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Computer-supported diagnosis for endotension cases in endovascular aortic aneurysm repair evolution

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ABSTRACT

An abdominal aortic aneurysm (AAA) is a localized abnormal enlargement of the abdominal aorta with fatal consequences if not treated on time. The *endovascular aneurysm repair* (EVAR) is a minimal invasive therapy that reduces recovery times and improves survival rates in AAA cases. Nevertheless, post-operation difficulties can appear influencing the evolution of treatment. The objective of this work is to develop a pilot computer-supported diagnosis system for an automated characterization of EVAR progression from CTA images. The system is based on the extraction of texture features from post-EVAR thrombus aneurysm samples and on posterior classification. Three conventional texture-analysis methods, namely the gray level co-occurrence matrix (GLCM), the gray level run length matrix (GLRLM), the gray level difference method (GLDM), and a new method proposed by the authors, the run length matrix of local co-occurrence matrices (RLMLCM), were applied to each sample. Several classification schemes were experimentally evaluated. The ensembles of a *k*-nearest neighbor (*k*-NN), a multilayer perceptron neural network (MLP-NN), and a support vector machine (SVM) classifier fed with a reduced version of texture features resulted in a better performance ($A_z = 94.35 \pm 0.30$), as compared to the classification performance of the other alternatives.

1. Introduction

Cardiovascular diseases are one of the most important causes of death in western countries and among them, abdominal aortic aneurysm (AAA) occupies an important place. Endovascular grafting of abdominal aortic is a modern minimally invasive treatment which yields good results and more rapid time recovery than classical open surgery [1,2]. In the endovascular aneurysm repair (EVAR) treatment, an stent graft is deployed inside the aneurysm cavity by an image-guided procedure. When successful,the endovascular stent

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graft diminishes the pressure inside the aneurysm reducing the risk of rupture. However, in a mid-long term perspective complications such as stent displacement or deformation can provoke leaks inside the aneurysm sac (endoleaks). These endoleaks may stop the exclusion of the aneurysm sac from the vascular pressure, what again increases the risk of rupture. To prevent further complications after EVAR, periodic follow-up scans of the prosthesis behavior are necessary. Nowadays, contrast enhanced computed tomographic angiography (CTA) is one of the most commonly used examinations for patients' follow-up periods. In practice, post operation analysis is quite laborious as it involves manual measurement of physical parameters of the aneurysm. At present, the maximum AAA diameter remains the most widespread criteria for the assessment of aneurysm evolution after EVAR treatment [3,4]. According to these measurements, the evolution of the aneurysm can be split up into favorable and unfavorable. In favorable evolution, a reduction of the diameter of the aneurysm sac is observed, meaning that the aneurysm has been correctly excluded from the bloodstream. In unfavorable evolution, a decrease in aneurysm diameter is not produced due to the existence of leakages (endoleaks) allowing the persistence of blood flow within the aneurysm sac. From general clinical criteria, endoleaks are classified into type I, II, III, IV and V, depending on the source of the leakage [5]. Type I, II, III and IV need the existence of a visual evidence of the endoleak for being classified, by contrary in type V endoleaks (endotension) the reduction of pressure load inside the aneurysm sac is not produced and there is not a direct radiologic evidence of a leakage (Fig. 1). Type V endoleaks are one of the most uncertain situations in EVAR treatment. Even today the cause for this behavior remains a source of controversy and there is not a clear consensus on treatment guidelines [6,7]. In these particular cases would be especially important to obtain more information about the evolution experimented inside the aneurysm cavity.

According to previous studies [8–10] texture of mass thrombus in favorable shrinking aneurysms differs from unfavorable expanding ones. In our approach, we extend the texture analysis to endotension cases in order to classify them into favorable evolution (a stabilized intrasac pressure) or unfavorable evolution (a recurrent increase of intrasac pressure). Our hypothesis is that shrinking aneurysm processes are related to coagulation and formation of thrombus or high-molecular-weight products, while expansion aneurysm mechanisms (intermittently leaks, local hyperfibrinolysis, or ultrafiltration through the graft), produce a liquefaction of intra-sac thrombus. From this point of view, intra-sac material in favorable aneurysm evolution could show textural differences from unfavorable evolution cases, even if there is no radiographic evidence of endoleaks.

At present, direct catheter pressure measurement is the most common technique for the intra-aneurysm sac pressure assessment. The proposed method may offer some benefits as compared to direct measurement, such as the elimination of risks of sac puncture and the reduction of radiation exposure or contrast-induced nephrotoxicity. Furthermore, the complementary information obtained by texture analysis might be clinically important as the strategy for endotension management is not unequivocal. A more complete assessment of endotension progression would be useful in re-defining patients' management, particularly if open surgical conversion is considered. With this idea in mind, we propose a computer assisted diagnosis (CAD) system based on texture analysis to help clinicians to determine the evolution of endotension aneurysm cases.

In recent years, many efforts have been put into the developing of computer-aided diagnosis (CAD) systems based on image processing methods. The principal motivation for the research on this kind of systems has been to assist the clinicians on the analysis of medical images, [11]. In many occasions this analysis implies the detection or measurement of subtle differences, usually difficult to appreciate by visual inspection even for experienced radiologist. CAD systems have been successfully utilized in a wide range of medical applications [12–16]. A particular field inside the image processing methods for CAD systems is the so named texture-based analysis. This analysis studies, not only the variation of the pixel intensity values along the image but also the possible spatial arrangement of them, and the more or less periodic repetition of such arrangement (primitives). From this point of view texture analysis can help on the functional characterization of different kind of organs, tissues, etc., at the evolution of disease. The textures features obtained from the analysis can be fed as inputs for a deterministic or probabilistic classifier, which assign each sample with its specific class.

Textures analysis methods can generally be classified into three categories: statistical methods, model based methods, and structural methods [17]. In our approach we have focused on the application of statistical texture methods, specifically, on spatial domain statistical techniques as the gray level co-occurrence matrix (GLCM) [18], the gray level run length matrix (GLRLM) [19] and the gray level difference method (GLDM) [20]. These three extended methods can capture second or higher order statistics on the relation between gray values in pixel pairs or groups of pixels in order to estimate their probability-density functions. Their validity has been proved in many studies [21–26]. In the last years, multiple classifier architecture has been proposed to improve the performance of CAD systems [27,28]. In multiple classifier systems, also called classifier ensembles (EC), an initial prediction is made by several separate classifiers and then fused into one final assessment through a combining strategy [29]. Our purpose in this study is to develop a preliminary support system based on textures analysis which provides clinicians with complementary information for a better managing of endotension cases after EVAR treatment. This would be clinically important because several techniques to treat endotension have been described and a better assessment of endotension evolution would be useful in selecting one of them.

The paper is organized as follows: Section 2 provides with information about the acquisition of CTA images, the theoretical background on the texture analysis methods, and the definition of classifier structures in the CAD system. The methodology, the results obtained from the performance evaluation of the classifiers, and discussion about them are presented in Section 3. Finally, some conclusions are given in Section 4.