Acetabular Cup Alignment Assessment in Total Hip Arthroplasty through Generative AI-Based 3D Reconstruction from a Single X-ray Image

Akira Fujita[1], Koji Goto[2], AKIHIKO UEDA[3], Yutaka Kuroda[4], Toshiyuki Kawai, Yaichiro Okuzu, Yugo Morita[5], Yasushi Okuno[3], Shuichi Matsuda[1]

[1]Grad Sch of Med, Kyoto Univ/Dept Ortho Surg, [2]orthopaedic surgery, Kindai University Hospital, [3]Department of Biomedical Data Intelligence, [4]Graduate School of Medicine, Kyoto University, [5]Kyoto University

INTRODUCTION:

Accurate assessment of the acetabular cup orientation is crucial for evaluating postoperative outcomes. Cup angle measurements are primarily performed using two-dimensional (2D) X-ray images due to their wide availability, cost-effectiveness, and low radiation exposure. However, recent studies suggest that computed tomography (CT) measurements should be the gold standard since they are more accurate than X-rays. Three-dimensional (3D) CT also provides a clear view of the positional relationship between the bone and implant in three dimensions. However, CT is more expensive and has higher radiation exposure, making X-rays the preferred clinical option. Therefore, a technique to estimate 3D CT from 2D X-ray images is desirable, as it combines the low cost and low radiation exposure of X-rays with the accuracy of CT. This paper proposes a generative AI-based 3D reconstruction system using generative adversarial networks (GANs), a deep learning algorithm, to generate 3D CT images of the hip from single anteroposterior (AP) postoperative X-ray images of total hip arthroplasty (THA). To assess the clinical applicability of this system, we validated the accuracy of cup angle measurements on CT images generated using the GAN.

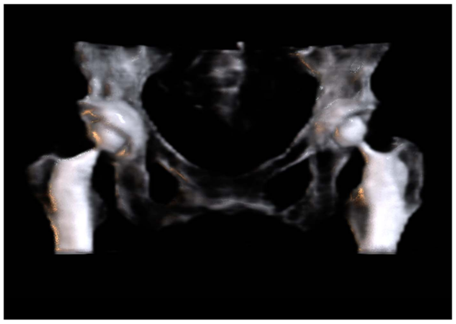
METHODS:

The study included 386 patients who underwent primary THAs with a cementless cup (AHFIX Q3; KYOCERA Corporation, Kyoto, Japan) between August 2013 and November 2022. There were 332 women (86%) and 54 men (14%), with a median age of 70 years (range, 17-89) at the time of surgery. The patient data were divided into 309 cases (80%) for training data and 77 cases (20%) for test data. The training dataset included 522 CT and 2282 X-ray images. Measurements from test data were obtained for 100 hips. The proposed deep learning-based 3D reconstruction system involves four steps: preprocessing, training, prediction, and validation. In the training and prediction phases, two GAN models, CycleGAN and X2CT-GAN, were employed to generate 3D CT images from X-ray images. Initially, X2CT-GAN was used to create 3D CT images from digitally reconstructed radiograph (DRR) images, which are 2D simulated images derived from CT data. To bridge the gap between DRR and actual X-ray images, CycleGAN translated real X-ray images into DRR-like images. By combining both models, the system successfully generated 3D CT images from X-rays. During the training phase, X-ray, CT, and DRR image data were utilized, whereas only X-ray input was required during the prediction phase. The image quality was validated using peak signal-to-noise ratio (PSNR) and structural similarity index measure (SSIM). The cup anteversion and inclination measurements on the GAN-generated CT images were compared with the actual CT measurements. Statistical analysis of absolute measurement errors was performed using the Mann-Whitney U test and nonlinear regression analysis.

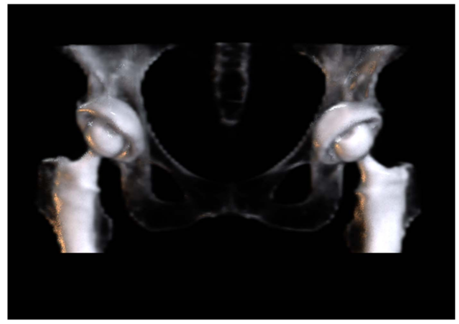
RESULTS: The study successfully achieved 3D reconstruction from single AP postoperative THA X-ray images using GANs, exhibiting excellent PSNR (37.40) and SSIM (0.74) (Figure). The median absolute difference in radiographic anteversion (RA) was 3.45° and the median absolute difference of radiographic inclination (RI) was 3.25°, respectively. Absolute measurement errors tended to be larger in cases with cup malposition than in those with optimal cup orientation.

DISCUSSION AND CONCLUSION:

We successfully generated 3D reconstruction from single AP postoperative THA X-ray images using GAN. Furthermore, the error between the angle measured on the true CT and the generated CT was approximately 3°, which shows promise for future practical use in clinical practice. This study is the first report of 2D-3D reconstruction of both the pelvic bone and the implant using deep learning. Previous studies have often only reconstructed 3D shapes from DRR images due to a lack of paired CT and X-ray images. Our study performed 3D reconstruction from X-ray images, suggesting concrete clinical applicability. The angle measurement errors were slightly higher than the expected 3°. This was due to large absolute errors in many cases, particularly in those with improper acetabular cup orientation. The current deep learning model had insufficient training data for cases with cup malposition, resulting in larger errors. This issue could be mitigated by increasing the number of such cases in the training dataset or using generative AI to create more training examples. Further investigation and refinement of this model are required to improve its performance.



Generated CT



True CT