HANDLING DIFFERENT DESIGNS OF FEMORAL STEMS FOR AUTOMATED THA PLANNING: DETERMINATION OF STEM ANTEVERSION ANGLE USING STATISTICAL PREDICTION

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INTRODUCTION

We have been developing an automated preoperative surgical planning system for total hip arthroplasty (THA) in order to reduce the work load in the manipulation of the planning and obtain optimal plans based on the objective criteria (Otomaru 2009, Otomaru 2012, Kagiyama 2012, Kagiyama 2013). In this manuscript, we treat the automated planning of femoral stems. Our previous method (Otomaru 2012) used a statistical model of contact areas of femoral canal and stem interface, which assumed anatomical stems are designed so as to keep a large contact area with the femoral canal. While the stem anteversion angle determined by Otomaru's method (Otomaru 2012) was sufficiently accurate for anatomical stem, it was often inaccurate for other types of stems such as taper wedge stems, which have only a small contact area with the canal surface. Therefore, we newly propose an automated method based on a statistical prediction model for estimating the stem anteversion angle even suitable for taper wedge stems.

MATERIALS AND METHODS

Figure 1 shows the system overview of the automated planning of stems. First, the stem anteversion angle is estimated based on the partial least squares regression (PLSR), which is a framework for statistical prediction. The outer and canal surfaces of the femur are used for estimation of stem anteversion angle. PLSR modelling of the stem anteversion estimation consists of training (calibration) and execution (regression) phases. In the training (calibration) phase, the prediction formula is obtained from the training datasets which include N pairs of the femur surface and its corresponding 3D preoperative stem plan including the anteversion angle. In the execution (regression) phase, given the femur surface of a new patient, the stem plan is predicted using the obtained prediction formula, and the stem anteversion angle is estimated from the predicted plan. Second, under the fixed stem anteversion obtained by PLS regression, the automated planning procedure optimizes the other two angles, three translation, and one size parameters (which define the stem plan) using the previous method (Otomaru 2012).

In the experiment, we used two types of stem: a taper wedge stem (Accolade TMZF, Stryker, Mahwah, NJ) and an anatomical stem (CentPillar TMZF, Stryker, Mahwah, NJ). The stem shapes were composed with surface models which had corresponding points among all sizes in the same type. The corresponding femur surface models were generated from preoperative CT images by the automated segmentation method (Yokota 2013). The stem plan datasets used in the experiments were prepared by the experienced surgeon and actually applied to the computer-navigated surgeries of the patients in Osaka University hospital. We applied the proposed method to 2 groups of patients in leave-one-out cross validation respectively: One group of patients had $N = 22$ (cases) which were operated with taper wedge stem and the other had $N = 27$ (cases) with anatomical stem. The positional and stem anteversion angle differences between the surgeon's preoperative plans and the plans determined by the automated methods were calculated as measurement of accuracy. The accuracy of planning using proposed method was compared with the previously proposed method (Otomaru 2012).

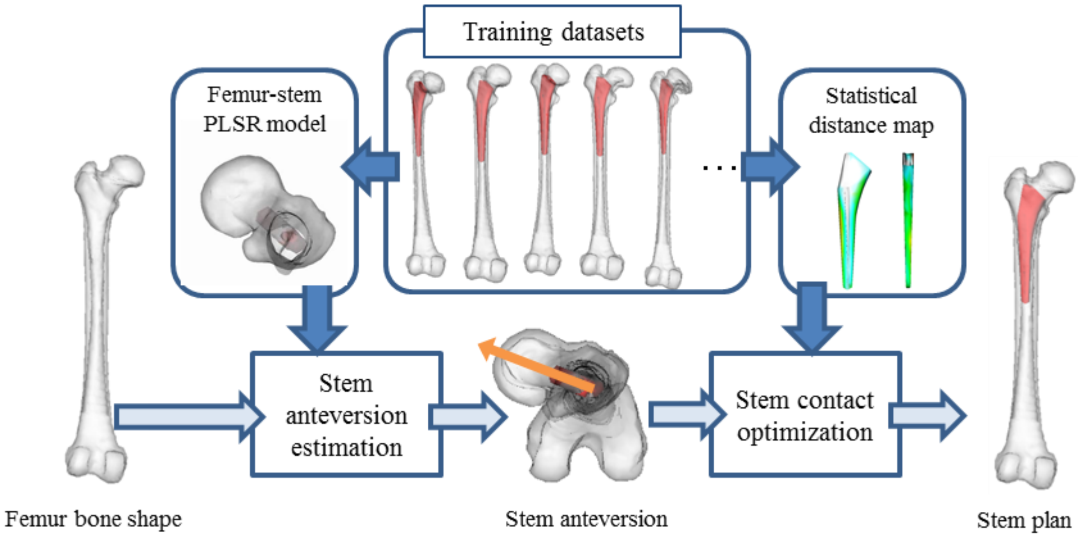

Figure 1: Overview of the automated planning of stem.

RESULTS

Figure 2 shows the boxplots of the difference of stem anteversion angle. As the results of taper wedge stems, the average differences of anteversion angle were 4.9±4.0 degrees and 2.5±1.7 degrees for the previously proposed method and the proposed method, respectively, which means that the proposed method decreased the differences significantly for 2.4 degrees ($p < 0.05$). As the results of anatomical stems, the average differences of anteversion angle were 3.0 ±2.3 degrees and 2.3±2.3 degrees, which did not show any significance. The average positional differences of both methods were 2.6±1.4 mm and 2.5±1.5 mm for taper wedge stems, 2.3±1.1 mm and 2.4±1.1 mm for anatomical stems, and there were no significances between them.

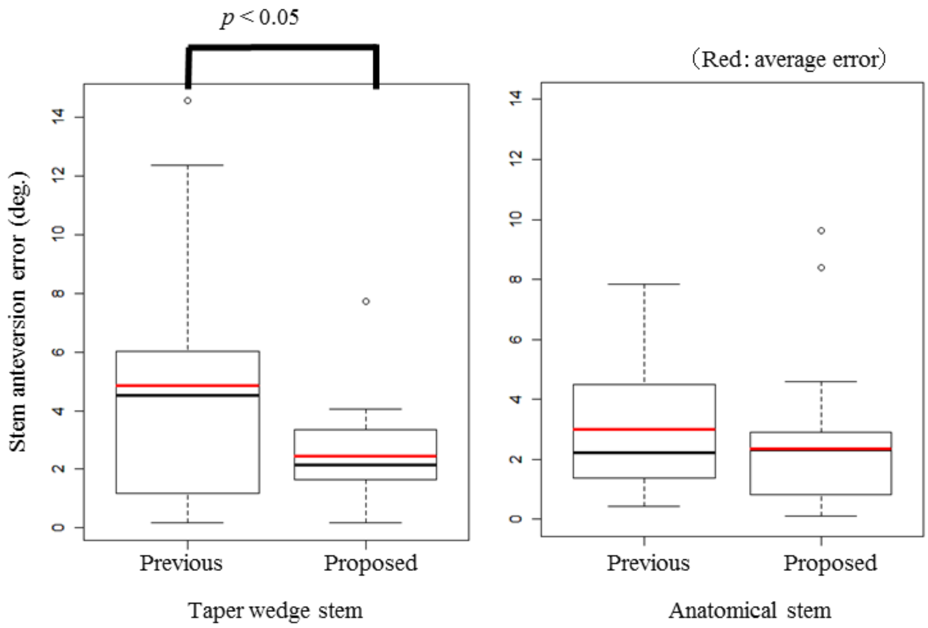

Figure 2: Boxplot of stem anteversion angle difference.

DISCUSSION

In the experiments, we compared the accuracy of the stem plans which were decided by the previous method and the proposed method for taper wedge stems and anatomical stems, and confirmed that the stem anteversion angles were significantly improved with taper wedge stem while positional accuracy was almost same. These results suggested that the statistical estimation of the stem anteversion angle based on PLSR improves the accuracy of automated preoperative planning.

The stem anteversion angle can also be estimated by using anatomical landmarks obtained from CT images, such as the femoral head center or the neck axis. However, such an anatomical landmark-based method has difficulty in landmark localization when the femurs are largely deformed due to diseases, which are sometimes observed in our dataset. In addition, manual specifications of the landmarks are involved, and thus inter-operator variability is a problem. In our PLSR-based stem anteversion angle estimation is fully automatic and showed good accuracy even for the deformed femurs.

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