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Ultrasound palpation sensor for tissue thickness and elasticity measurement – Assessment of transverse carpal ligament

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Abstract

Palpation is a traditional diagnostic procedure for health care professionals to use their fingers to touch and feel the body soft tissues. It is a common clinical approach, though it is rather subjective and qualitative and the palpation results may vary among different people. Tissue ultrasound palpation sensor (TUPS) provides a feasible solution that makes the palpation of soft tissues not subjective feeling any more. It is comprised of an ultrasound transducer together with a load cell to form the finger-sized probe. The probe is used to push against the soft tissue surface to measure the thickness and elasticity of the soft tissues. TUPS has been successfully applied to the assessment of various human tissues. Recently, we have improved TUPS, which can now be linked to personal computer (PC) via universal serial bus (USB) and provide a better user-interface. The information of ultrasound signal and indentation force is displayed on PC in real time during measurement. In this paper, we introduce the recent application of TUPS for the assessment of the transverse carpal ligament. The tissues at the carpal tunnel regions of five normal male subjects were tested using TUPS. The results showed that the average thickness of the tissues covering the carpal tunnel ligament and the tunnel region was 7.98 ± 1.05 mm and 9.59 ± 1.12 mm, respectively. Under a compression force of 20 N applied by a cylindrical ultrasound indentor with a diameter of 9 mm, the stiffness of the soft tissue layer and the tunnel region was 6.72 ± 2.10 N/mm and 15.63 ± 8.42 N/mm, respectively. It is expected that TUPS can be a potential tool for non-invasive assessment of carpal tunnel syndrome.

Keywords: Palpation; Ultrasound; Ultrasound palpation; Tissue elasticity; Soft tissue; Carpal tunnel syndrome

1. Introduction

Carpal tunnel syndrome (CTS) is a common musculoskeletal disease caused by the compression to the median nerve in the carpal tunnel. As median nerve is a mixed motor and sensory peripheral nerve, compression of it may cause losing of sensation, clumsy and even powerless of the palm sides from the medial half of thumb to the lateral half of the ring finger [1]. There are several clinical tests for CTS to check the sensory and mobility of the hand including provocative tests, Phalen's test and Tinel percussion test [1]. However, the appearance of these clinical symptoms of CTS means that the patient may suffer from CTS severely. If we can develop a non-invasive approach to test the thickness and elasticity at the carpal tunnel region, it might be feasible to be a tool for diagnosing of CTS in the early states. So, health care professionals may apply non-surgical management such as anti-inflammatory drugs injection or hand support for neutral position to release the carpal tunnel pressure [1,2]. It is because surgical management, which cuts the transverse carpal ligament (TCL), can help to release the carpal tunnel pressure (CTP) but it may cause the weakness of finger flexion [3].

TCL forms the volar aspect of the carpal tunnel at the wrist. The increase of CTP may be due to fluid retention, infection and excessive use of the fingers, which may cause swelling of the tendons or their synovial sheaths [4]. In pervious studies, TCL was found to be thickened with the increase of the CTP and it is relevance to CTS [5,6]. In this

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study, the newly developed version of ultrasound palpation sensor (TUPS) was used to examine the thickness and the stiffness of the carpal tunnel in vivo.

TUPS has been used to determine different kinds of soft tissues including residual limb tissues [7], burn and surgical scars [8], fibrotic tissues induced by radiotherapy [9] and plantar foot tissues with diabetes [10]. The studies mentioned above considered the soft tissue and measured the tissue thickness and elasticity in whole. In this CTS study, an improved version of TUPS and its software were used in order to consider the soft tissues in the wrist region into two layers which are the soft tissues superior and interior to the TCL. Therefore, we are able to estimate the effects of the TCL to CTP.

2. Methods

TUPS is an ultrasound indentation with a finger size probe which consists of 5 MHz ultrasound transducer with a diameter of 9 mm and an in series load cell [11]. Fig. 1 shows the block diagram of the TUPS system. Ultrasound was emitted from the ultrasound transducer to measure the thickness and deformation of different layers in the wrist region during indentation using the information of the time-of-flight and the sound speed. The average sound speed in soft tissues of human body was assumed to be 1540 m/s [12]. The load cell was used to record the indentation force. In this study, 20 N force was applied to the subject's palm via the measuring probe within 3 s.

Fig. 2 shows the user interface of the custom-developed program for the TUPS system. It can show the ultrasound and force signals during indentation in real time. The ultrasound signal can also be shown in M-mode to present the overall displacement profile of the ultrasound echoes reflected or scattered from the tissues at different depths. As we introduced in earlier papers [9,11], signal peak or cross-correlation tracking approaches could be used to track the shift of a selected echo, which corresponded to a tissue interface, such as tunnel-bone interface. However, these methods could not be well used for the ultrasound signals collected in this study. Since the applied load was very large and tissues were deformed significantly, the tracking using signal peak or cross-correlation for a segment of signals did not work very well for the interfaces of TCL due to the obvious change of the interface echoes (de-correlation). In this study, we used the M-mode image to trace the shift of echoes quasi-automatically by selecting a number of critical points in the M-mode image for each interface echo under different loading levels. As an example, two groups of manually selected points were shown in the M-mode image of Fig. 2. The software then automatically links the points together to form a deformation profile under different loads using a linear interpolation. Normally, at least 10 points were manually selected for tracking of each interested interface echo. The obtained deformation-time data were then further analyzed together with load–time data to obtain the stiffness information.

Five normal male subjects were recruited in this study with an average age of 29.8 ± 5.1 years old. They have no neuro-musculoskeletal disorders in their upper limbs. The location for the indentation of the palm is on the skin overlying the TCL. A line was firstly drawn to connect the palpable pisform and scaphoid and a point 10 mm distal from the mid-point of this line was marked as the centre of indentation. During the testing, the hand was supinated on a testing table with the palm side facing upward. Ten trails were recorded for each subject.

3. Results

The ultrasound echoes reflected from the carpal bone surfaces were obviously identified (Figs. 2 and 3). The original thickness of the tissues between the skin and the TCL and between the TCL and bone surface were 7.98 ± 1.05 mm and 9.59 ± 1.12 mm, respectively, for the five subjects. We applied about 5 N to compress the soft tissue between the skin surface and TCL, it is because the stiffness of that layer was assumed to be softer. In the M-mode display of ultrasound signals as shown in Fig. 2, we can observe that the level of deformation is different between the layer of skin–TCL and TCL–Carpal bone. Fig. 3(a)–(c) show the ultrasound echo trains and different tissue interfaces obtained with the applied load of 0 N, 5 N and 20 N, respectively. In Table 1, the total deformations in skin–TCL layer and TCL–carpal bone layer are 3.18 ± 0.75 mm and 1.16 ± 0.42 mm, which are 38.1% and

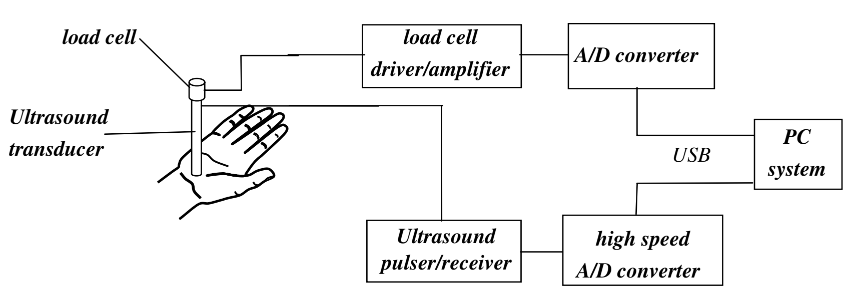

Fig. 1. Schematic of the TUPS system including the finger size probe together with other electronic parts as a control system of the load cell and ultrasound transducer. The control unit can be directly linked with personal computer via USB to have fast transmission of signals as real time measurement.