EFFECTS OF THRESHOLD VALUE ON ACCURACY OF SHAPE-BASED REGISTRATION IN A CT-BASED NAVIGATION SYSTEM

INTRODUCTION
Various computer assisted surgical navigation systems have been developed for use during hip surgeries such as total hip arthroplasty (THA) and pelvic osteotomies. Many systems utilize preoperative CT scan data in conjunction with a specific position sensor. These kinds of CT-based navigation systems consist of the following three steps: (1) making a computer model of the object to be operated upon from preoperative CT data; (2) registration of the computer model and the real object; and (3) tracking and measurement of the object and surgical equipment during operation. The accuracy of registration affects the total accuracy of the system, and accuracy depends on the quality of the preoperatively constructed computer model and the quantity of data acquired intraoperatively. Using cadaveric phantoms, we have studied the effects of preoperative CT scan imaging parameters, intraoperative data sampling area, and data sampling volume on the accuracy of registration for hip surgery. However, it is difficult to evaluate the effects of CT threshold value to make a surface bone model on accuracy of shape-based registration with cadaveric phantoms without soft tissues. The purpose of this study is to determine the effects of the CT threshold value on the accuracy of a shape-based registration method used in a CT-based navigation system for hip surgeries.

MATERIALS AND METHODS
THA was performed in thirty patients using a CT-based navigation system with an optical localizer (OPTOTRAK 3020). Preoperative CT data was obtained for each patient using a CT scanner (Lemage, GE Yokogawa Medical Inc) at 120kVp and 100mA. Contiguous 3mm slices of the pelvis were scanned. Image data were reconstructed using the standard reconstruction kernels of the CT machine, with a 42cm FOV, corresponding to a pixel size of 0.82mm on a 512 X 512 matrix. The image data were transferred to a SUN workstation and converted into a series of 512 X 512 arrays with 12 bit (4096) values in each pixel. The stored 12 bit CT values were expressed as Hounsfield units (HU), which define the densities of air and water as –1000 and zero, respectively. Surface models of the pelvis were made for clinical use by contouring the peristemeal boundary at thresholds ranging from 140HU to 260HU (mean 200HU). The threshold was determined to be approximately 200HU in each case, based on the balance between soft tissue noise and surface defects.

Intraoperatively, shape-based surface registration of the pelvic models to the real pelvis was performed in two steps. First, the surgeon digitized four surface points to provide a starting position for matching. Next, 30 surface points were digitized for final registration. The up to 30 points were selected from the Osteotrace™ probe of 24 LED markers. Mathematical calculation was performed using the iterative closest-point (ICP) algorithm and the least square method. The mean residue of registration in 30 patients was 0.37mm (range: 0.19mm to 0.61mm, SD: 0.12mm) at 100 repetitions of the ICP algorithm. The calculation converged within 100 repetitions.

In this study, 10 pelvic surface models were made from each patient’s clinically obtained CT data (30 patients), using 10 different CT threshold values ranging from 50HU to 320HU, with an increment of 30HU. With these 10 surface models of each patient (totally 300 models), registration was done using the surface points obtained from each patient intraoperatively. The average residue of registration was compared between the 10 different threshold models. Because there were no fiducials or absolute coordinates in clinical data, it is difficult to know the relationship between the residue of registration and accuracy of registration. Therefore, the center of the acetabulum in each model was defined as the target point in each set of CT data, so that all 10 surface models from each patient should have the same reference point for measuring the positional and rotational differences after registration. Registration was also conducted using a set of surface points that was obtained from the surface models made at 200HU. Using these points, the target registration error (TRE) for position and rotation of the models was measured, and correlation between the TRE and the residue of registration was evaluated.

RESULTS
When the intraoperatively obtained surface point data were applied to the models, the lowest average residue of registration (0.35mm) was seen with the models made at the threshold of 200HU. However, there were few differences among the models made at thresholds ranging from 110HU to 320HU. The average residue of registration for the models made at thresholds below 110HU was significantly greater than those of the other models, due to model noise produced by the soft tissues. When the surface points which were obtained from the 200HU models were used for registration, the average residue of registration reached its nadir (0.06mm) with the models made at the threshold of 200HU, but there were no significant differences in residue of registration among the models made at thresholds ranging from 110HU to 320HU. The average residue of registration was significantly greater (0.5mm to 2mm) for the models made at thresholds below 110HU than for other models. The target registration errors for position and rotation reached their nadirs (0.26mm and 0.32degrees) with the 200HU models. There was no significant difference TRE for position or rotation among the models made at thresholds ranging from 110HU to 320HU. There were very strong correlations between the residue of registration and the TREs for position (R=0.879) (Fig. 6) and rotation (R=0.880) (Fig. 7).

DISCUSSION
Most CT-based navigation systems use a threshold method to make computer bone models. Because of partial volume artifacts and noise, the threshold value affects the shape and dimension of the bone model, and it may affect the accuracy of surface registration. However, there are few descriptions in the literature of determination of the optimum threshold value for making computer models for navigation. Recommended thresholds for contouring of the periosteal boundary range from less than 300HU to 700HU, and threshold depends on the scanner, the scanning parameters, and the reconstruction kernel. Thus, it may not be appropriate to generalize about the optimum threshold for making bone models from the results obtained in this study. However, it may be worthwhile to generalize from the present results regarding the sensitivity with which the threshold affects the accuracy of surface registration. Clinically, we determined the threshold by macroscopically assessing the balance between soft tissue noise and bone surface defects at approximately 200HU. The average residue of registration reached its nadir with the 200HU models, and there were no significant differences in residue of registration among the models made at thresholds ranging from 110HU to 320HU. The TREs for position and rotation showed strong correlation with the residue of registration. That is, a smaller residue of registration indicates more accurate registration. Therefore, accurate surface registration can be obtained with computer models made at thresholds ranging from 110HU to 320HU, by assessing the balance between soft tissue noise and bone surface defects.

REFERENCES

Poster No: 0986