Results:

The prototype functions without any user interaction. Registration improves image quality by motion correction without compromising contrast enhancing lesions. Calculating the mean signal intensity of the whole subtraction series before and after applying the registration algorithm results in a mean signal intensity reduction by 32%. Detection algorithms identify 8.58 contrast-enhancing lesions on average per investigation. The first ANN is able to reduce the number of detected lesions by a mean of 6.16 which are considered to be artefacts. A mean of 1.55 true lesions are verified within the subtraction series. The remaining 0.87 false positive findings mainly consist out of chest wall and heart beat artefacts. 37 of 39 histologically proven lesions have been detected and classified to be malignant, two lesions were missed by detection (sensitivity and specificity: 94.9%/92.3%). 25 out of 50 benign lesions were detected, 23/25 correctly classified to be malignant, two falsely classified to be malignant.

Discussion:

The combination of different means of medical image interpretation, namely image registration, image processing and artificial intelligence leads to a functioning prototype for Computer Aided Diagnosis. The software was designed to carry out all necessary steps to analyze contrast-enhanced MR-images of the female breast automatically. It is currently programmed to analyze investigations of a single scanner and a certain protocol [1]. Adapting all algorithms to be able to investigate images of different origins will be a heavy workload. Therefore the next step towards a helpful CAD tool for second opinion must be the commercialization of the prototype.

Conclusion:

A software prototype for Computer Aided Detection and Classification of lesions in MR-Mammography was successfully programmed. Further investigations at larger samples will show whether it is robust and capable to be used as second opinion. Industrialization of the software is planned.

**Computational and Visualization Techniques for Understanding the Shape Variations of the Bicipital Groove**

Aaron D. Ward, MSc, Simon Fraser University; Mark E. Schweitzer, MD, Ghassan Hamarneh, PhD

Background:

Bicipital root and proximal tendon disorders are an important symptom generator in the shoulder. The accuracy of the diagnosis of many shoulder disorders by imaging is limited, motivating a clinical need for some ancillary method to access the proximal biceps. Because of the known inter-relationship of the shape of the bicipital groove (BG) with several types of disorders, measurements of BG shape correlate to incidence of shoulder disorders and injuries. Research into this correlation has been ongoing for decades, but classically, measurements are 2D, taken from a single axial tomographic slice of the shoulder, as shown in figure 1. Such measurements usually include depth, width, and angles of medial and lateral BG walls. Clearly however, they do not capture full information about these BG dimensions, as they are limited to individual measurements on a single 2D slice.

![Figure 1. Diagram of an axial cross section of the humerus in standard anatomical position depicting the BG indentation on top. A, B, and C indicated measurements of the BG used in many previous works. A: The medial opening angle. B: The total opening angle. C: The depth of the BG.](image)

We are therefore motivated to develop an approach to 3D shape description of the BG that captures information relevant to disorders of the shoulder. Medial representations of shape represent shapes as measured thickness values, relative to some medial geometry (e.g. a medial axis in the 2D case; a medial sheet in the 3D case). Medial representations are an attractive choice for this clinical application because BG width, depth, and wall angles are correlated to shoulder malady, and thickness values computed relative to the medial sheet yield such measurements directly.

In this work, we describe a system for computing a medial representation of the BG that permits the decomposition of shape variations into rich, clinically meaningful and understandable

![Figure 2. Flowchart describing the overall process of computing the visualizing the shape description of the bicipital groove](image)
measurements. The system's pipeline is shown in figure 2. Beginning with an image of the shoulder (MR or CT), the first step is to segment the BG from the rest of the shoulder data. In the case where the input is CT data, we have created a software tool to perform this process semi-automatically; the user need only input the superior and inferior axial slices containing the BG, and click two points on an initial slice within the BG, defining a rectangle containing the BG on that slice. Starting at the initial slice, the tool computes an edge map within the rectangle (thus extracting the bone-soft tissue boundaries), and eliminates all edges not having line-of-sight to the rectangle center. Because of the concave appearance of the BG surface on each axial slice, the rectangle center is likely to lie within the groove; thus, the remaining edges are points lying on the surface of the BG. Segmentation proceeds in a slice-by-slice manner. After each slice is segmented, the centroid of the extracted BG surface points on that slice is computed, and the rectangle is displaced such that its center coincides with this centroid. In this manner, the rectangle is displaced to remain centered over the BG (as it appears on an axial slice) as segmentation proceeds. In the case where the input is MR data, due to lower contrast between bone and soft tissue, more manual input is required on the part of the user; the user may need to select some points (usually no more than 5) lying on the BG surface on each axial slice. With a few hours' practice, we found that a user can perform this task consistently in less than 1.5 minutes for each data set.

A smooth spline surface is then interpolated using the BG surface points determined during segmentation. This allows the visualization of the BG surface with subvoxel accuracy; this is especially important in our data sets where the inter-slice spacing (along the axial dimension) can be as high as 3mm. Our tool can output the spline surface to a variety of standard data formats (e.g. Analyze, DICOM, VTK), so that it can be visualized using popular tools available to the clinician. The BG can be visualized in context with the surrounding data (e.g. figure 3(a)) or out of context (figure 3(b)).

From the spline surface, two sheets (surfaces) are computed. First, an intertubercular sheet is computed that joins the tuberosities of the humeral head at each axial slice of BG (figure 3(c)). Next, a medial sheet is computed to be perpendicular to the intertubercular sheet at each axial slice, intersecting the intertubercular sheet at some point. This intersection point could be computed as the point of greatest BG depth, depth being defined as follows: at any point P on the BG surface, BG depth at P is defined as the perpendicular distance from that P to the intertubercular sheet. This is motivated by a desire to position the medial sheet along the deepest points (the trough) of the BG. However, this approach makes the position of the medial sheet very sensitive to small variations in BG depth, and results in a non-smooth medial sheet (figure 3(d)). Such discontinuities will carry over into the thickness fields computed based on the medial sheet, making the determination of smoothness of the BG walls difficult for the clinician during visualization of the thickness fields. To overcome this problem, dynamic programming is used to find the optimal path through the trough of the BG, giving equal weight to groove depth and medial sheet smoothness result shown in figure 3(e)).

From the medial sheet, three thickness fields are computed: a lateral wall field (figure 3(h)), showing the distances from the medial sheet to the lateral BG wall, respectively, a medial wall field (figure 3(i)), and a width field, showing the sum of the two wall fields (figure 3(g)). Additionally, a depth field can be computed relative to the intertubercular sheet (figure 3(f)).

Figure 3. (a) BG visualized in contest with coronal and sagittal slices and axial slices. (b) BG visualized out of contest. (c) BG with intertubercular surface fitted. (d) BG with medial sheet computed using BG depth as the only criterion. Note discontinuities. (e) BG with medial sheet computed using smoothness and depth as criteria, weighted equally. (f) Depth field. (g) Width field. (h) Lateral wall field. (i) Medial wall field. In (f) through (i), the horizontal axis of the figures corresponds to the axial dimensions from the volume data set. Darker values indicate larger thickness.

Evaluation:

The computed thickness fields allow the clinician to visualize clinically relevant measurements of depth, width, medial, and lateral walls independently of one another, in search of anomalies such as a shallow/wide or deep/narrow groove, or the presence of spurs. Examine the shape of the entire BG, rather than using a single axial slice as in previous work, 3. reduce a complex 3D shape analysis problem to several 2D fields that are easier to understand. To facilitate the understanding of the thickness fields, see figure 4. This figure shows the correspondence of points on the intertubercular (blue point) and medial (red point) sheets to points on the 2D thickness fields. As shown in figure 5, it is also possible to explore the quantitative measurements contained within the thickness fields in an interactive way. MATLAB's imtool (The MathWorks, Inc.) is used for this purpose in the figure.
Discussion:

In this work, we demonstrate an application of the medial shape representation to the problem of analysis and visualization of the shape of the bicipital groove of the proximal humerus. The medial representation is a natural choice, because the thickness fields computed from the medial sheet, as well as that computed from the intertubercular sheet, intrinsically yield measurements of interest to the clinical and research communities concerned with the incidence of shoulder injury. These thickness fields allow for an understanding of measurements of depth, width, and the BG walls in both a qualitative and quantitative sense.

Further work in this area, currently in progress within our research group, is primarily in the direction of statistical analysis of the data contained within the thickness fields. One of our main goals is to design a classifier that can classify a BG as being within normal or abnormal ranges of BG shapes, and to further classify within the abnormal group according to the type of shoulder injury to which the given BG shape predisposes the subject. Other future work includes the application of this representation and visualization method to the analysis of other anatomic structures.

Conclusion:

We conclude from this investigation that the medial shape representation is appropriate for visualization and analysis of the bicipital groove of the proximal humerus. It allows for intuitive qualitative and quantitative inspection by the clinician, and we aim to show in future work that it also permits meaningful statistical analysis of BG shape.

Relative Approach to Optical Density Image Analysis for Quantitative Fracture Healing Assessment

Wojciech M. Glinkowski, MD, PhD, Medical University of Warsaw; Maciej Kornacki, MS

Background:

Bone is able to regenerate itself with bone, after fracture. Structurally healed fracture returns to its intact state after remodeling. Fracture healing monitoring assessment in the clinical setting remains very traditional because of the use of subjective manual manipulation of the fracture site and evaluation of classic or digital radiographic images. The conventional radiography remains the mainstay of routine fracture assessment. How-