An Iterative Active Deformational Methodology for Tumor Delineation

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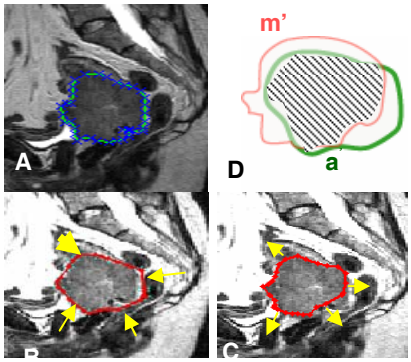
Purpose: Tumor delineation is a critical component for monitoring cancer progression. Such delineation is dependent on the expertise and experience of the delineator regardless of subspecialty [1,2]. Thus, there is significant motivation to improve automation of tumor delineation. These methods enhance objectivity and can improve efficiency in the clinical environment. However, methods that rely purely on an automated image processing method, which are also capable of producing high quality tumor delineation, are still not clinically optimal. To test our semi-automated segmentation methods, we have selected cervical cancer tumors due to our clinical practice's expertise as well as for the inherent delineation complexities. Specifically, some delineation challenges include parametrial fat proximity, frequency of tumor invasion to adjacent organs, edematous changes, and artifacts from organ motion. Our goal is to assess the degree to which results from our newly developed iterative active deformational segmentation method match results with the manual segmentation method. This comparison is quantified by volume comparison and 'mutual agreement' metrics.



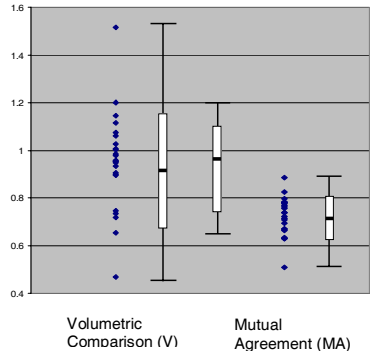


Figure 1: *A*) Green line illustrates the manual tumor segmentation (m'). Iterative active deformation model (a') from the B) 'outside' and C) 'inside' are shown with red contours, *D*) Illustration of how manual and active deformation segmentation is used to calculate 'mutual agreement' (*MA*). Note, shaded area is the overlap in delineation (m' and a'). E) *left*: statistics of volumetric size (V) agreement. Note, second box-whiskers plot is without two outliers and *right*: statistics of distribution of mutual agreement (*MA*) factors which is defined as: $MA = \frac{a' \bigcap m'}{a' \bigcup m'}$

Method: Thirty-one stage II-IVb cervical cancer cases were delineated using active deformation and by manual segmentation. Iterative active deformation was performed using in-house software implemented in Matlab (Natick, Ma) and 'C' based on the original active deformation formalism originated by Terzopoulos [3] as follows: find a contour v(s) that minimize the energy functional $\mathbf{E}_{Snake} = \int_0^1 \left(\alpha(s)|\mathbf{v}_s|^2 + \beta(s)|\mathbf{v}_{ss}|^2\right) + \mathbf{E}_{Image}(\mathbf{v}(s))ds$ using variational calculus solve: $\alpha\mathbf{v}_{ss} - \beta\mathbf{v}_{ssss} - \nabla\mathbf{E}_{Image} = 0$ The procedure for iterative active deformation is as follows: 1) points are initialized by user on outside of tumor (~4-6 points); 2) blocking/cut lines are applied to structures outside of the region of interest such as the colon and bladder; 3) active deformation is initiated from starting points until stopped by the user for registration; 4) A morphological filter (optionally) on the enclosed curve is used to reduce the delineation shifting points by choosing the closest point to the new filtered patch. 5) From that point the operation is applied in the opposite direction to grow from the inside to outside; 6) for each iteration, the user has an option to force node locations at any time; 7) Due to the growing number of points with each iteration the numbers of points are reduced by a thinning algorithm based on Euclidean distance and priority score; 8) procedure iterates back to step 3 or the contour points saved.

Results: Two methods were used to assess the iterative active deformation procedure: volumetric size metric was used to measure variation in size differentiation between the manual and automated method which produced an average only 14% difference between manual and active deformation method with $\mu_{Volumetric}$=0.95 and $\sigma_{Volumetric}$=0.14 (after removal of 2 outliers). The measure of agreement (MA) produced μ_{MA}=0.72 with σ_{MA}=0.08. The distributional results are shown in figure 1E across the 31 patient studies.

Discussion: It is well known that standard active contour methods have limitations because of their sensitivity to become unstable. These methods are particularly sensitive to the procedure's parameters. In some cases, shrinking and flattening can occur particularly when executed without user supervision. For example, one particular challenge is with multi-finger structures that are required to adequately delineate tumor invasion. In these cases, even semi-automated methods can resist the creation of the invaginating demarcations. However, solutions requiring routine manual tumor delineation on a large scale are very time consuming and can provide significant clinical burden. One compromise is through the use semi-automated methods. Such methods also may have the promise in reducing physical range of motion required in manual segmentation which can perhaps reduce incidence of carpal tunnels or tendonitis in our physicians. Further, supervised methods may also permit parameter adjustment that may incorporate the supervising radiologist/radiation oncologist specific knowledge. These methods can be used to serve as a 'verification' check during the delineator's progress and in some cases can be turned over to a resident or radiation oncology dosimetrist to improve clinical efficiency. In summary, active contours provide the ability to introduce a degree of automation and semi-objectivity which can be specified to a quantifiable degree of precision (sizes are within 5% and mutual agreement within 28% of each other) even in cases of difficult cervical cancer delineation. This may be useful in certain situations where functional measures are less sensitive to variation in tumor delineation or simply for gross serial measurement of tumor size with these new methods.

References:

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