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Circumferential Resection Margin Assessment on MRI of Rectal Cancer

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Abstract— **The circumferential resection margin (CRM) has been shown to be a good predictor of the outcome of the Total Mesorectal Resection surgical procedure in colorectal cancer. The CRM is increasingly used as a key parameter in patient management for colorectal cancer. It has been proposed that CRM can be estimated from MRI volumes taken pre-operatively; but to date the estimation of CRM is slice-based, hence two dimensional. We report a fully three-dimensional method to estimate the CRM, taking account of the MRI slice orientation used during the acquisition process. Prior to this, we segment the rectum and mesorectum. Preliminary results are reported for 10 patient cases, and a further large set are currently being analysed and results will be available at the time of the conference.**

I. Introduction

Colorectal cancer is the second most common form of cancer in the Western world, with approximately 500,000 new cases annually, and with a five-year survival rate of 50%. Currently, surgery is the only curative therapy, typically after chemo/radiotherapy which is used in 65% of cases. Following symptomatic presentation at a primary care physician, colorectal cancer is most often diagnosed using endoscopy and/or CT, and confirmed by histopathology. It is then staged, often on the basis of MRI. According to the familiar TNM staging criteria, this requires estimates of the primary tumour size and degree of invasion of the submucosa and related structures, the extent of nodal involvement, and an assessment of whether or not the disease has metastasised. Approximately half of colorectal cancers are rectal carcinomas, which require accurate staging in order to optimise patient management. The poor prognosis of rectal cancers result from the high risk of metastasis and local recurrence [1]. Quirke et al. [2] have shown a local recurrence rate of 83% for microscopically positive resection margins. Pelvic recurrence after rectal-cancer surgery leads to distressing morbidity. Inadequate surgical excision is considered to be the major factor in local recurrence after rectal cancer surgery [3].

MRI is considered to be the optimal imaging modality for staging rectal cancer as the large field of view and the relatively high spatial resolution enables assessment of the entire mesorectum, which includes the nodes, as well as the relationship between the tumour and the mesorectal fascia, the boundary of the mesorectum and the structure which defines the radial margins in total mesorectal resection for rectal cancer [4], [5]. The primary tumour site is assessed to determine if the tumour has extended into the adjacent fat and involved the adjacent tissue planes, including the mesorectum.

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a. b.

Fig. 1. Circumferential margin involvement by tumour. a) Axial MRI showing tumour near the mesorectal fascia indicating potential involvement of the CRM. b) Corresponding histological section of the resected specimen showing tumour within 1 mm of the lateral CRM.

Previously, the decision to offer adjuvant therapy has depended upon histological assessment of the tumour stage after resection of the primary tumour. The ability to downsize the tumour and treat micrometastatic disease with radiotherapy and chemotherapy prior to surgery offers the possibility to reduce the risk of systemic spread and improve local resectability [6]. It follows that accurate, quantitative measures are required for planning and evaluating the best possible course of treatment, as well as for deciding whether or not to administer neo-adjuvant chemo/radiotherapy prior to surgery and to measure the response of a tumour to such chemo/radiotherapy. Of the pre-operative prognostic features, the circumferential resection margin (CRM) has emerged as one of the most powerful predictors of the outcome of surgery [7], and on the rates of local recurrence, distant metastasis and thus survival [8], [9].

The potential CRM is defined as the mesorectal fascia which forms the plane of dissection in rectal cancer surgery, while the surgical CRM is defined as the surgical cut surface of the connective tissue that encases the rectum. The CRM is conventionally evaluated using the shortest distance from the tumour to the circumferential margin. Positive CRM status implies a rectal carcinoma where the tumour is within 1*mm* of the circumferential margin. One example of positive CRM is shown in Figure 1. Accurate estimation of the CRM is thus

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crucial in patient management.

However, evaluation of the CRM in MRI is error-prone. Figure 2 illustrates how the orientation of the obtained images can result in an underestimation of the CRM which in turn can result in the wrong assessment and treatment plan. Note that defining the margin in terms of the shortest distance from the tumour to the mesorectal fascia intrinsically regards the data as 2-dimensional (axial slice images), despite the fact that the MRI volume is a 3-dimensional dataset; that is, the data is not used to its full potential.

There appear to be no previous attempts to evaluate the actual (3 dimensional) CRM from the MRI images taking into account the imaging orientation. This paper describes a method to evaluate the CRM using the mesorectal fascia as the circumferential margin. The algorithm depends on the segmentation and reconstruction of the rectum that provides the long axis of the rectum as well as the circumferential region, thereby taking full advantage of the 3-dimensional dataset.

II. Methodology

Figure 2 is a diagram of a rectal cancer and the surrounding mesorectum. The figure also includes two sets of imaging planes: one set is perpendicular to the long axis of the rectum, the second set is imaged at a small additional angle. As can be seen in Figure 2, the estimated CRM depends on the orientation of imaging. The algorithm we have developed provides for a correction to the length of the CRM depending on the imaging angle with respect to the long axis of the rectum.

First, the algorithm estimates the orientation of the imaging planes. Then, the rectum and mesorectum are segmented in each of the MRI slices. The segmented regions provide the basis for a basic reconstruction of the mesorectum. The reconstructed volume in turn provides the principal axis of the rectum needed for evaluating the angle between the normal to the plane of imaging and the principal axis of the anatomical volume. The angle between the two planes is used to correct the measured CRM.

A. Evaluation of the Imaging Plane

Coordinate systems are an important part of assessing any medical image. Medical scanners create regular, "rectangular" arrays of points and cells. The topology of the arrays is implicit in the representation. The geometric location of each point is also implicit. Initially, the Imaging plane needs to be evaluated using information in the DICOM header [10], [11] and the standards for MRI imaging of the colorectum [5].

The only reliable way to order the slices is to use the "Image Orientation Patient" and "Image Position Patient" tags in the DICOM image header. These tags always use the same coordinate system, where "x" is left to right, "y" is posterior to anterior, and "z" is foot to head (RAH). The "Image Orientation Patient" (IOP) tag gives the direction cosines for the rows and columns for the three axes defined above. The typical axial slices will have a value 1/0/0/0/1/0:

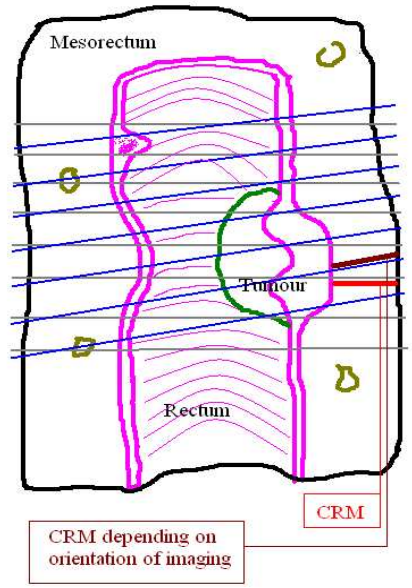

Fig. 2. Illustration of the potential CRM. The illustration includes two different imaging planes, in order to illustrate how the CRM is affected by the image orientation.

rows increase from left to right, columns increase from posterior to anterior. The "Image Position Patient" tag gives the coordinates of the first voxel in the image in the "RAH" coordinate system, relative to some origin.

The vector normal to the plane of the MRI slices can be calculated from the "Image Orientation Patient" tag. Let the 6 values in the IOP tag be represented by $[xr/yr/zr/xc/yc/zc]$. Let the normal vector be denoted by N_{or}:

$$N_{or}(x,y,z) = \nabla f(x,y,z) = \frac{\partial f}{\partial x}\,\hat{x} + \frac{\partial f}{\partial y}\,\hat{y} + \frac{\partial f}{\partial z}\,\hat{z}. \qquad (1)$$

The normal vector is evaluated using cross product as follows:

$$\frac{\partial f}{\partial x} = \cos(yr)*\cos(zc) - \cos(zr)*\cos(yc) \qquad (2)$$

$$\frac{\partial f}{\partial y} = \cos(zr)*\cos(xc) - \cos(xr)*\cos(zc) \qquad (3)$$

$$\frac{\partial f}{\partial z} = \cos(xr)*\cos(yc) - \cos(yr)*\cos(xc) \qquad (4)$$

This only has to be done once and is the same for all slices in the volume.

B. Segmentation of the Rectum and Evaluation of the Principle Axis

The following step involves a basic reconstruction of the rectum and, if needed, of the mesorectum. The rectum needs to be detected and segmented in each of the MRI slices in the volume in question. To achieve the segmentation, we use active contours [12] in each image/slice to find the rectum outline. The segmentation of the rectum in the first slice can help constrain the search region for applying the active contours algorithm. Representing the position of a snake by

$v(s) = (x(s), y(s))$ we use the following energy functional:

$$E_{snake} = \int_{\Omega} [w_1(s)|v_s(s)|^2 + w_2(s)|v_{ss}(s)|^2] ds + \int_{\Omega} \mu |\nabla u(v(s))|^2 ds \quad (5)$$

where $w(s), \mu$ are weighting functions and $u(s)$ is an image energy functional. The segmented rectum outlines in each slice can be combined to provide a rough reconstruction of the rectum. The outlines of the rectum resulting from the slices provide the long axis of the corresponding anatomy. The long axis is evaluated as the line closest to the curve resulting from the centres of the segmented outlines in a least squares sense. The orientation of the long axis of the rectum is denoted by $N_{rec}(x, y, z)$.

The segmentation of the rectum in each of the MRI slices can be accompanied with an automatic segmentation of the mesorectum. The boundary of the mesorectum is much harder to identify using conventional imaging techniques as it is very poorly defined. Nevertheless, segmentation of the mesorectum is crucial, as it is the boundary of the mesorectum that is used to estimate the CRM. Note that only the section of the mesorectum involved in the evaluation of the CRM needs to be reconstructed, and if needed the reconstruction can be based on a clinician's annotation of the mesorectum on the corresponding MR slices. We use the segmentation technique developed in [13] and [14]. The segmented rectum along with other anatomical landmarks such as the hips and coccyx provide a local coordinate frame, an anatomical frame in which the mesorectum is much easier to determine. Following a shape model [15] provides a more refined segmentation [13]. The segmentation in each of the slices can also in turn be combined using interpolation to provide a reconstruction of the 3-dimensional anatomy.

C. Evaluation of the Circumferential Margin

The error in the imaging orientation can be evaluated by estimating the angle between the normal to the imaging orientation used $N_{or}(x, y, z)$ and the direction of the long axis of the rectum $N_{rec}(x, y, z)$. The angle between these two directions is the same as the angle between the actual imaging plane and the ideal imaging plane(perpendicular to the rectum). Let this angle be denoted by α_{CRM}.

As noted above, the CRM is conventionally measured as the shortest (2D) distance between the margin of the tumour and the mesorectum. Let the uncorrected measurement be denoted by d_{CRMw}. The CRM may be evaluated in two different ways. The $d_{CRMangle}$ can be evaluated as the projection of d_{CRMw} on the plane perpendicular to the long axis of the rectum $d_{CRMangle} = d_{CRMw} \cos(\alpha_{CRM})$. The $d_{CRMangle}$ value provides a correction of the CRM by taking into account the angle difference. An even more precise measurement may be estimated by finding the intersection of the plane defined by the point of the tumour closest to the mesorectum and α_{CRM}, and the reconstructed part of the mesorectum. The exact value of the CRM d_{CRMr} is shortest distance between the tumour and the intersection of what should have been the ideal imaging plane with the reconstructed mesorectum. However, this measurement is more computationally expensive and may be reserved for use in cases where a precise value is required.

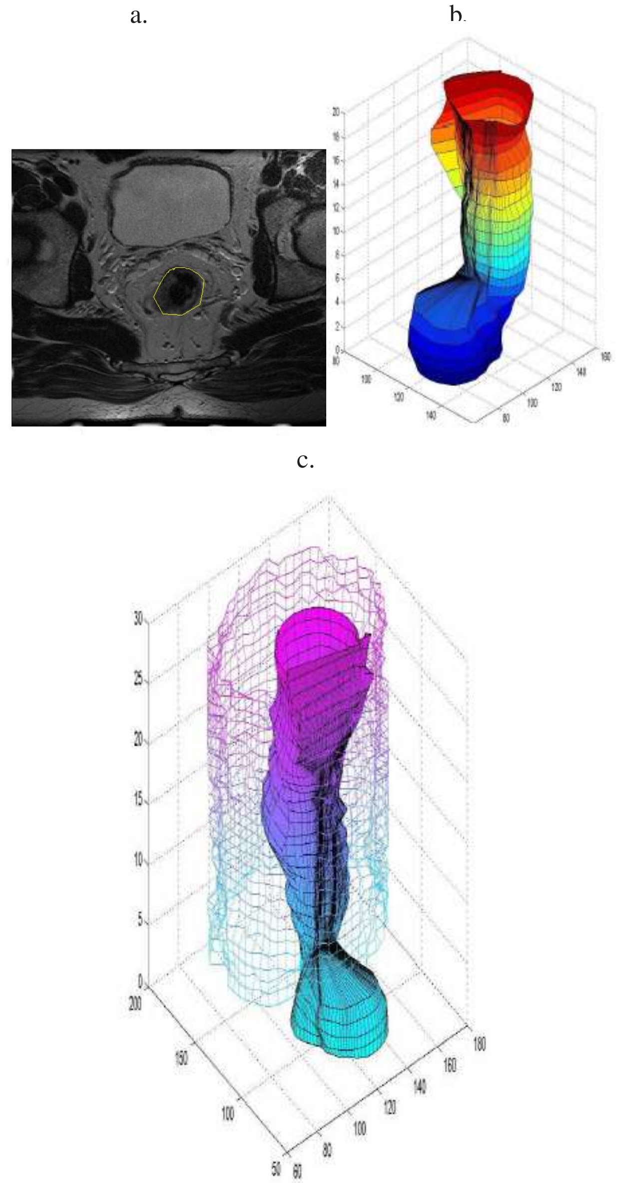

Fig. 3. Reconstruction of the rectum and the mesorectum for the evaluation of the CRM. a) Axial MRI showing tumour near the mesorectal fascia. This is the image used by the radiologist to evaluate the CRM. b) Reconstruction of the corresponding rectum using the entire dataset. c) Reconstruction of the corresponding mesorectum for the evaluation of the CRM.

III. Results - Discussion

The algorithm has to date been evaluated on ten cases; but results from a larger set will be available by the time of the Conference. The algorithm has been applied to axial small field of view T2 weighted MR images. The datasets are 3-dimensional each comprising of 256x256x25 voxels of size 0.78 mm x 0.78 mm x 3mm and corresponding with patients with confirmed colorectal cancer.

Figure 3a shows the MRI slice used to manually determine the CRM. The segmentation and reconstruction of the rectum can be seen in Figure 3b. This reconstruction provides the long axis of the rectum and in turn the ideal imaging orientation. Figure 3c provides the reconstruction of the corersponding mesorectum. The difference between the manual and the corrected CRM using the presented algorithm is 2.1mm and is in agreement with the pathology evaluation.

The results reinforce the importance of MR imaging and the use of objective measures in determination the CRM as this information is useful to the clinicians in their assessment and evaluation of the best course of treatment.

IV. Conclusions

The patient management decisions for colorectal cancer is the result of the combination of information from many different modalities and the combination of the decisions of many clinicians at different stages of the patients journey. Image analysis methods can aid the clinicians in their diagnosis and patient management decision.

We present a method for the evaluation of the CRM, a measure which materially affects the treatment management. As far as we are aware this is the first time an automated method has been developed for the accurate evaluation of the CRM. The results show how the CRM, traditionally accurately accessible post-surgery from histopathology, may be accurately evaluated from MRI and provide the needed information pre and post treatment.

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