How to mimic the stiffness of the thoracolumbar layers using a phantom?

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Keywords

Thoracolumbar layers, phantom, stiffness assessment tools; reliability

Introduction

Lumbopelvic pain is one of the most prevalent musculoskeletal disorders. Tissue stiffness measurement techniques can help in evaluation [1]. The study aimed to compare the precision of these stiffness assessment tools (SAT), and to evaluate reliability and validity of different SAT on a multi-layered phantom tissue model (MPTM).

Methods

A phantom made of four individual layers has been developed to reproduce the four layers of the thoracolumbar tissue which are the cutis, subcutaneous connective tissue, fascia profunda (FPR), and erector spinae. These layers were manufactured with polyurethane-based gel (Technogel®). The gel is homogeneous and shows memory foam behaviour, demonstrating viscoelastic properties. To mimic the real morphological and mechanical properties of the tissue, phantoms (N=10) with varying stiffness parameters (specified in Shore OOO) were produced for each tissue layer. Durometer, Tissue Compliance Meter, IndentoPro [2], myotonometry (Myoton Pro®) [3], ultrasound imaging [4] and elastography techniques [5] were used to evaluate the stiffness of each layer. The artificial relative stiffness changes in the MPTM were measured blindly by two different examiners, and the concurrent validity of the stiffness assessment tool (SAT) was established using the correlation coefficients and linear regression analysis. Between the two examiners, the inter-rater reliability of the SAT was determined.

Results

A thickness of 3mm, 6mm, 1mm and 10mm was chosen for the cutis, the subcutaneous connective tissue, the fascia profunda and the muscle, respectively (Fig.1A). Gel pads with several stiffness values were manufactured in the range from 38 to 118kPa to take potential alterations of the tissue into account. Among the different tools ultrasound elastography shows no propagation of the wave due to the homogeneity of the gel while MR elastography was able to measure surface waves (Fig.1B). A total of 1840 measurements were conducted. Significant correlations were found for stiffness changes in all layers of the MPTM except for the fascia profunda layer, ranging from 0.70 to 0.98 (all $p < 0.01$) (Fig.1C). The inter-rater reliability ranged from good to excellent ($ICC_{(2,2)} = 0.75$~0.98).

Discussion

Indentometry and myotonometry detected stiffness changes in three MPTM layers, whereas ultrasound measured only layers thicker than 3mm. No stiffness assessment tools can detect stiffness changes in the thin (<= 1mm) layer simulating the FPR. The multi-layered phantom could possibly be improved by adding diffusers inside the gel. This tissue-mimicking phantom for the thoracolumbar layers is a first step allowing the comparison of the performances of stiffness measurement apparatus in the context of evaluation of low back pain. Application of the MPTM for assessing (and training) the human hand as a SAT, then in comparison with the best tools found in this examination, appear as a promising next step.

References

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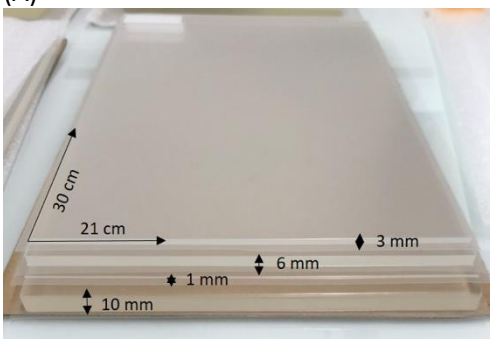
Content Image Chart/ Graph upload

(A)



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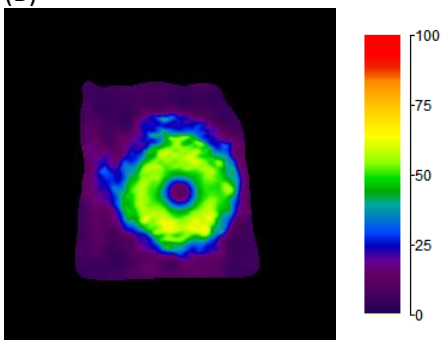

(C)

Property / Measurement	Detecting changes in layers				Inter rater reliability
	CUT	SCT	FPR	ERS	
Durometer	✓✓✓	✓✓			✓✓
Tissue compliance meter	✓	✓✓✓		✓✓✓	✓✓
IndentoPro	✓✓✓	✓✓✓		✓✓✓	✓✓✓
Myoton Pro®	✓✓✓	✓✓✓		✓✓✓	✓✓✓
Ultrasound		✓✓✓		✓✓✓	✓✓

Figure 1. (A) Pads of the four polyurethane layers (300 x 210 mm) for the cutis, subcutaneous connective tissue, fascia profunda and muscle (erector spinae). (B) Cartography of stiffness in kPa obtained with magnetic resonance elastography technique on a phantom with a thickness of 10 mm. (C) Correlation of stiffness measurements and inter-rater reliability. CUT: cutis. SCT: subcutaneous connective tissue. FPR: fascia profunda. ERS: erector spinae. Blank denotes "not applicable". ✓ denotes moderate correlation (> 0.4). ✓✓ denotes strong correlation (> 0.7). ✓✓✓ denotes very strong correlation (> 0.9).