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Wearable Ultrasonic Transducer for Monitoring Skeletal Muscle Contraction

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1. Introduction

Ultrasonic imaging equipment is capable of providing real-time dynamic images of internal tissue motion associated with physical and physiological activities. Monitoring skeletal muscle activities is useful not only for diagnosing neuromuscular disorders but also for understanding musculoskeletal dynamics and for evaluating the effectiveness of physical training and rehabilitation. Ultrasonic methods have been applied for diagnosis of neuromuscular disorders [1,2] and injury [3], assessment of muscle fatigue [4] and monitoring of muscle motion [5,6].

One of the challenges for monitoring muscle activities is the motion artifacts caused by random movements of an employed ultrasonic probe [7]. In addition, the probe pressed against a body surface may limit underlying muscle activities. Therefore, the objective of this study is to develop and test a lightweight, wearable ultrasonic transducer that does not affect muscle and other tissue movements for accurate monitoring.

2. Transducer Development

2.1 Design and Construction

Fig. 1 depicts the structure of the developed wearable ultrasonic transducer. Polyvinylidene fluoride (PVDF) polymer was chosen as the piezoelectric material because of its lightweight, flexibility and good acoustic impedance matching to biological soft tissues. A 110-μm thick PVDF sheet having top and bottom silver-ink electrodes was cut into the desired size of the ultrasonic transducer. Electrical wires were attached to the electrodes, and then the top and bottom sides of the entire structure were covered by a 38-μm polyimide film with a silicone adhesive for protection and electrical insulation purposes. Note that no matching layer or backing material was constructed.

Fig. 2 presents photographs of the developed wearable ultrasonic transducer. The total weight and thickness of the transducer were less than 1 g and 200 μm, respectively. The transducer is flexible as shown in Fig. 2 (b).

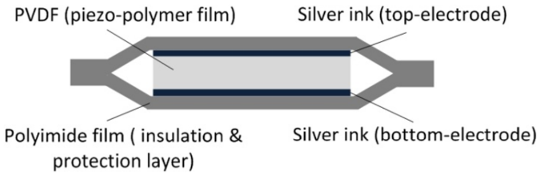

Fig. 1: Diagram of a wearable ultrasonic transducer.

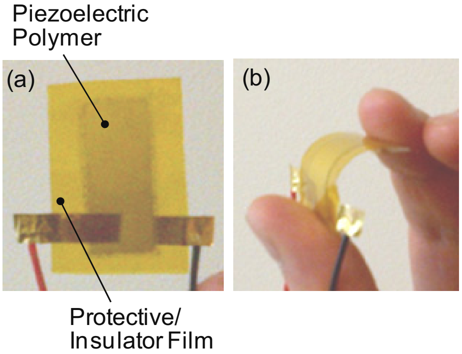

Fig. 2: Photographs of an ultrasonic transducer developed: top view (a) and side view with bending (b).

2.2 Evaluation

Ultrasonic performance of the developed transducer was investigated using a 12.5-mm thick Plexiglas plate sample. The transducer was attached on the top surface of the sample with ultrasonic gel couplant. Then, ultrasonic signals reflected from the bottom surface of the sample was obtained using an ultrasonic pulsar/receiver (Model: DPR300, JSR Ultrasonics, Pittsford, NY) with an ultrasonic pulse-echo technique. The signals were acquired by a PCI digitizer (Model: ATS420, AlazarTech, Montreal, QC, Canada) with a sampling rate of 125 MS/s and a 14-bit resolution. The measured signal and its frequency spectrum are shown in Figs. 3 (a) and (b), respectively. The peak frequency was 1.7 MHz and the 6-dB bandwidth was 1.6 MHz (94%). Therefore, the transducer has a bandwidth broad enough for pulse-echo measurements.

In addition, the transducer was attached on the posterior side of a lower leg, in order to investigate an ultrasonic penetration depth in a human body. The signal reflected from the tibia bone was clearly observed at the depth of 25 mm.

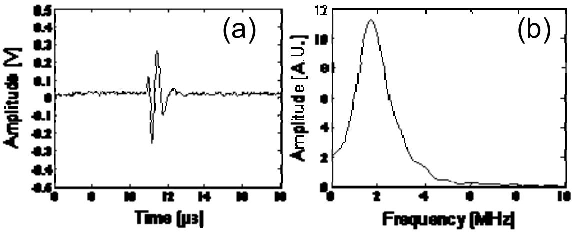

Fig. 3: Ultrasonic signal reflected from the bottom surface of a Plexiglas plate (a) and its frequency spectrum (b).

3. Monitoring Muscle Contraction

A preliminary experiment for monitoring tissue thickness variation during isotonic muscle contraction was conducted using the developed ultrasonic transducer. The transducer was attached on the superior side of a left forearm, approximately 3-cm away from the wrist with gel couplant and fixed using an adhesive tape. The ultrasonic signals reflected from the muscle/bone (radius) interface were acquired in M-mode for 10 seconds while the muscle beneath the transducer contracted voluntarily by bending the wrist backward every 2 seconds.

The tissue thickness between the transducer (body surface) and the bone was calculated from the time-of-flight of the acquired signals and the speed of ultrasound in muscle. As presented in Fig. 4, the tissue thickness varied up to approximately 0.4 mm (5%) in accordance with the isotonic muscle contraction performed. The tissue thickness was around 7.7 mm at the relaxed state (where the wrist was not bending) while it increased to around 8.1 mm at the contracted state.

4. Summary

A wearable ultrasonic transducer was developed for continuous monitoring of muscle contraction. The transducer was constructed using a PVDF polymer film without a matching layer or backing material. The developed transducer has desired ultrasonic performance for pulse-echo measurements. The tissue thickness variation at a wrist in accordance with the performed isotonic muscle contraction was successfully monitored using the developed transducer. The flexibility, small size and lightweight of the transducer allow attachment to the body area of interest without restricting the underlying tissue movements.

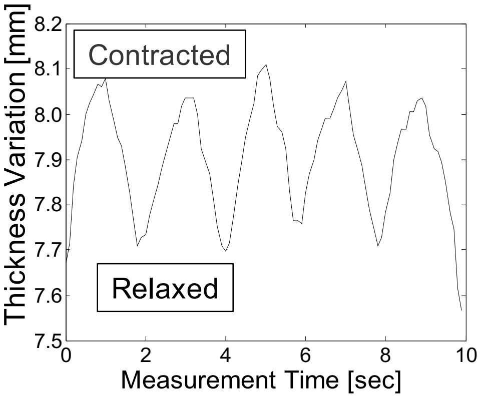

Fig. 4: Tissue thickness variation measured using the transducer developed. The transducer was attached on a forearm near the wrist that was bending backward every 2 seconds.

Acknowledgments

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References

1. S. Pillen, I.M.P. Arts and M.J. Zwarts: Muscle & Nerve **37** (2008) 679.
2. C.D. Lee, Y. Song, A.C. Peltier, A.A. Jarquin-Valdivia and P.D. Donofrio: Muscle & nerve **42** (2010) 814.
3. J.B. Woodhouse and E.G. McNally: Seminars in Ultrasound, CT, and MR, **32** (2011) 91.
4. J. Shi, Y.P. Zheng, X. Chen and Q.H. Huang: Medical Engineering & Physics **29** (2007) 472.
5. T. Deffieux, J.-L. Gennisson, M. Tanter and M. Fink: Appl. Phys. Lett., **89** (2006) 184107.
6. J.-W.H. Korstanjea, R.W. Sellesa, H.J. Stama, S.E.R. Hovius and J.G. Bosch: J. Biomechanics **43** (2010) 1373.
7. J. Silver, Y. Ono and A. Adler: Proc. IEEE Ultrason. Symp. (2009) 2441.