Shear Vertical Wave Detection for characterization of skeletal muscles using Shear Wave Elastography: A Comparison of Single and Dual Probe Setups

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Summary

Towards improved muscle characterization using Shear wave elastography, this study compares ex-vivo detection of shear vertical wave mode in a single- and dual-probe setup. Both setups detected the wave mode with similar velocity values.

Introduction

Shear wave elastography (SWE) measures isotropic tissue elasticity, but is limited in the assessment of skeletal muscles because muscles exhibit transversely isotropic (TI) behavior, generating both shear horizontal (SH) and shear vertical (SV) wave modes [1]. The SH mode assesses the longitudinal and transverse shear moduli while the SV mode is needed to evaluate tensile anisotropy, enabling full tissue characterization [1]. Detecting the SV mode clinically is challenging as its particle displacement occurs perpendicular to the ultrasound's axial direction when push and fiber directions are perpendicular. SV mode detection can be enabled using a dual-probe setup, with one probe generating the push and another at 90° detecting the SV mode. However, the dual-probe setup would be geometrically challenging in clinical contexts. Alternatively, a single-probe setup can detect the SV mode using a rocking angle between fiber and push directions [2]. To enhance SV mode detection for clinical applications, this study aimed at comparing SV mode detection using SWE in a single- and dual-probe setup in ex-vivo muscle tissue.

Methods

Two setups were designed for SWE on bovine semitendinosus muscle using Verasonics V1 (L7-4): a single-probe setup (Fig. 1a) and a dual-probe setup (Fig. 1b). The single-probe setup featured a custom holder, initially aligning the probe along the fibers with a 20° rocking angle (B-mode in Fig. 1c). SWE was performed at 10° rotation intervals for full 360° coverage. For each position, a push (20 mm focus depth, 4 MHz, 235 µs, 70 V, F#1.2) was followed by plane wave imaging (5 MHz, PRF 10 kHz). Axial velocities were computed via 2D auto-correlation, and SH (slower) and SV (faster) group velocities were estimated using a Radon sum algorithm, Fig. 1d. The dual-probe setup used two perpendicularly mounted transducers, both aligned with the muscle fibers and at a 0° rocking angle. The vertical transducer generated the push (20 mm focus depth, 5 MHz, 200 µs, 90 V, F#2), while the horizontal transducer acquired plane wave images (6.4 MHz, PRF 12.5 kHz). Axial velocities were computed using 1D auto-correlation, and the SV mode velocity (the only mode detected) was estimated by manually tracking the wave front in axial velocity maps (Fig. 1e) and averaging six time-frame differences from 1.36 ms to 3.04 ms at -40° from the horizontal axis aligned with the muscle fibers.

Results and Discussion

The SV mode was detected in both setups (Fig.1d-e). In the dual-probe setup, at -40° from the horizontal axis of the axial velocity map, SV mode velocity was 6.07 m/s, while in the single-probe setup at equivalent rotational angle, the SV and SH mode velocity, were 7.46 m/s and 4.92 m/s, respectively. The SV mode velocities are comparable, confirming SV mode detection feasibility with the single-probe setup for clinical use and with the dual-probe setup for SV mode quantification for all rotational angles in one acquisition. Further studies will to compare wave speeds at all rotational angles, as well as shear and tensile moduli between the methods.

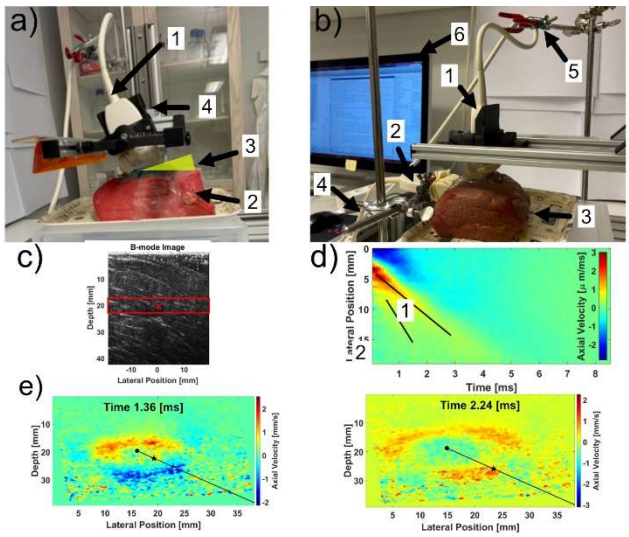

Fig. 1: **a)** Single-probe setup (1) rocked by 20° (2) relative the tissue's (3) fiber direction with a probe holder (4). b) Dual-probe setup with two perpendicular probes (1: pushing probe, 2: imaging probe) parallel to the tissue's (3) fiber direction, supported by statics (4, 5), connected to V1 (6). c) B-mode image (push and ROI position in red). d) SH (1) and SV (2) modes in axial velocity map (group velocity=black line) from the single-probe setup. e) Axial velocity maps (time 1.36 ms and 2.24 ms from push) in the dual-probe setup (push position: black dot, wave front: black star at -40° on black line)

Conclusions

SV mode detection was achieved in both setups. Further research is needed to compare shear wave speeds and moduli to determine result consistency between methods.

References

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