Percutaneous Posterior Stabilization of the Spine

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Abstract. We have demonstrated the use of computer assisted techniques for performing posterior spine stabilization in a series of *in-vitro* studies. The techniques are still under development but have undergone early laboratory verification. Registration is the biggest limitation of conventional IGS systems when attempting to use them for percutaneous implantation of pedicle screws. This can be overcome by palpating structures beneath the skin or by implanting special tracked fiducial arrays attached prior to CT-scanning. Visualization of the posterior elements and placement of bone graft can be performed using a combination of endoscopic and IGS techniques, and pedicle screws placed using percutaneous approaches. Assembly of the stabilization construct is performed by subcutaneously threading the rods onto top-loading screws. Four cadaver studies have shown good results and demonstrated the possibilities and difficulties of registration, pedicle screw placement, and construct assembly using the minimally invasive techniques.

1 Introduction

The placement of posterior pedicle screws has been made safer and more accurate through the use of image guided surgery (IGS) workstations. Radiation exposure to the surgeon from intraoperative fluoroscopy has also been reduced but there has been little improvement in morbidity or patient recovery time despite the added equipment. This is primarily because the surgical exposure is essentially unchanged. In some cases the exposure may be even larger, especially if tissues are aggressively retracted in order to obtain access to potential registration locations. Use of IGS equipment also increases the time spent performing the surgical procedure.

Computer assisted techniques initially appear to be ideal for assisting with accurate *percutaneous* screw placement. Unfortunately, the need to register (or "match") the system to the underlying anatomy makes this more difficult. Registration in the spine for IGS systems is normally performed by touching carefully selected anatomical landmarks over each vertebral body, or by randomly selecting 20-40 surface points on the vertebra, or a combination of these methods.

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Unlike cranial surgery, skin fiducials placed on the back move too much after the scan to make external registration reliable.

Techniques suitable for assisting with registration for percutaneous pedicle screw placement include fluoroscopy, intraoperative ultrasound, intraoperative CT and interventional MRI. All these techniques have limitations, however.

Image guided fluoroscopic methods can be used either in either a purely 2D manner with graphic image overlay as demonstrated by Hofstetter et *al.* [1], or in conjunction with 2D to 3D matching techniques. The first approach has the advantage of automatic registration, since images are taken while the spine is being dynamically referenced. Intraoperative navigation however, must be performed on the stored fluoroscopic images, which may suffer from poor image quality compared to that available from CT based IGS systems. In addition, these systems require careful calibration and correction of distortions in the images and of the fluoroscope's support structure itself. The second approach, 2D-3D registration [2], is also potentially automatic but is still computationally expensive, especially when using poor quality fluoroscope images. Ultrasound to 3D registration algorithms [3] also suffer from difficulties with distortions and may require manual intervention. Intraoperative CT and MR [4] are still extremely costly, and cumbersome to work with.

Our own work has used two simpler approaches that show promise, namely percutaneous matching and tracked fiducial arrays. These techniques also have disadvantages but are simple to apply.

In this paper we report recent developments in percutaneous image guided spine stabilization, particularly in the registration techniques required to perform the procedure closed.

2 Materials and Methods

2.1 Techniques

The operative procedures required for percutaneous image guided spine stabilization differ significantly from conventional image guided spine surgery as well as the non computer-assisted approach. Both the order and the actions performed are different. Some additional steps are required, and a preoperative CT is mandatory. Not all aspects of a full decompression/stabilization are possible using these techniques, but a significant subset of spinal procedures are potentially treatable.

Several studies were performed to demonstrate aspects of the procedure. Many of these are described below. This work was conducted using the SCOUT IGS workstation (SNS, Mississagua, Ontario, Canada) although almost any system could have been used.

Dynamic Referencing Dynamic referencing of vertebral bodies in image guided spine surgery is required to compensate for vertebral body motion. Normally, a clamp is attached to the spinous process of the segment. An optically tracked dynamic reference body (DRB) is then attached to this clamp enabling the location and orientation of the vertebra to be monitored. While it is possible to percutaneously attach a clamp to the vertebra, a solution that we have employed is a small locking screw (Traxtal Technologies, Bellaire, Texas) placed into the spinous process or the facet. Such a device can be inserted through the skin and locked onto the bone surface. It is necessary to target the placement of the pin using fluoroscopy, which also is used to confirm the vertebral level.

Registration We used two methods of registering. The first (see Glossop et al. [5]) is a percutaneous matching technique. Stab incisions were made posterolaterally, and locations along the transverse processes and medial pars were selected for a paired point matching. Surface fitting was then used to assist and improve this initial registration. Although difficult at first, it was possible to obtain good registrations through tactile feedback alone, especially if 3D reconstructions of the vertebra are available for the surgeon to view on the computer during the process.

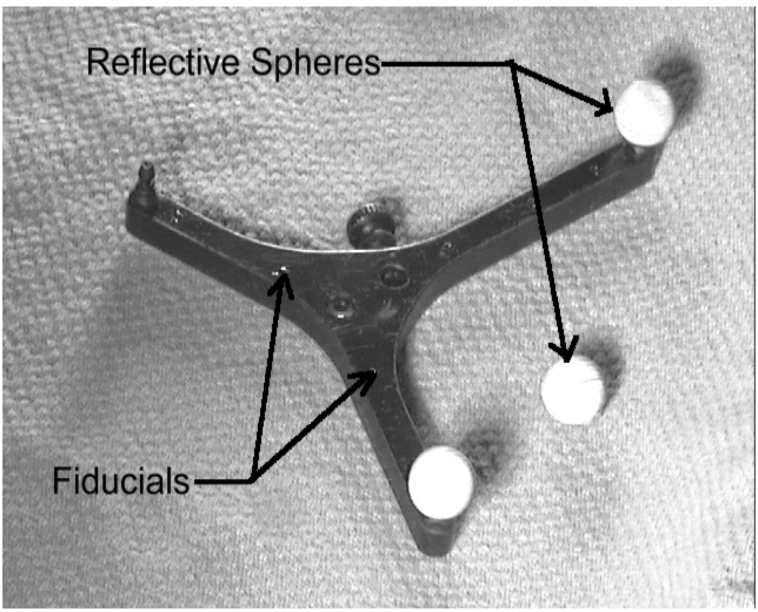

Fig. 1. The radiolucent trackable fiducial array/DRB used in these studies (Traxtal).

The second registration method used is reminiscent of traditional frame-based neurosurgery. Arrays of radiolucent, trackable fiducial carriers were attached to the vertebrae of interest using locking screws prior to the scan. The carriers (also described in [5]) contained fiducials that were imaged and selected as registration points on the preoperative scan. By using a carrier that also functions as a passive DRB with the Polaris position sensor (Northern Digital, Waterloo, Ont., Canada), it was possible to register the carrier - and the vertebra - semi-automatically, since the patient-space positions of the fiducials are accurately known *a priori* from the carrier's construction. We wrote software to perform the matching and to generate a valid registration file for the SCOUT system to use. All that was required was to locate and save the fiducial coordinates in image-space prior to surgery and execute this progam. The fiducials never had to be touched with a probe as in our original technique [6].

Pedicle screw and graft placement After registration, channels can be made in the pedicles in the conventional manner, using an optically tracked pedicle awl to puncture the cortex, followed by a pedicle probe to create the hole. Although a tracked drill guide was available, we were more comfortable with hand instruments that provided more tactile feedback. K-wires can be inserted into the holes and paths confirmed with fluoroscopy before proceeding. A tracked screwdriver was not used to follow the progress of the screw into the hole although this can be done if required.

We were able to place bone grafts through direct visualization of posterior spinal elements through an endoscope. Although it is not necessary to register to visualize the anatomy in this manner, a tracked endoscope and probe were sometimes used. This enabled the positions of the instruments to be displayed on the IGS workstation.

Construct Assembly Top-loading pedicle screw systems are generally required for the system to work easily. Rods are threaded beneath the subcutaneous facia and secured using the screws.

Corrections of kyphosis etc. may best be performed using image-guided techniques to manipulate the vertebrae into an "ideal" location, but so far this has not been attempted, and would require significant changes to the software of the IGS system.

2.2 Studies

We have performed parts of the described techniques on four cadaver specimens with good success. We have still to evaluate the absolute accuracy to which the procedures have been performed, but the qualitative results have been very successful.

The first study examined the feasibility of percutaneous endoscopic navigation and visualization in the spine. An endoscope was inserted using a posterolateral approach and used to visualize the spinal anatomy.

The next two studies considered the possibility of registration using the paired point/surface fitting technique detailed above. The surgical approach used the concepts of the paraspinal posterolateral approach to access the transverse processes and most medial aspects of the pars in order to register the vertebral body. This enabled us to use the workstation to target the pedicles and implant screws percutaneously directly into the vertebra.

Finally, a combined study sought to evaluate the possibility of performing a complete procedure. Vertebrae were registered using both techniques detailed above and screws placed in the pedicles and pelvis. Rods were then threaded through the incisions and secured using a top loading fixation system.

3 Results and Discussion

We have been able to demonstrate percutaneous registrations using bony landmarks is an effective technique, with 4/6 screws being placed successfully in the cadavers. One miss was identified (from the videotape made during the procedure) to have been caused by a movement of the DRB after registration and prior to making the pedicular tunnel. It should have been detected while the surface of the vertebra was being checked with the probe, but this step was accidentally skipped for this side of the segment.

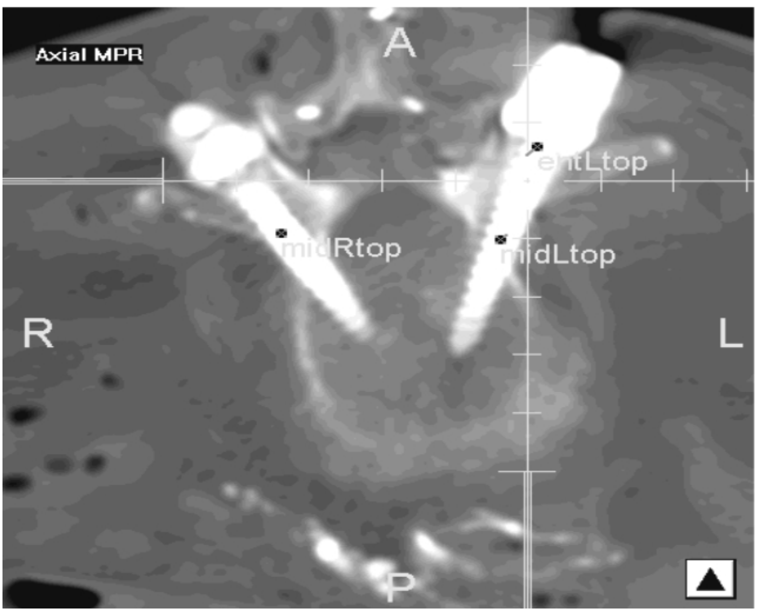

Fig. 2. Screw placed into the L2 body using the trackable fiducial array

The second misplacement was actually perfectly placed in the pedicle of the segment beneath the intended target. This could have been avoided by preplanning the screw path. Although offered in the software, we did not elect to pre-plan the screw's path because the excellent real-time feedback offered by the workstation during conventional IGS cases was always sufficient. In the percutaneous approach where there is little relative motion between vertebral levels (as in the cadaver study), simple surface checking will not reveal "off-by-one" errors of this nature and it is easy to become confused.

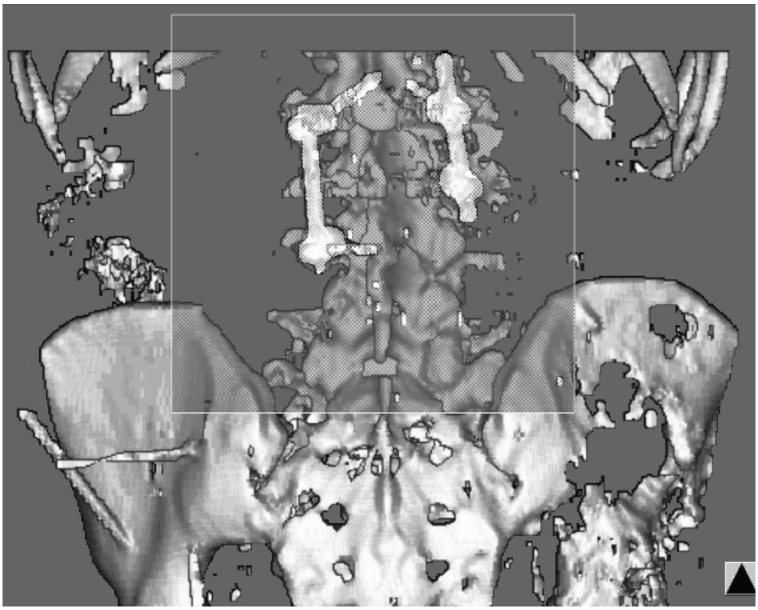

Fig. 3. Three dimensional reconstruction showing the misplaced screw in L3.

This miss alludes to another potential problem with percutaneous registration, namely inadvertent multi-segment or different-segment registration. It is always recommended to perform separate registrations on each level undergoing screw placement. The lack of direct visual confirmation of the location and level makes it extremely easy to accidentally perform all or part of the registration on an adjacent vertebra than the one intended. It is almost impossible to tell from the surface of the skin when the incorrect level is being accessed.

Registration based on trackable fiducial carriers was more successful, with 7/7 screws being correctly targeted in the pelvis and spine. It eliminates the need to register during surgery but does require an extra surgical intervention before the scan to insert the pins for the tracker. Two iliosacral screws, an anterior column screw and 4 pedicle screws were placed using the technique.

This type of registration is potentially extremely accurate, since matching errors introduced by inaccurately touching the registration landmark are eliminated. In addition, no errors attributable to the position sensor and probe are introduced during registration.

Both solutions have been shown to be able to cope with the requirements of registration. The trackable fiducial carrier was felt to be qualitatively more accurate and convenient for the surgeon, with more rigorous accuracy studies currently underway. The additional surgery that is required for implantation of the carrier may be justified if it can be shown that there is improved morbidity and recovery time for the stabilization procedure. Work in the open MRI scanner indicates that this is indeed the case [4]. We are currently working to improve the logistics of this procedure to make it more acceptable for the patient. The current procedure is probably acceptable in its current form for pelvic ring disruptions, where an external fixator is often applied as part of the resuscitation effort prior to the CT scan.

While it will be some time before percutaneous posterior spine stabilization becomes realistic in all situations, there is a large subset of surgical candidates for whom such a procedure is beginning to be practical using these techniques. The new methodology clearly demonstrates the reduced the morbidity that percutaneous stabilization might attain.

4 Conclusion

Despite the progress that has been made, we urge caution. The results are preliminary and it will be some time before instrumentation and procedures are developed enough to perform percutaneous posterior stabilization on a routine basis. Indications for this intervention currently include no prior surgery with short 2-3 segment runs. We also recommend the larger vertebrae, with L4-L5 ideal. Constraints on the current instrumentation also suggest that thin patients would also be most amenable to these techniques. In all cases, verification using fluoroscopy is and will continue to be indicated.

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