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Fast automatic segmentation of mitral valve structures from 3D transesophageal echocardiography for transcatheter procedures: training and validation of a 3D U-Net convolutional neural network

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Introduction - Nowadays, mitral valve (MV) repair can leverage on transcatheter technologies, which allow for implanting devices on the target MV substructures while the heart is beating. To compensate for the lack of direct view of the target structures and of the catheter, operators must rely on clinical imaging. Once the catheter reaches the heart, they rely on real-time 3D transesophageal echocardiography (RT3DTEE) [1] to visualize the key landmarks to define the final pose of the catheter. However, landmark detection is manually performed, and time-consuming. This downside could be mitigated by making the detection process automated and accurate. Convolutional neural networks (CNNs) have proven suitable to this aim [2]. On this basis, in this work we developed, trained, and evaluated a CNN with a 3D U-Net architecture to perform automated segmentation of the MV anulus and leaflets.

Methods - 100 RT3DTEE volumetric datasets of patients affected by MV prolapse were retrospectively selected. These were all resampled to a size of 218x146x178 voxels to cope with different original dimensions. The MV anulus, anterior and posterior leaflets were manually segmented by three independent and expert operators. 90 datasets with the corresponding ground truth segmentations were randomly selected and used to train the CNN, which was implemented in PyTorch and whose architecture consisted of an encoder and decoder branches, with skip connections, performing 4 levels of down-resolution. The model was trained for 1000 epochs using Adam optimizer (learning rate of 0.001), minimizing a combination of Dice and cross-entropy loss. Training was carried out on an Nvidia V100. A data augmentation routine consisting of flipping, elastic deformation, affine transformation, Gaussian blurring and bias field correction was implemented and performed during training.

Results - The CNN was able to perform automatic segmentation on the test set. Mean Dice scores of 0.62 0.56 and 0.12 were obtained for the anterior leaflet, the posterior leaflet and the annulus, respectively. The low value obtained for the annulus is likely due to the fact that the annular profile is thin, i.e., the region labelled as annulus is only one voxel wide at each position on the profile. In fact, good results were obtained in terms of Hausdorff distances, with values of 9.2 mm, 11 mm and 10 mm for the anulus, anterior leaflet and posterior leaflet, respectively.

Discussion - We implemented, trained, and evaluated a CNN with a 3D U-Net architecture to perform automatic segmentation of mitral valve structure from 3D TEE images. Given the low inference time of our model (< 1 second), our approach represents a promising tool for providing mitral valve quantitative 3D measurements and models in real time during intervention.

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