Automatic detection, segmentation and quantification of of Abdominal Aortic Aneurysm using Computed Tomography Angiography

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Abstract

Computer-aided detection (CAD) systems, which automatically detect and indicate location of potential abnormalities in scan digital images, have the capacity to increase the accuracy of the radiologists' interpretations and finding. This paper presents an efficient new CAD .for automatic and accurate detection and quantification of Abdominal Aortic Aneurysm (AAA). The system first detects and extracts the lumen and then identifies the location of the abdominal aortic from the total lumen. The extracted abdominal aortic lumen is then used as an initial surface to segment the abdominal aorta which might contain aneurysm. The geometrical and morphological features of both lumen and aorta are examined for the presence of aneurysm based on predefined criteria set by incorporating prior understanding of the normal expected variation of aorta. The experimental result of the proposed system on 60 CTA datasets indicated a 98% success in detection (CAD) and a 95% in segmentation results (CAM).

1. Introduction

An Abdominal Aortic Aneurysm (AAA) is a localised dilation (swelling or enlargement) of an aorta. An AAA usually consists of two sections – the lumen (the inner part) and the thrombus (the outer part). Blood flows in the lumen and its visibility can be enhanced when CT Angiography (CTA) is used. The progressive growth of an aneurysm may eventually cause a rupture if not diagnosed or treated. This can be life threatening as the rupture would cause massive internal bleeding. The probability of a rupture occurring depends on its size. Currently, in routine clinical practice, the size of AAA is estimated by manual measurement of aortic diameters. Therapeutic decision making as well as the surveillance program are decided based on the diameter masurement. For example, patients exhibiting an AAA of 5 cm or more in diameter should be treated to replace the weakened section by open surgery or using a stent-graft (endovascular procedure). For a 4 cm AAA, if the aneurysm increases by 5 mm or more in six months, treatment should be considered. However, manual measurement of diameters may be subject to large intra and interobserver variability. Significant interscan and/or intermodality variability is also expected since the morphology of the aneurysms could be changed depending on the breath hold level of the patient during image acquisition. As a follow-up after the operation, a frequent life-long monitor will be used to ensure that no further expansion has occurred to prevent the chance of further ruptures. The volume of thrombus after endovascular repair of AAA has been reported to be the most effective indicator of the AAA exclusion.

Typically, the radiologist visualize the enlarged portions of the aorta on a number of cross-sectional CTA images to identify AAA. For thrombus volume measurement, the radiologist manually identifies the thrombus on each image in order to obtain a full volume measure. This extremely tedious and time-consuming process may take up to 30 minutes and is inconvenient for physicians. Furthermore, this approach becomes impractical as the datasets produced by the latest CT scan machines increase. In addition, such manual methods are subjective, prone to error and non-reproducible. As the reliability of the measurement (CAM – Computer Aided Measurement) depends on how accurately the regions of interest can be segmented, the proposed system concentrates on the development of an automatic and accurate segmentation of AAA as a first and essential stage for accurate measurement. In comparison to the manual identification, segmentation and measurement of AAA, the proposed system can offer more accurate, reproducible, rapid and cost-effective results.

There are a few research publications on computerized AAA segmentation from which computerized measurements can be achieved. References [1-3] provide studies of various approaches to segmenting both the aneurysm and the aortic flow channel employing a level set framework using either edge strength or region intensity information. In [4-7] 2D and 3D active shape models are introduced for AAA segmentation. These methods are not fully automatic and require one or several external seed points for initialization. Further, they have not been robustly validated.

An interesting method in AAA segmentation is presented in [8]. This method estimates a rough initial surface, and then refines it by using a level set segmentation scheme augmented with a global region and a local feature analyzer. One drawback is that the deformable model segmentation assumes that the aneurysm is roughly circular in a transaxial cross section, thus resulting in failure of the segmentation for non-circular shaped aneurysm. The system was only tested on 20 CTA AAA datasets.

In this paper, an automatic segmentation of the abdominal aortic aneurysm is presented. It provides an accurate segmentation of the aorta (CAM) and detects the presence of the aneurysm (CAD) in the abdominal portion which is automatically located. The proposed method does not require any user intervention. The robustness of the system has been validated over 60 CTA datasets.

2. Methodology

Figure 1 shows the overall design of the automatic and accurate segmentation of AAA. The CTA image is first smoothed using the anti-geometric diffusion method in the pre-processing stage. Lumen is then extracted from the pre-processed image using segmentation and morphological operation. The abdominal portion of the lumen is identified using geometrical information and mathematical morphology. The full segmentation of the aorta is performed before identifying the presence of the aneurysm. This identification involves evaluating both segmented lumen and the full aorta segmentation. It should be noted that aorta is the same as lumen when there is no aneurysm.

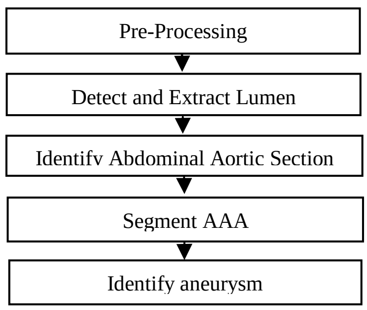

Figure 1. Overall system

2.1 Lumen extraction

Accurate segmentation of lumen is not necessary since lumen will be used as an initial region to detect and segment the aneurysm. The segmentation of the lumen is performed using a threshold-based segmentation with low and high threshold of T_l and T_h; these threshold limits were found experimentally to be 150 and 600 respectively. Due to the partial volume effect, the extracted lumen often has loose connection with objects of similar intensity such as spine and kidneys (through renal arteries). To separate lumen from other objects, the morphological erosion operation is applied which may result in several isolated 3D objects. Among these isolated objects, the lumen can be identified as the object that is relatively long in Z direction and narrow (in coronal view), plus it resides approximately in the middle of the body.

Once the lumen is found, the abdominal section is identified. This is done by finding the positions of the Celiac Trunk and the Iliac Junction.

The Celiac Trunk is the first artery branching off from the aorta below the diaphragm which is approximately where the lung ends. With regard to this, the lung is identified first. Lung regions appear as hollowed objects in the CT images due to the existence of large volume of air. Using threshold based segmentation together with the morphological hole-extraction algorithms, lung regions can be extracted. Each extracted hollowed object (lung region) is then examined to see if it contains several small holes. These small holes are the result of cross sectional axial views of many blood vessels in the lung regions. In order to extract the small holes, each lung region, in each slice, is first flood-filled then subtracted from the original segmented lung. The identification of lung objects can thus be carried out by counting the number of the isolated objects of a considerable size within the hollowed regions; i.e. tiny isolated objects are not considered because they might be due to noise. Let O_k be the *kth* extracted hollowed object in the current slice, then O_k is part of the lung region ($O_k \in L$) if the following condition holds,

$$if\,([\sum_{p=0}^{N} S\,(\mathrm{O}_k\,(p))] > T_{cnt}) \quad then \quad \mathrm{O}_k \in \mathrm{L} \tag{1}$$

Where N is the total number of isolated objects inside the *Kth* object O_k, $O_k(p)$ is the pth isolated object, T_{cnt} is an object count threshold, and

$$S\,(x) = \begin{cases} 1 & if\,(size(x) > T_{size}) \\ 0 & otherwise \end{cases} \tag{2}$$

Where T_{size} is the object size. Experimentally T_{size} = 5 and T_{cnt} =10.

This process of identifying the lung regions is continued slice-by-slice until no lung region is found. This will be the approximate location of the diaphragm or the end of the lung regions.

The end location of the lung regions only provides an approximate position where the search for the Celiac Trunk can be carried out. After projecting all voxels in the sagittal view of the lumen into one 2D sagittal image, two morphological operations of erosion and dilation with different window sizes will result in separating the branches from the main lumen. The Celiac Trunk can then be identified as the first isolated branched from the top of the 2D sagittal projection image.

The Iliac Arteries junction is the last location to be found for the identification of abdominal portion of the aortic lumen. This is where the aorta splits into two major arteries running down the legs. To identify this location, the centre-line of the lumen is obtained, then is passed through a smoothing filter and followed by conversion to the cluster connectivity. A cluster analysis based on length and angle is used for every branches stemming from the main centre-line of the lumen. As regard to this, the length of all branches, except for the Iliac arteries, will be relatively short and their angle with respect to the main centre-line will be relatively sharp.

2.2 AAA segmentation

In order to segment the aneurysm, first objects with obvious intensity and morphological features that cannot be part of the aneurysm are found. These non_AAA objects include fat, spine and blood vessels. They will be used a mask to confine the segmentation process.

Fat regions are darker (less than -10 HU) than the aneurysm and can easily be extracted by using segmentation followed by morphological opening operation. In some large size aneurysm, small dark regions might exists that could be due to image acquisition artefact or the natural composition of the thrombus. Therefore, fat regions with a relatively small size are ignored. The size limit for the fat region identification was found empirically to be $50m^3$.

Spine is another object that is located very close to the aorta and hence it is useful to use it as a non_AAA mask region. Extracting the spinal bones can easily be done due to their high intensity values. However the spine is made of pieces of bones that are held together with a muscle-like object called Disk. The Disks have intensity values that are similar to that of the thrombus. This leads to the formation of openings in the slices where the Disk regions touch the borders of the aneurysm. These openings (or gaps) can easily be filled by interpolating between the bone edges of the spine, which are located a few slices above and below.

There are several tiny blood vessels that stem out of the lumen. They appear as small circles in consecutive axial images. They can easily be mistaken with the calcified regions when viewed on the axial images. Unlike the calcified regions, the blood vessels are not part of the aneurysm and thus should be included in the non-AAA regions. One prominent feature that can be used to distinguish between the blood vessels and the calcified regions is that the blood vessels have compact and circular cross section that span over a relatively large number of slices. Although calcified regions might have similar contrast and their cross sections might be compact and circular, they are generally small 3D objects with elongated surface that occupy a few slices. Therefore a combination of circularity-compactness and 3D connectivity analysis is used to identify the blood vessels.

Following the generation of the non_AAA mask, an ellipsoid fitting algorithm is used to segment the aorta which might contain aneurysm. The ellipsoid fitting is generated based on evaluating the distance map of the region within which the lumen resides with respect to the borders of the non-AAA mask.

2.3 Identification of aneurysm

Several features from both lumen and aorta are examined to detect the presence of aneurysm (CAD). The maximum diameter of the aorta provides a good indication of the possible expansion of the aorta due to the effect from the aneurysm. Another feature is the irregularity of the shape of the lumen cross section, which, for normal patients, should have a circular shape. The displacement of the lumen is also used as one feature for detection of the aneurysm. The abdominal aortic lumen sometimes takes a fairly sharp bent due to the pressure exerted from the aneurysm. By comparing the geometrically transform lumen (straightened lumen), using its 3D centreline, with the original lumen a degree of displacement can be obtained.

3. Experimental result

Sixty CT Angiography scans, fifty with aneurysm and ten normal patient datasets, were used to test our automatic detection and segmentation. The patients were aged between 55 and 85 with 4 female and 36 male. The GE LightSpeed VCT machine was used to obtain the images. Scan parameters were 120 kV, 300 to 400 mA and slice thickness 1.0 to 2.0 mm. Three Radiologists manually identified and segmented all AAA areas independently using in-house software. For each of the three manual segmentations, an "average" AAA region was obtained by taking the overlapping part of the three manual segmentations and the result were used as our "gold standard" for development and evaluation of the automatic method.

To evaluate the CAD algorithm (detection of aneurysm), the system was made to produce an output flag for each dataset to indicate whether it contains aneurysm or not. With regards to this, 49 out of 50 CTA datasets from the patients with aneurysm had "yes" flags while the remaining 10 datasets from normal patients produced "no" flag; thus indicating a 98% success of the CAD algorithm. The system failed on one dataset which contained a large metal object in the hip area. This produced a significant artefact in the abdominal section.

To Evaluate CAM, the segmentation results of the system were compared with the "gold standard" based on the Mean Overlap (*MOv*):

$$MOv = \frac{1}{N}\sum_{i}^{N} Ov(i)$$

Where N is the number of CTA images and Ov is given as:

$$Ov = 2\frac{V(C) \cap V(T)}{V(C) + V(T)}$$

Where $V(C)$ and $V(T)$ are the volume of the current and test object respectively.

The outcome of the experimental result on all CTA datasets was $MOv = 0.95$ (1.0 meaning 100% overlap), indicating that the outline segmentation of AAA was very close to that defined manually by the radiologists. This, in turn, signifies the high accuracy of the quantification (CAM) of the proposed system.

Figure 2 shows examples of the segmentation results of AAA using the proposed system on two different CTA datasets.

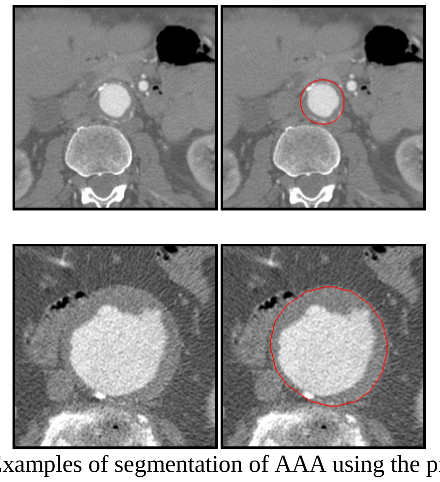

Figure 2. Two Examples of segmentation of AAA using the proposed system.

An example of a 3D volume rending of an enhanced CTA image following the AAA segmentation performed by the proposed system is provided in Figure 3. This clearly illustrates the enlargement of the aorta due to the aneurysm. It should be noted that any 3D volume rendering of the original image (without segmentation result) fails to highlight the aneurysm as the thrombus region (thus borders of the aneurysm) has similar intensities with the surrounding tissues.

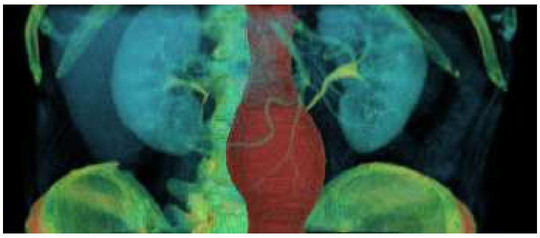

Figure 3. 3D volume rendering of an enhanced CTA image following the AAA segmentation performed by the proposed system.

3. Conclusion

This paper presented an efficient system for an automatic and accurate detection and segmentation of abdominal aortic aneurysm. The experimental results showed a 98% success in detection of the aneurysm with 95% segmentation result when tested on 60 CTA datasets.

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