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● *Original Contribution*

COMPUTER-AIDED DIAGNOSIS OF DIFFERENT ROTATOR CUFF LESIONS USING SHOULDER MUSCULOSKELETAL ULTRASOUND

Ruey-Feng Chang,*† Chung-Chien Lee,*‡§ and Chung-Ming Lo*¶

*Graduate Institute of Biomedical Electronics and Bioinformatics, National Taiwan University, Taipei, Taiwan; †Department of Computer Science and Information Engineering, National Taiwan University, Taipei, Taiwan; ‡Department of Orthopedic Surgery, New Taipei City Hospital, New Taipei City, Taiwan; §Department of Orthopedic Surgery, National Taiwan University Hospital, Taipei, Taiwan; and ¶Graduate Institute of Biomedical Informatics, College of Medical Science and Technology, Taipei Medical University, Taipei, Taiwan

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Abstract—The lifetime prevalence of shoulder pain approaches 70%, which is mostly attributable to rotator cuff lesions such as inflammation, calcific tendinitis and tears. On clinical examination, shoulder ultrasound is recommended for the detection of lesions. However, there exists inter-operator variability in diagnostic accuracy because of differences in the experience and expertise of operators. In this study, a computer-aided diagnosis (CAD) system was developed to assist ultrasound operators in diagnosing rotator cuff lesions and to improve the practicality of ultrasound examination. The collected cases included 43 cases of inflammation, 30 cases of calcific tendinitis and 26 tears. For each case, the lesion area and texture features were extracted from the entire lesions and combined in a multinomial logistic regression classifier for lesion classification. The proposed CAD achieved an accuracy of 87.9%. The individual accuracy of this CAD system was 88.4% for inflammation, 83.3% for calcific tendinitis and 92.3% for tears. Cohen's *k* was 0.798. On the basis of its diagnostic performance, clinical use of this CAD technique has promise. (E-mail: leecc@ntu.edu.tw or buddylo@tmu.edu.tw) © **2016 World Federation for Ultrasound in Medicine & Biology.**

Key Words: **Rotator cuff lesions, Shoulder ultrasound, Computer-aided diagnosis, Texture.**

INTRODUCTION

The prevalence of shoulder pain is high in many countries. The lifetime prevalence of shoulder pain approaches 70% (Luime et al. 2004), second only to the prevalence of lower back pain (84%) (Walker 2000). In America, shoulder pain costs the health care system $7 billion per year and is the cause of 13% of sick leave time (Hidalgo-Lozano et al. 2010). Up to 70% of shoulder pain is attributed to rotator cuff lesions (Macfarlane et al. 1998; Mitchell et al. 2005). According to Neer's classification system, lesions of the rotator cuff can be classified as inflammation, calcific tendinitis and full- or partial-thickness tears. Inflammation is thickened, irregular and hetero-echoic, with a loss of homogeneous texture and no signs of tears. Calcific tendinitis has several forms; foci of hyper-echoic microcalcification without acoustic shadows are the common form. However, large foci of calcification may be soft or hard, solitary or lobulated (Beggs 2011). Soft calcification is fragmented and hyper-echoic with a well-defined margin and with or without acoustic shadows. Hard calcification has a hyper-echoic convex superficial contour, often with acoustic shadows (Beggs 2011). On ultrasound, supraspinatus tears appear as hypo-echoic areas with irregular margins (Allen and Wilson 2001; Kurol et al. 1991; Vlychou et al. 2009). They could extend from the bursal to the articular surface as full-thickness tears or affect only a part of tendon thickness as partial-thickness tears (Beggs 2011).

Patients with rotator cuff lesions have shoulder pain, positive impingement signs, limited forward elevation, weak abduction and external rotation, which may cause difficulty in holding things. Rotator cuff tears, with an overall prevalence rate of 20.7%, are the most severe type, causing severe shoulder pain and impingement

Address correspondence to: Chung-Chien Lee, Department of Orthopedic Surgery, New Taipei City Hospital, New Taipei City, Taiwan, ROC and Chung-Ming Lo, Graduate Institute of Biomedical Informatics, College of Medical Science and Technology, Taipei Medical University, Taipei, Taiwan, ROC. E-mail: leecc@ntu.edu.tw or buddylo@tmu.edu.tw

signs, limited forward elevation and weak abduction and external rotation. As the population ages, the prevalence rate of rotator cuff tears is expected to increase.

In the treatment of rotator cuff tendinopathy, the status of rotator cuff integrity determines surgical intervention or conservative treatment. Clinical symptoms and a physical examination are considered unreliable for diagnosis of rotator cuff lesions (Park et al. 2005) because the severity of the rotator cuff tendinopathy affects the diagnostic values of commonly used clinical tests. Additionally, considerable inter-observer variability exists between physicians (Beaudreuil et al. 2009). Consequently, clinical assessment relies on imaging modalities to evaluate the integrity of rotator cuff tendons (Murphy et al. 2013). Shoulder X-ray, ultrasound, magnetic resonance imaging and more specific arthrography are imaging techniques available for clinical examination (Shahabpour et al. 2008). The literature recommends shoulder ultrasound as useful in detecting rotator cuff lesions (Allen and Wilson 2001; de Jesus et al. 2009; Middleton et al. 2004) and full-thickness rotator cuff tears when performed by experienced musculoskeletal radiologists or shoulder orthopedic surgeons (Smith et al. 2011). The accuracy of ultrasound performed by experienced operators is comparable to that of magnetic resonance imaging (MRI) (de Jesus et al. 2009; Teefey et al. 2004). Diagnostic performance based on ultrasound is likely reduced on examination by general radiologists and ultrasonographers in identification of partial-thickness rotator cuff tears and other intrasubstance tendon abnormalities (Smith et al. 2011). To strengthen the clinical use of ultrasound, the inter-operator variability should be further reduced.

Ultrasound is useful as a diagnostic tool for shoulder disorders and as an initial imaging study for detecting rotator cuff lesions. With respect to its advantages in the detection of shoulder lesions, ultrasound is relatively inexpensive, easy to access and has few contraindications (Beggs 2006). Most published shoulder ultrasound studies report its sensitivity and specificity in diagnosing rotator cuff tears. The accuracy of shoulder ultrasound in detecting partial- and full-thickness rotator cuff tears has a sensitivity of 46% to 95% and a specificity of 50% to 97% (Alasaarela et al. 1998; Brandt et al. 1989; Kurol et al. 1991; Mack et al. 1985; Miller et al. 2008; Read and Perko 1998; Roberts et al. 2001; Soble et al. 1989; Teefey et al. 2000; van Holsbeeck et al. 1995; Wiener and Seitz 1993). Sensitivity and specificity are better for the assessment of full-thickness rotator cuff tears than for partial-thickness rotator cuff tears (Middleton et al. 2004; Smith et al. 2011; Teefey et al. 2004). The use of ultrasound for the assessment of partial-thickness rotator cuff tears is controversial (Martin-Hervas et al. 2001; Mitchell et al. 2005; Moosmayer et al. 2007) and is an uncertain clinical issue. According to the literature reviews, inter-observer agreement on diagnosis of rotator cuff lesions with shoulder ultrasound is only poor to moderate because of the differences in experience of operators (de Winter et al. 1999; Kamwendo et al. 1991; O'Connor et al. 2005), which implies that additional diagnostic tools such as computer-aided diagnosis (CAD) are needed for less experienced general and junior operators.

The use of computer-aided diagnosis systems to distinguish between benign and malignant lesions such as breast and prostate cancer (Doi 2005; Giger et al. 2008; Joo et al. 2004; Lo et al. 2015a; 2015b; Moon et al. 2012a) and identify carotid atherosclerosis (Bonanno et al. 2015) has been proposed. The advantages of CAD systems include quantitative ability, efficiency and consistency. After the quantitative features have been extracted from a lesion area, the complementary abilities of various features are combined in an artificial intelligence classifier to estimate the likelihood of a specific type of lesion. With the assistance of CAD, the diagnostic performance of seven radiologists in distinguishing between benign and malignant breast lesions was improved (Kashikura et al. 2013). However, few studies have addressed the application of CAD in shoulder musculoskeletal ultrasound. One study used a fixed rectangle to enclose the region of interest (ROI) for feature extraction, which may not reveal the properties of the entire lesion tissue (Horng and Chen 2009).

The purpose of this study was to create a CAD system using shoulder musculoskeletal ultrasound to improve operators' performance in diagnosing rotator cuff lesions. This tool could assist general radiologists and ultrasonographers in shoulder musculoskeletal ultrasound and improve the practicality of shoulder ultrasound examination. Based on the success of CAD systems in interpreting ultrasound images, in this study we proposed a CAD system based on shoulder ultrasound that classifies rotator cuff lesions as inflammation, calcific tendinitis and thickness tears. Numerous textural features and lesion areas were implemented in the experiment to diagnose rotator cuff lesions. To the best of our knowledge, this is the first study exploring the performance of quantitative features extracted from whole rotator cuff lesions in shoulder ultrasound for lesion classification. The results would be especially helpful to junior physicians in distinguishing lesions with similar properties on clinical examination.

METHODS

Patients and data acquisition

Institutional review board approval was obtained and informed consent was waived for this retrospective study. The database consisted of 99 shoulder ultrasound images in 93 adult patients collected from January 2011