Eur Spine J
DOI 10.1007/s00586-017-5233-1

CASE REPORT

Simultaneous navigated cervico-thoracic and thoraco-lumbar fixation

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Received: 18 September 2016 / Revised: 19 January 2017 / Accepted: 19 July 2017

Abstract
Study design Case report.
Objective To investigate the feasibility of using two independent image guidance systems to simultaneously fix multiple segment spine fractures.
Summary of background data Image guidance is increasingly used to aid spinal fixation. We describe the first use of multiple navigation systems during a single procedure allowing for multi-segment spinal fixations to be performed simultaneously and capitalizing the advantages of navigation.
Method Two Medtronic Stealth Station S7™ systems with O-arm image capture were used to guide fixation of C6 and T12, unstable, AO A4, three-column fractures, in a patient with ankylosing spondylitis.
Results Two surgical teams were able to perform cervico-thoracic and thoraco-lumbar fixations simultaneously. Operative time was 2.5 h. Post-operative imaging showed accurate instrumentation placement. The patient recovered without any neurological sequelae.
Conclusions Optical independence of the Medtronic Stealth Station™ system allowed for simultaneous navigation guided fixation of multiple segment fractures without compromising accuracy. This may result in shortened operative time and morbidity associated with prolonged prone positioning of polytrauma patients, as well as reducing radiation exposure for theatre staff.

Keywords Multisegment fixation · Image guidance · Stealth™ · Percutaneous · Minimally invasive · Ankylosing spondylitis

Introduction

The advancement of percutaneous minimally invasive (MIS) pedicle screw (PS) placement over the last decade has allowed for spinal fixations to be performed with less intra-operative trauma to paraspinal tissues, preservation of midline ligamentous structures, as well as a reduction in associated blood loss, post-operative pain, and length of hospital stay compared to open surgery and is becoming increasingly popular [1–3]. Navigated spinal fixation has also been reported to reduce radiation exposure to the surgical team when compared to fluoroscopic guided fixations [4–7]. Multi-level non-contiguous fractures requiring more than one construct are normally fixed sequentially. This has implications for operative time and surgical morbidity especially in patients with polytrauma [8]. We report the first application of spinal navigation using two independent navigation systems to stabilize cervico-thoracic and thoraco-lumbar fractures simultaneously. When available, the use of a second navigation system may allow for such fixations to be performed with shorter operative times.

We present a case of a 49-year-old man with ankylosing spondylitis (AS) who was admitted following a fall off a lorry during a seizure. He complained of intractable neck and back pain, but was neurologically intact. Diagnostic imaging revealed three-column fractures at C6 and T12 (Fig. 1).

The patient had a C6 'burst' fracture (AO A3.3) with loss of height anteriorly, posterior displacement of the C6 vertebral body into the spinal canal and focal kyphosis. The C6/7 facet joint was disrupted. MRI indicated high signal

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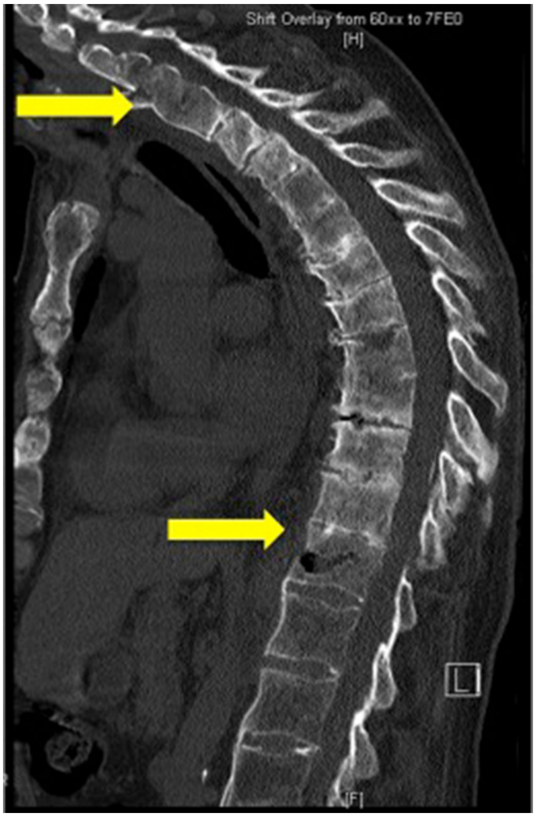


Fig. 1 Sagittal 3D reconstruction of cervical and thoracic spine showing C6 and T12 three-column fractures (*yellow arrows*)

Fig. 2 Cranial reference frame (*yellow arrow*) and iliac percutaneous reference frame (*red*)

in the C6/7 disc space and posterior longitudinal and interspinous ligaments at this level. This was consistent with a flexion, compression injury. The patients' subaxial cervical spine injury classification (SLIC) [9] score was 4 with the confounder of ankylosing spondylitis present. The T12 fracture was a complete axial burst fracture (AO A3.3). Both fractures were deemed to be unstable.

Fractures in patients with ankylosing spondylitis present a unique surgical challenge. The enthesopathy in this sero-negative arthritis results in osteoporotic 'square appearing' vertebral bodies with bridging syndesmophytes, calcified intervertebral discs, ossified ligaments, and bony overgrowth. Together with a marked kyphotic deformity, these pathological changes mean that identification of normal anatomical landmarks and optimal screw trajectories can be challenging. Intra-operative image guidance can be used as a tool to identify entry points and trajectories in such cases to achieve accurate screw placement.

Procedure

Following consent, the patient was anaesthetised and positioned prone on a Jackson table with the aid of three-pin Mayfield head fixation. A cranial navigation reference frame was attached to the Mayfield head fixator and used for the cervical fracture (Fig. 2, yellow arrow). A separate reference frame was attached to a percutaneous anchoring pin placed aseptically into the iliac crest (Fig. 2, red arrow). The O-arm system (Medtronic, Minneapolis, USA) was used for two separate image acquisitions, centered on the C6 and T12 vertebral bodies, respectively. Images were uploaded onto two separate stealth seven workstations (Medtronic) positioned at the cranial and caudal ends of the operative fields (Fig. 3, yellow arrow for cranial and red for caudal). The stealth stations were positioned within the operating theatre in such as way as to enable the laser from the cranial stealth station to be detected only by the cranial reference frame and the beam from the caudal stealth station to be detected only by the iliac crest reference frame only. This ensured that the respective stealth stations, reference frames, and stealth probes interacted with each other only without interfering with the other stealth system.

A posterior midline incision was made from C3 to T2. Dissection was performed in the midline avascular raphe and bilateral lateral masses and pedicles were exposed from C3 to T2. The image-guided Suretrack^{TM} mobile tracker (Medtronic) was used to place bilateral lateral mass screws into C3, C4, C5, and C7 and pedicle screws at T1 and T2 (Mountaineer, Depuy). The construct was then completed with a tapered rod across the cervico-thoracic junction. Simultaneously, a second surgical team utilised the second Stealth navigation system to guide percutaneous insertion of pedicle screws into T9–T11 and L1–L3 pedicles. Despite the close anatomical proximity of both operative sites, two teams of two right-handed surgeons working opposite each other allowed both procedures to be performed in tandem. As the cervical fixation required open dissection from C3 to T2 to expose screw entry points, whereas the thoracic fixation was completed

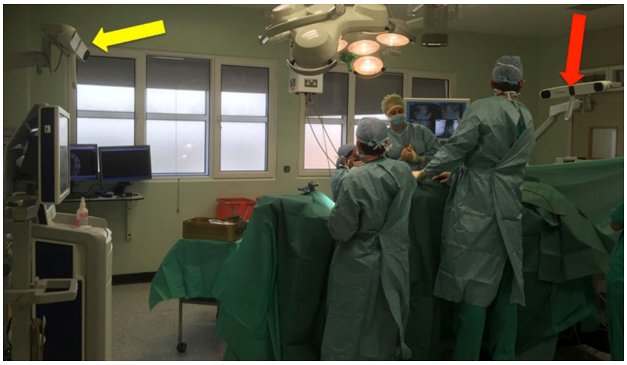


Fig. 3 Operative room setup with cranial stealth station (*yellow*) angled to cranial reference frame and caudal stealth station (*red*) angled to iliac reference frame

entirely percutaneously this allowed the team fixing the thoracic spine to be able to mark out and insert guide wires with stealth guidance, whilst the cervical team was performing the soft-tissue dissection. The total operative time was two and a half hours.

As previously described and widely accepted [10], the accuracy of pedicle screw placement was categorized based on post-operative CT imaging (Figs. 4, 5) using the following grading system: Grade 0, no pedicle cortex perforation, Grade 1, 0–2 mm cortex perforation, Grade 2, 2–4 mm cortex perforation, and Grade 3, pedicle cortex breach of more than 4 mm. Of the 16 pedicles cannulated (T1, T2, T9–11, and L1–3 pedicles bilaterally), no cortical breaches were seen on the post-operative CT scan. In addition, none of the eight lateral mass screws (C3, C4, C5, and C7 bilaterally) showed a cortical breach.

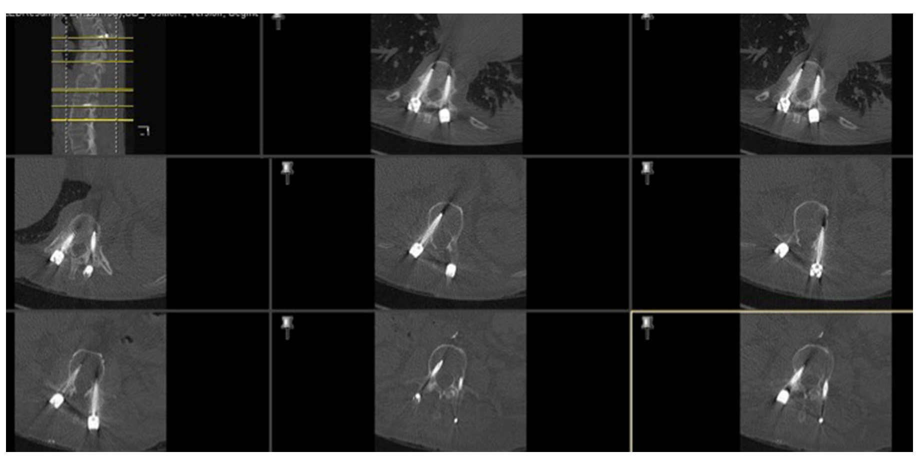
The patient was mobilising the next day and discharged from hospital on post-op day 2. At the 3-month follow-up visit, he reported a significant resolution of both cervical and back pain and had returned to his routine daily activities.

Fig. 5 Post-operative sagittal 3D reconstruction CT image of the cervical spine

Discussion

In AS, inflammation promotes new bone formation leading to ossification of the ligaments of the spinal column, the intervertebral discs, endplates, and apophyseal structures. Extensive ectopic bone formation leads to remodeling of vertebral bodies and formation of syndesmophytes, which span the intervertebral discs. Over time, these processes contribute to the progressive rigid hyperkyphotic spine deformity. Paradoxically, increased osteoclast activity and bone resorption occurs in parallel at an unregulated rate within the vertebrae causing reduction in bone mineral density and weakening of the spinal column. Altered spinal biomechanics coupled with the brittleness of the osteoporotic bone increase the susceptibility to spinal fractures which are four times more common in AS patients then in general population with a lifetime incidence of 5–15% [11, 12]. Because of the extensive ankylosis and syndesmophyte formation, fractures often extend through the disc space and often involve both anterior and posterior elements thus making them highly unstable [13].

Fig. 4 Post-operative sagittal 3D reconstruction CT image of the thoraco-lumbar spine with axial sections at level of pedicle screws



Many surgeons do not routinely employ percutaneous fixation techniques to treat patients with ankylosing spondylitis fractures, preferring to stabilize and fuse via an open approach. In patients and fractures not suitable for an MIS strategy, such as cervical fractures, identification of normal anatomical landmarks to guide pedicle/lateral mass screw placement is often difficult due to bone overgrowth; therefore, intra-operative guidance offers an advantage in achieving accurate placement of instrumentation. Given the hyperostotic properties of the bone in AS, healing can usually be achieved without the need for open fixation and fusion making MIS surgery a viable alternative for thoraco-lumbar fractures.

Here, we present a case of a patient who underwent cervico-thoracic and thoraco-lumbar fixations using a minimally invasive technique with 3D-guided O-arm navigation. Our use of simultaneous navigated percutaneous thoracic fixation and open cervical fixation is on the background of our experience of over 350 navigated fixations (192 using 3D-C-Arm and 162 using O-Arm), with comparable operative times, reduced radiation exposure and greater pedicle screw accuracy for O-arm-guided fixations compared to the traditional fluoroscopic fixations. In our experience, the use of 3D navigation significantly reduces the risk of instrumentation malplacement when compared to traditional fluoroscopy (1 versus 5%, respectively; unpublished data) or the available literature on the open, 'free-hand' technique (5–30%) [10, 11]. The introduction of image guidance to direct PS placement has significantly improved accuracy and it is becoming evident that the use of 2D or 3D fluoroscopy-based spinal navigation provides further benefits [6, 14–18].

When we analyzed our institutional radiation exposure in 20 consecutive patients, the overall intra-operative radiation dose delivered to a patient during a long-segment cervical and a long-segment thoraco-lumbar MIS fixation is similar for O-Arm and 2D-fluoroscopy assisted fixation (approx. 5.5 vs 3–6 mSv, respectively) and lower than a standard thin slice CT spine (which delivers 9mSV of radiation). Effective doses of ionizing radiation were calculated using the PCXMC 2.0 software (STUK, Helsinki, Finland, 2008), which uses Monte Carlo modelling to estimate organ and effective doses for plain X-ray projections using a mathematical phantom. For 3D-navigated procedures, the effective dose is a sum of the 2D and 3D components of the procedure and a post-instrumentation check acquisition. Typical effective doses for post-operative CT scans were obtained for each of five on-site CT scanners using the ImPACT CT Patient Dosimetry Calculator (ImPACT, St George's Hospital, London, 2011). Except for the patient, all other theatre personnels leave the radiation area during image acquisition eliminating any radiation exposure to them.

Performing multi-segment fixations simultaneously meant that the patient was anaesthetised and intubated for a shorter duration that we would normally have expected if both fractures were fixed sequentially. Based on our records of previous similar fixations for cervical and thoracic spine, we would normally have expected an operative time of approximately 5 h if both fractures had been treated sequentially. The overall operative and anesthetic time was significantly shorter than this (2.5 h) reducing the risk of a wide array of surgical and medical complications including respiratory complications, operative site infections, sepsis, wound dehiscence, and deep vein thrombosis [19].

AS patients are more likely to die following spinal fractures than general population. The most frequent cause of death in the acute phase as well as at later follow-up is respiratory complications such as pneumonia [13]. Reducing the operative time and time of prone positioning, especially in patients with pre-existing pulmonary pathology as is the case with many AS patients, is beneficial. Furthermore, the benefits of the MIS approach such as earlier mobilization, reducing post-operative pain, and the use of opiate analgesia further reduce the risk of respiratory complications.

We have shown that with careful planning, it is possible for simultaneous image-guided fixations to be performed in the same patient. A second navigation system does incur significant additional cost, but when available to the surgical team, multi-level non-contiguous fractures requiring more than one construct can be considered for such approaches. In the present case, we have confirmed that accuracy is not compromised, but the operative time can be substantially reduced. In addition, the overall estimated radiation dose delivered to the patient during this procedure was less than that of a standard, non-contrasted CT spine performed at our institution. This approach has potential implications in reducing morbidity associated with prolonged prone positioning, particularly when applied to patients presenting with polytrauma or elderly patients with co-morbidities.

Compliance with ethical standards

Funding No sources of funding received for this work.

Conflict of interest None of the authors has any potential conflict of interest.

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