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# RELATIONSHIP BETWEEN SUPERSONIC SHEAR WAVE ELASTOGRAPHY MEASUREMENT AND PASSIVE MUSCLE FORCE: AN EX-VIVO CHICKEN STUDY

**Terry K. Koo[1], Jingyi Guo[1], Jeffrey H. Cohen[2], Kevin J. Parker[3]**

[1] Department of Research
New York Chiropractic College
Seneca Falls, NY 13148
United States

[2] Nimmo® Educational Foundation
Pittsburgh, PA, 15213
United States

[3] Dept. of Electrical & Computer Engineering
University of Rochester
Rochester, NY, 14627
United States

## INTRODUCTION

As a skeletal muscle is being stretched, it reacts with increasing passive resistance. This passive force component is important for normal muscle function [1]. Unfortunately, direct measurement of muscle force is still beyond the current state-of-the-art. In the present study, we investigate the feasibility of using Supersonic shear wave elastography (SWE) to indirectly measure passive muscle force using an ex-vivo chicken model.

## METHODS

Sixteen gastronomies pars externus (GE) and 16 tibialis anterior (TA) muscles were dissected out from 10 fresh roaster chicken (PERDUE). For each muscle specimen, the proximal bone-tendon junction was kept intact with its tibia or femur (depending on the muscle being tested) clamped in a fixture. Calibration weights were applied to the distal tendon via a pulley system (Figure 1).

An Aixplorer ultrasound scanner (Supersonic Imagine, Aix en Provence, France), coupled with a 50mm, 14-5 MHz linear ultrasound transducer was set to SWE mode, which uses acoustic radiation force to perturb underlying tissues and at the same time, measures the propagation velocity ($V$) of the shear waves induced by the radiation force. Assuming muscle is a linear elastic transverse isotropic material, Young's modulus ($E$) is related to propagation velocity as follows [2]:

$E = 3\rho V^2$, where ρ is the muscle density (1000 kg/m$^3$).

A multi-articulated arm (Manfrotto, Italy) was used to rigidly hold the transducer so that the same measurement site could be imaged at the same orientation throughout the experiment. The transducer was placed on the muscle belly of each dissected muscle along its longitudinal axis (Figure 1). The passive load was increased from 0 to 395g in 25g per increment. The loading cycle (i.e. from 0 g to 395g) was repeated three times with the 1st cycle regarded as pre-conditioning. Elasticity-load relationship of each tested muscle for each loading cycle was analyzed by fitting a least square regression line to the data. Slope and y-intercept of each regression line were computed. Test-retest reliability of the SWE elasticity was evaluated based on the data of the 2nd and 3rd cycles using a single-rating, absolute agreement, 2-way mixed model (i.e. intraclass correlation coefficient [ICC]$_{3,1}$).

In addition, the accuracy of SWE to measure quantitative values of elasticity was evaluated using an elasticity QA phantom (Model 049, CIRS, Norfolk, VA). The phantom consists of 4 spherical inclusions with different elasticity values embedded within the background material. Five elasticity measurements were made for each spherical inclusion as well as the background material and their ensemble means were calculated and compared with those specified by manufacturer.

## RESULTS

ICCs of SWE elasticity were 0.996 and 0.985 respectively for the slope and y-intercept parameters, indicating excellent reliability. More importantly, our data demonstrated that the relationship between SWE elasticity and passive muscle force is highly linear for all the tested muscles (coefficient of determination ($R^2$) values ranged from 0.9708 to 0.9988 among all tested muscles) (Figure 2).

Results of QA Phantom experiment are shown in Table 1, indicating excellent accuracy of the SWE measurements.

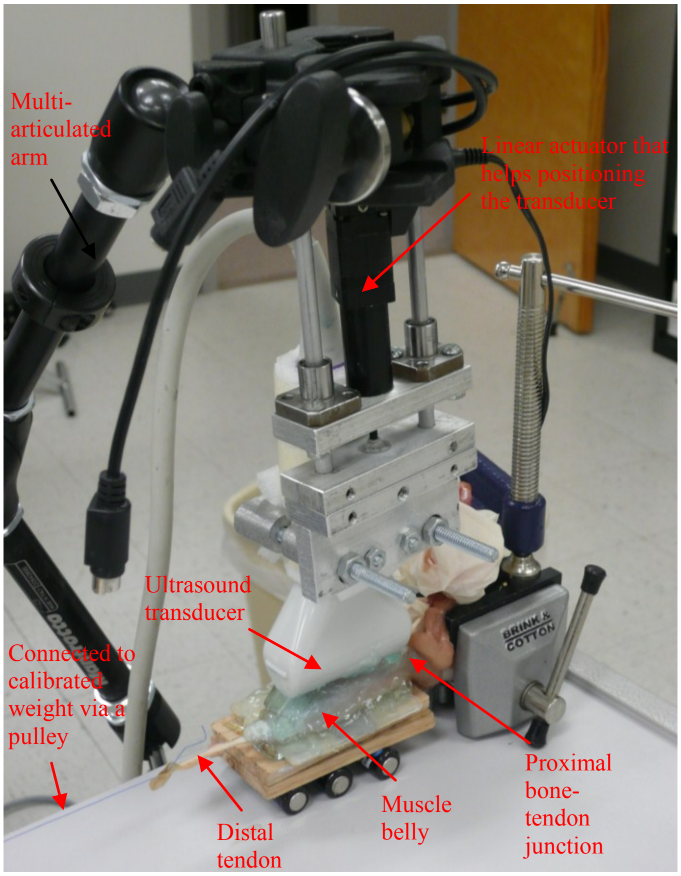

**Figure 1: The experimental setup**

**TABLE I.** ACCURACY OF THE SWE ELASTICITY MEASUREMENT

| | Type 1 | Type 2 | Type 3 | Type 4 | Background |
|---|---|---|---|---|---|
| **Reference Elasticity (kPa)** | 8±3 | 14±4 | 45±8 | 80±12 | 25±6 |
| **Elasticity measured by SWE (kPa)** | 9.20± 0.18 | 13.56± 0.08 | 43.97± 0.58 | 77.31± 3.31 | 25.93± 0.07 |

## DISCUSSIONS

Maisetti [3] conducted a human subject experiment on gastrocnemius muscle that provided the first evidence to support SWE elasticity may provide an indirect estimation of passive muscle force. They found a high correlation ($0.964 < R^2 < 0.992$) between the elasticity-muscle length curve based on direct SWE measurement and the passive force-muscle length curve predicted by a musculoskeletal model developed by Hoang [4]. Since Hoang's model involves many assumptions that may affect the prediction of the passive force-muscle length relationship and the model prediction cannot be validated directly, their finding is far from conclusive. The current ex-vivo chicken study supports their finding. To our knowledge, this is the first study that directly correlates passive muscle force with Young's modulus measured by SWE. Future studies should direct towards the potential applications of SWE in muscle diagnosis and treatment evaluation.

## CONCLUSIONS

SWE is a highly accurate and reliable technique for muscle elasticity measurements. The linear relationship between SWE elasticity and passive force identified in this study demonstrated that the elasticity may be used as an indirect measure of passive muscle force.

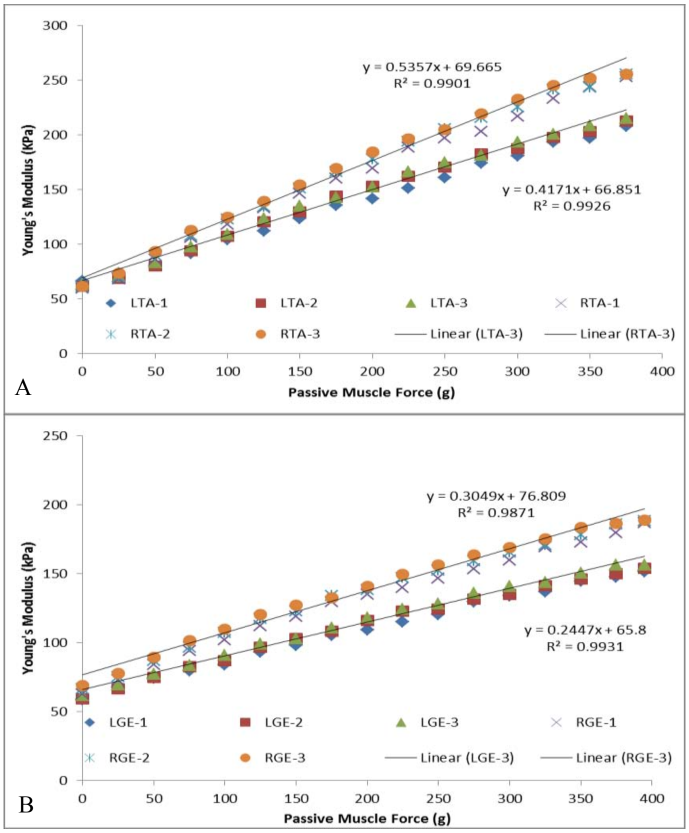

**Figure 2: Typical example of elasticity-passive muscle force plots of (A) tibialis anterior and (B) gastronomies pars externus muscles.** All data is from chicken 5. Salient findings include:: (1) data is very repeatable among cycles; (2) a highly linear relationship was noted between elasticity and passive muscle force. LTA-n: left tibialis anterior, cycle 1; RTA-n: right tibialis anterior, cycle n; LGE-n: left gastronomies pars externus, cycle n; RGE-n: right gastronomies pars externus, cycle n; Linear(LTA-3): linear regression line for LTA-3; Linear (RTA-3): linear regression line for RTA-3; Linear(LGE-3): linear regression line for LGE-3; Linear(RGE-3): linear regression line for RGE-3; and $R^2$: coefficient of determination.

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