Automated anatomical labeling of abdominal arteries from CT data based on optimal path finding between segmented organ and aorta regions: A robust method against topological variability

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Purpose
Segmentation and anatomical labeling of the abdominal vessels from medical 3D data are key issues for computer-aided diagnosis and therapy planning. In previous work, machine learning and statistical classification techniques were effectively utilized for anatomical labeling of segmented vessels [1]. However, the inter-patient topological variability in the branching patterns of the abdominal vessels is highly large compared with other parts of the body. In the previous methods, there are limitations on dealing with the topological variability.

In this paper, we describe a method to overcome the above problem by utilizing a fundamental anatomical constraint that artery branches for a specific abdominal organ are a set of curvilinear structures connecting the organ region and aorta region. Previously, the anatomical labeling method using the constraint was proposed [2]. However, the constraint was not fully utilized because the segmentation accuracy of the organ regions was insufficient. We have recently developed a method for fully-automated segmentation of the abdominal organs including the liver, spleen, kidneys, pancreas, gallbladder, aorta, and inferior vena cava [3]. Among them, the segmentation of the liver, spleen, and kidneys as well as the aorta is now sufficiently stable and accurate in contrast-enhanced CT data. Therefore, the constraint can be fully utilized for artery branches related to these organs. We formulate an anatomical labeling method, which is not affected by the topological variability, from the abdominal contrast-enhanced CT data.

Methods
A main assumption of the proposed method is that the regions of the abdominal organs and aorta have already been segmented from the CT data [3]. Given the segmented organ and aorta regions, we extract the paths imaged as curvilinear structures which connect the aorta with the organ regions by using the following procedure. (1) Candidate vessel centerlines are extracted by skeletonizing the regions which have high intensities in both of the original CT and its line-enhancement filtered images. (2) Candidate flow-in and flow-out points are detected where the vessel branches enter the organ regions and leave the aorta region, respectively. The detection is performed by finding the intersection points of the candidate centerlines and the surfaces reconstructed from segmented organ and aorta regions. Regarding the organ surfaces, the possible area of flow-in points (around the hilum and its extended area) is defined in the statistical shape model for each organ and patient-specifically selected by fitting it to the organ surface of each patient. (3) An optimal path-finding algorithm is applied to determine a specific artery branch as a subset of candidate vessel centerlines which connects between a flow-in point and a flow-out point if a connected path exists. We currently use the shortest path length along the centerlines as the optimization criterion. Because multiple flow-in and flow-out points are usually detected for each organ and the aorta, the path-finding is performed for every pair of the flow-in and flow-out points.
By using the above procedure, the detected paths are labeled based on the organ where their flow-in points are located (we call it “flow-in organ”). The detected paths whose flow-in organs are "liver", "spleen", "left kidney" and "right kidneys" are labeled "hepatic artery", "splenic artery", "left renal artery" and "right renal artery", respectively. The shared portions of "hepatic artery" and "splenic artery" at the proximal part is labeled "celiac artery". The paths having the same label typically form one or more tree structures.

**Results**

We tested the methods using ten cases of late arterial phase images of contrast-enhanced abdominal CT data. Given the CT data, the methods were performed in a fully automated manner, including organ segmentation and anatomical labeling of the artery branches.

Fig. 1(a) shows a typical result. Fig. 1(b) shows an illustrative example in which the proposed method could successfully deal with the topological irregularity. In Fig. 1(b), the right renal artery consisted of two independent branches bifurcated directly from the aorta. This example demonstrates a particular utility of the proposed method.

We evaluated the accuracy of segmentation and anatomical labeling by the sensitivity (recall) defined as TP/(TP+FN) and precision defined as TP/(TP+FP), where TP, FN, and FP are the numbers of true positives, false negatives, and false positives, respectively. Fig. 2 shows sensitivity and precision for each artery branch. Main cause of false positives was accidental path formation by coincidental multiple false connections of different vessels (e.g. portal vein) and bone regions. False negatives occurred due to disconnection of target branches during the initial segmentation stage. Although the basic vessel segmentation schemes should be improved, the method mostly could properly perform both segmentation and identification of the target vessel branches from candidate centerlines including a lot of false positives.

**Conclusion**

We have developed a novel vessel labeling method from 3D data. The method could successfully deal with irregular topology of abdominal artery branches. The accuracy (sensitivity and precision) was mostly satisfactory as an initial experiment. Future work will include improvement of optimal-path finding algorithm so as to deal with small gaps of centerline disconnection for reduction of false negatives and use of different phases (e.g. portal phase) of CT data for anatomical labeling of different vessels (e.g. portal vein) which also will disambiguate the false positives.

**References**