

## A Robot Arm-type Navigation System for Pedicle Screw Placement: A Feasibility Study

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### – Abstract –

**Study Design :** The study involved the development and accuracy testing of an intra-operative navigation system

**Objectives :** This study was undertaken to develop a navigation system using a robot arm-type three-dimensional digitizer. And, to apply the developed system to pedicle screw insertion, and to evaluate its accuracy.

**Summary of Literature Review :** To the best of our knowledge, no navigation system has been developed using a robot arm-type three-dimensional digitizer.

**Materials and Methods :** We have developed a navigator using a three-dimensional digitizer (Microscribe 3-D G2, Immersion, USA) supported by a personal computer. Four types of patient-to-image registration techniques were implemented. During navigation, the central axis of the robot arm's stylus and arm extension can be displayed over multi-planar and three-dimensional images, which are reconstructed from axial CT scan images. Registration errors and target localization errors of the navigation system were evaluated using a phantom made from a plastic lumbo-sacral bone model. The accuracy of pedicle screw insertion was also evaluated by placing 18 pedicle screws in such bone models.

**Results :** The registration error was  $0.78 \pm 0.27$  mm at fiducial registration and  $0.76 \pm 0.24$  mm at hybrid registration, and the target localization error was  $1.34 \pm 0.32$  mm at fiducial registration and  $1.28 \pm 0.29$  mm at hybrid registration. Of the 18 screws placed in the plastic bone models, one (6%) screw breached the pedicle wall.

**Conclusions :** We have developed a robot arm-type three-dimensional digitizer-based navigation system for pedicle screw insertion, and found that its accuracy is equal or slightly better than that of optical tracker-based navigators.

**Key Words :** Pedicle screw, Robot arm, Three-dimensional digitizer, Navigation system

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(intra-operative navigation system)

21

(computer assisted surgery, CAS)

(image-guided surgery, IGS)

(optical tracking system)

(magnetic tracking system)<sup>12)</sup>

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가 가 가

가 6,12) , 3

(robot arm-type three-dimensional digitizer)

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**Fig. 1.** A robot-arm type three-dimensional digitizer is shown. The stylus portion is arrowed.

1.

3 (Microscribe 3-D

G2, Immersion Co., USA) 5 가 (5

) (mechanical arm) 가 (Fig. 1).

(stylus) (tip)

RS-232C USB 1.1

(personal computer)

(spatial resolution) 0.13 mm,

(accuracy) 0.38 mm, 63.5 cm

(foot switch)

Pentium IV 2.0 GHz 1 GB

OpenGL(Silicon graphics, USA) 가 가

Microsoft

Windows 2000 Professional

RS-232C

2. - (patient-to-image registration)

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(CT ) 3

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CT

(fiducial pin) CT

( )

(fiducial registration) CT

(pinless registration)

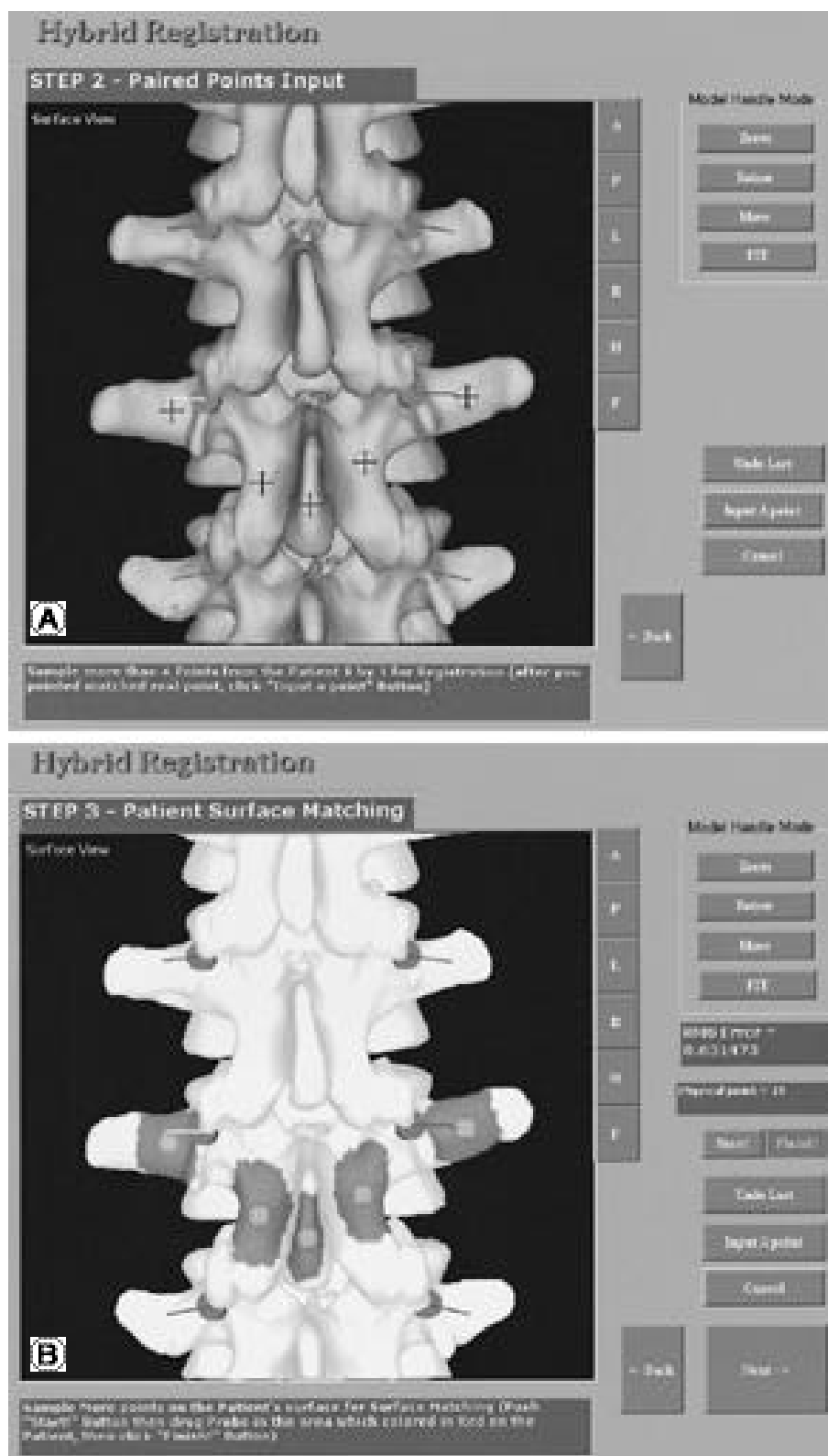
가 4~6

(anatomical landmarks) CT

(paired point registration)

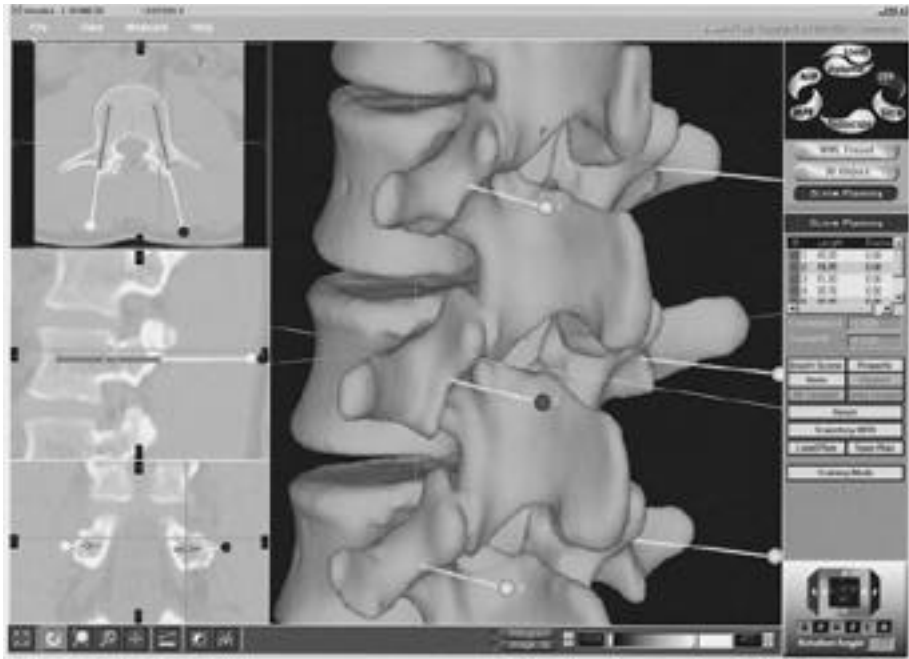
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CT, 3, 3 (surface registration) 4~6 (Fig. 2A) 10 가 (Fig. 2B) (hybrid registration) (Fig. 5). (Model number 1340-3, Sawbones, USA) 78 26G 3~4 mm CT (slice thickness) 1 mm, (table feed) 1 mm/ (rotation time) 0.75 (reconstruction incremental) 1 mm DICOM(digital imaging and communication in medicine) 3.0 (multi-planar reconstruction) 3 ( 1~2 CT (registration error) (target localization error) 가 (root mean squares error, RMSE) ( CT ) 3 Xi (i=1, 2, 3, 4) Yi (transformation matrix) T Xi (Xi ' = T \* Xi ) 10~12 mm (navigation) 가 CT ( Fig. 4 ) 1~7 (window) 30 Xi 가 가 30 (Fig. 4A) (3 orthogonal views) (trajectory multi-planar reconstruction images) (Fig. 4B) 가 1~7 가



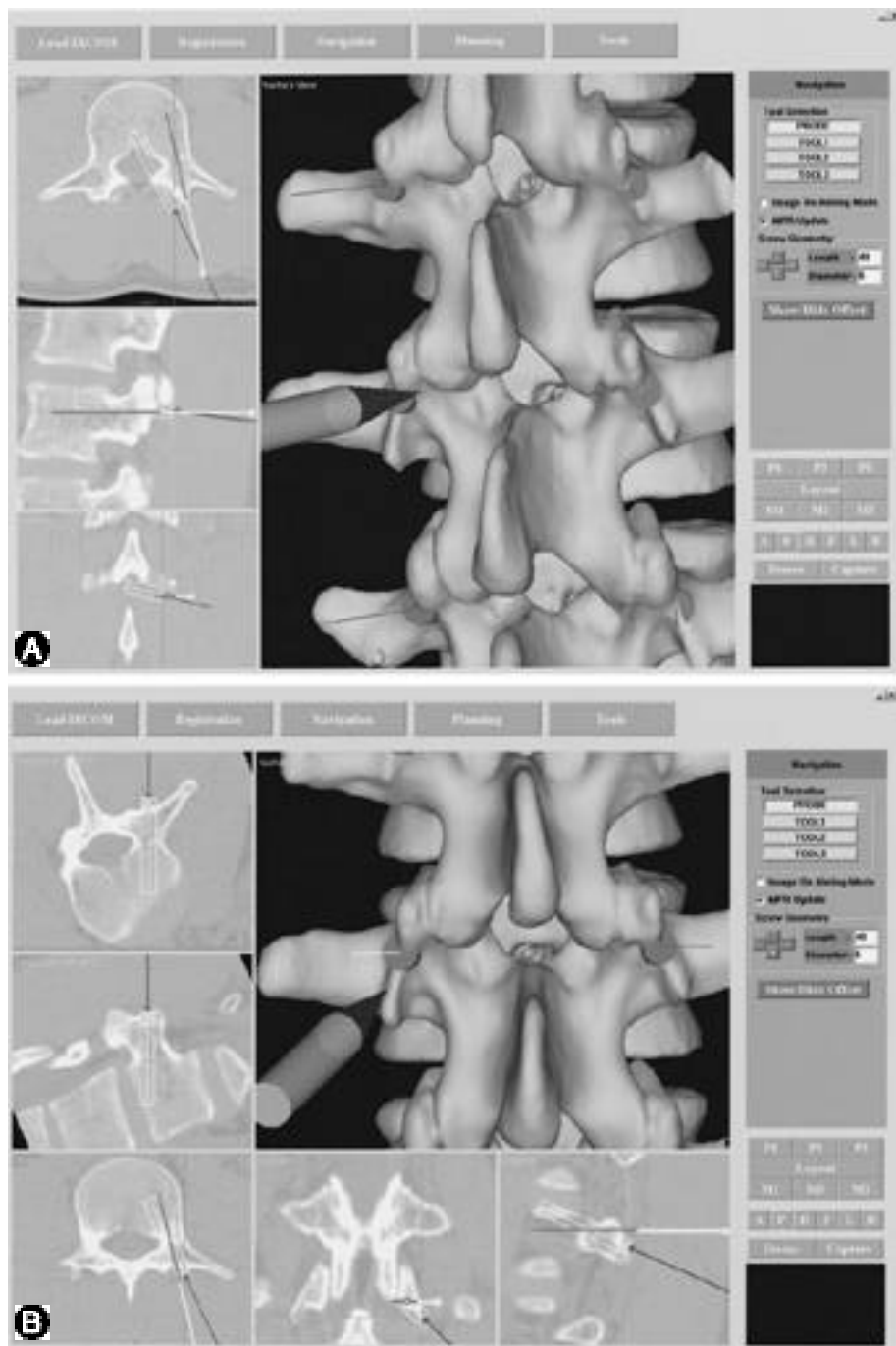
**Fig. 2.** The user interface of hybrid registration is shown.

- A. Paired point registration is carried out first, which approximately matches 4~6 points on real bones with those on three-dimensional images.
- B. Then, surface registration is carried out by additionally inputting 10~12 arbitrary points.



**Fig. 3.** Planning software is shown. Optimal entry points and trajectories of screws can be determined pre-operatively using multi-planar and three-dimensional images reconstructed from axial CT scan images.

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18 ( 45 mm, 6.5 mm; 4CIS, Solco, Korea)  
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1 가  
3  
가 ( 20 ) 4  
30 cm  
가  
5. 2  
(Model number 1340-3, Sawbones, USA)  
8 가  
가 1 가  
가 8 ( )가  
12 3  
mm, 3 mm/ , 0.75 ,  
1 mm CT  
8  
1 가 1 , 8 가 5  
0.78 ± 0.27 mm, 0.76 ± 0.24 mm  
0.7 mm (Table 1).  
가  
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**Fig. 4.** The user interface of navigation software is shown.

- A.** The central axis of the robot arm's stylus along with the planned trajectory is displayed on multi-planar and three-dimensional images.
- B.** They can also be displayed on two-dimensional images reconstructed along the axis of the stylus (the two upper left windows).

)  $1.34 \pm 0.32$  mm, 1, 1 (6%)  
 $1.28 \pm 0.29$  mm, 1.3 mm  
 18, 16  
 (88%), 1 (6%)

**Table 1.** Registration error and target localization error of the navigation system.

Registration method	Error (mm)	
	Registration error	Target localization error
Fiducial registration*	$0.78 \pm 0.27$	$1.34 \pm 0.32$
Hybrid registration**	$0.76 \pm 0.24$	$1.28 \pm 0.29$

\*Four points were used for each registration process.

\*Fourteen points were used for each registration process.



**Fig. 5.** A phantom made with a plastic lumbosacral bone model is shown. It was used for the accuracy test.

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(noise)

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가( 5 )

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가 가 (0.38 mm,

) (0.3 mm )

CT (CT

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ters),

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8) 0.7 mm

1.3 mm 가

(1 mm

1~3 mm)<sup>1,6,8)</sup>

CT 가

CT CT(multi-

detector CT)

[illegible]

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: 3 (Microscribe 3-D G2, Immersion, USA)  
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. 18 ,

:  $0.78 \pm 0.27$  mm,  $0.76 \pm 0.24$  mm ,  $1.34 \pm$   
0.32 mm,  $1.28 \pm 0.29$  mm . 18 ,  
1 (6%) .  
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