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Fully Automatic Retinal Vascular Tortuosity Assessment Integrating Domain-Related Information †

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Abstract: The fundus of the eye is the only part of the human body that allows a direct non-invasive observation of the circulatory system. Retinal vascular tortuosity presents a valuable potential for diagnostic and treatment purposes of relevant vascular and systemic diseases. This work presents a computational metric for the tortuosity characterization that combines mathematical representations of the vessel segments with anatomical properties of the fundus image such as the vessel caliber, the distance to the optic disc, the distance to the fovea and the distinction between arteries and veins. The evaluation of the prognostic performance shows that the incorporation of the domain-related information allows a reliable characterization of the retinal vascular tortuosity that provides a better representation of the expert perception.

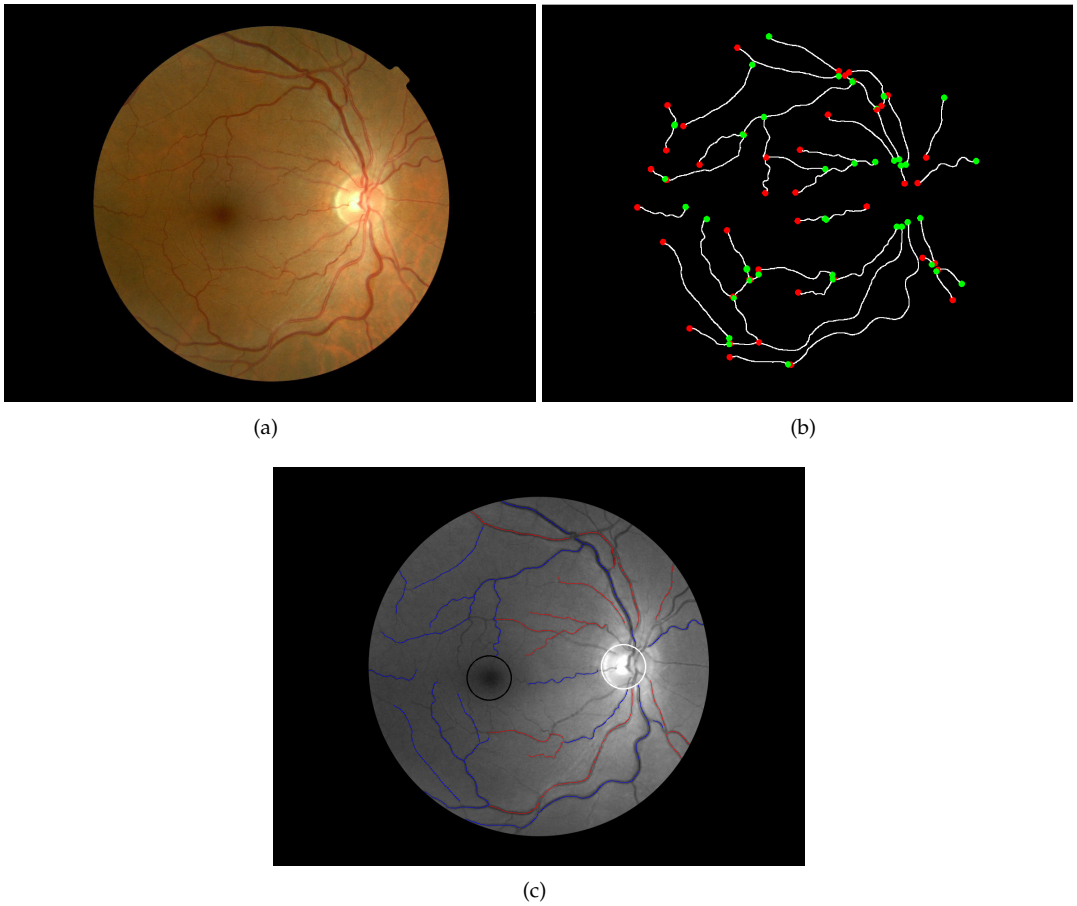
Keywords: retinal circulation; vascular tortuosity; fundus images; computer-aided diagnosis; image analysis; clinical knowledge

1. Introduction

The retinal vascular tortuosity, characterized by an abnormal course of the blood vessels, has relevant potential as a clinical biomarker of a significative number of relevant diseases such as diabetic retinopathy, cerebrovascular disease, stroke, and ischemic heart disease, among others. Several computational approaches to address the assessment of the retinal vascular tortuosity have been proposed in the literature. These metrics are mostly based on mathematical properties of the vessel centerlines to describe the tortuosity according to the curvature, the amplitude, or the number of turns and twists of the vessel segments. However, the specialists, on the basis of their experience, besides the analysis of the vessel course, also consider additional domain-related parameters that are not incorporated in the computational metrics of reference. In particular, a set of anatomical factors, including the vessel caliber, the distinction between arteries and veins, the distance to the fovea, and the distance to the optic disc were identified as relevant for the tortuosity assessment. This work presents a computational methodology that combines mathematical properties of the retinal vessels with relevant domain-related information for a better representation of the expert criteria [1].

2. Methodology

The proposed computational metric consist of a tortuosity quantification based on a mathematical metric of reference [2] combined with the identified anatomical factors. For this purpose, first, the arterio-venous tree is extracted and decomposed into its constituent vessel segments. Then, a local tortuosity based on the mathematical representation of the vessel course weighted by the anatomical properties is computed for each individual vessel. The optimal configuration to incorporate the anatomical factors was set by means of a multi-objective optimization process. Finally, the local tortuosity values are combined in order to compute the global tortuosity measurement for the whole retina. Figure 1 shows examples of the intermediate steps for the computational tortuosity measuremet.



(a) (b)

(c)

Figure 1. (**a**) Original fundus image. (**b**) Retinal arterio-venous tree extraction and vessel decomposition. (**c**) Domain-related information including the vessel caliber, the distance to the optic disc, the distance to the fovea and the distinction between arteries and veins.

3. Results and Conclusions

In order to evaluate the impact of the integration of domain-related information for the tortuosity characterization, the prognostic performance of the proposed metric was compared to the effectiveness of the baseline metric of reference, based exclusively on a mathematical representation of the vessel segments. The evaluation was performed over a dataset composed by 200 fundus images manually annotated by a group of five experts according to the binary relevant/non-relevant classification. The AUC achieved by the proposed metric was 93.8%, whereas the AUC of the baseline metric exclusively based on mathematical properties was 89.8%. The results show that the incorporation of the anatomical factors allows a reliable characterization of the retinal vascular tortuosity that better represents the specialists' perception.

Author Contributions: L.R., J.N., J.R. and M.O. made substantial contributions to conception and design of the retinal vascular tortuosity assessment, analysis of data and interpretation of the results. S.R. and M.D.A. were involved in the acquisition of the dataset, the rating procedure and the identification of the relevant domain-related information. L.R. performed the experiments and drafted the manuscript and all the authors participated in its critical revision and final approval. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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