Accuracy of 3-D Fluoroscopic Navigation System using a Flat Panel Detector-equipped C-arm

INTRODUCTION:
Three-dimensional (3-D) fluoroscopic navigation systems using Iso-C3D, a mobile 3-D C-arm equipped with an image intensifier, have been successfully validated for surgeries of the spine, the pelvis and the long bone \(^1\)\(^-\)\(^4\). Near the edges of the scan, volume image distortions were observed using the conventional image intensifier-equipped C-arm. The new 3D C-arm with flat-panel detector offers the advantages of flat-panel technology for intraoperative 3D imaging, whereby the image distortion inherent to conventional image intensifiers should be eliminated. A mobile C-arm equipped with a flat panel detector might increase the feasibility of 3-D fluoroscopic navigation surgery by improving the quality in the border area of the radiation field. The aim of the present study was to evaluate the accuracy of a novel 3-D fluoroscopic navigation system using the flat panel detector-equipped C-arm.

METHODS:
The navigated procedure was performed with Stryker Navigation System Il-Cart (Stryker Navigation, MI, USA) and Ziehm Vision FD Vario 3D (Ziehm Imaging, Nuremberg, Germany). Prior to the procedure, two directional C-arm images were obtained prior to the scanning to assure that the scanned volume was correctly centred over the subjects. The C-arm was connected to the navigation system and calibrated by registering the 3 points on the detector using a pointing device. Subsequently, 110 single images from a cubic area of 12 cm\(^3\) were acquired during 60 s automated orbital scan of 135 degrees.

To assess whether the distance from the center of fluoroscopic imaging affect navigation accuracy, we made a phantom of cubic styrofoam, where 25 fiducial markers with a metal ball of 1.5 mm diameter were fixed crosswise at an interval of 1 cm. Four sets of 3-D fluoroscopic images were obtained with the phantom upward, downward, and sideways to the C-arm and the opposite side. The tip of navigation probe was directed to each marker. Virtual screws were planned and superimposed with positions of metal markers images for subsequent accuracy measurement. The tip of navigation probe was then directed to each metal marker. The target navigation error was recorded and measured as the distance between the virtual tip of navigation probe and virtual screws head on navigation display. The procedures were repeated 3 times.

To simulate surgeries around the hip joint, a human dry pelvis and femur were placed on the operation table in the lateral decubitus position. A total of 8 fiducial markers with a metal ball of 1.5 mm diameter was fixed to the following locations of the acetabulum and the proximal femur: the anterior, posterior, superior and inferior acetabular edges, the tip of great trochanter, the base of lesser trochanter, the proximal head-neck junction and the anterior cortex of the femoral neck. Two dynamic reference trackers were inserted into the ipsilateral pelvic crest and the femoral shaft. Navigation accuracy was evaluated using the similar method as the phantom study. Visual assessment of navigation accuracy was also performed to pointing the landmarks where the fiducial markers were inserted with the navigation probe. The matching was accepted if the bony contours on navigation display were consistent with real bony surface. The image quality improved in the border area of the radiation field would increase the usefulness of the 3-D fluoroscopic navigation system in the real surgery.

RESULTS:
In the phantom study, the mean target navigation error was 1.2 mm (range, 0.6 to 2.1 mm). The distance of markers from the center did not affect the target registration error. (Fig.1)

In the cadaver study, the mean target navigation error over the acetabulum was 1.2 mm (range, 0.6 to 1.9 mm). The mean target navigation error over the proximal femur was 1.0 mm (range, 0.7 to 1.4 mm). There was no significant difference in target registration error between the acetabulum and the proximal femur (Fig.2). The matching was accepted in all trials with bony contours on navigation display showing < 1 mm difference (Fig.3).

DISCUSSION:
The mean target navigation error of the novel 3-D fluoroscopic navigation system was almost within 2 mm. We used a metal ball of 1.5 mm diameter, which is a limitation of this accuracy evaluation. In visual assessment, bony contours around the acetabulum and the proximal femur on navigation display were consistent with real bony surface. Therefore, the accuracy of the novel 3-D fluoroscopic navigation system was considered to be acceptable for clinical application. The image quality improved in the border area of the radiation field would increase the usefulness of the 3-D fluoroscopic navigation system in the real surgery.

REFERENCES: