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Quantifying the complexity of the collagen fiber arrangement

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It is known that all stages of tumor progression are followed by an extraordinary remodeling of collagen fibers in the extracellular matrix. In the case of colorectal cancer, alignment and straightness have been described. Therefore, a proper measuring of this directional orderliness could be helpful for early detection of tumor presence. An experienced histopathologist's task is to estimate the degree of straightness of collagen fibers. It is a demanding manual endeavor, and possible automatization of the procedure is welcoming. We have gathered images of healthy human colon mucosa, colon mucosa 20 cm away from the cancer, 10 cm away from the cancer, and at the cancer itself via non-linear second harmonic microscopy. In each image, collagen fibers were identified. To quantify the degree of straightness of a collagen bundle in an image, we have divided each fiber into equal-length segments and calculated the distribution of segment angles relative to a fixed, predetermined direction. Information about preferable directions of collagen fibers is contained in the distribution's maxima. The distribution's mean value and standard deviation are of no use since these values contain no information on the shape of the distribution. We modeled obtained distribution by the polymorphic beta-distribution, a two-parameter family of functions, to study transformation of its extrema. We found that imaged tissue samples could be classified into four categories: patterns without any preferable orientation whose beta-distribution has no extrema, transitional forms whose beta-distribution has a broad single maximum, and highly oriented forms whose beta-distribution has two minima and single very narrow maximum in between. We have demonstrated that variation of collagen directional orderliness can be linked to the shape transformation of the corresponding beta-distributions. We found that samples of healthy individuals have an almost uniform distribution over beta-distribution forms. At 20 cm and 10 cm from the tumor, transitional forms with one broad maximum redistribute over unoriented and highly oriented forms. At the cancer itself, only highly oriented forms are present. To further improve the approach, we have calculated the structural complexities of tissue images. The structure is said to be more complex the more it differs from itself when considered at different scales. We used a measure of structural complexity based on interscale dissimilarities of images. Sample images taken from the healthy tissue, 20 cm and 10 cm away from the tumor and at the tumor itself, were mapped to points in a three-dimensional parametric space. The first two coordinates in this abstract three-dimensional space are beta-distribution parameters, and the third is the corresponding structural complexity value. We have calculated means and covariance matrices of data points for different tissue types. Obtained covariances define ellipsoids in a parametric space. To quantify the distinction between points belonging to different tissue types, we calculated a number of data points within the disjunctive union of each pair of ellipsoids. Consideration of structural complexity enhances the distinction between healthy tissue and tumor by more than 30 percent. We concluded that defined quantifications of directional orderliness and the complexity of collagen fibers could be helpful in the early detection of cancer tissue presence.

References

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