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Thesis/dissertation Title

Preoperative assessment of vessel-to-acetabular rim distances in non-contrast CT images for total hip arthroplasty

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Introduction: Blood vessel and nerve injuries during total hip arthroplasty (THA) present life-threatening risks, highlighting the importance of enhanced preoperative assessments. This research aims to explore the use of non-contrast CT images to advance the preoperative planning process, notably addressing the segmentation of external iliac vessels, a task not previously tackled in non-contrast images, which are widely used for surgical planning. Two principal challenges are: the low contrast of vessel and nerve boundaries against neighboring muscles in non-contrast CT images, and the subsequent application of these segmentation results for accurate risk assessment. By proposing solutions to these obstacles, the research attempts to improve surgical planning and outcomes, thereby significantly contributing to the mitigation of risks associated with vessel injuries during THA.

Materials and methods: Thirty-six non-contrast CT images of patients with hip osteoarthritis (OA) and 18 pairs of contrast-enhanced/non-contrast CT images of non-hip OA patients who underwent imaging for vascular treatment (referred to herein as the internal database). Ten non-hip OA CT images collected from a publicly available database were used for external validation. In the internal hip OA database, ground truth (GT) labels were manually annotated. On the other hand, the arterial GT labels for the internal non-hip OA database were constructed based on contrast-enhanced CT and non-contrast CT, which were not for hip surgery but for vascular treatment where arteries were clearly imaged. Specifically, through non-rigid registration, arterial labels extracted accurately from contrast-enhanced CT were mapped onto non-contrast CT. Nerve GT labels were manually annotated

for 20 cases among non-contrast CT images of hip OA patients in the internal database. The vessel-to-rim distances assessment comprises four steps: region-of-interest extraction, automatic vessel/pelvis segmentation, defining the acetabulum rim, and computing distances.

Experiments and analyzes: For the automated segmentation of vessels, two deep learning models (2D Bayesian U-Net and 3D nnU-Net) were employed. This experiment utilized the internal hip OA database and internal non-hip OA database for training /validation. The external database, not involved in model training, to evaluate model generalizability for automated segmentation. The Dice coefficient (DC) and average symmetric surface distance (ASD) were used to evaluate segmentation accuracy. The accuracy of vessel-to-rim distance assessment was assessed using mean absolute error (MAE) and Pearson correlation coefficient (PCC).

Results and discussions: DC for the internal hip OA patient data was 0.877 and 0.892 from artery and vein, respectively, 0.901 and 0.909 for internal non-hip OA patient data, and 0.846 and 0.858 for external non-hip OA patient data using a 3D nnU-Net model. Furthermore, it was demonstrated that using a 3D nnU-Net model significantly improves the segmentation accuracy compared to a 2D U-Net model. PCCs between the GT and auto-segmentation-based vessel-to-rim distances were larger than 0.97, with a mean MAE smaller than 0.5 mm in the high-risk location. Preliminary experiments on nerve segmentation obtained DCs of 0.42-0.45, but ASDs were below 3mm, indicating a certain utility in detecting the presence of nerves. Comparing the robustness and generalizability of 2D and 3D segmentation models across different datasets, emphasized the superior performance of 3D nnU-Net models in handling variations in anatomy and image quality. This research demonstrates advancements over previous methods by providing a more accurate, automated approach to vessel and nerve segmentation in non-contrast CT images. This is critical for improving the preoperative assessment in THA and potentially reducing the risk of surgical complications. The limitations acknowledged include the need for a larger and more diverse dataset to improve the models' generalizability. Future directions involve exploring more advanced AI techniques, integrating additional anatomical features for a

comprehensive preoperative assessment, and validating the proposed methods in clinical settings to assess their impact on surgical outcomes.

Conclusions: This study introduces a novel preoperative methodology for evaluating vessel-to-acetabular rim distances using non-contrast CT images, showcasing substantial accuracy in the automated segmentation of vessels and their distance assessment. Additionally, the study explores the capability of extending this approach to nerve segmentation. The findings indicate that assessing the risk of vessel injury during THA planning through non-contrast CT images is not only feasible but also highly effective, suggesting significant implications for improving surgical outcomes and patient safety.