Stiffness and echogenicity: Development of a stiffness-echogenicity matrix for clinical problem solving

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Abstract

The assessment of soft tissue stiffness is important to evaluate many neuromusculoskeletal conditions. Several tools have been proposed for the assessment of stiffness, but ultrasonography appears to be most practical. The reflection of ultrasound waves as it travels through tissue enables assessment of tissue echogenicity, which is influenced by the characteristics of the sound wave as well as the characteristics of the tissue through which it passes, such as the amount of fat and fibrous tissue. However, tissue stiffness is not directly proportional to its echogenicity. Hence evaluation of echogenicity, as a stand-alone technique, is inadequate to describe its mechanical properties. The aim of this manuscript is to present a method of combining echogenicity evaluation by ultrasound and stiffness evaluation by palpation to better describe the mechanical properties of muscle using a stiffness-echogenicity matrix.

Key Words: stiffness, echogenicity, ultrasound, elastography.
muscle echogenicity when compared with young populations. Older men show an inverse association between muscle echogenicity and strength. Similarly, an inverse association is noted between muscle echogenicity and stiffness on palpation, where high echogenicity did not correspond with high stiffness, but instead was associated with soft, flaccid sarcopenic muscle in the elderly. It has been suggested that structural and biochemical changes in muscle ECM may contribute to age-related loss of muscle function. A recent experimental study in animals observed increased accumulation of interstitial connective tissue and thickened basal lamina in the skeletal muscle of older animals compared with the muscles in young animals. In addition, during contraction, muscle stiffness increases in the young but does not change in the elderly, perhaps due to substitution of muscle fibers with non-contractile fibrous tissue. Consequently, surrogate measures of muscle stiffness are needed along with echogenicity to understand muscle dysfunction.

**Elastography in clinical practice**

Elastography involves the measurement of local tissue deformation in response to applied mechanical stress. The way in which the tissue deforms provides information about the tissue’s mechanical properties. Elastographic techniques can be categorized based on how the stress is applied and how the deformation is measured. For example, stress application can be by direct compression using the ultrasound probe, or via ultrasonic radiation force, while deformation can be evaluated via ultrasound imaging. In quasi-static ultrasound elastography, the deformation is induced by manually pressing on the anatomy with the transducer and assessing its deformation or strain using B-mode ultrasound. This is also known as strain elastography (SE), which is a qualitative technique to relate stiffness of a specific area or lesion to that of the background tissue (strain ratio). In contrast, quantitative elastography is based on shear wave speed, and is known as shear wave elastography (SWE). However, both SE and SWE are highly user dependent, are affected by technique such as tissue pre-compression, and have a steep learning curve. The accuracy of SE can differ for superficial and deep tissues due to variable displacement of tissues at different depths. The accuracy of SWE can be reduced if the B-mode image shows extremely low signal (anechoic), leading to unsuccessful shear wave detection. SWE is also limited in deeper tissues due to the attenuation of the acoustic radiation force impulse (ARFI pulse). It has been suggested that shear elastic modulus measurements show large temporal variability and poor inter-session reliability because the shear wave has to pass through highly heterogeneous tissue.

**A practical solution: the stiffness-echogenicity matrix**

We propose that combining echogenicity evaluation by ultrasonography along with evaluation of stiffness by manual palpation can better describe the mechanical properties of muscle in a clinical setting. We present a stiffness rating scale to assess muscle stiffness by palpation to be used in combination with echogenicity assessment using Heckmatt’s rating scale.

**Heckmatt’s rating scale**

Muscle echogenicity can be graded by ultrasound using Heckmatt’s rating scale, where:

- **Grade 1**: Normal.
- **Grade 2**: Increase in muscle echo while bone echo is still distinct.
- **Grade 3**: It is possible to compress 75% of the relaxed muscle tissue.
- **Grade 4**: It is possible to compress only 50% of the relaxed muscle tissue due to mild resistance.
- **Grade 5**: It is possible to compress only 25% of the relaxed muscle tissue due to moderate resistance.
- **Grade 6**: It is impossible to compress the relaxed muscle due to high resistance (bone-like).

**Fig 1.** The stiffness rating scale assesses the compressibility of the underlying muscle by palpation to estimate the resistance of the tissue to displacement.
Grade 3: Marked increase in muscle echo and reduced bone echo.
Grade 4: Very strong muscle echo and complete loss of bone echo.

**Stiffness rating scale**
The stiffness rating scale assesses the compressibility of the underlying muscle by palpation to estimate the resistance of the tissue to displacement (Figure 1). Tissue resistance may be graded as follows:
- Grade A: The muscle feels soft to the palpating thumb or index finger. It is possible to compress 75% of the relaxed muscle tissue.
- Grade B: It is possible to compress only 50% of the relaxed muscle tissue due to mild resistance.
- Grade C: It is possible to compress only 25% of the relaxed muscle tissue due to moderate resistance.
- Grade D: It is impossible to compress the relaxed muscle tissue due to high resistance (bone-like).

Figure 2 presents a stiffness-echogenicity matrix (SEM) which combines stiffness rating on the y-axis with echogenicity rating on the x-axis. Each quadrant of the matrix can represent a wide spectrum of conditions seen in clinical practice. Figure 3 represents individual cells in the matrix. The combined stiffness and echogenicity grades range from 1A (acutely denervated but otherwise normal muscle on ultrasonography) to 4D (non-compressible stiff muscle with fibrosis).

**Clinical utility of the stiffness-echogenicity matrix**
Common clinical conditions can show variable stiffness and echogenicity and require a practical method for evaluation in ambulatory clinical settings. The purpose of the SEM is to better characterize muscle in clinical practice. Examples of clinical conditions that correspond to the various cells of the SEM are described below.

The upper left quadrant of the SEM represents cells that show mild variations in echogenicity, but when combined with the rating of muscle stiffness may permit differentiation of clinically important conditions. Healthy muscle appears dark with sharp bright lines, which represents the connective tissue rich perimysium responsible for mechanical properties of the muscle. On palpation, healthy muscle encounters minimal resistance due to normal muscle tone and presents as grade 2B on the SEM. In acute denervation, characteristic echoes of fascial planes appear less intense, making the muscle slightly hypoechoic. On palpation, the examiner
may encounter little resistance and may easily palpate the surface of the bone through the muscle, presenting as grade 1A on the SEM. In contrast, a hypertrophic muscle has thicker muscle fibers relative to connective tissue, hence it is likely to be slightly hypoechogenic compared to normal particularly in young healthy males, and present as grade 1B on the SEM. However, mildly atrophic muscle, for example due to disuse, and may have smaller muscle size but may not be stiff, presenting as grade 2A on the SEM.

The lower left quadrant of the stiffness-echogenicity matrix represents cells that show mild variations due to stiffness which is greater than that seen with normal muscle tone. Myofascial pain syndrome is characterized by the presence of trigger points. Travell defined a trigger point as a hyperirritable spot in skeletal muscle that is associated with a hypersensitive palpable nodule in a taut band. The evolution of a trigger point starts with a taut band, i.e. a stiff area of muscle; which shows greater than normal muscle tone. Such areas may be “densified” perhaps due to increased ECM viscosity from aggregation of high molecular weight semi-flexible chains of hyaluronan (macromolecular crowding). These areas may be hypoechogenic on ultrasonography, presenting as grade 1C on the SEM. As a trigger point evolves, discrete regions in the taut band become stiffer but remain hypoechogenic on ultrasonography, presenting as grade 1D on the SEM. A chronically stiff muscle can stimulate the deposition of connective tissue due to lack of movement, making the muscle slightly more echogenic, and presenting as grade 2C on the SEM. If a patient has a central neurogenic condition characterized by increased muscle tone, such as stroke or multiple sclerosis, the echogenicity may be preserved in the early stages, but the muscle can demonstrate increased stiffness, presenting as grade 2D on the SEM.

The upper right quadrant of the SEM represents changes in muscle that may be associated with weakness from various causes. Sarcopenia is the degenerative loss of skeletal muscle mass (0.5-1% loss per year after the age of 50), quality, and strength associated with aging. Sarcopenic muscles have more connective tissue compared to muscles in non-sarcopenic individuals, and may present as grade 3A on the SEM. Muscle ultrasound in elderly athletes and untrained men has shown that echo intensity is higher in untrained men, corresponding to age-related replacement of contractile tissue by other tissues, such as fat. In contrast, in severe...

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**STIFFNESS-ECHOGENICITY MATRIX**

| STIFFNESS RATING | ECHOCENICITY RATING |
|------------------|---------------------|
| A                | 1A Acute denervation | 2A Atrophic muscle |
|                  | 3A Sarcopenia       | 4A Severe Sarcopenia |
| B                | 1B Hypertrophic muscle | 2B Normal |
|                  | 3B Early peripheral neurogenic | 4B Early myogenic |
| C                | 1C Densification    | 2C Chronic densification |
|                  | 3C Late peripheral neurogenic | 4C Late myogenic |
| D                | 1D Trigger Points   | 2D Early central neurogenic |
|                  | 3D Central neurogenic | 4D Late central neurogenic |

*Fig 3. The cells in the SEM represent clinical conditions that show various degrees of muscle stiffness and echogenicity. The color of each cell in the matrix reflects the echogenicity grey-scale.*
sarcopenia and cachexia, the muscle echo intensity will be even higher, presenting as grade 4A on the SEM. Neurogenic and myogenic conditions can also produce muscle weakness. Peripheral neurogenic conditions may show normal or moderate increase in echogenicity, presenting as grade 3B on the SEM. On the other hand, myogenic conditions, such as muscular dystrophies and myositis, tend to show increased echogenicity compared to neurogenic conditions due to replacement of muscle tissue by fibrofatty tissue (muscle lipomatosis, but not muscle fibrosis). Late peripheral neurogenic conditions may present as grade 3C on the SEM, whereas late myogenic conditions tend to show higher echogenicity, and may present as grade 4C. However, in central neurogenic disorders such stroke and multiple sclerosis, the degree of stiffness tends to be greater, while the echogenicity may be normal or slightly increased, presenting as grade 3D on the SEM. Gao et al. described a significant difference in muscle strain ratios in the affected muscles of patients with multiple sclerosis with Modified Ashworth Scale (MAS) score of 1 or higher. In patients with late central neurogenic conditions, such as those with severe spasticity, the combination of hyper-echogenicity and stiffness is well recognized, and may present as grade 4D. The hyper-echogenicity can result from gradual collagen deposition, which can result in contractures. The SEM can aid in distinguishing between viscous stiffness, which may be reversible for SEM grades 2D and 3D, and irreversible for grade 4D.

In conclusion, similar to elastography, the SEM may be limited in the evaluation of deeper muscles. Furthermore, both the assessment of echogenicity and stiffness are qualitative because it is not possible to compare echogenicity values obtained using different devices or expect that examiners will use the same amount of pressure duration palpation. Nevertheless, the stiffness-echogenicity matrix developed using palpation and simple B mode ultrasonography may provide a practical and inexpensive approach to screen muscles, assess disease progression and define an appropriate treatment plan. The next step would be to validate the clinical utility of the matrix in a diverse sample of patients.

**List of acronyms**

ECM - Extracellular matrix  
MAS - Modified Ashworth Scale  
MS - Multiple Sclerosis  
SE - Strain elastography  
SEM - stiffness-echogenicity matrix  
SWE - Shear wave elastography

**Authors contributions**

Each author has participated sufficiently, intellectually or practically, in the work to take public responsibility for the content of the article, including the conception and design. All authors have read and approved the final manuscript.

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**Conflict of Interest**

None of the authors have conflict of interest related to employment, consultancies, stock ownership, honoraria, paid expert testimony, patent applications/registrations, grants or other funding. Drs. Raghavan and Stecco report a patent on the use of hyaluronidase for muscle stiffness licensed to Movease, Inc. broadly relevant to the present work.

**Ethical Publication Statement**

We confirm that we have read the Journal’s position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

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