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A comparative approach of four different image registration techniques for quantitative assessment of coronary artery calcium lesions using intravascular ultrasound

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ABSTRACT

In IVUS imaging, constant linear velocity and a constant angular velocity of 1800 rev/min causes displacement of the calcium in subsequent image frames. To overcome this error in intravascular ultrasound video, IVUS image frames must be registered prior to the lesion quantification. This paper presents a comprehensive comparison of four registration methods, namely: Rigid, Affine, B-Splines and Demons on five set of calcium lesion quantification parameters namely: (i) the mean lesion area, (ii) mean lesion arc, (iii) mean lesion span, (iv) mean lesion length, and (v) mean lesion distance from catheter.

Using our IRB approved data of 100 patient volumes, our results shows that all four registrations showed a decrease in five calcium lesion parameters as follows: for Rigid registration, the values were: 4.92%, 5.84%, 5.89%, 5.27%, and 4.57%, respectively, for Affine

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registration the values were: 6.06%, 6.51%, 7.28%, 6.50%, and 5.94%, respectively, for B-Splines registration the values were: 7.35%, 8.03%, 9.54%, 8.18%, and 7.62%, respectively, and for Demons registration the five parameters were 7.32%, 8.02%, 10.11%, 7.94%, and 8.92% respectively.

The relative overlap of identified lesions decreased by 5.91% in case of Rigid registration, 6.23% in case of Affine registration, 4.48% for Demons registration, whereas it increased by 3.05% in case of B-Splines registration. Rigid and Affine transformation-based registration took only 0.1936 and 0.2893 s per frame, respectively. Demons and B-Splines framework took only 0.5705 and 0.9405 s per frame, respectively, which were significantly slower than Rigid and Affine transformation based image registration.

1. Introduction

Plaque deposition in coronary arteries leads to coronary artery disease, which is a large component of the broad disease process known as atherosclerosis. During the atherosclerosis disease formation, soft plaque is formed turning to calcium at later stage of the disease [1]. The calcium measurement and location provides information which can help during the interventional procedures [2,3].

During the IVUS imaging procedure, the catheter pullback maintaining a linear constant velocity and a constant angular velocity of 1800 rev/min causes the calcium to get displaced laterally, longitudinal and/or rotational fashion [4]. Cardiac pulsatility along with motion related to catheter pullback can cause faulty measurements of calcium lesions in subsequent frames. To reduce these errors, IVUS image registration is required.

Though, the accurate registration of medical images is an active research field, the amount of work done in the field of IVUS image registration is relatively small. Strain measurement in coronary arteries using IVUS and deformable images was proposed by Veress et al. [7]. The main focus of this study was to calculate the efficacy of an image registration technique warping. From paired IVUS images, warping helped to determine the strains in plaques and coronary arteries. Multimodal registration of IVUS images and angiography was proposed by Rotger et al. [8]. The objective of this work was to develop a technique which would fuse information from angiograms and IVUS images by utilizing a point of the vessel in the angiograms and its corresponding IVUS image. Katouzian et al. [9] proposed a framework that was capable of tissue labelling and then registering against histology [10]. The correspondence was achieved by making a 3-D reconstruction of the IVUS catheter's path from its projection in the angiography [12]. Non-rigid registration of vessel structures in IVUS images [11] was introduced by Amores and Radeva [13]. An algorithm applicable to grey level medical images of non-rigid bodies such as coronary vessels was proposed in this work. With the help of IVUS image registration [14] managed to quantify the cross-sectional artery wall motion. In this work, a robust method was reported to track cross-sectional displacements of an artery wall using two different intravascular ultrasound (IVUS) images acquired at two different pressure levels respectively. The report defines the correspondence by creating a 3-D reconstruction of the IVUS catheter's path from its projection in the angiographic data and using this information to set the IVUS planes.

A fast rigid registration of vascular structures in IVUS sequences was proposed by Gatta et al. [15]. In this work, an algorithm was proposed which not only reduced the saw-shaped oscillation, but also aligned the vascular structures successfully. An automatic approach of vessel lumen segmentation was proposed by Balocco et al. [16]. This automated system used grow cut algorithm to extract the combined model-based temporal information from successive frames of the sequence. With the help of iconic and geometric features, Gupta et al. [17] introduced a new registration system for carotid ultrasound images. A novel hybrid registration technique was proposed in this study which closed the difference between the feature-based image registration techniques as well as the intensity-based registration techniques. Analysis of this work was done with the help of image registration. Non-rigid image registration metric using self-similarity weighted mutual information was proposed by Rivaz et al. [18]. In this work, a self-similarity weighted graph-based implementation of α mutual information (α-MI) for non-rigid image registration was introduced. Image-based co-registration of angiography and IVUS was reported by Wang et al. [19]. This work presented a new hybrid technique which was able to solve the problem created during the registration of 2-D angiography and IVUS. Bidirectional elastic image registration using B-Splines Affine transformation was proposed by Gu et al. [20]. In this work, a registration scheme was proposed which was termed as B-Splines Affine transformation (BSAT). It was capable of elastically aligning two images.

To the best of our knowledge, no previous work has analyzed the size and shape change of calcium lesion after applying an IVUS image registration paradigm. Similarly, to our knowledge no previous study has compared the quantification of lesion changes using four types of IVUS image registration methods. In this work, we studied the effect of registration using Rigid (which involves rotations and translations) and Affine transformation [21], and compared them to local transformation based non-rigid registration techniques using B-Splines and non-parametric Demons registration.

Our purpose was to analyze changes in calcium quantification parameters and study the effect of four different registration techniques: Rigid transformation based, Affine transformation based, B-Splines-based non-rigid free form