Available online at www.sciencedirect.com
ScienceDirect
journal homepage: www.elsevier.com/locate/radcr

Case Report

Novel 2D long film imaging utility to avoid wrong level spinal surgery☆,☆☆

Rajiv Dharnipragada, BA[a,$,*], *Bryan Ladd, MD*[b], *Kristen Jones, MD*[b], *David Polly Jr., MD*[b,c]

[a] *Medical School, University of Minnesota, 420 Delaware St SE, Minneapolis, MN 55455, USA*
[b] *Department of Neurosurgery, University of Minnesota, Minneapolis, MN, USA*
[c] *Department of Orthopedic Surgery, University of Minnesota, Minneapolis, MN, USA*

ARTICLE INFO

Article history:
Received 9 March 2022
Revised 18 March 2022
Accepted 20 March 2022

Keywords:
Surgical navigation
Thoracic surgery
Deformity
Imaging
Technology

ABSTRACT

Wrong-level spinal surgery (WLSS) can lead to increased morbidity, cost, and worse long-term outcomes. Current intraoperative localization methods rely on counting spinal levels from a known reference location using fluoroscopy. Miscounting from a reference is an intraoperative error that leads to WLSS, especially for those with anatomical variations. The problem is exacerbated when fluoroscopy is not able to produce images with the clarity needed to confidently count levels, a prevalent issue for obese patients.

A new feature called the "2D Long Film" is available for the Medtronic (Minneapolis, MN) O-arm Surgical Imaging System. Using this novel technology and standard fluoroscopy, this study reports the imaging of two obese adult female patients with a body mass index of 36.9 and 42.0 undergoing transforaminal thoracic interbody fusion. Fluoroscopy images of obese patients are difficult to capture for two reasons: increased scatter and restricted field of view. This report demonstrates that 2D Long Film can improve both these issues for obese patients in need of thoracic localization. The 2D Long Film captures existing instrumentation, localization needles, and the vertebral levels in a clear single image.

We display the differences between standard fluoroscopy and the 2D Long Film for thoracic level localization, demonstrating a potential new standard of care and better visualization, leading to a less challenging vertebrae localization process, potentially mitigating WLSS risk. The quality of this new 2D Long Film feature could also reduce time in the operating room and the necessity of other visualization methods.

☆ Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.
☆☆ Conflict of Interest: ***RD:*** Nothing to disclose. ***BL:*** Nothing to disclose. ***KJ***: Nothing to disclose. ***DP:*** Consultancies: SI-Bone, Springer textbook (royalties), Medtronic (royalties), Globus Medical (royalties); Research support: MizuhoOSI, Medtronic.
* Corresponding author.
E-mail address: dharn001@umn.edu (R. Dharnipragada).
$ 0000-0002-2522-3433
https://doi.org/10.1016/j.radcr.2022.03.078
1930-0433/

Introduction

Wrong-level spinal surgery (WLSS) can lead to increased morbidity, cost, and worse long-term outcomes. Of surveyed surgeons, 50% reported performing WLSS at least once in their career, and it is strongly associated with legal action [1]. An estimated rate of WLSS is 0.09 to 4.5 per 10,000 surgeries with 8% performed on the thoracic region [1,2]. These rates are variable across studies and likely underreported.

Current intraoperative localization methods rely on counting spinal levels from a known reference location using fluoroscopy. For example, starting from the sacrum, standard fluoroscopy will capture a limited number of vertebrae, and using an external marker, the imaging apparatus will be walked up to the next set of vertebrae. Percutaneous needles can be placed at every third level. This will continue until the operative level is reached. Required preoperative imaging will also be referenced to properly count levels for patients with abnormal segmentation.

This time-consuming process can lead to human error and inaccuracy, such as simple poor communication of whether to count up or down vertebrae levels [3]. Also, miscounting from a reference is an intraoperative error that leads to WLSS, especially for those with anatomical variations such as lumbosacral transitional vertebrae or a different number of lumbar vertebrae or thoracic ribs [4]. The problem is exacerbated when fluoroscopy is not able to produce images with the clarity needed to confidently count levels, particularly if no clear reference is located. Using standard fluoroscopy, various preoperative and intraoperative methods have aimed to mark the operative level with a visual contrast to overcome a distorted visual field [5–9]. However, each method relies on the same visualization tools to make accurate decisions.

With the current tools, localizing the accurate location of the vertebrae can be challenging in patients with obesity, anatomical variations, and at the cervicothoracic junction. Of the reported WLSS cases from 1999 to 2010, 42.3% were still due to misinterpretations of images [10].

Case presentations

This study reports the imaging of two obese adult female patients. Fluoroscopy images of obese patients are difficult to capture for two reasons. The excessive soft tissue envelope leads to poor radiation penetration and increases scatter, decreasing quality of images [11]. In addition, limitations of film size may restrict the field of view for important anatomical features in larger patients. To identify the operative level, the subjects had standard fluoroscopy images taken. In addition, imaging of a new feature called the "2D Long Film'' was used. This feature is available for the Medtronic (Minneapolis, MN) O-arm Surgical Imaging System. The figures display the improvement of localization imaging using 2D Long Film compared to standard fluoroscopy for these two patients undergoing thoracic surgery.

Case 1

The first case is a patient with a body mass index of 36.9 undergoing transforaminal thoracic interbody fusion at levels T7-T9. Figure 1 demonstrates that 2D Long Film can improve upon the increased scatter and restricted field of view seen in standard fluoroscopy for obese patients in need of thoracic localization. Panel C utilizes the 2D Long Film and shows improved image quality compared to standard fluoroscopy in Panel B.

Case 2

The second case is a patient with a body mass index of 42.0 undergoing transforaminal thoracic interbody fusion at levels T6-T7. Comparing the subject's images, in Figure 2, the 2D Long Film in Panel C demonstrates both the improved image quality and the increased area of visibility compared to Panel B. Such enhancements can clarify ambiguous imaging intraoperatively for patients and allow surgical procedures to proceed with more confidence.

Discussion

WLSS is a "never event" in spine surgery that unfortunately continues to occur and may be under-reported in the literature. Visualization of vertebral landmarks such as the C7 spinous process can be difficult for many patients with obesity, low bone mineral density, and anatomical variations. Methods such as skin markers, injected polymethylmethacrylate cement or methylene blue dye, and reference frames have been used to aid visualization, but each comes with its own inherent disadvantage [12]. The 2D Long Film is a new tool for clinicians to use with minimal drawbacks to get a better visualization of the operative level and avoid WLSS.

The 2D Long Film allows surgeons to look at one long construct of the spine, similar to other computed and digital radiography methods, but with an increased image quality when compared to other long film xrays [12,13]. Radiographic images of long constructs are typically confirmed outside the operating room (OR), but newer methods are allowing for automatic digital stitching of fluoroscopy images. Long radiographic images can be acquired using CT or the EOS Imaging system in settings outside the OR. In the OR, the Medtronic O-arm captures ~4-6 vertebrae in one fluoroscopic image [14]. The new 2D Long Film in the O-arm allows for ~12-16 vertebral levels to be in one image [15]. If the O-arm is a part of the surgeon's typical workflow, the 2D Long Film could be used with minimal disruption.

Traditional stitching of long cassette-type images has been done manually and can lead to increased distortion. Sembrano et al. 2015 concluded that shoulder–pelvis balance and T1–pelvic angle were not reliable measurements on manually stitched images, which can be created by unintended motion of the imaging apparatus, imager, and/or patient, creating a parallax discrepancy [16]. Manual stitching of images introduces human variability to a tedious, time-constrained task and can lead to inaccuracy and potential WLSS.

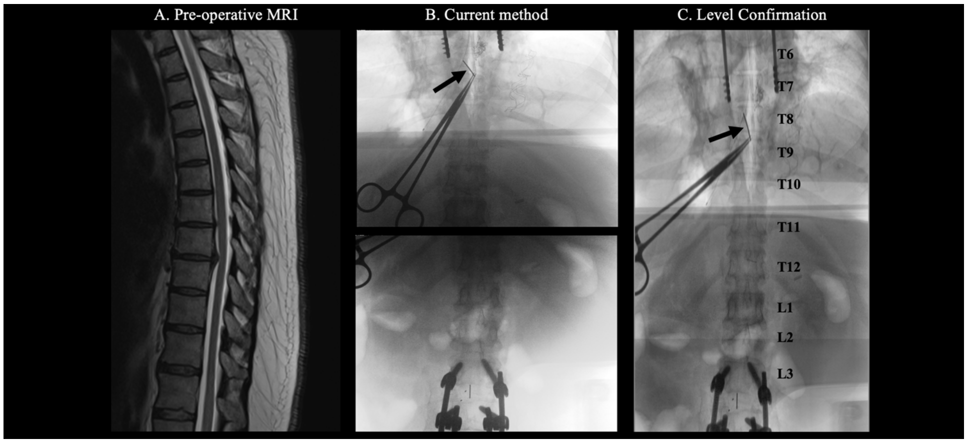

Fig. 1 – The first case is an obese (BMI 36.9) adult female with thoracic myelopathy, who underwent a decompression of spondylosis and TTIF at levels T7-T9 (A). Standard fluoroscopic images were taken, and the upper instrumented level, known to be L3, was used to count up to a K-wire over 2 images for level confirmation, indicated by the arrow (B). The 2D Long Film captures the known L3 instrumentation and K-wire in a single image for localization of the K-wire in the T8 pedicle (C). BMI, body mass index; TTIF, transforaminal thoracic interbody fusion.

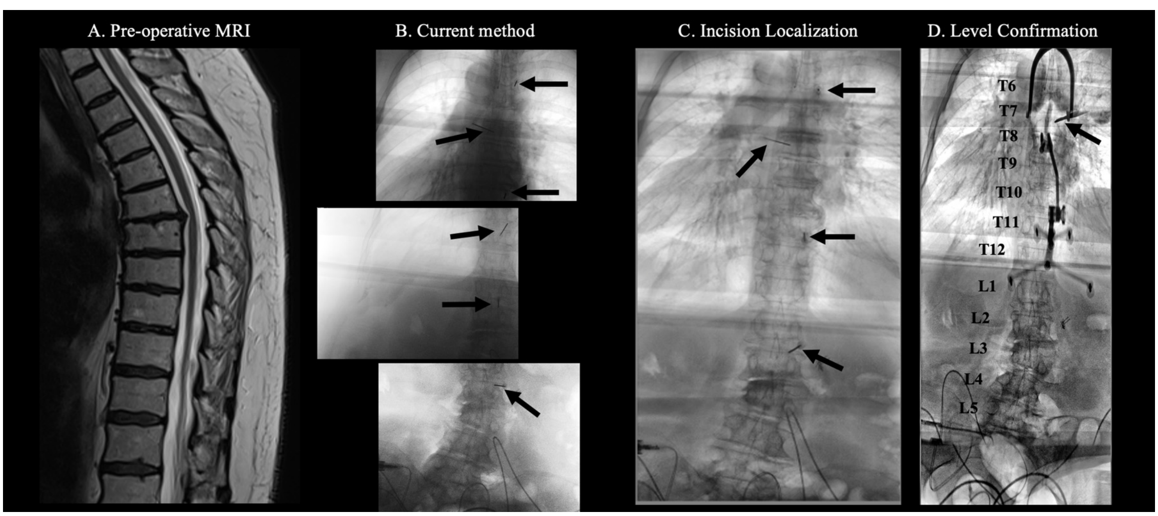

Fig. 2 – The second case is an obese (BMI 42.0) adult female who also underwent a TTIF at the T6-T7 levels for spondylosis (A). The standard fluoroscopic images display arrows to the localization needles (B). The 2D Long Film clearly depicts all four incision localization needles (C). Level confirmation with the pedicle probe is localized to the T5 level, shown with an arrow (D). BMI, body mass index; TTIF, transforaminal thoracic interbody fusion.

More modern automatic stitching methods have also been reported to be a cause of misdiagnosis, inaccurate measurements, and miscounting of vertebrae [17–19]. A case report demonstrated the misalignment of images in an automatic stitching software, which created a false image that appeared to have a broken rod. However, the rod was completely intact intraoperatively [17]. Another report found a missing vertebra from the automatic stitching of a long cassette-type image, which would have ultimately led to WLSS in many cases [18]. These errors are reported rarely in the literature. Despite improvements, the image artifacts from other automatic stitching methods can lead to mismanagement due to technological errors. The largest study on error rates in stitched imaging for the spine reported 16% of 86 scoliosis patients had a misdiagnosis when based solely on the long film imaging [19]. The novel technology of 2D Long Film is only reported in one clinical study, and it is important to emphasize the utility of this new feature to aid proper localization, not just as an alternative to unclear imaging, but also as a new standard of care [20].

The Medtronic O-arm gathers the 2D Long Film via a multi-slot collimator along a gantry which is not used in any other current apparatus. The EOS imaging apparatus uses a single slot scanning system, while several other imaging systems utilize one source and detector along the longitudinal axis of the spine [15]. This unique method of 2D Long Film imaging minimizes the x-ray scatter that is caused by long film images through a reduction in noise and increased spatial accuracy [13,14]. The multi-slot collimator is an improvement to the current stitching methods since it captures different angles of the object as the gantry travels, leading to increased sampling size and resolution. The images are acquired with less radiation than standard fluoroscopy and reconstructed using tomosynthesis methods to form the final 2D Long Film. A cadaver study demonstrated this new technology improves depth resolution and rejection of out-of-plane clutter compared to traditional fluoroscopy [14]. These factors could allow for improved localization of vertebrae and a reduction of WLSS.

Conclusion

The thoracic spine can be difficult to visualize due to the uniformity of the levels, variation of the number of ribs, and scapulohumeral shadows. However, the non-anatomical factors of intraoperative radiographic imaging are among the most commonly reported causes of WLSS [4]. Our report displays the differences between standard fluoroscopy and the 2D Long Film for thoracic level localization, demonstrating a potential new standard of care for better visualization, leading to a less challenging vertebrae localization process, potentially mitigating WLSS risk. The quality of this new 2D Long Film feature could potentially reduce time in the operating room, the necessity of other visualization methods, and lead to accurate localization. A large multicenter study is likely needed to demonstrate and expand upon the utility of this new feature presented in this study. This tool could also help surgeons verify the construct before closure and allow for other quantitative measurements of spinal alignment. Visualization of long constructs with 3D-2D registration, automatic vertebral labeling and measurements are some potential developments that could follow this new technology.

Patient consent

Patient consent was obtained, and all identifying patient information is redacted.

REFERENCES

[1] Mody MG, Nourbakhsh A, Stahl DL, Gibbs M, Alfawareh M, Garges KJ. The prevalence of wrong level surgery among spine surgeons. Spine (Phila Pa 1976) 2008;33(2):194–8.

[2] Longo UG, Loppini M, Romeo G, Maffulli N, Denaro V. Errors of level in spinal surgery: an evidence-based systematic review. J Bone Joint Surg Br 2012;94(11):1546–50.

[3] Mayer JE, Dang RP, Duarte Prieto GF, Cho SK, Qureshi SA, Hecht AC. Analysis of the techniques for thoracic- and lumbar-level localization during posterior spine surgery and the occurrence of wrong-level surgery: results from a national survey. Spine J 2014;14(5):741–8.

[4] Shah M, Halalmeh DR, Sandio A, Tubbs RS, Moisi MD. Anatomical variations that can lead to spine surgery at the wrong level: Part III lumbosacral spine. Cureus 2020;12(7):e9433.

[5] Rosahl SK, Gharabaghi A, Liebig T, Feste CD, Tatagiba M, Samii M. Skin markers for surgical planning for intradural lesions of the thoracic spine. Surg Neurol 2002;58(5):346–8.

[6] Paolini S, Ciappetta P, Missori P, Raco A, Delfini R. Spinous process marking: a reliable method for preoperative surface localization of intradural lesions of the high thoracic spine. Br J Neurosurg 2005;19(1):74–6.

[7] Hsu W, Sciubba DM, Sasson AD, Khavkin Y, Wolinsky JP, Gailloud P, et al. Intraoperative localization of thoracic spine level with preoperative percutaneous placement of intravertebral polymethylmethacrylate. J Spinal Disord Tech 2008;21(1):72–5.

[8] Sammon PM, Gibson R, Fouyas I, Hughes MA. Intra-operative localisation of spinal level using pre-operative CT-guided placement of a flexible hook-wire marker. Br J Neurosurg 2011;25(6):778–9.

[9] Thambiraj S, Quraishi NA. Intra-operative localisation of thoracic spine level: a simple "'K'-wire in pedicle" technique. Eur Spine J 2012;21(Suppl 2(S2)):S221–4.

[10] DeVine JG, Chutkan N, Gloystein D, Jackson K. An update on wrong-site spine surgery. Global Spine J 2020;10(1 Suppl) 41S–44S.

[11] Uppot RN. Technical challenges of imaging & image-guided interventions in obese patients. Br J Radiol 2018;91(1089):20170931.

[12] Upadhyaya CD, Wu J-C, Chin CT, Balamurali G, Mummaneni PV. Avoidance of wrong-level thoracic spine surgery: intraoperative localization with preoperative percutaneous fiducial screw placement: Clinical article. J Neurosurg Spine 2012;16(3):280–4.

[13] Uneri A, Zhang X, Ketcha MD, Doerr SA, Jones CK, Helm PA, et al. Multi-slot intraoperative imaging and 3D-2D registration for evaluation of long surgical constructs in spine surgery Medical Imaging 2020: Image-Guided Procedures, Robotic Interventions, and Modeling. Fei B, Linte CA, editors. Houston, Texas: SPIE; 2020.

[14] Zhang X, Uneri A, Wu P, Ketcha MC, Doerr SA, Jones CK, et al. Multi-slot extended view imaging on the O-Arm: image quality and application to intraoperative assessment of spinal morphology Medical Imaging 2020: Image-Guided Procedures, Robotic Interventions, and Modeling. Fei B, Linte CA, editors. Houston, Texas: SPIE; 2020.

[15] Zhang X, Uneri A, Wu P, Ketcha MD, Jones CK, Huang Y, et al. Long-length tomosynthesis and 3D-2D registration for intraoperative assessment of spine instrumentation. Phys Med Biol 2021;66(5):055008.

[16] Sembrano J, Peterson E, Yson S, Santos ER, Polly D Jr. Comparison of intraoperative stitched fluoroscopic images to postoperative standing full spine radiographs. Global Spine J 2015;5(1_suppl) s-0035-1554336-s-0035-1554336.

[17] Salem KH, Ladenburger A, Schoth F, Ohnsorge JA. Chimera of digital radiography in spine surgery: False diagnosis of implant failure. J Clin Orthop Trauma 2019;10(4):645–9.

[18] Ikwuezunma I, Fayad LM, Sponseller PD. Case of the missing vertebra: a report of a radiographic stitching error in a scoliosis patient. JBJS Case Connect 2021;11(3). doi:10.2106/jbjs.cc.21.00295.

[19] Shetty CM, Barthur A, Kambadakone A, Narayanan N, Kv R. Computed radiography image artifacts revisited. AJR Am J Roentgenol 2011;196(1):W37–47.

[20] Ladd B, Jones K, Polly D. 2-dimensional long film O-arm imaging, an alternative when intraoperative fluoroscopy is inadequate. World Neurosurg 2021;150:54–5.