High-resolution, 3D knee MR imaging facilitates the visualization of all components of the knee joint structures. With its excellent tissue contrast, MR imaging has increasingly been used to assess osteoarthritis (OA), in particular, the knee cartilage. Detection of changes in cartilage is an important biomarker to monitor the disease progression of OA. Because structural changes in OA may be subtle and progress slowly, quantitative measurement of cartilage structures, such as volume, thickness, and area via MR images, has been widely advocated and used to assess disease progression in clinical OA studies (1-2).

Because knee cartilage is only 1.3-2.5 mm thick in healthy subjects (3) and even thinner in OA subjects, high resolution imaging is required for quantitative analysis of cartilage morphology. Quantitative evaluation of knee cartilage requires segmentation of the cartilage, which is a painstaking process due to its complex geometry, small size, and inherently low MR signal contrast with surrounding tissue such as meniscus and synovial fluid. A number of different methods for the segmentation of cartilage were published, ranging from manual to semi-automated to fully-automated methods. Since each method has strengths and weaknesses, the appropriateness and practical values of different methods remain controversial. The most laborious method is the manual outlining of cartilage regions on each MR image by an analyst (4-6), which is the technique most widely used in clinical studies. Although the process of manual segmentation is straightforward, it is resource intensive, time-consuming (requiring several hours to segment the cartilage in each knee from high-resolution MR images) and is subject to analyst bias and error. To overcome these limitations, development of an automated approach is highly desirable (7).

At present, semi-automated segmentation methods that combine the perceptual recognition of a human expert and the reliability of a computer seem to be the most appropriate and practical approaches for cartilage segmentation. An optimally implemented semi-automated segmentation method would yield accurate and precise segmentation results in a reasonable amount of time with minimal variability. A number of semi-automated segmentation techniques
have been proposed and published, such as edge detection (7), region growing (6, 8-12), active shape models (11), b-spline snakes (13-16), live wires (17), and multispectral analysis (18). Recently, graph-cuts algorithms were suggested to be promising solutions to a wide range of image processing problems, including segmentation of knee cartilage (19-23). Although these semi-automated techniques for knee cartilage are much more efficient than manual boundary delineation, they still require tens of minutes and careful annotations.

Several recent studies (24-27) reported to the development of fully-automated segmentation of knee cartilage with no user interaction. In particular, two methods (25-26) are based on a framework that first segments each bone compartment in the knee joint and then segments the corresponding cartilage compartments. The segmentation of bone was performed using a mesh model of each bone surface and identification of vertices on the bone-cartilage interface (BCI) by training. From the extracted BCI, the outer cartilage boundary was determined by examining the intensity profile orthogonal to the BCI (25) or an optimal multi-surface segmentation method (26). A more recent method for fully-automated segmentation of cartilage at different compartments is also composed of bone segmentation, BCI classification, and cartilage segmentation (27). Utilizing this method, new approaches were introduced to increase flexibility and accuracy in each subprocess including a modified branch-and-mincut method (28) based on shape priors for automatic segmentation of bones. These recent studies using fully automated segmentation of knee cartilage showed promising overall results that closely align with results obtained using semi-automated or manual methods. However, it is yet to be determined whether fully automated methods without expert supervision can yield a consistently reliable segmentation of highly disfigured cartilages from advanced OA knees.

References


