may be not the answer to solving the discrepancy with the study of Liu et al. Mitomycin C may not only induce thinning and perforation of the sclera, but also produce those complications with dura, because both dura and sclera have similar vascularity and are structures composed of Type I collagen.4,12 Moreover, long-term complications need to be monitored, because the ischemic process after MMC use can continue for more than 2 years. Therefore, it is important to carefully observe patients who have been administered MMC at the epidural space over a long-term period in an effort to prevent late complications.

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Response: We are grateful for the insightful comments of Drs. Lee and Kim, as they point out that topical use of MMC should be considered cautiously due to its potentially devastating complications. Because MMC was explored as an antibiotic drug to control postoperative scarring, it presented impressive benefits for inhibiting the wound healing response and reducing postoperative scarring. But the safety of invasive MMC use remains controversial. Many studies, including some meta-analyses, have demonstrated that MMC is safe and effective in lower doses (no more than 1 mg/ml) for a short time (2–5 minutes), although there continue to be concerns regarding long-term safety.2,3 On the other hand, as Drs. Lee and Kim point out, devastating complications including loss of vision, endophthalmitis, hypotony and maculopathy, severe progressive scleral thinning with or without calcified plaques, and necrotizing scleritis were reported in some studies. Cytotoxic effects of MMC on cells are dose- and time-dependent, so further studies are warranted to determine the optimal dosage of MMC for preventing scarring. From our study, topical application of 0.5 mg/ml of MMC for 5 minutes was the optimal concentration in preventing epidural fibrosis.4

Mitomycin C is an alkylating agent interfering with replication of DNA and suppressing cellular RNA and protein synthesis. Thus, MMC should be largely effective in proliferating cells. Local treatment of laminectomy sites with MMC inhibits the proliferation and differentiation of fibroblasts, which prevents dural adhesions. To clarify the safety of MMC during application in spinal surgery, we need to pay close attention to its toxic effects on dura and nerve. Following nerve injury, Schwann cells—in collaboration with regrowing axons, macrophages, and fibroblasts—contribute to the supportive microenvironment for regeneration of peripheral nerves. A peripheral nerve locally infused with MMC can disrupt the collaboration between Schwann cells and regrowing axons, macrophages, and fibroblasts, and eventually result in severe regenerative failure.1,5 Although there are no clinical articles to identify the side effects of MMC on normal dura and nerve, concerning its inhibiting effects on nerve and dural revision, we still suggested that MMC is not recommended if the dural tear occurs during the operation. Mitomycin C can be easily and rapidly absorbed into cells to suppress the proliferation and differ-
entiation of fibroblasts. To prevent the significant adverse events or complications of MMC, it is essential to rinse surgical areas with saline to eliminate surplus MMC after short-term use.

We completed the 2 years of follow-up before December 2012, and all patients had uneventful postoperative recoveries and experienced no adverse effects attributable to MMC application, such as CSF leak or neurological deficit. But we still do not know the long-term side-effect developments of MMC. As indicated in the commentary by Drs. Lee and Kim, a longer follow-up period is needed to evaluate the long-term influence of MMC and determine whether MMC induces severe progressive dural thinning and nerve root injury.

We again express our appreciation for the thoughtful commentary of Drs. Kim and Lee on our study and hope that our response may provide some useful information.

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