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Homodyned-*K* quantitative ultrasound and machine learning for detection of lateral epicondylosis of the elbow

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***Abstract*—Lateral epicondylosis (LE) of the elbow is a common syndrome found among working-age individuals, leading to degenerative changes of the common extensor tendon (CET). Ultrasound (US) is well suited for the investigation of LE because of its relative affordability and good spatial resolution. Among quantitative ultrasound (QUS) imaging techniques, homodyned-*K* (HK) statistical modeling of the echo envelope aims at characterizing tissue microstructures. The goal of this study was to assess the potential of HK parameters in detecting LE. In this prospective study, 30 LE elbows in 27 patients and 24 asymptomatic elbows in 13 volunteers underwent US imaging of the CET and radial collateral ligament (RCL). After US imaging examination per clinical standard practice, a long-axis, 3-second loop of a radiofrequency US image sequence of the CET and RCL was acquired using a Terason t3000 US scanner (Teratech, Burlington, MA) equipped with a linear 12L5-MHz transducer. Three statistical parameters based on HK modeling were estimated on the CET region-of-interest: 1) mean intensity normalized by its maximum value; 2) reciprocal $1/\alpha$ of the scatterer clustering parameter; 3) coherent-to-diffuse signal ratio k. Moreover, HK parametric maps were calculated on the CET-RCL region based on local estimation of the same parameters, from which were extracted additional features, as well as area of the two regions. Random forest classifier modeling identified the most discriminating combination of 3 features or less. The best combination of features was: CET global estimate of $1/\alpha$, CET-RCL area, and inter-quartile range of local estimate of k. The area under the receiver operating characteristic curve, sensitivity, and specificity of the QUS-based model were 0.82 (95% confidence interval [CI], 0.80–0.85), 0.73, and 0.79, respectively. These values are comparable with values obtained in a meta-analysis: pooled sensitivity of 0.82 (95% CI, 0.76–0.87) and pooled specificity of 0.66 (95% CI, 0.60–0.72) when using US in the diagnosis of suspected LE.**

Keywords*—elbow, lateral epicondylosis, random forests, quantitative ultrasound (QUS), homodyned K-distribution

I. Introduction

Lateral epicondylosis (LE) of the elbow is a common syndrome found among working-age individuals, leading to degenerative changes of the common extensor tendon (CET). Ultrasound (US) is well suited for the investigation of LE because of its relative affordability and good spatial resolution. Among quantitative ultrasound (QUS) imaging techniques, homodyned-*K* (HK) statistical modeling of the echo envelope aims at characterizing tissue microstructures. The goal of this study was to assess the potential of HK parameters in detecting LE in a prospective study.

II. METHODS

A. Study population and image acquisition

In this prospective study [1], which received Institutional Review Board approval, all participants gave written informed consent. Thirty LE elbows in 27 patients and 24 asymptomatic elbows in 13 volunteers underwent US imaging of the CET and radial collateral ligament (RCL).

After US imaging examination per clinical standard practice, a long-axis, 3-second loop of radiofrequency US image sequence of the CET and RCL was acquired using a Terason t3000 US scanner (Teratech, Burlington, MA) equipped with a linear 12L5-MHz transducer. Further information on the study population and ultrasound imaging can be found in [1].

B. QUS analysis

Three statistical parameters based on HK modeling were estimated on the CET region-of-interest [2]: 1) mean intensity normalized by its maximum value; 2) reciprocal $1/\alpha$ of the scatterer clustering parameter; 3) coherent-to-diffuse signal ratio k. Moreover, HK parametric maps were calculated on the CET-RCL region based on local estimation of the same parameters, from which were extracted the mean and inter-quartile range (IQR) [3,4], as well as area of the two regions. In total, there were 11 features. See [1] for further details on the QUS analysis performed in this study.

C. Machine learning

Random forest classifier modeling [5] identified the most discriminating combination of 3 features or less among the 11 considered features. It was also used for determining the receiver operating characteristic (ROC) curves and confidence intervals (CI) of estimated features. Areas under ROC curves (AUC) were calculated with the 0.632+ bootstrap cross-validation method [6]. Pre-selection of feature combinations was performed based on the G-mean [7]. Further information on the statistical learning analysis can be found in [1], as well as other statistical analyses performed in the study [1].

III. RESULTS

Based on the estimated AUCs, the best combination of features of 3 parameters or less was: CET global estimate of $1/\alpha$, CET-RCL area, and inter-quartile range of local estimate of k over the CET-RCL region. The area under the receiver operating characteristic curve, sensitivity, and specificity of the QUS-based model were 0.82 (95% CI, 0.80–0.85), 0.73, and 0.79, respectively. See [1] for further results obtained in the study.

In Figures 1 and 2, examples of homodyned-*K* parametric maps of the coherent-to-diffuse signal ratio k are presented in the case of volunteers with an asymptomatic elbow. In Figures 3 and 4, the parametric k maps are displayed in the case of two patients with left and right symptomatic LE elbows, respectively.

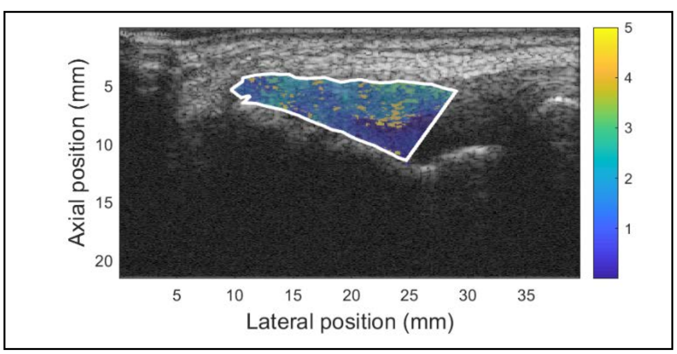

Fig. 1. Parametric map of the homodyned-*K* parameter k (coherent-to-diffuse signal ratio) in the CET-RCL region for a volunteer with an asymptomatic right elbow. The mean value of k was 2.6 and its inter-quartile range was 2.7 in this case.

IV. DISCUSSION

In the four examples illustrated in Figures 1 to 4, one observes that both the mean value and inter-quartile range over the CET-RCL region of the coerent-to-diffuse signal ratio k are larger in the case of the volunteers with an asymptomatic elbow than in the case of the two patients with a symptomatic LE elbow. Based on the study [3] and the relation between parameter k and the diffuse-to-total signal power ratio [2], this observation suggests that structural spatial organization of scatterers and its variability within the CET-RCL decrease in the presence of epicondylosis. See [1] for further insight on the clinical interpretation of these quantitative biomarkers.

As noticed in [1], the values obtained on the ROC curve are comparable with values obtained in a meta-analysis [8]: pooled sensitivity of 0.82 (95% confidence interval [CI], 0.76–0.87) and pooled specificity of 0.66 (95% CI, 0.60–0.72) when using US in the diagnosis of suspected LE.

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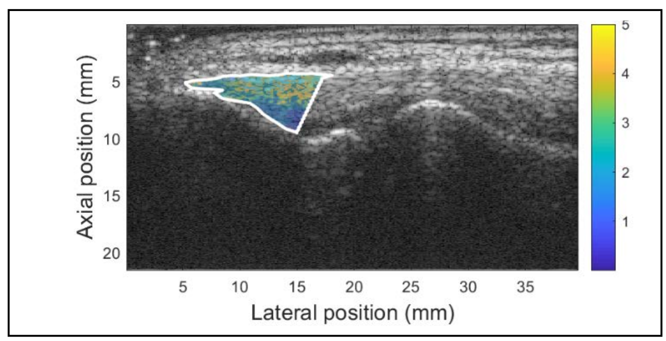

Fig. 2. Parametric map of the homodyned-*K* parameter k (coherent-to-diffuse signal ratio) in the CET-RCL region for a volunteer with an asymptomatic right elbow. The mean value of k was 2.7 and its inter-quartile range was 2.0 in this case.

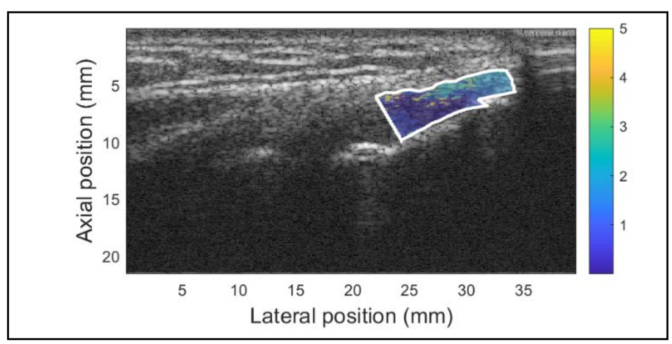

Fig. 3 Parametric map of the homodyned-*K* parameter k (coherent-to-diffuse signal ratio) in the CET-RCL region for a patient with a symptomatic left LE elbow. The mean k value was 1.2 and its inter-quartile range was 1.8 in this case, indicating less structural organization in the LE case than for the asymptomatic volunteers.

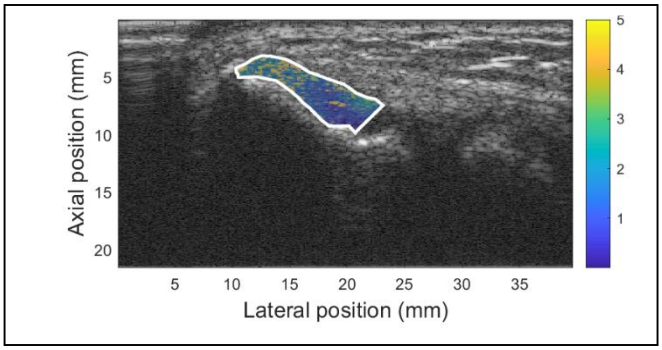

Fig. 4 Parametric map of the homodyned-*K* parameter *k* (coherent-to-diffuse signal ratio) in the CET-RCL region for a patient with right symptomatic LE elbow. The mean value of *k* was 1.6 and its inter-quartile range was 0.9 in this case, indicating less structural organization in the LE case than for the asymptomatic volunteers.

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