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A Hydrogel Glove for Emergency Ultrasound Screening

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***Abstract*—Ultrasound without ionizing radiation has been shown to have excellent sensitivity and specificity in the diagnosis of hand fractures, which is used to replace X-ray and CT in the emergency department. The water bath technology further solves the problem of suboptimal contact between the ultrasonic transducer and the skin, but the water flow caused by the movement of the probe produces severe ultrasonic artifacts. In addition, open wounds are not allowed to be placed in the water. In this study, we produce a hydrogel glove with excellent acoustic impedance matching and combine with a scanning device to achieve fast 3D ultrasonography for hands, enabling more rapid and stable programmed emergency ultrasound screening.**

Keywords—ultrasound, hydrogel glove, emergency department

I. Introduction

X-ray imaging is the standard imaging modality used in the hand trauma. Its advantages include its easy accessibility and wide availability. Despite these advantages, it has some intrinsic drawbacks such as unavailability outside a hospital setting, prolonging the emergency department (ED) stay, and ionizing radiation [1]. Ultrasound (US) is characterized by short procedure time, non-invasive and non-ionizing radiation, availability for use at nonhospital setting or bedside, portability, and repeatability [2].

In US screening, bone tissue interface is observed as a hyperechoic line with post-acoustic shadow due to its high reflective property, and the destruction of this line in linear fractures appears as angulation of pieces of fracture on the US. Based on these properties, US has been increasingly used to diagnose fractures in ED. On the other hand, ultrasound has obvious advantages in soft tissue and blood flow examination. Basically, Doppler ultrasound provides rich blood flow information, while ultrasound elastography further enriches imaging modes [3, 4]. The recent emergence of ultrasound super-resolution technology provides promising tools to observe the hand microvascular network [5]. Many studies have reported that ultrasonography can be successfully used to diagnose fractures involving humerus, sternum, femur, clavicle, scaphoid, forearm [6-9], and ribs as well as ligamentous, tendon, and soft tissue injuries [10, 11].

There are still some challenges in applying ultrasound for hand injuries, and particularly, the sonographic evaluation of the hands and feet requires a high-resolution ultrasound. In addition, the curved surface of the hand results in suboptimal contact between the transducer and the skin. Pressing the probe on an injured tissue will easily cause significant discomfort for the patients, and using an ample amount of coupling gel has not been satisfactory [12]. The water bath technique (WBT) or placing the limb in a water bath while performing an ultrasound examination overcomes these problems by increasing the resolution of images and eliminating the probe–skin contact [13]. However, the problem with the WBT is that the water flow caused by the movement of the probe produces severe ultrasound artifacts, and an open wound cannot be allowed to place in the water.

In this study, we produce a hydrogel glove with excellent acoustic impedance matching, which retains the benefits of WBT due to the solid properties of hydrogels. In addition, considering the 3D reconstruction imaging tends to provide more comprehensive diagnostic information, we combined hydrogel gloves with a scanning device to achieve fast ultrasonic 3D imaging of the hand.

II. Materials and Methods

A. Phantom preparation

A hydrogel glove phantom is fabricated by available material acrylamide (AAm). In brief, 360 mL of degassed water is mixed with 54 g acrylamide and 0.0246 g N, N'-methylenebisacrylamide (MBAA). To this solution, 2.08 g ammonium persulfate (APS) is added. Next, 150 µL of N, N, N, N -Tetramethylethylenediamine (TEMED, Sigma-Aldrich, St. Louis, MO, USA) is added. The entire solution is quickly poured into a hand mold and allowed to polymerize for 30 min.

B. *Ultrasound imaging*

The right hand of a healthy adult volunteer is placed in a hydrogel glove. Ultrasonograms were obtained using an L11-3u ultrasound imaging transducer of the Mindray Resona 7 System (Mindray, China) from the hydrogel glove phantom. The scan is performed horizontally from the fingertip to the wrist, and the ultrasonic signal is acquired by the transducer fixed to a scanning device. The scanning probe has a step of 2 mm/s for 80 seconds. Since the transducer width is smaller than the width of the palm, three consecutive scans were performed to obtain a complete palm ultrasonic image. The ultrasound focus-pulse with a mechanical index (MI) of 1.4 was applied to acquire B-mode images. The frame rate collected by the ultrasonic video is 30 frames per second.

C. *3D reconstruction*

The ultrasound images of the three scans were spliced using the Matlab 2017a (The MathWorks Inc., USA). 3D reconstruction of ultrasound images was performed using the ImageJ 1.52a (Rasband, 2018). ImageJ is a public domain image processing program based on Java and was designed with an open architecture that provides extensibility via Java plugins (available at http://rsb.info.nih.gov/ij/).

III. Results

A photo of the hydrogel glove is shown in Fig. 1 (a). Fig. 1 (b) and (c) show the side view and elevation view of ultrasound emergency screening using the hydrogel glove. The ultrasonic probe is clamped with a clamp fixed on the scanning device so that the probe can move horizontally with the device and collect ultrasonic video data.

Fig. 2 shows the excellent acoustic matching properties of the prepared uniform hydrogel gloves. Fig. 2 (a) and (b) show cross-sections of the phalanges at different positions of the four

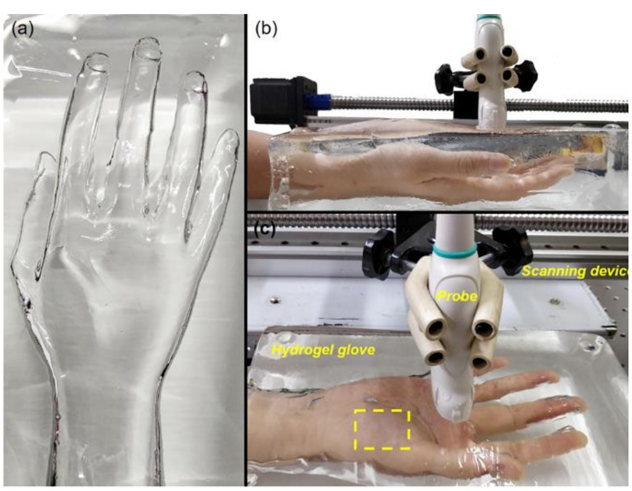

Fig. 1. A hydrogel glove and scanning device

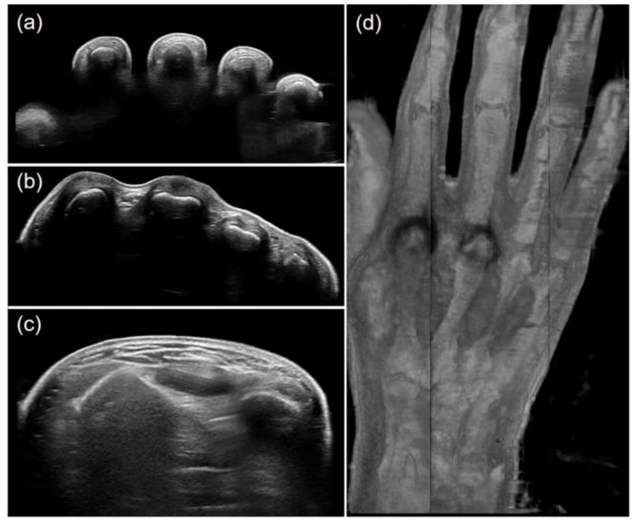

Fig. 2. 2D and 3D typical ultrasound images of the hand

fingers. Fig. 2 (c) shows the ulna and radius of the volunteer, while some muscle and blood vessel sections are clearly observed.

Fig. 2 (d) reconstructed the 3D ultrasonic image of the whole right hand of the volunteer through three data collection. With the exception of the thumb, the distribution and outline of the entire hand bone are clearly displayed. Since images are spliced, there are two obvious gaps in 3D reconstruction results.

In addition, Doppler imaging was performed on the greater thenar muscle at the position of the yellow square in Fig. 1 (c), and 60 2D blood flow images were continuously collected, among which typical images were shown in Fig. 3 (a) and (b). These 2D images were reconstructed and a 3D image containing the structure and texture of greater thenar muscle and the distribution of blood flow network was obtained.

IV. Discussion

Although direct radiography is the most commonly used imaging technique for diagnosing fractures, there are still some limitations, including radiation exposure and increased ED waiting times. On the other hand, ultrasound examination has

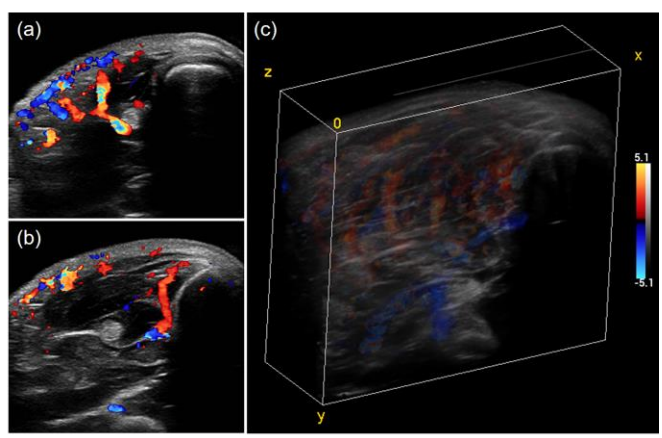

Fig. 3. 2D and 3D typical ultrasound Doppler images of the greater thenar muscle

significant advantages such as easy implementation, repeatability, and non-exposure to ionizing radiation [14]. Since the ultrasonography can be completed in a short time and can be used at the bedside [15], the patient's ED stay-time can be shortened. And bones can be scanned in real-time from different angles (volar, dorsal, oblique) and different planes (longitudinal and transverse), which is also beneficial to US diagnosis in guiding fracture reduction[7]. Moreover, ultrasonography can provide information about local hematomas near the fracture and tendon and vascular damage associated with the fracture [16, 17].

Actually, hydrogel is a material with excellent acoustic properties for ultrasound, and has been used to make ultrasonic coupling pads [18, 19]. The hydrogel is a flowing liquid before polymerization and becomes solid when it is polymerized, so it can be used in the design of various profiled models. For instance, one can try hydrogel socks for imaging Achilles tendon and ankle. At the same time, the properties of this solid hydrogel make it very friendly to those open wounds, avoiding ultrasound imaging of wound in water. In addition, hydrogels have adjustable ductility, tensile and compression resistant [20, 21], which ensures to adapt to palms of all sizes without being damaged or crushed by the probe. Finally, this hydrogel material is relatively inexpensive and can be used at one time. Avoid frequent disinfection of the ultrasound probe, ensure the patient's hygiene needs, and have the potential for antifungal [22].

However, it is undeniable that ultrasound has a lower resolution for bone contours and structures than X-rays, which also requires more experience from emergency doctors. And we try to make up for these shortcomings: 3D imaging can provide more abundant structural information, and patients with general hand injuries will only perform X-ray examination instead of CT. In addition, the fixed hydrogel glove model and scanning device as a complete hand emergency examination device can help doctors reduce the difficulty of ultrasound operation and provide a highly consistent ultrasound image. At the same time, combined with the soft tissue and blood flow information unique to ultrasound, it forms a complete and typical ultrasound image of a hand injury, which may reduce the difficulty of diagnosis for emergency doctors [23].

At present, there is a little interference between the volunteer's hand and the hydrogel glove, which will interfere with the ultrasound imaging. This problem may later be solved by reducing the size of the hydrogel glove. There are some gaps in the stitching of the ultrasound image, and a wider probe may be a good solution.

In this study, we produce a hydrogel glove with excellent acoustic impedance matching and combine with a scanning device to achieve fast 3D ultrasonography for hands, enabling more rapid and stable programmed emergency ultrasound screening.

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