SONOELASTOGRAPHY: REAL TIME MEASURE OF TISSUE STIFFNESS IN IDIOPATHIC LOW BACK AND PELVIC GIRDLE PAIN

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Introduction

Low back (LBP) and pelvic girdle pain (PGP) is considered to be idiopathic if no specific cause can be identified on X-Ray, MRI, CT-Scan. Practitioners doing a physical exam palpate the fascia and muscles. They look for areas of increased stiffness based on the assumption that they are related to pain, limited range of motion and dysfunction. Exerting manual pressure onto stiff tissue areas can provoke local pain and sometimes referred pain. A stiff area reacting this way can be termed a myofascial trigger area. With these finding from a practitioner's point of view the LBP becomes specific if indeed the trigger areas are proving to be the cause of the pain and dysfunction. When a treatment regimen is effective the tissue stiffness usually lessens significantly. Since the beginning of the 20th century the medical literature focuses on tissue stiffness using varying terminology (Cornelius 1902, Lange 1931, Gutstein 1938, Kellgren 1938, Travell 1942). In the past 160 years the medical establishment shied away from these concepts relying more on what they see on X-Ray, MRI, CT-Scan or Ultrasound. The idea never occurs, that there might be more to look for other than what conventional image technologies reveal. Ultrasound elastography is an alternative to conventional imaging, because it shows tissue stiffness giving a visual impression of what can be palpated during a physical exam. Elastography can discern differences in stiffness which the palpating fingers can't and it can reach into deep tissue layers far beyond where palpation reached its limit.

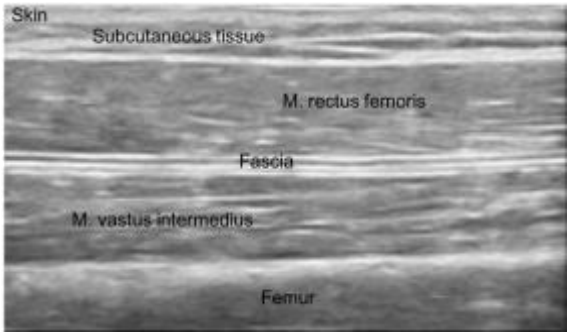


Figure 1
Conventional Ultrasound scan of muscle and fascia. The scan appears to be normal even though on palpation the area appeared stiff.

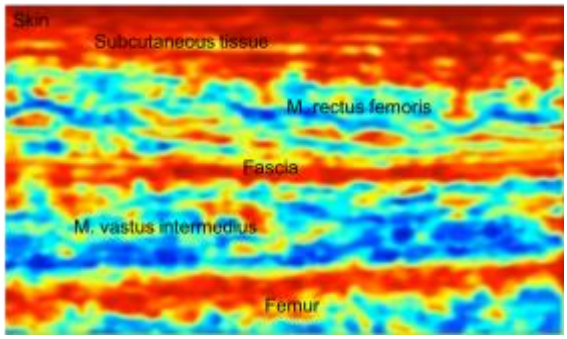


Figure 2
Scanning of the same area with strain elastography. The red and yellow areas are stiffer compared to the blue and turquoise ones. Pressure application to the area elicited referred pain.

With the development of Strain - Elastography (Ophir, Cespedes et al. 1991) a new imaging technology emerged. Even though elastography started with in vitro testing of muscles (Ophir, Miller et al. 1994) the potential for the field of musculoskeletal medicine was unrecognized. The direction went into cancer research aiming to detect tumors in the prostate, later breast, liver, thyroid, pancreas, lymph nodes and other tissues. A first in vivo evaluation of fascia and muscle stiffness was done with a newly developed real time elastography (Pesavento 1999, Pesavento, Perrey et al. 1999) on the thoracolumbar fascia and back muscles. Pesavento was able to produce for the first time clear images of the myofascia.

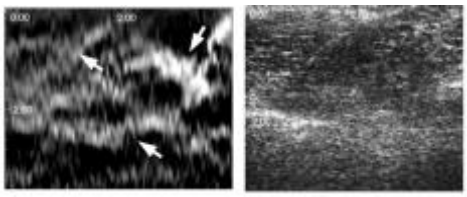


Figure 3 (Pesavento 1999)

"Real time elastogram (left) and conventional B-scan (right) of a non-traumatized back muscle. Dimensions in cm. Details like Fascia are better recognizable in the elastogram (arrows)"

The myofascia before and after shockwave application

Based on Pesavento's real time elastography myofascial stiffness was examined before and after therapeutic shockwave application *(Bauermeister 2000, Bauermeister 2001).*

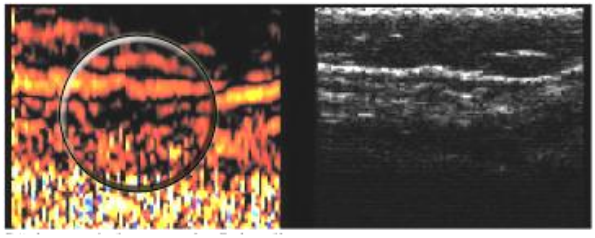


Figure 4

Real time elastogram (left) and conventional B-scan (right) of the thoracolumbar fascia (circle) and the back muscles before shockwave application. Stiffer areas are dark red and black.

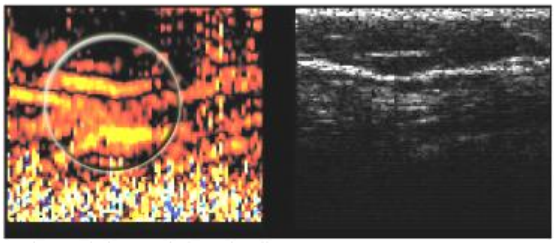


Figure 5

Real time elastogram (left) and conventional B-scan (right) of the thoracolumbar fascia after shockwave application. The previously stiffer fascia (circle) changed color to bright yellow and brighter red, indicating less stiffness. The back muscles below the fascia show brighter colors, indicating less stiffness as well. The resolution of the images with 60 x 84 Pixels was relatively low and the region of interest with 3,0 cm x 3,7 cm was small.

Modern High Definition Elastography

With advancing PC - calculating power the number of images which can be processed and the resolution has significantly increased. Stiffness areas of down to 200 µm can be imaged and regions of interest can cover the entire area which the ultrasound probe can image. This is a significant improvement compared to the region of interest of only 3,0 cm x 3,7 cm in the first laboratory setup.

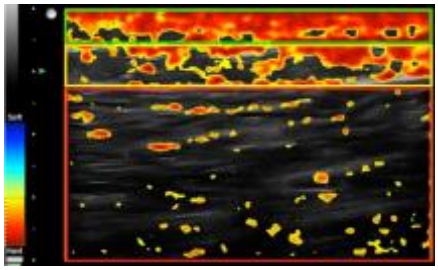


Figure 6

Real-Time Elastogram of the erector spinae muscle with high resolution. Green box: Skin and subcutaneous tissue; Yellow box: Thoracolumbar fascia; Red box: Erector spinae muscle.

Elastography control of treatment effects

The effect of a therapy can be easily assessed during, immediately after or in a later follow-up exam. Stiff areas are red and yellow, soft areas are blue and turquoise.

Figure 7 Before shockwave therapy

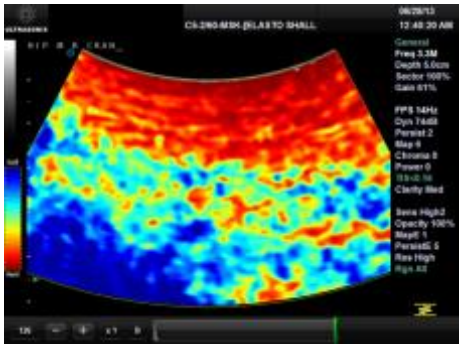
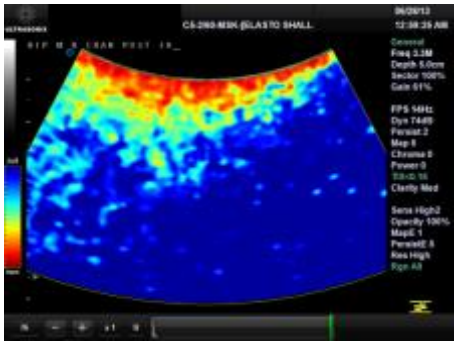


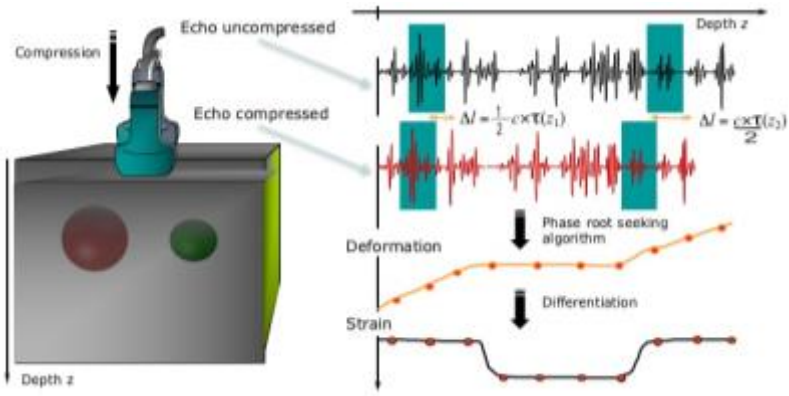
Figure 8 After shockwave therapy



Principles of Real Time Strain Elastography

Strain- compression-, or static- ultrasound elastography is the oldest and most widely used form of elastography imaging. (Ophir, Cespedes et al. 1991).

Figure 9



(Ophir, Cespedes et al. 1991, Khaled and Ermert 2008)

High frequency signals of uncompressed tissue are compared to signals of compressed tissue. Deformation is calculated and from that the strain. Deformation (displacement) is higher in soft tissue.

Current trends in musculoskeletal elastography research

One focus of musculoskeletal research is to establish normal values for muscle stiffness examining isolated muscle spots (Hoyt, Kneezel et al. 2008) or to examine tendons using shear wave elastography (Yamamoto, Yamaguchi et al. 2016).

Myofascial pain and dysfunction appears to be a problem of tissue stiffness not just in one particular muscle but along a myofascial chain(Myers T.W. 2001). To assess only isolated spots of the myofascia does not appear to allow for a comprehensive assessment of the entire myofascia at this point of time.

Shear wave elastography has the advantage of providing absolute stiffness values whereas strain elastography gives an impression of relative stiffness. But shearwave elastography requires more time compared to strain elastography. This is due to the necessary off-line analysis to define the areas for the measurement of absolute tissue stiffness in kPas or shear wave conduction velocity. Strain elastography appears to be for all practical purposes the easiest way to scan the entire myofascia within a reasonable time with the limitation, that the elastograms show relative stiffness. A semi quantitative measurement is the calculation of the strain ratio between two areas of different stiffness.

At the present time elastographers have difficulties to interpret the color variations of the fascia and muscles (Drakonaki, Allen et al. 2012) since they are not correlating the findings to established approaches of tissue assessment like indentometry or pain pressure threshold measurements.

Elastograms can be interpreted meaningfully if they are correlated to pain location (Bauermeister 2012), pain quality, pain intensity, pressure pain threshold (Bauermeister 2015, Farasyn and Lassat 2015), range of motion (Bauermeister 2012), tissue indentometry (Bauermeister 2015) and Myotonometry (Nair, Masi et al. 2013) (Jaeger H. 2013) and changes after therapeutic interventions (Bauermeister 2011).

Validation of Strain – Elastography against standard tissue assessment tools

The following hypotheses were tested:

Real Time Strain – Elastography can image stiffness validated through indentometry measurements?

There is a difference in the pain pressure threshold between softer versus stiffer tissue areas

Materials and Methods

A sequential clinical protocol with no fixed sample size was applied to patients with idiopathic low back pain, in a private clinic setting. Real time strain elastography (Ultrasonix Tablet – Analogic USA) was performed on 30 patients at 70 sites left and right side, back, hip and legs yielding 140 images. With ImageJ software (NIH) the hardest, yellow-red pixels were counted. – A significant difference was considered at $\geqslant$ 5%. After the Sonoelastography Pressure Algometry (Model 320.1kN –TesT GmbH Germany) was done on the test sites with a 1 cm^2 tip and a range from 1-1000 N. A significant difference was considered at $\geqslant$ 2 N. The Indentometer (Custom made) was applied to the test sites, left and right, until pain was perceived, considering a difference of 10 Newton to be significant. The results were plotted onto a sequential clinical trial chart (Bross's Sequential Plan) with fixed boundaries until the 0 Hypothesis was rejected or accepted.

Results
Sonoelastography: Out of 70 pairs of SEL images 75,71 % had red pixel count differences of ⩾ 5%, max/min 27,39%,/0,40%. Pressure Algometry: Out of the 70 pairs 95,71% were above the cutoff point of 2 N, max/min 54/0,3 N, mode 5,4 N. Hypothesis 1 was accepted after 35 exams with the Bross's Sequential Plan. Indentometry: Min/Max 53/2 N, Mode 10 N. Hypothesis 2 was accepted after 11 exams with the Bross's Sequential Plan.

Conclusions
The findings of Compression-Sonoelastography can be validated with Pressure Algometry and Indentometry. Inelastic fascia and muscle identified by Compression-Sonoelastography has a significantly reduced pain threshold supporting the clinical observation. Indentometry can be used to identify hardened inelastic fascia- and muscle identified by Compression-Sonoelastography.

Advantages and limitations of shearwave - and real time Strain – Elastography

Materials and Methods
Population: n=40; 28 f, 12 m -, age $\bar{x}$=54 years, with a history of LBP. Examination of the Trapezius, TLF, Hips and legs. The Strain – Elastography with Ultrasonix-Tablet (Analogic, USA) and Aplio 500 (Toshiba, Japan) tested the reliability to pick up a difference of the yellow–red pixel count ⩾ 5% comparing corresponding body sites. Shearwave elastography with Aixplorer (Supersonic, France), and Aplio 500 (Toshiba, Japan) tested the hardness in kPa. Prior to the in vivo exams the strain elastography and shearwave elastography was done on a gel phantom with fascia and muscle inclusions (Ulm University, H. Jäger) and on a Elasticity QA Phantom Model 049A (CIRS, USA).
Results
Shearwave elastography: Gel-phantom and in vivo testing showed a significant number of artifacts and inconsistent finding. The depth of penetration of the shearwaves was limited to 2,5–3,0 cm. The Interrater-reliability showed no agreement with K=0,2. Strain elastography showed a substantial agreement with K=0,8.

Discussion
Shearwave elastography claims to be operator independent, a notion which cannot be upheld for musculoskeletal applications at the present time. The limited depth of penetration makes it more usable in superficial but not in deeper areas. The measurements have to be done after the acquisition of the images which is time consuming. Strain – Elastography is real time, is operator dependent but shows a good Interrater-reliability when only the relative differences in pixel numbers between corresponding body sites are evaluated.

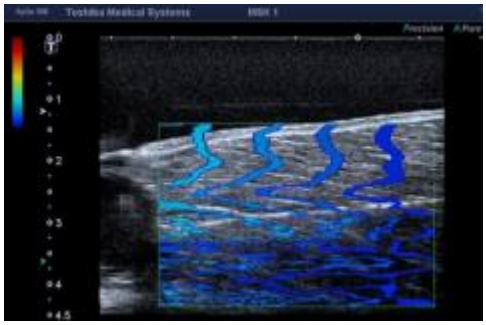


Figure 10
In this gel phantom the propagation of the shearwaves is parallel and therefore free of artifacts until a depth of approximately 2.5 cm. From then on there is a significant distortion can be observed.

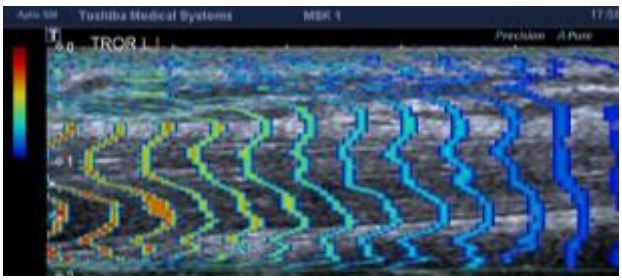


Figure 11
Shear wave elastography of the trapezius muscle. Starting around 8 mm the propagation waves are parallel and free of artifacts. The distortion starts at 2.0 cm.

Conclusion

Idiopathic LBP requires a complex evaluation of the musculoskeletal system to locate the cause of the pain like MTrPs, which can be located well above or below the pain site. They present as focal or areal stiffening of the fascia (TLF) and muscles and can therefore be visualized only with ultrasound elastography but not with conventional imaging techniques. Often they are located deeper than 3,0 cm where shear wave elastography has reached its limits. Therefore, at the present time strain elastography appears to be the best approach since it can reach into deeper tissue areas, it is real time and has an excellent Interrater reliability.

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