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Practical Use of Augmented Reality Modeling to Guide Revision Spine Surgery: An Illustrative Case of Hardware Failure and Overriding Spondyloptosis

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BACKGROUND AND IMPORTANCE: Augmented reality (AR) is a novel technology with broadening applications to neurosurgery. In deformity spine surgery, it has been primarily directed to the more precise placement of pedicle screws. However, AR may also be used to generate high fidelity three-dimensional (3D) spine models for cases of advanced deformity with existing instrumentation. We present a case in which an AR-generated 3D model was used to facilitate and expedite the removal of embedded instrumentation and guide the reduction of an overriding spondyloptotic deformity.

CLINICAL PRESENTATION: A young adult with a remote history of a motor vehicle accident treated with long-segment posterior spinal stabilization presented with increasing back pain and difficulty sitting upright in a wheelchair. Imaging revealed pseudoarthrosis with multiple rod fractures resulting in an overriding spondyloptosis of T6 on T9. An AR-generated 3D model was useful in the intraoperative localization of rod breaks and other extensively embedded instrumentation. Real-time model thresholding expedited the safe explanation of the defunct system and correction of the spondyloptosis deformity.

CONCLUSION: An AR-generated 3D model proved instrumental in a revision case of hardware failure and high-grade spinal deformity.

KEY WORDS: Augmented reality, Spine surgery, Spondyloptosis

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Augmented reality (AR) is a relatively novel technology that integrates data visualization into diagnostic and therapeutic procedures to improve work efficiency and safety.[1-5] Since its introduction to the field of neurosurgery in the 1980s, AR has demonstrated its clinical utility and has gained popularity among neurosurgeons.[2,4] Many studies have supported the advantages of AR-assisted surgery for target accuracy, safety, and even surgical training.[1,6,7]

In deformity spine surgery, AR has primarily been used to facilitate the safe and precise placement of pedicle screws.[1,8] The use of AR in the operating room offers several potential advantages including improved accuracy, lower rate of complications, and decreased radiation exposure.[9] A number of cadaveric studies have demonstrated AR's superb accuracy[10] and its superiority to the freehand technique.[11] In 2019, Elmi-Terander et al[12] reported AR's application in thoracic and lumbosacral pedicle screw placement in the very first prospective study. The aforementioned studies[10-12] provide favorable results that promote the integration of AR into the spine surgeon's armamentarium when tackling straightforward cases.

Contrasting the widespread potential applications to minimizing spine surgery, far fewer applications have been described in cases requiring "maximum invasiveness," such as in long-segment instrumentation and revision cases. Herein, the authors present one such pragmatic application of this emerging technology in which a nonintegrated AR-generated 3D model enhanced preoperative planning, expedited the removal of embedded instrumentation, and accelerated the reduction of an overriding spondyloptotic deformity.

ABBREVIATION: AR, augmented reality.

CLINICAL PRESENTATION

Clinical Presentation

A young adult with a remote history of a motor vehicle accident resulting in a midthoracic

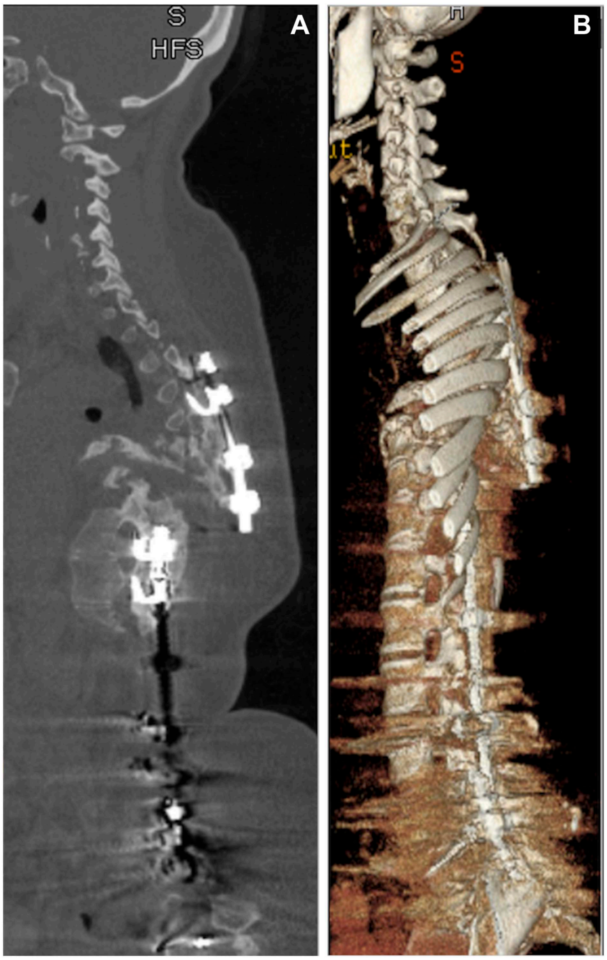

FIGURE 1. A, *Sagittal computed tomography and* **B**, *3-dimensional reconstructed images of the extreme displacement and distortion of the patient's hardware and vertebral column anatomy.*

traumatic spine fracture and complete spinal cord injury treated with long-segment posterior stabilization at an outside institution presented with increasing back pain and difficulty sitting upright in a wheelchair. The patient had a newborn child, and the inability to sit upright had severely negatively affected adequate bonding with and caring for the baby. Notably, the patient had been paraplegic with a T6 sensory level since the accident. The index surgery was 20 years before presentation. Multiple revisions had been performed at outside facilities, and sparse information was available regarding the types of surgery and instrumentation used. Radiographic workup including noncontrasted computed tomography and MRI (Figure 1) revealed multiple sites of hardware failure secondary to pseudoarthrosis and focal kyphosis with resultant degeneration of T7 and T8, all leading to a dramatic overriding spondyloptosis of T6 on T9.

FIGURE 2. *An augmented reality–generated 3-dimensional model of the patient's spondyloptosis. The existing hardware has been defined as a region of interest by the neurosurgeon and then contoured by the technologist.*

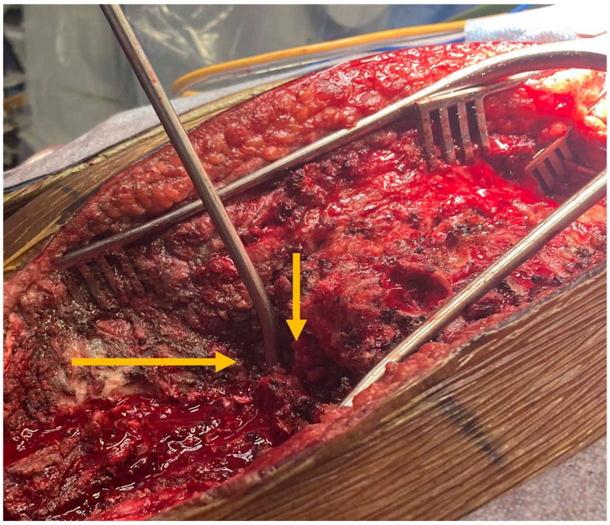

FIGURE 3. *The exposed step-off (yellow arrows) is shown by the suction resting on the caudal lamina of the spondyloptosis deformity.*

Preoperative Planning with AR

In planning for an extensive revision operation, a 360° virtual model (*Surgical Theater*) was generated from fusion of the aforementioned modalities, and an AR volume-based rendering was automatically generated. The in situ hardware was "contoured" from the surrounding anatomy in conjunction with the neurosurgeon (Figure 2). The resolution of the resulting model with highlighted hardware is limited only by the fidelity of and degree of artifact on the source scans.

Operation and Outcome

After obtaining the patient's consent to the procedure, we proceeded to the operating room for 2-level vertebral column resection of T7 and T8 with reduction of the spondyloptotic deformity, T6-T9 anterior spinal fusion, and revision of the hardware with so-called "quad-rod" long-segment instrumentation. The step-off deformity was apparent after exposure (Figure 3). The in situ hardware was, as expected given the time interval since implantation, buried under overlying ossification. The AR-generated 3D model was displayed on a large mobile external monitor provided by the company. The model allowed for real-time review of the in situ multifarious instrumentation system. A nonsterile assistant remained able to manipulate and further threshold the previously contoured hardware to direct the surgeon toward hidden screw heads, rod breaks, and sublaminar hooks (Figure 4). Furthermore, the model identified multiple components of this obsolete system which would have otherwise inhibited the case's progress. This significantly facilitated the expeditious but safe removal of the defunct hardware. Thereafter, the vertebral column resections and deformity correction proceeded per established techniques,[13,14] achieving a satisfactory result without intraoperative complications (Figure 5). The patient recovered without new neurological deficits and had an uncomplicated hospital course. The patient remained satisfied with the functional outcome.

DISCUSSION

AR has repeatedly demonstrated its ability to enhance precision in spine surgery.[1,8,15,16] Aside from facilitating intraoperative navigation, this technology harbors the potential to improve postoperative outcomes. A recent systematic review by Sumdani

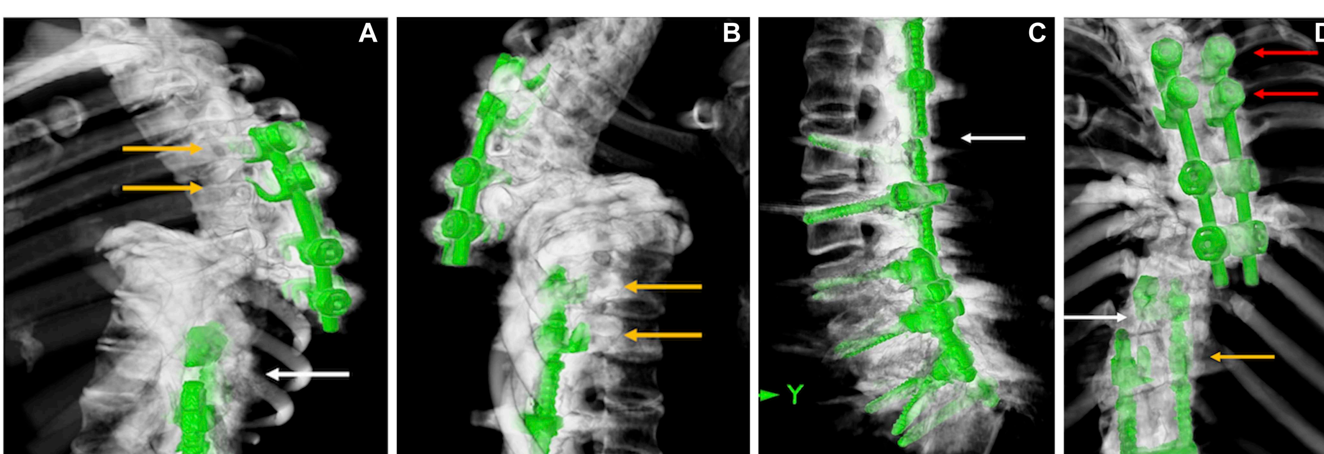

FIGURE 4. **A-D**, *Actual intraoperative stills of the augmented reality 3-dimensional model in various planes assisting in the localization of rod breaks (***A***,* ***C***, *and* ***D***, *white arrows), ossified screw heads (***D***, red arrows), and sublaminar hooks (***A***,* ***B***, *and* ***D***, yellow arrows).*

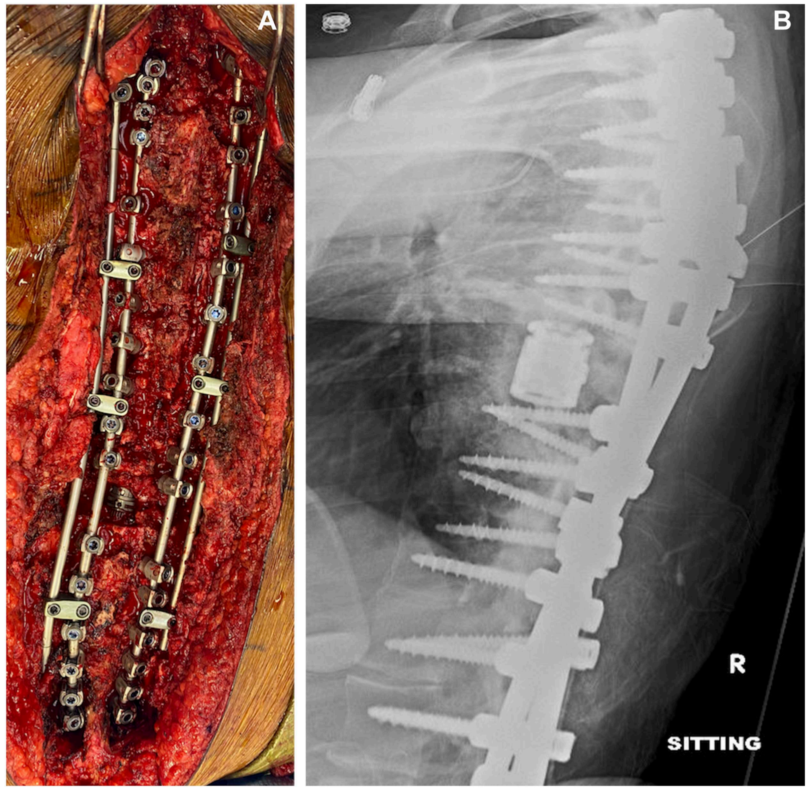

FIGURE 5. A, *Intraoperative picture and* B, *postoperative lateral x-ray demonstrating satisfactory reduction and instrumentation of the previous spondyloptosis.*

et al[1] noted more accurate pedicle screw placement, decreased operative time and blood loss, and better clinical outcomes in patients treated with use of AR compared with those treated without. Such findings[1] not only reinforce AR's ability to improve technical efficiency but also advocate for its potential to improve patient outcomes.

The trend toward minimizing invasiveness in neurosurgical cases, particularly spine operations, has accelerated with the advent of technology enabling the development of new approaches and techniques. AR may be chief among these.[1,2] Its niche in maximally invasive revision spine surgery has been less carved out by comparison. Related work by Thayaparan et al[17] reported the effective use of 3D printing in preoperative planning of revision lumbar spine surgery and promoted the use of image-guided technology for complex cases. However, there remains a dearth of pragmatic applications in the literature.

AR technology has a clear fungible role in the development of minimally invasive cranial and spine surgery. It has already been applied in neuro-oncology and neurovascular cases by pioneers in these subspecialties,[18,19] and its association with decreasing operative time[20] and favorable patient outcomes[12,21,22] has been well described. Although perhaps unintended, the byproducts of this ever-refining sieve are serendipitous applications such as ours. In this case example, we described how a dynamic model became an adjunctive tool that meaningfully informed and accelerated a deformity correction surgery. The next step would be to integrate the 360° model into the head-mounted displays to further streamline the real time identification of hardware and enhance the accuracy in complex revision spine surgery.[1]

CONCLUSION

The utility of AR technology can be extended to cases in which minimal approaches are not feasible. We present one such practical application of an AR-generated 3D model to aid in the revision of a previously instrumented high-grade spinal deformity secondary to hardware failure. This case endorses further integration of this promising technology and its facets into complex spine surgeries.

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