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SIMULTANEOUS REGISTRATION WITH CT-FLUORO MATCHING FOR SPINAL NAVIGATION SURGERY

A Case Report

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ABSTRACT

Computer-assisted surgery, which provides simultaneous, multiplanar images of bone structures, has become widely used. However, registration maneuvering remains time consuming. The objective of this paper is to document the usefulness of CT-fluoro matching for spinal navigation. A spinal navigation system (VECTORVISION® compact; Brain LAB, Germany) and a digital imaging system (OEC9800; CATHEX, Tokyo, Japan) were used for CT-fluoro matching in cases of L4/5 and L5/S1 posterior lumbar interbody fusion. A reference array was attached to the L4 spinous process. Preoperative CT images and intraoperative fluoro-shots including L4, L5, and S1 were superimposed on the navigation monitor. Following insertion of L4 screws, a reference array remained to be attached to the L4 spinous process, after which a level definition and pre-registration of L5 and S1 vertebrae were performed and the screwing procedure of L5 and S1 was completed without additional fluro-shots. Registration of three vertebrae was completed without paired-point or surface-matching procedures. The calculation time for the registration in a single vertebra was 30 sec. All pedicle screws were seen to be successfully inserted on postoperative CT images. We performed the navigation surgery by matching the preoperative CT images to the intraoperative fluoro-shots without manual registration. This technique may prove useful in the future for anterior spinal surgery and percutaneous screwing without the need for total exposure of the bone surface.

Key Words: Navigation surgery, Registration, CT-fluoro matching, Pedicle screw

INTRODUCTION

Spinal navigation systems enable surgeons to provide simultaneous, multiplanar images of spinal structures as well as trajectory views during pedicle screwing.[1-5] In such systems, registration maneuvering is essential to precisely match the operative anatomy to the image anatomy displayed on the computer workstation monitor. To accomplish this, two registration methods are available. For paired-point matching, surgeons identify a minimum of four distinct 3D landmarks on the reformatted CT images and corresponding 3D landmarks in the surgical field. This method sometimes requires additional surface matching, a process in which a number of random points

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on the exposed bone surface must be selected due to its irreproducibility.[4,6-8] However, these procedures are not only time consuming, require special skill, and increase invasiveness, but registration may be impossible to achieve in cases with highly degenerated and pathologically altered vertebrae, because of the imprecise definition of the landmarks and registration. Moreover, when navigation is performed for a number of vertebrae, repeated registrations for each vertebra are indispensable to maintain registration accuracy due to confusion with neighboring vertebrae, which constitutes a major drawback in manual registration. With a view to devising a less time-consuming method adapted to more than one vertebra, we performed simultaneous registrations with CT-fluoro matching in which preoperative CT images are superimposed on intraoperative fluoroscopic images during spinal navigation surgery without intraoperative manual registration.

SUBJECTS AND METHODS

A 61-year-old female who had a 1-year history of bilateral sciatica, low back pain and intermittent claudication was recruited for this trial. Spondylolisthesis of L4 and L5, and instability in L4/5 and L5/S1 were found on lateral radiograph (Fig. 1). These findings were considered to reveal the causes of both the low back pain and claudication. Decompression of L4/5 to L5/S1 together with posterior interbody lumbar fusion (PLIF) at L4/5 and L5/S1 was planned to resolve the compression of cauda equina and nerve roots, thus eliminating segmental instability. Pedicle screws (TSRH; Medtronic Sofamore Daneck, Memphis, TN) were installed in bilateral L4, L5 and S1 for PLIF at L4/5 and L5/S1 using the spinal navigation system (VECTORVISION® compact; Brain LAB, Germany). The digital imaging system (OEC9800; CATHEX, Japan) was used for CT-fluoro matching.

The patient underwent preoperative CT (Aquilion TSX-101A; TOSHIBA, Japan) of the spinal segments to be conducted at a slice thickness of 2.0 mm, an interval of 2.0 mm, and a pitch of 3.0°. Image data were preserved once using Digital Imaging and Communications in Medicine (DICOM) and then transferred to the navigation system *via* a network, allowing reconstruction of a three-dimensional image.

The patient was kept in the prone position to expose the L4 spinous process and the entry portions of pedicle screws at L4, L5, and S1 in the usual manner. A reference array fitted with passive marker spheres was firmly attached to the spinous process of L4 vertebra to reflect infrared flashes from the cameras, thus creating individual infrared reflection images. The x-ray registration kit with reflective marker discs was mounted on an image intensifier in a sterile environment (Fig. 2). Both AP and lateral fluoro-shots were obtained including those of three vertebrae, L4, L5, and S1, where we intended to install the pedicle screws, and the computer workstation acquired these fluoro images. The positions of the reference array and X-ray registration kit were detected automatically as each new fluoroscopic image was acquired.

While surgeons prepared the C-arm image intensifier and obtained fluoro-shots, the navigation operator managed VECTORVISION outside of the operating field. Once images had been acquired, the segmentation of L4 vertebra to which the reference array was attached was completed prior to CT-fluoro matching (Level Definition). The segmented vertebra was superimposed over the AP and lateral fluoroscopic images. Matching a segmented vertebra as closely as possible to the corresponding vertebra in the fluoro image thus ensured the highest possible registration accuracy (Pre-registration, Fig. 3). Once the vertebra had been correctly positioned, a button was pressed to confirm the placement and to activate automatic matching, at which point the result of the CT-fluoro matching procedure was displayed (Fig. 4). After verification of CT-fluoro matching on the navigation monitor, the trajectory of the screw pathways could be seen in multiple CT planes

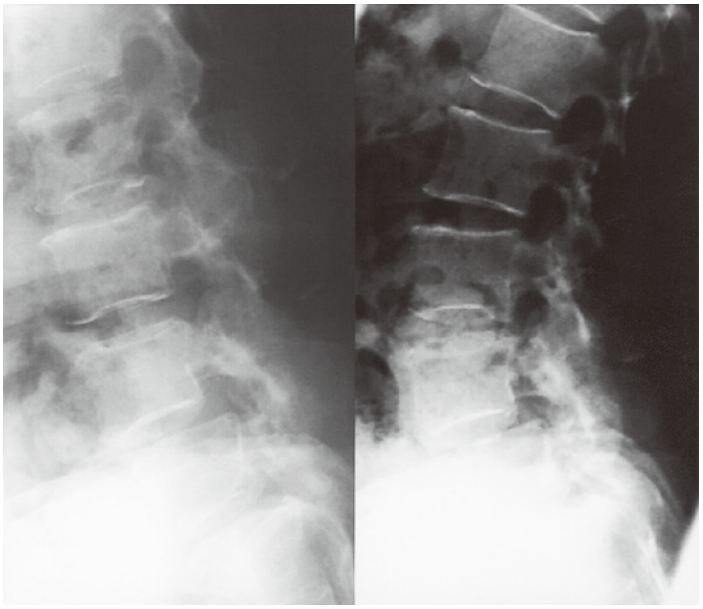

Fig. 1 A 61-year-old female sustained L4 and L5 spondylolisthesis.

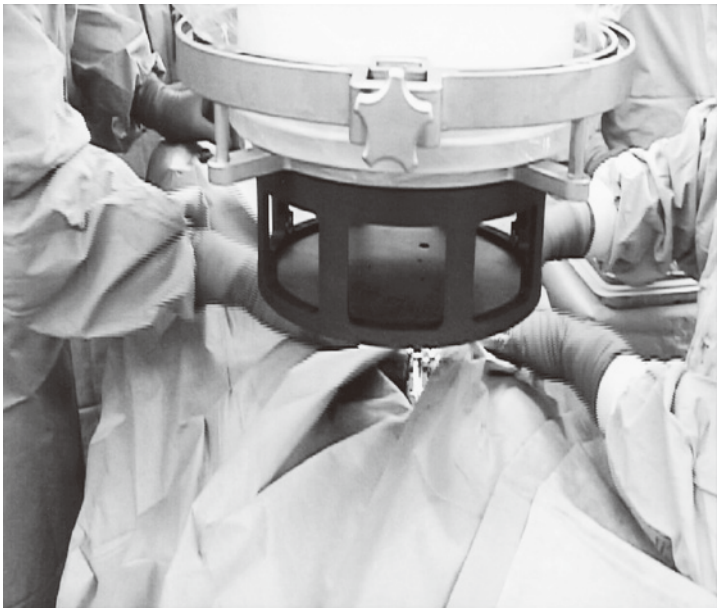

Fig. 2 X-ray registration kit with reflective marker discs was mounted on image intensifier in a sterile environment. Both AP and lateral fluoroshots included three vertebrae, L4, L5, and S1.

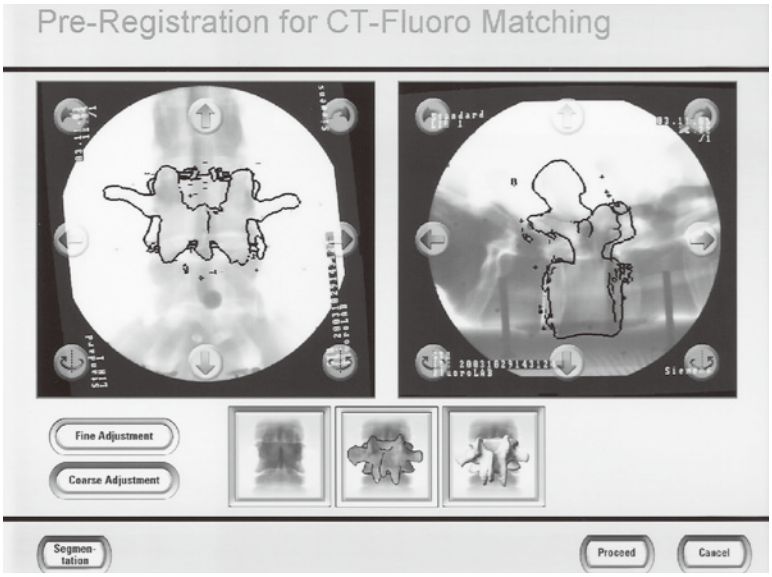

Fig. 3 Pre-registration for CT-fluoro matching. Segmented vertebra is positioned over AP and lateral fluoroscopic images. Matching segmented vertebra as closely as possible to corresponding vertebra in fluoro image ensures best possible registration accuracy.

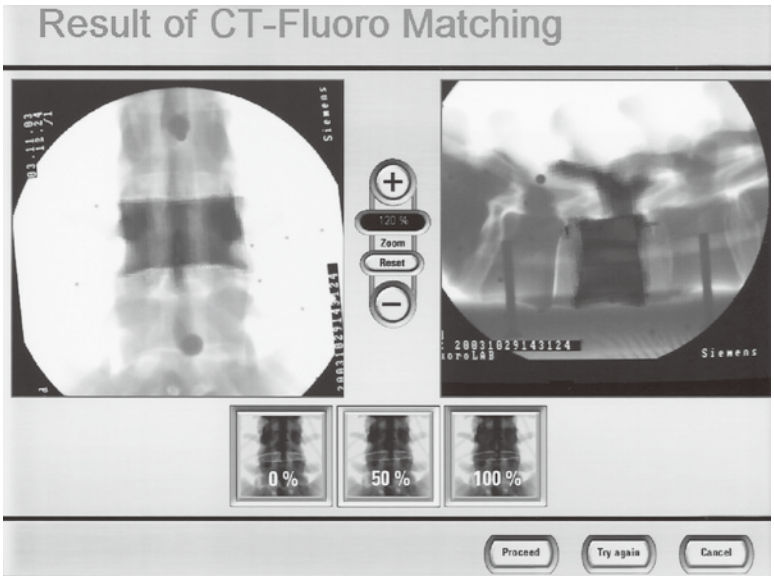

Fig. 4 Result of CT-fluoro matching. Once vertebra has been correctly positioned, pressing a button to confirm placement activates automatic matching, at which point CT-fluoro matching procedure is displayed.

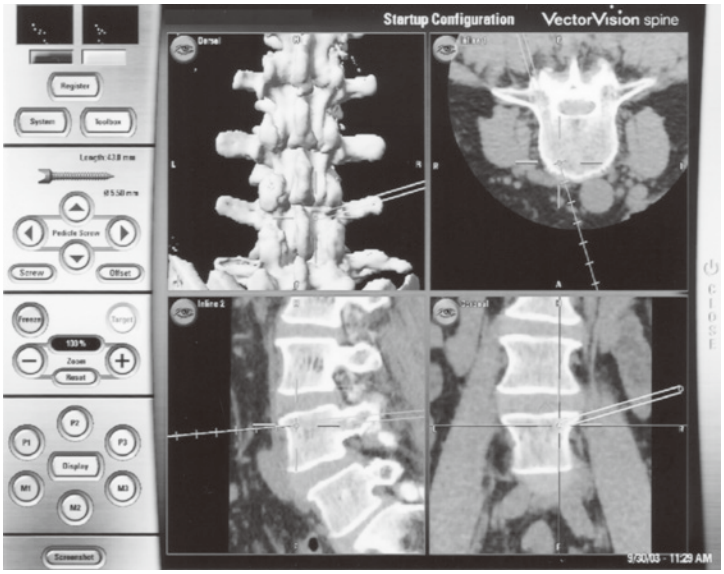

Fig. 5 Intraoperative view confirming accurate navigation of trajectory of screw pathways.

(Fig. 5). The adapter consists of a reflective marker array mounted on a T-handle pedicle probe, and pedicle screw holes were made under the navigation guide. Tapping and screw insertions were performed manually.

After L4 pedicle screw insertion, a reference array remained to be attached to the L4 spinous process, Level Definition and Pre-registration of L5 and S1 vertebrae were performed, and the screwing of L5 and S1 was completed without additional fluoro-shots.

Informed consent for using this method had been obtained before the operation.

RESULTS

Registration of L4, L5 and S1 vertebrae was completed without using paired-point and/or surface-matching procedures. Calculation time for the registration of a each vertebra was 30 sec. All pedicle screws were successfully inserted (Fig. 6).

DISCUSSION

Virtual fluoroscopy has been introduced as a new technology combining image-guided surgery with C-arm fluoroscopy to reduce radiation exposure.[9] This method also has the advantage of rendering unnecessary the time-consuming registration step, though it does not provide the multiplanar images generated by 3-D systems. It has, however, become possible to generate 3-D images from C-arm fluoro shots using ISO C (Siemens, Germany). This application allows a CT-like visualization with a quality superior to that of 2-D images, but inferior to that of a standard CT-scan.[8] The use of a CT scanner in the operating room is indispensable to obtain

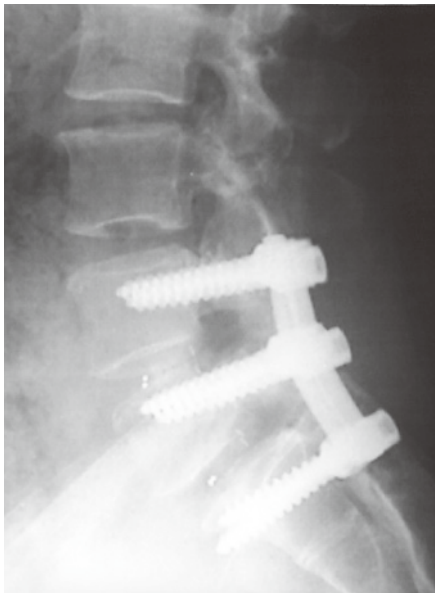

Fig. 6a

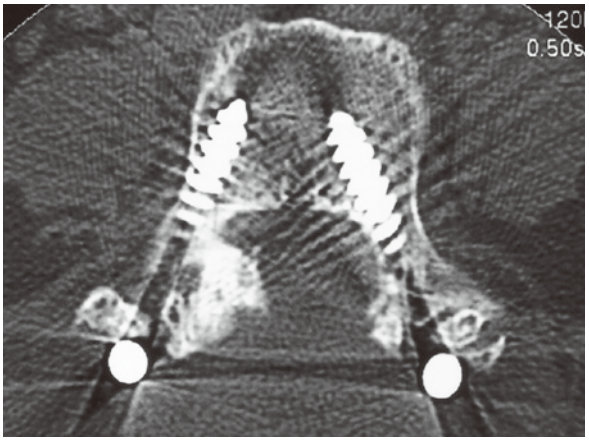

Fig. 6b

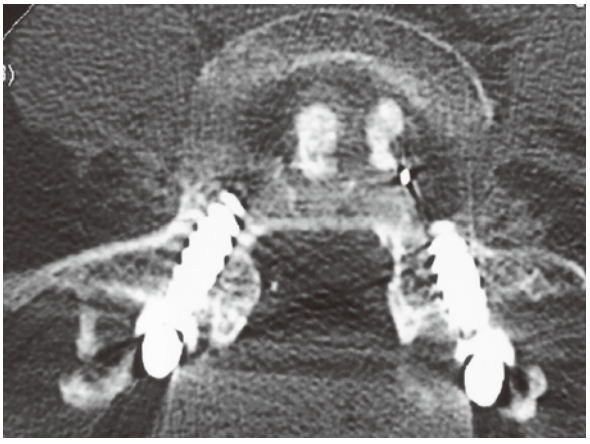

Fig. 6c

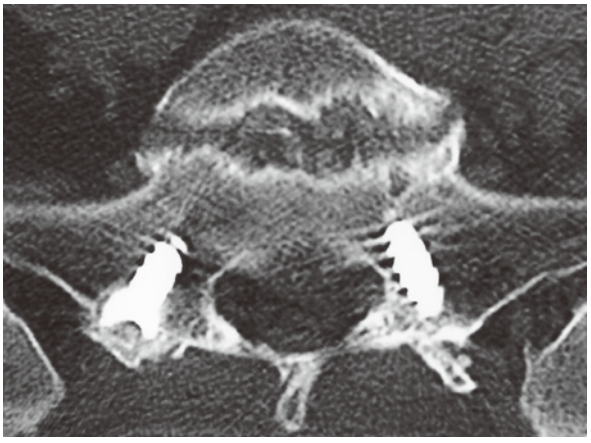

Fig. 6d

Fig. 6 Postoperative X-P and CT images. Pedicle screws were accurately positioned. a: lateral X-P; b: L4; c: L5; d: S1.

3-D navigation images without intraoperative surgeon-controlled registration. However, among its many disadvantages are the cost of purchase, the need to use a specially designed operating table, and certain ergonomic issues.[7] Recently, *fiducial marker registration* has been reported as a semiautomated registration using implantable markers in the surgical field.[10,11] Repeated registration and additional placement of spinal markers are needed for precise registration, and anatomical exposure is necessary to install such markers. In this respect, there is substantially no difference compared with the manual registration. Although various registration methods have been reported,[12,13] the majority are based on anatomical landmarks and depend on a combination of paired-matching and surface-matching to enhance accuracy. With regard to registration problems, Hamadeh *et al.* demonstrated the validity of an approach in carrying out accurate 3-D and 2-D registrations.[14] Brendel *et al.* have presented a method for the registration of preoperative CT datasets and intraoperative ultrasound data,[15] neither of which, however, has been attempted in clinical practice.

We have successfully performed navigation surgery by matching the preoperative CT images to intraoperative fluoro-shots without manual registration. The major advantage of such CT-fluoro matching is to reduce the surgeon's difficulty with registration points and to lessen the "human inaccuracy factor" arising from freehand manual registration. Once the vertebrae for screwing can be visualized as intraoperative fluoro-shots, registration can be accomplished on the navigation monitor. Thus, the level of occupational radiation exposure is considerably less than that in conventional image-guided surgery. In CT-based navigation, a reduction in operation time can be achieved by a "single registration" performed on only one of the vertebrae, with adjacent vertebrae registered using the registration data of the first vertebra without a subsequent registration procedure. However, the issue of segmental mobility under general anesthesia and/or discrepancies between preoperative CT images in the supine position and surgical spinal alignments in the prone position cause registration errors. In this respect, intervertebral mobility counts for nothing in CT-fluoro matching which requires the matching by extraction of each vertebra. If instrumented vertebrae are contained in the fluoro-shots, reattachment of the reference array to the adjacent spinous process becomes unnecessary. Registration procedures, in which the surgeon must originally work in the surgical fields can be performed in adjacent vertebrae by the navigation operator outside the surgical field. Moreover, paired and surface matching necessitate the total removal of soft tissue and complete exposure of the bony elements for precise registration at the spinous process or lamina where the points are placed. Thus, muscle damage associated with unnecessary exposure could be avoided by CT-fluoro matching. In the anterior approach using navigation surgery, Klein *et al.* stated that the smooth topology of the anterior cervical spine and the relatively small exposure involved when performing anterior cervical discectomy and fusion may make registration difficult.[16] According to Ohmori *et al.* in anterior thoracolumbar corpectomy, one of the major limitations in using navigation is the time required for registration, which on average is 7.6 min.[17] The difficulty of registration in the anterior approach may be overcome by using CT-fluoro matching. One drawback of this technology, however, is that its accuracy is not indicated as it would be in ordinary preoperative CT-based navigation, so that verification of the registration depends on the surgeon's judgment, and considerable experience and skill with pedicle screwing are essential. There are still some problems with the intraoperative looseness of a reference array attached to the spinous process, which poses a risk of inaccurate navigation. On the other hand, CT-fluoro matching enables precise and simultaneous registration without total exposure of the anatomical bone surface, and should facilitate future percutaneous pedicle screwing on 3-D images.

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