

Computer Assisted Surgery for Iliosacral Screw Placement-How Far have we gone?

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Abstract

Unstable pelvic ring injuries require definite operative fixation. While the posterior ring can be fixed utilizing open approaches, percutaneous screw fixation has become the treatment of choice avoiding the complications of open approaches. As the pelvis is a complex three-dimensional (3D) shape with many neurovascular structures situated within it, a thorough knowledge and understanding of the anatomy and radiographic imaging is required to accomplish the task of percutaneous iliosacral screw placement, while avoiding potential complications.

Recent advances in computer assisted surgery (CAS) has provided some powerful tools in overcoming the obstacles associated with this procedure. This review examines the evolution of image guided surgery used for iliosacral screw placement, the current available options, and future perspectives.

Keywords: Computer assisted surgery; Percutaneous screw fixation; Iliosacral screw placement; Conventional fluoroscopy; Posterior pelvic ring

Background and Conventional Fluoroscopy

Percutaneous iliosacral screw fixation gained increased popularity in the mid and late 1990's as a sound alternative for open reduction and internal fixation of posterior pelvic ring injuries [1]. Pelvic ring fracture rate in western countries ranges from 20 to 35/100,000 per year, and mostly are referred to trauma centers [2-4]. out of them 25% to 30% requires operative fixation. The indication of posterior ring fixation includes of certain AO/OTA type B and type C fractures. These indications include a posteriorly widened sacroiliac joint with type B injuries, and vertically unstable fractures after closed or open reduction [5]. The percutaneous approach for the posterior ring avoids potential soft tissue complications associated with open approaches for the posterior pelvic ring.

Over time and as this technique evolved it became the treatment of choice for minimally displaced or reduced sacroiliac dislocations and sacral fractures.

However, this technique is not risk free, mainly due to anatomical considerations. The anatomical safe corridor which allows for the fixation of the ilium to the first and second sacral vertebrae can be narrow, limited by exiting nerve root anteriorly, neural foramina caudally and sacral canal posteriorly. Furthermore the size and shape of the safe corridor is anatomically varied among individuals [6].

In order to achieve percutaneous iliosacral screw fixation, a 2D, multi-planar, conventional fluoroscopy is used for image guidance. Avoiding damage to nerve root structures, requires that correct pelvic inlet, outlet and lateral views are taken intraoperatively [7]. Furthermore, the safe zone for iliosacral screw placement should be considered by careful inspection of the preoperative CT scan-especially in regards to the relation of the iliac wing to the anterior sacral body.

Although this procedure is very common, the complication rate are not as low as can be expected or previously described [1]. Keating reported a screw misplacement rate of 13% [8]. Moreover, a very recent study of mathematical models for calculating the safe zone, a cortical breach was noted in 30% of patients treated with percutaneous iliosacral screw fixation [9]. Other Studies show, that even if the screws are implanted according to the radiographic guidelines, misplacement can still occur even in the presence of "perfect" fluoroscopic views, and may eventually result in nerve root damage [10,11]. Some authors suggested modifications of the standard fluoroscopic views for screw placement, but these haven't gained widespread use yet [12,13].

These disturbing facts and the highly technically demanding nature of this procedure lead several researchers to seek other means of intraoperative imaging for the insertion of iliosacral screws. Placing the screws in a conventional computer tomography suite with local anesthesia was suggested in the past, but this technique is limited by the nature of the pelvic ring injury and precludes the ability to add additional procedures when needed (such as anterior ring fixation, or open reduction of the posterior ring if closed reduction fails) [14].

2D Fluoroscopic Navigation

The introduction of computed assisted surgery (CAS) during the early 2000's has changed the paradigm of iliosacral screw placement. A brief explanation of the basic concept of CAS in the context of trauma surgery, is detailed herein below. The core principle of CAS is image guided surgery (IGS) in which an acquired anatomical image (fluoroscopy, CT scan, intraoperative 3D fluoroscopy etc.) is stored in computer memory. The actual anatomy of the patient is then matched to the image by a coordinate system (x,y,z) built by an algorithm. At that point a surgical tool or a virtual trajectory of a tool is tracked by the system, usually using an optical tracking system. While tracking the tool the virtual image of the tool or its projected trajectory is depicted on the previously acquired images without actually re-imaging the anatomy. Thus, a multiplanar projection of trajectory can

be seen simultaneously on the screen prior to the actual surgical procedure itself.



Figure 1: The setup of a 2D fluoroscopic navigation system for iliosacral screw fixation after symphyseal plating. (A) an optical tracking camera is used to track the dynamic reference frame (B) mounted on the ASIS (C) the c-arm fluoroscope is tracked by a handheld device.

In a trauma case, for example, it is pertinent to acquire the image of the fracture in its reduced state. Therefore, with displaced fractures, the use of an old CT or radiographic image acquired prior to reduction or even patient positioning can be problematic. In contrast, the use of intraoperative 2D fluoroscopy is readily available in the operating room and therefore was the mainstay of CAS for over a decade [15]. In this modality, when an iliosacral screw is inserted, a dynamic reference body (DRB) is placed on the anterior superior iliac spine (ASIS) and the C-arm fluoroscope is tracked by a calibration target or a handheld device mounted with optical reflecting devices (Figure 1). Immediately, pelvic inlet, outlet and lateral views are acquired. Planning of the screw(s) on the images can now be performed (Figure 2a) and actual navigation with a tracked drill guide is done without need for further fluoroscopic images (Figure 2b). The result is an almost absolute match between planned and performed images.

This technique has proven to be fast, accurate and saves significant amount of radiation as compared to standard fluoroscopy [16,17].

However, it failed to gain vast popularity in clinical practice due to the costs of the navigations platforms and the sharp learning curve associated with their use.

Furthermore, despite resulting in simultaneous multiplanar images, the systems still utilizes 2D fluoroscopy. Lastly, this modality still harbors hazards in iliosacral screw placement due to anatomical variations not readily observed, where adequate fluoroscopic placement of screws can result in cortical breaching or even intra-foraminal inadvertent implant placement [8,9,18,19].

Several recent attempts to calculate the exact 2D fluoroscopic placement of screws based on preoperative CT scans were recently made but their practical use in the operating room remains questionable [9,20].

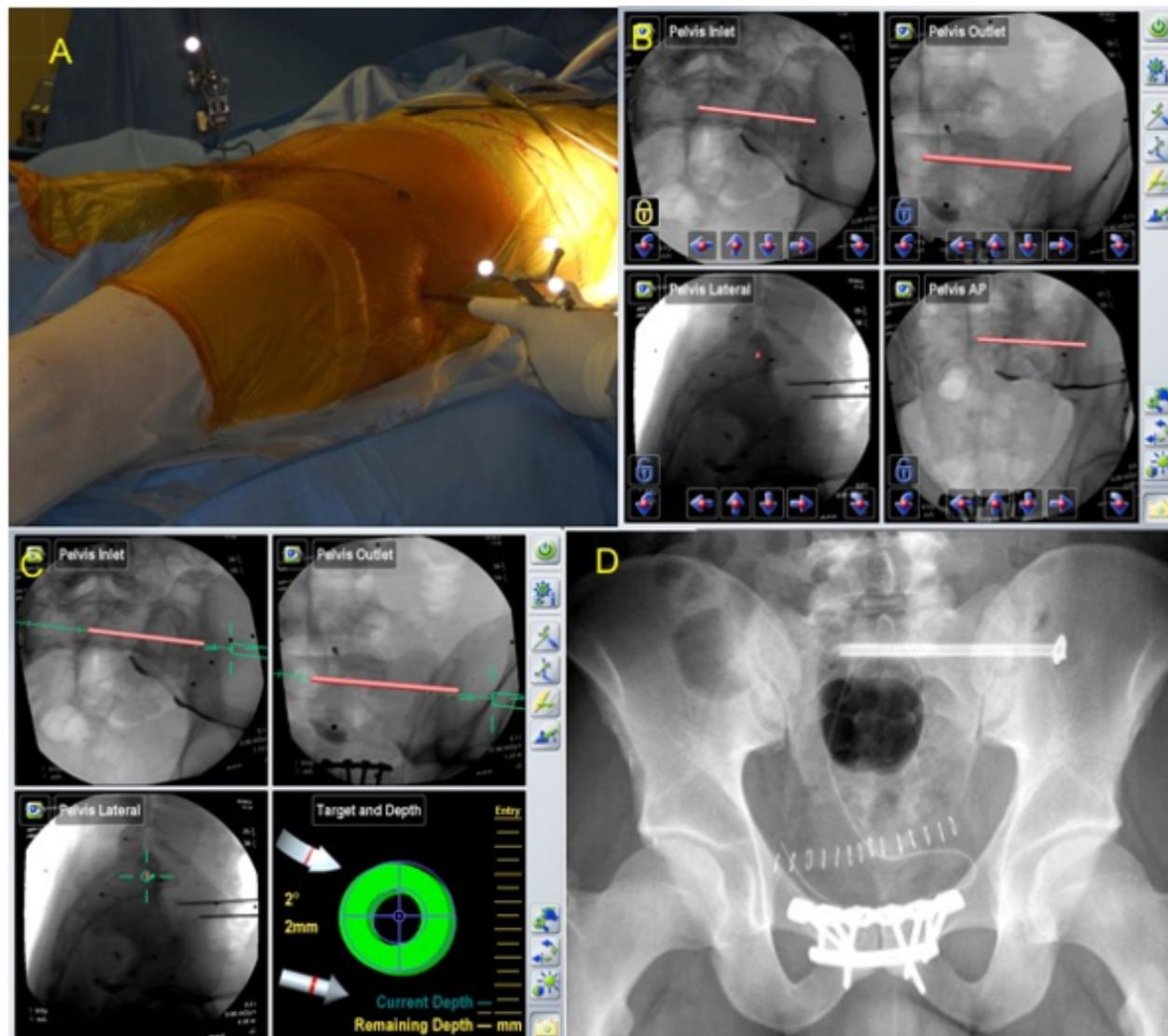


Figure 2: The surgeon is tracking a drill guide (A) after planning the desired iliosacral screw trajectory (B). Intraoperatively, the navigated drill guide projected image (green line and cross, C) should match the planning as confirmed by the green circle at the bottom right corner of the screen. (D) Post-operative AP pelvic X-ray matches the navigated plan.

The ultimate question that concerns the trauma surgeon, is how to translate a 3D reality into 2D imaging intraoperatively. This may be adequate in some cases, but in a case of a dysmorphic pelvis, for example, this task is not always possible [6]. Therefore, intraoperative 3D imaging should be ideal for the safe placement of an iliosacral screw.

Indeed, such systems exist. The first prototypes were iso-centric C-arm fluoroscopes allowing a 190 degrees of fluoroscopy around a fixed point, such as the Siremobil Iso-C 3DTM. This system allowed use of CT-like images produced by acquiring 100 fluoroscopic images with volume rendering after post-processing [21].

The next obvious step is connecting a tracking systems on these c-arm and use 3D navigation for iliosacral screw placement. Over the past few years this task has been successfully accomplished. In fact, there is overwhelming evidence that using 3D image guidance during iliosacral screw placement eventually eliminates misplacement and cortical breaching of screws. The latter was proven on cadaveric studies, retrospective and prospective clinical trials [18,22,23].

Matitiayhu et al. have shown in a large, multicenter prospective study that none of the screws inserted using 3D navigation were misplaced when examined on postoperative CT scanning [18].

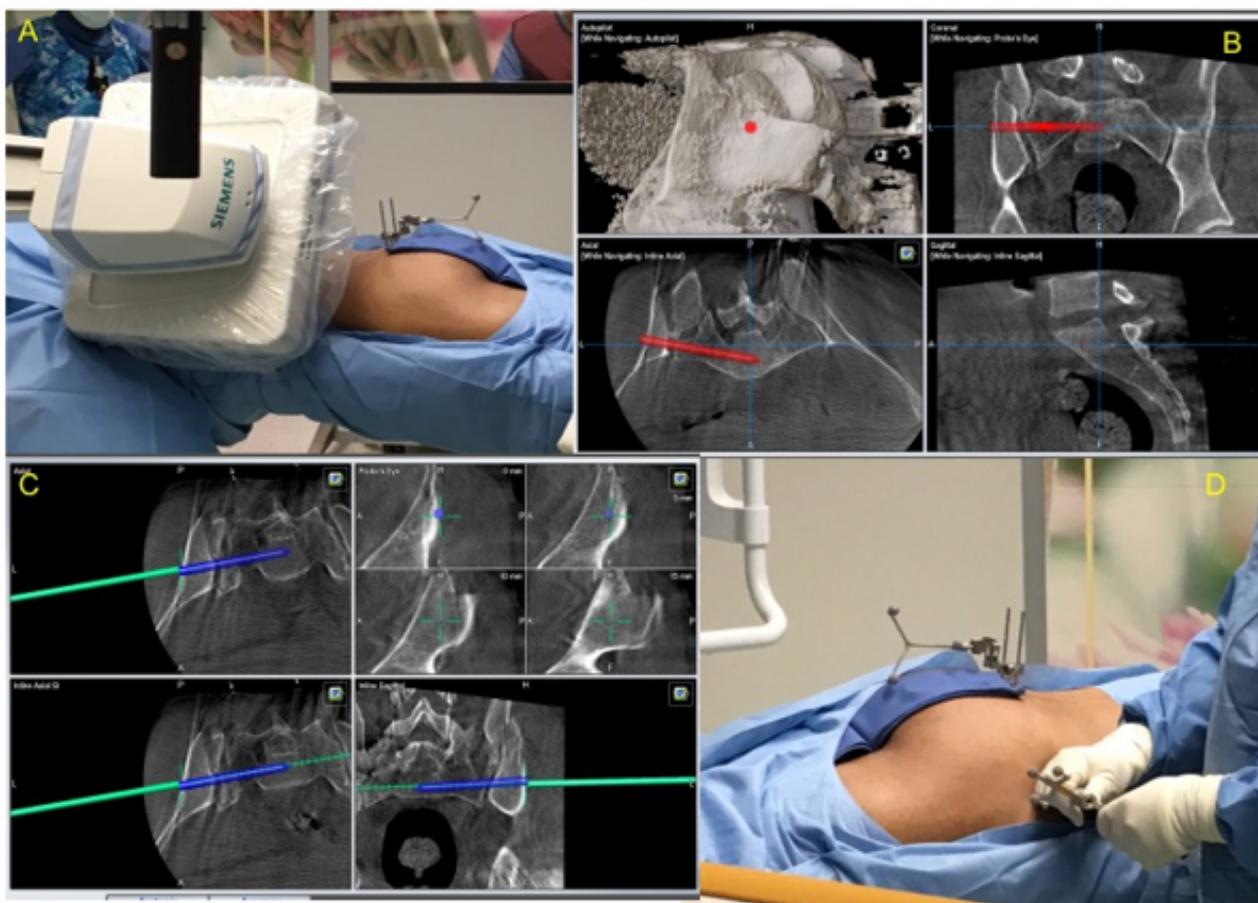


Figure 3: (A) a flat panel robotic c-arm is used in a hybrid room to scan a pelvis for navigated iliosacral screws. The DRB is mounted on the PSIS (patient is in prone position). B the planning of an S1 screw in a highly dysmorphic pelvis with a minimal safe zone due to a deep recess in the sacral ala. C+D the screw is navigated using multiplanar 2D reconstructions of axial sagittal and coronal images.

In the normal sacra, breaching rate was 27% and 12% with 2D navigation and conventional fluoroscopy, respectively. Interestingly, even with dysmorphic sacra, 3D navigation remained safe with 0% breaching rate while the 2D navigation and conventional fluoroscopy breaching rates increased to 67% and 32%, respectively.

Despite these encouraging results-the utilization of 3D fluoroscopy using navigation did not become the standard of care in treating posterior pelvic ring injuries. An example of the problems associated with its use is a relatively narrow field of view limited to 9 inches (22.9 cm) that impedes placement of transiliac screws and imaging in obese patients, requiring some modification of the technique [24]. Another problem is pinpointing the precise localization of the C-arm in order to avoid possible collisions and centering of the image around the affected area.

A possible solution for these obstacles is the utilization of robotic C-arms equipped with a large, flat-panel detector that can scan a large field within 10-15 seconds. These machines are placed in a hybrid operating room [25,26]. The results from using a robotic, high quality C-arm are far superior in quality to the older-generation 3D fluoroscope and result in significantly less screw misplacement reaching utmost precision [25].

Richter et al describes the experience of using this system in inserting 45 iliosacral screws and 20 transiliac-transsacral screws. Of the first group (45 screws) all were within bone while breaching still occurred at the transsacral screw group. A sample case of screw insertion in a severely dysmorphic placement with a narrow safe zone using this system is demonstrated in Figures 3 and 4.

The role of robotics in iliosacral screw fixation is yet to be determined. A miniature robot for pedicle screw placement has been introduced a few years ago [27,28]. This hexapod mini-robot uses information derived from a previously acquired CT-scan. A CT-fluoroscopy merging algorithm enables the robot to match intraoperative fluoroscopy with a previously acquired CT.

Hence, it can travel into the desired starting point of the desired screw, mechanically adjust the arm towards a trajectory planned in advance, and accurately guide the surgeon in inserting the guidewire. We successfully utilized the spine robot in order to place iliosacral screws with or without lumbo-sacral fixation.

However, this technique is limited to non-displaced fractures, since intraoperative CT scanning and re-planning after fracture reduction is still not feasible with this system. A sample case of a lumbo-pelvic fixation is depicted in Figures 5 and 6.

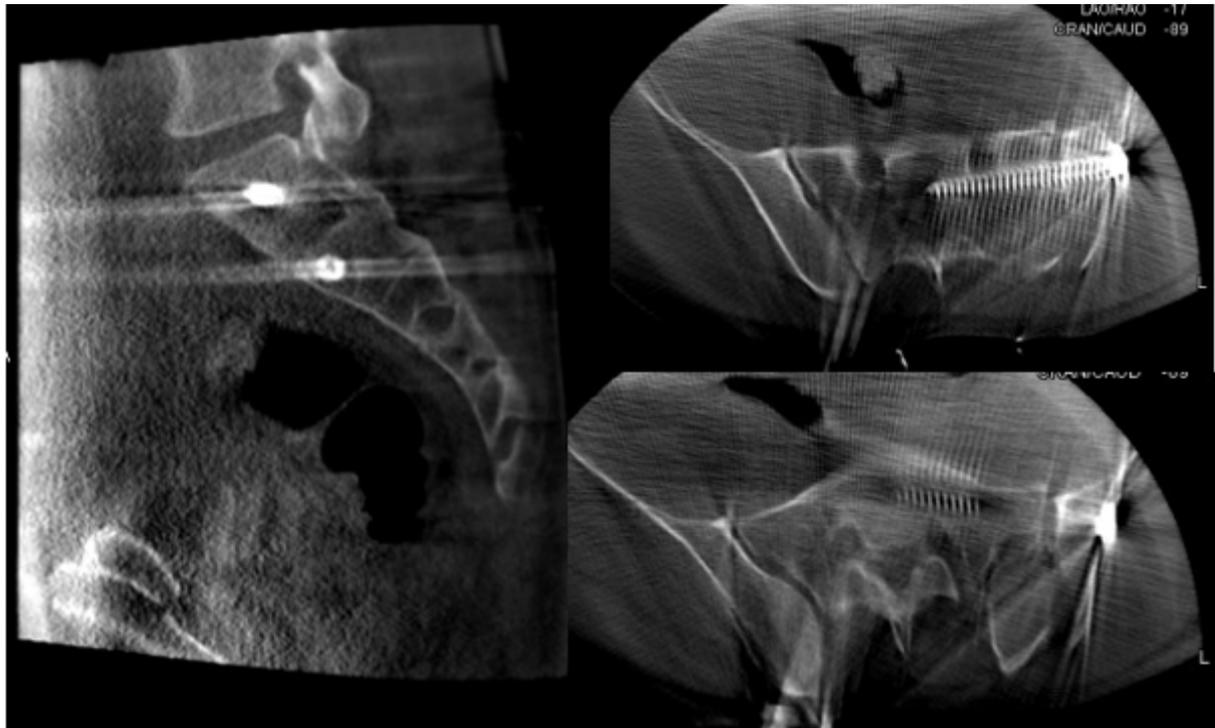


Figure 4: Intraoperative CT scan demonstrating an intraosseous course of both the above S1 screw and an additional S2 screw placed in the same fashion.

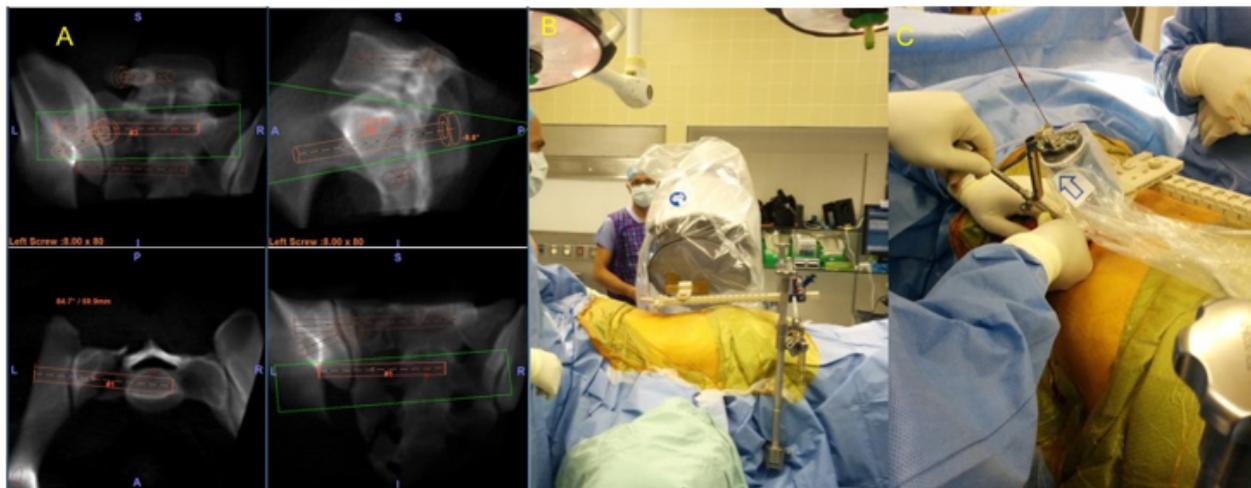


Figure 5: (A) preoperative planning of lumbopelvic fixation of a sacral and L5 fractures caused by a fall from height. The screws are planned based on a preoperative CT (B) the robot frame is mounted on the patient and fluoroscopic views are used to match the existing anatomy with the preoperative CT scan using a specialized algorithm (C) the robot travels to the desired screw position and the mechanical arm is aimed at the right trajectory.



Figure 6: Postoperative CT of the previous case demonstrates intra-osseous position of all pedicle and iliosacral screws placed. The patient recovered uneventfully.

Further Thoughts and Conclusions

The role for minimally invasive fixation of posterior pelvic ring injuries is now well established. While surgical reduction is still a challenge, the adequate, precise and quick placement of iliosacral screws can become an uneasy task even among experienced surgeons. As we reviewed judging from the progress of image guided surgery during the past decades it is obvious that a 3D imaging environment should become a standard of care in the upcoming years. The size of machinery, the immense costs, and the steep learning curves associated with these devices is a major setback still to be confronted. Other obstacles include the software incompatibility between devices such as a surgical robot with a certain intraoperative 3D imaging system or a navigation system. An open source platform or at least shared application platform interfaces (API's) that will ease the development of applications would probably expedite the development of more universal and flexible systems. These in turn, will allow communications between older and newer systems and across platforms including the outside world such as mobile devices. Also, surgeon education and awareness of the modern IGSs' and their availability will probably create more enthusiasm among the younger generation of pelvic and acetabular surgeons. In summary, the iliosacral screw placement is still a major test case for emerging IGS technologies, and not by chance. It is a technically demanding procedure requiring clear imaging, a thorough realization of anatomy, and a 3D insight that now can be facilitated by modern image guided devices.

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