Title
A new vessel-based method to estimate automatically the position of the non-functional fovea on altered retinography from maculopathies.

Authors
Calabrèse Aurélie[1], Vincent Fournet[2], Severine Dours[1], Frédéric Matonti[3], Castet Eric[1], Kornprobst Pierre[2]

Affiliations
1 Aix-Marseille University, CNRS, Marseille, France
2 Université Côte d'Azur, Inria, France
3 Centre Paradis Monticelli, Marseille, France

Purpose:
In pathological fundus images with maculopathies, the fovea position is usually located using Normative Anatomical Measures (NAM). This simple method relies on two conditions: that images are acquired under standard testing conditions (primary head position and central fixation) and that the optic disk is entirely visible on the image. However, these two conditions are not always met in the case of maculopathies, especially during fixation tasks. Here, we propose a new Vessel-Based Fovea Localization (VBFL) approach.

Methods:
The spatial relationship between fovea location and vessel characteristics (density and direction) is learned from 840 annotated healthy fundus images and then used to predict the precise fovea location in new images. We evaluate our method on three different categories of fundus images: healthy (198 images from 21 eyes, each acquired with the combination of five different head positions and two fixation locations), healthy with simulated lesions (3564 images, with lesions ranging from 20 to 400 deg^2) and 89 pathological fundus images collected in AMD patients.

Results:
For normal images taken under standard conditions, the NAM method yields a mean fovea localization error of 1.03° of visual angle (95% CI [0.80, 1.33]), which is slightly, but not significantly reduced by 37% with VBFL. For all conditions where the head is tilted to the side, the NAM estimation error is significantly multiplied by 4.42° (95% CI [3.45, 5.64], $p < 0.001$) while the VBFL method yields no significant increase in error prediction, with an average value of 1.21° (95% CI [0.93, 1.56]), representing a 73% reduction in prediction error compared to the NAM method. With simulated lesions, performance of the VBFL method decreases significantly as lesion size increases, with a mean error ranging from 0.83° at 20 deg^2 up to 2.3° at 400 deg^2. Overall, performance of VBFL remains better than NAM until lesion size reaches 200 deg^2. For pathological images, the error distribution with VBFL is not higher than for healthy data, suggesting that actual AMD lesions do not negatively affect the method's performance.

Conclusions:
The vascular structure provides enough information to precisely locate the fovea in fundus images in a way that is robust to head tilt, eccentric fixation location, missing vessels, and real macular lesions.