A distance weighted directional gradient method for fully automatic bone segmentation of knee MRI

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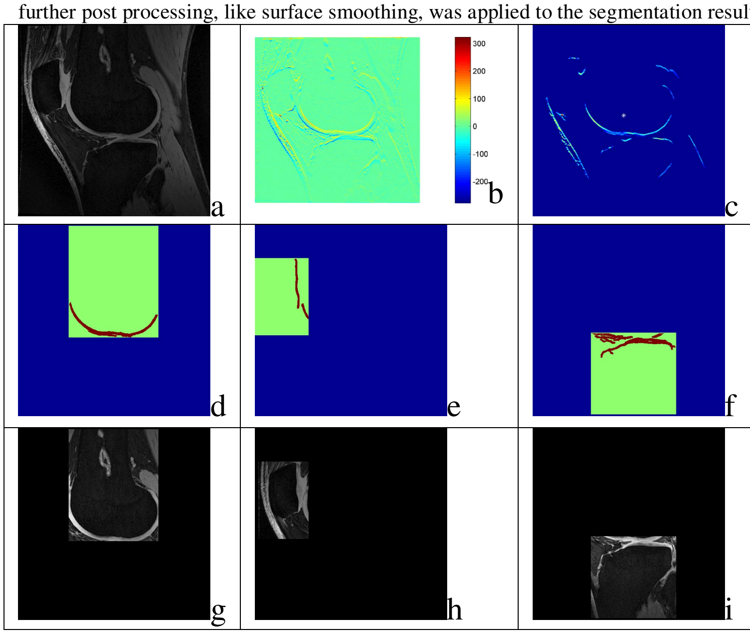
Introduction: Accurate knee segmentation is important for MRI-based diagnosis and therapy of cartilage diseases such as osteoarthritis [1]. Fully automatic segmentation is desired since it is both time- and cost-efficient. The widely adopted Chan-Vese (CV) model [2] could be used to implement a fully automatic segmentation technique. CV model segments an image into predefined number of intensity levels. However, direct application of CV model on knee segmentation has a difficulty in separating different bones (Femur, Tibia and Patella) since these bones have similar intensity level. In this study, a distance weighted directional gradient method is proposed to automatically separate these bones, and define masks for further bone segmentation. With this technique, different bones can be isolated and fully automatic bone segmentation can be achieved without using any prior shape information. The proposed method was tested on 14 data sets of knee MRI. These data sets were acquired using different pulse sequences, and have different contrast between bones and surrounding tissues. Results show that the proposed location detection technique can always provide accurate bone locations.

***Methods*: distance weighted directional gradient**: The proposed method is based on the fact that there is sufficient contrast between bones and cartilages. Using Femur as an example, this method is illustrated in Figure 1. Fig 1a shows a typical keen MRI, where significant increase of intensity from femur to femoral cartilage can be observed. This means high directional gradient value near bone cartilage interface (BCI), where directional gradient is defined as the vertical or horizontal component of the image gradient. By calculating directional gradient of the image in vertical direction, high value can be observed at the femoral BCI (Fig 1.b). By using thresholds to exclude low value regions and some isolated small regions, a shortlist of candidate BCIs can be found (Fig. 1c). The purpose of this step is to reduce the number of candidates to speed-up the computation. Hence a flexible threshold could be used. The white star in Fig. 1c shows the mass center of the image. BCIs are close to this mass center since cartilages are usually located at the center of the field of view (FOV). Therefore, it is reasonable to define the possibility of being a BCI to be a distance weighted directional gradient value, which is calculated by dividing the directional gradient value by the distance from the connected regions to the mass center. The higher this value is, the more possible the candidate belongs to BCI. Thus, connected regions that have high directional gradient and short distance to the mass center are treated as coarsely defined BCI. The red region in Fig. 1d shows the coarsely defined femoral BCI using weighted directional gradient. Using this BCI, a mask of femur can be defined (Fig. 1d). Fig. 1g shows the corresponding image in the mask. Clearly, the femur is isolated in the mask. Similarly, the masks of patella and tibia can be defined (Figs. 1e and 1f). Figs. 1h and 1i show the isolated patella and tibia in the masks. **Bone segmentation**: In these defined masks, either edge-based or region-based segmentation technique can be applied to define bones. In our implementation, CV model was applied to the masked region to segment the image into several intensity levels. Experimentally, it is found that 2~4 intensity levels are enough for bone segmentation. With the segmented intensity levels, bone can be easily picked, since it is the largest block in the masked region with the lowest intensity level (Figs. 1g~1i).

Results: Fourteen 3D data sets were acquired on a Philips Achieva system. Two data sets were acquired using proton density weighted turbo spin echo (PDW TSE) sequence; the other twelve data sets were acquired using water saturated fast field echo (FFE wats) sequence. These two pulse sequences provide different contrast of bone. For PDW TSE, the bone is bright. For FFE wats, bone is dark. For all fourteen data sets, the locations of bones were accurately defined using the weighted directional gradient method. Further segmentation was based on intensity levels generated by CV model. Fig. 2 shows some results. Figs. 2a and 2b show the segmentation of a 2D slice of a PDW TSE data set and a FFE wats data set, respectively. Fig2c shows the 3D segmentation with an image acquired with FFE wats. No further post processing, like surface smoothing, was applied to the segmentation result in Fig. 2c.



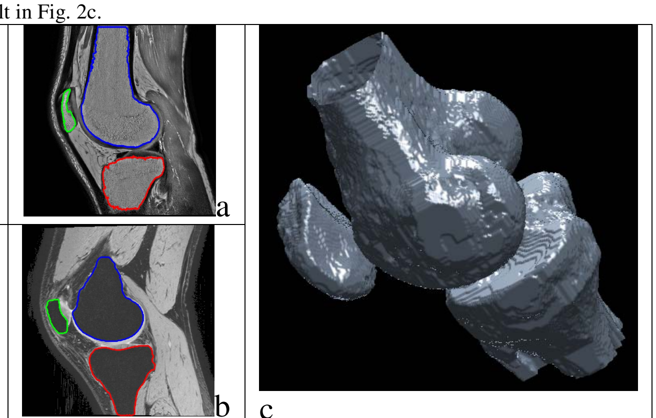


Figure 1. (Left) Explanation of the proposed method;
Figure 2. (Top) Examples of application of the proposed method

***Reference*:**
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Discussion and Conclusion: Using the high contrast between bone and cartilage in knee MRI, the proposed distance weighted directional gradient method finds the rough location of BCI. Eventhough the location information of BCI is not perfect, it is good enough to be used to isolate and segment the bone. In all experiments, locations of bones were accurately found regardless of the pulse sequence with which the MR images were acquired. It is possible that bone and surrounding tissue have similar intensity; hence CV model cannot distinguish them in some regions and leak will happen. With the mask defined by the proposed method, leak will only happen in the mask. Hence it is easier to remove these missegmented regions. Compared with the existing fully automatic segmentation techniques [1, 2], the proposed method avoids the requirement of prior shape information. The definition of masks and further segmentation of a 320×320×170 image took about 100 seconds in Matlab enviroment (3.2 GHz CPU and 2 GB RAM). In conclusion, weighted directional gradient can accurately locate bones from knee MRI with different pulse sequences, and can be applied for fully automatic bone segmentation technique without using prior shape information.