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● *Clinical Note*

A NOVEL METHOD OF SYNOVITIS STRATIFICATION IN ULTRASOUND USING MACHINE LEARNING ALGORITHMS: RESULTS FROM CLINICAL VALIDATION OF THE MEDUSA PROJECT

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Abstract—Ultrasound is widely used in the diagnosis and follow-up of chronic arthritis. We present an evaluation of a novel automatic ultrasound diagnostic tool based on image recognition technology. Methods used in developing the algorithm are described elsewhere. For the purpose of evaluation, we collected 140 ultrasound images of metacarpophalangeal and proximal interphalangeal joints from patients with chronic arthritis. They were classified, according to hypertrophy size, into four stages (0–3) by three independent human observers and the algorithm. An agreement ratio was calculated between all observers and the standard derived from results of human staging using κ statistics. Results was significant in all pairs, with the highest p value of 3.9×10^{-6}. κ coefficients were lower in algorithm/human pairs than between human assessors. The algorithm is effective in staging synovitis hypertrophy. It is, however, not mature enough to use in a daily practice because of limited accuracy and lack of color Doppler recognition. These limitations will be addressed in the future. (E-mail: pawel.franciszek.mielnik@helse-forde.no) © 2017 World Federation for Ultrasound in Medicine & Biology. All rights reserved.

Key Words: **Synovitis, Arthritis, Ultrasound, Machine learning.**

INTRODUCTION

Ultrasound (US) is a recognized diagnostic method in rheumatology, especially in arthritis. Semiquantitative scoring of synovitis is widely used in medical practice and research, both for synovial hypertrophy (SH) (Scheel et al. 2005) and for vascularization (Østergaard and Szkudlarek 2005).

Computer science has undergone rapid development in recent y and has resulted in dramatic changes in our daily life. Machine learning and image recognition can advance us into a new era of radiology. These methods are already used in many aspects in CT computed tomography (CT), nuclear magnetic resonance (NMR) and positron-emission tomography (PET) (Maier et al. 2015; Özsavaş et al. 2014).

In this article we describe the results for validation of the automated ultrasound system for synovitis grading in comparison to human assessment. The work described is a collaborative research project by a multicenter consortium in the project MEDUSA (Automated Assessment of Joint Synovitis Activity from Medical Ultrasound and Power Doppler Examinations Using Image Processing and Machine Learning Methods) (Wojciechowski et al. 2016).

METHODS

The assessment program is a result of collaborative work by specialists in rheumatology and different areas of computer science. The aim was to develop a prototype of a software that can recognize and grade the state of synovitis state in ultrasound images of joints. In the early stages of our work, we recognized that no such prototype is reported in the literature. Therefore, we decided to introduce essential simplification in our work.

We decided to limit the area of investigation to the dorsal projection of the metacarpophalangeal (MCP) and proximal interphalangeal (PIP) joints from the second to fifth fingers. We did not analyze Doppler images at this stage, although we do plan to conduct such analyses in the future. One of the objectives was to use machine

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learning techniques so it would be possible to use the algorithms in other joints. The PIP and MCP finger joints were chosen because of their clear ultrasound (US) anatomy and frequent involvement in chronic arthritis, such as rheumatoid arthritis and psoriatic arthritis. Development of the software prototype was divided into several stages: collection of the learning database of images, annotation of the images by medical experts, enhancement and segmentation of images, detection of anatomic hallmarks detection of synovial hypertrophy detection and staging.

To build the learning database we collected and annotated more than 2500 US images from 57 patients with a chronic arthritis and peripheral joint involvement. The B-mode images were taken in the medial joint line with a Logiq S8 GE machine, using a L8-18 i linear probe. The annotated images were used afterward in the development of algorithms and software. The algorithms used in this project are described thoroughly elsewhere (Wojciechowski et al. 2016). We describe them only briefly hereafter.

Several assumptions were made initially to avoid bias in detecting and staging synovitis. We decided that both segmentation methods for synovitis detection and anatomic hallmark detection would be applied. As anatomic hallmarks we used bones, articular space, skin and tendon. Based on knowledge of synovitis development, we rejected algorithm prototypes that detected areas of synovitis area separately from the joint space or recesses. The algorithms used in the final prototype can detect synovial hypertrophy (both hypo- and hyper-echogenic), but effusion is included in the "synovitis" area.

Several segmentation methods (Watershed, Connected Threshold, Confidence Connected, Neighborhood Connected, KLM Region Growing, Fast Marching Level Set and Geodesic Active Contour) were implemented to detect anatomic regions and synovial hypertrophy. Different trainable classifiers were tested in detection of ultrasound structures. Finally, two classifiers, the Speeded Up Robust Features (SURF) and Support Vector machines (SVMs), were used in the software (Bay et al. 2008; Shmilovici 2010). A new method for estimating the degree of synovitis using a trainable classifier was developed later. This method uses an SVM-based classifier with four classes, corresponding to the four degrees of synovitis (0, 1, 2, 3). The feature vectors are calculated from a synovitis area. The main features are the enclosed area of the convex hull, axes of enclosing ellipse and based on projection distance to the skin and bone and the x-coordinate of the joint space. The software has modular design organized in a pipeline, as illustrated in Figure 1. In the initial stages, hyper-echogenic bone line and skin line are detected. In the next stage, the joint space is recognized. The method was designed to detect disruption of the bone line adjusted for artifacts. Those ultrasound structures were used as hallmarks for synovitis area detection; it was assumed that synovitis cannot be found beyond skin and bone lines and should have connections to joint spaces. Detection methods were discussed above. We refer to previously published works for technical details (Wereszczyński et al. 2014, 2015). The algorithms have been implemented mainly in Python and C++ programing languages. The method contains a number of adjustable parameters that are used in an optimization approach that minimizes the number of errors at the machine training stage. The prototype is, however, designed to work fully automatically and no adjustments are available for the end-user.

The software works directly on DICOM (Digital Imaging and Communications in Medicine) format. It has

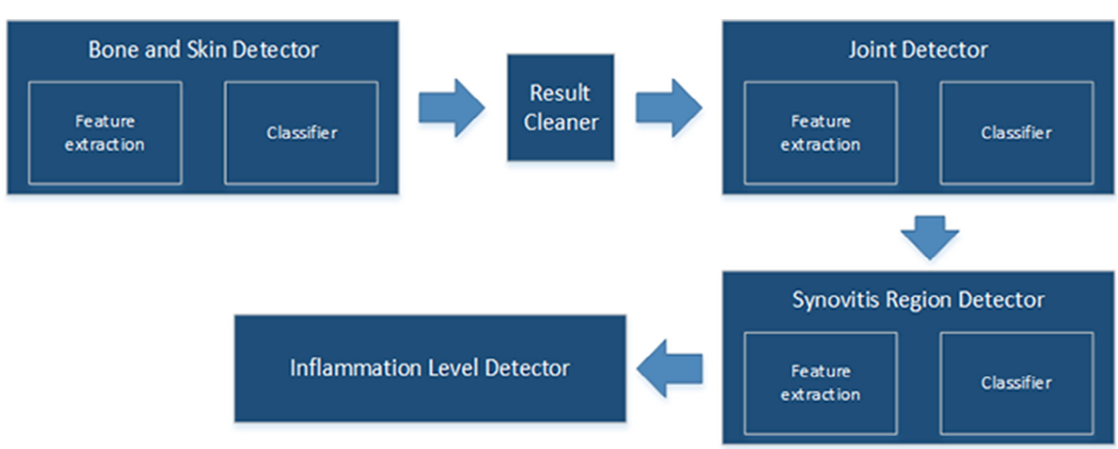

Fig. 1. Pipeline used in the prototype MEDUSA software (after Wojciechowski et al. 2016). Names of modules used in our software do not correspond exactly to regular anatomic and ultrasound terminology. As such, the "bone and skin detector" is a module that detects those structures, the "joint detector" detects the joint spaces area, the "synovitis region detector" performs segmentation of the synovitis area and the "inflammation level detector" assigns the degree of synovitis.