Shear wave ultrasound elastography: from physics to future

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Elastography uses ultrasound to assess elasticity. Shear wave elastography (SWE) is a new technique that estimates tissue stiffness in real time. It provides quantitative data, tissue stiffness heterogeneities are displayed on a color coded map. It is user independent, no manual transducer push is required. Elasticity imaging is possible for nearly every tissue.
Shear wave is a transverse wave that occurs in an elastic medium when it is subjected to periodic shear. Shear is the change of shape, without change of volume, of a layer of the substance, produced by a pair of equal forces acting in opposite directions along the two faces of the layer. If the medium is elastic, the layer will resume its original shape after shear, adjacent layers will undergo shear, and the shifting will be propagated as a wave. The velocity (v) of a shear wave is equal to the square root of the ratio of shear modulus (G), a constant of the medium, to density (ρ) of the medium, v = \sqrt{G/\rho}.

The stiffness of tissue, quantified by the Young's Module E (kPa), corresponds to the speed of the shear wave propagation (v) following the formula E = 3xv². By measuring the speed of the propagation of the shear wave at every point in the image, a quantitative elasticity map can be deducted in kilo Pascal (kPa). The concept of introducing the shear waves into the body: ultrasound beams are successively focalized and sent at supersonic speeds into different depths of tissue creating a Mach cone (the focalized beams travel faster than the shear wave itself). This permits a natural amplification of the shear waves (by confining the shear waves into a Mach cone) while at the same time minimizing the acoustic energy levels sent into the tissue. In order to be able to image shear waves, thousands of images must be acquired per second (typically 5 000 per second), while conventional ultrasound can only acquire a few hundred images per second. Therefore "ultrafast" imaging technology is developed which permits image acquisition of 20 000 images per second. The concept of "ultrafast" imaging involves sending a flat insonification into a medium while simultaneously using parallel channel processing to allow for the generation of one complete 2D image. This process results in images of tissue being acquired 100 to 200 times faster than conventional methods.

The end result is real-time, quantifiable, user-independent and reproducible Shear wave elastography. A color-coded image of local tissue elasticity is displayed, showing softer tissue in blue and stiffer tissue in red. Quantitative information is delivered, elasticity index (EI) is expressed in kilo-Pascal (kPa). Multiple areas of interest can be compared and quantified simultaneously. Q-box E Ratio tool compares stiffness of two regions as a ratio. Both steps of SWE are achieved using a linear US probe without requiring any intervention (as pressure) by the operator.
Imaging findings OR Procedure details

Liver:

Transient elastography (FibroScan) was proposed as a tool for assessing liver fibrosis by measuring liver stiffness. It is safe, available, non-invasive and can reduce the number of unnecessary liver biopsies. It is promising tool to monitor disease progression and the antifibrotic efficacy of antiviral therapy. FibroScan values are clinically useful for predicting fibrosis stages and helpful in managing chronic therapy in Wilson's Disease patients. Measurements are limited in in obese patients and in patients with ascites.

SWE useful in differentiating metastatic from nonmetastatic liver nodules.

Helps to guide biopsies and monitor ablation therapy requirements in real time.

Used to monitor transplants.

Shear wave velocity ("acoustic biopsy") is a useful marker for managing nonalcoholic steatohepatitis with the possibility to distinguish mild fibrosis from severe fibrosis or cirrhosis with substantial accuracy.

Gallbladder:

Elastography is an accurate technique for differentiating between benign and malignant gallbladder wall thickening and can be combined with sonography as the prime imaging tool for diagnosing gallbladder carcinoma at an early stage.

Pancreas:

Endosonographic elastography has been employed in the examination of lymph nodes and the pancreas. The method seems to be useful to select lymph nodes suitable for biopsy. The elastographic pattern of malignant tumours of the pancreas is different from that of the normal pancreas, but similar to that of chronic pancreatitis due to the same biomechanical architecture. Therefore, the early diagnosis of cancer within chronic pancreatitis will probably not be improved by elastography.

Prostate:

The systematic prostate biopsy ("ten-core biopsy") is now the "gold standard" of prostate cancer diagnosis but may miss prostate cancer. SWE may change the role of US for prostate cancer diagnosis. Targeted biopsies have shown that the targeted approach detects more cancers and cancers with higher Gleason scores with a reduced number of biopsy cores.

**Thyroid:**

SWE enables quantitative tissue characterization and differentiation between cystic and solid thyroid nodules. It is helpful in directing FNAB to the most suspicious lesions (selecting FNA target in multinodular goitres).

**Parotid glands:**

Characteristic elastographical patterns: The "garland" sign is found significantly more frequently in malignant tumours, a "dense core" sign is specifically defined for pleomorphic adenomas and a "half-half" sign for Warthin's tumours. Parotid cysts show an elastographical "bull's-eye" sign.

**Salivary glands:**

SWE of focal salivary glands has suboptimal performance for ruling out malignancy, because of overlapping indices for malignant and benign lesions, thus limiting its use in routine practice.

**Breast:**

The mean elasticity values are significantly higher in malignant masses (153.3 kPa ± 58.1) than in benign masses (46.1 kPa ± 42.9). The average mean elasticity values of invasive ductal (157.5 ± 57.07) or invasive lobular (169.5 ± 61.06) carcinomas were higher than those of ductal carcinoma in situ (117.8 kPa ± 54.72). The average mean value was 49.58 ± 43.51 for fibroadenoma, 35.3 ± 31.2 for fibrocystic changes, 69.5 ± 63.2 for intraductal papilloma, and 149.5 ± 132.4 for adenosis or stromal fibrosis. The optimal cut-off value was 80.17 kPa.

SWE provides a specific elastic pattern, which is sufficient for differentiating between a fibroadenoma and a phyllodes tumor. All phyllodes tumors have a similar elastic pattern with an elastic center and inelastic outer limits, referred to as the "ring sign". It was found in 5% of all fibroadenomas.

B-mode imaging and elastography are able to predict mammographic density. The application of ultrasound for breast tissue characterization could enable comprehensive research concerning breast cancer risk and breast density in young and pregnant women.
SWE in diagnosing mucinous carcinoma: although mucinous carcinoma has an elastography score similar to that of usual invasive carcinoma, elastography may be useful for distinguishing mucinous carcinoma from benign fibroadenoma.

**Cervical lymph nodes:**

Malignant are stiffer (median 25.0 kPa, range 6.9-278.9 kPa) than benign nodes (median 21.4 kPa, range 8.9-30.2 kPa). SWE is unsuitable for cancer screening but may detect a subset of malignant nodes.

**Axillary lymph nodes:**

SWE demonstrates axillary lymph nodes and differentiates benign from malignant nodes.

**Intravascular:**

Intravascular elastography appears to be a unique tool to determine local mechanical properties in atherosclerotic lesions to identify fibrous and fatty plaque tissue. Experiments have demonstrated the feasibility of this technique to be applied in vivo.

**Heart:**

Time harmonic elastography is introduced as a modality for assessing myocardial elasticity changes during the cardiac cycle. Systolic myocardial stiffness provides a noninvasive index of myocardial contractility. The proposed method provides reproducible elastodynamic information on the heart in real-time and may help in diagnosing myocardial relaxation abnormalities in the future.

**Musculoskeletal:**

Characterization of abnormal tissue, small local injuries, calcifications and monitoring of changes after patient re-education or surgery.

SWE can help in the localization of soft tissue damage in polymyalgia rheumatica.

Sonoelastography may help in the differential diagnosis between rheumatoid nodules and tophi.

Musculoskeletal applications of elastography: plantar fascia, achilles tendon, supraspinatus, synovium, soft tissue lesions, ganglion cyst, lateral epicondylitis, inflammatory myositis, lipoma arborescens, inflamed nerve, pigmented villonodular synovitis.
Elastography in estimation of individual muscle force.

**Eye:**

High-resolution quantitative imaging of cornea elasticity.

Real-time elastographic imaging of ocular and periocular tissues.

**Gynaecology:**

Cervical elastography allows differentiation of malignancy from normal findings. CIN cannot be identified with this modality. Elastographically, cervical tissue is of medium hardness and does not change with age.

ShearWave Elastography could improve diagnostic confidence by determining new growth of fibroids or confirming cystic, complex or solid ovarian masses. In addition, ShearWave Elastography could be useful in post-fibroid embolization follow-up assessment.

SWE seems to be a valuable tool in differentiating endometrial pathologies from normal or atrophic endometrium in perimenopausal women with endometrium thickness above 5 mm in transvaginal ultrasound examination.

SWE could be considered a useful tool in the diagnosis of adenomyosis.

Endovaginal elastography increased the diagnostic confidence of US in emergency gynecological pathology, especially in the cases with haemorrhagic cysts, haematosalpinx, and free blood in the Douglas pouch. Real-time elastography performed in addition to conventional US and serum blood b-hSG levels: improved early detection of ectopic pregnancy (the sign "blue eye").
Fig. 1: Breast fibroadenoma with its characteristic elastogram.

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Fig. 6: Benign thyroid nodule.

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**Fig. 4:** Small breast cancer depicted with SWE.

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**Fig. 5:** Breast papilloma, "soft" lesion on elastography.

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Fig. 3: Breast carcinoma with typical elastogram.

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**Fig. 2:** Breast lesion resembling fibroadenoma on B-mode, but "hard" on elastography, turned out to be a carcinoma.

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**Fig. 7:** Malignant cervical lymph node.

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Conclusion

Elastography has emerged as a useful adjunct tool for ultrasound diagnosis. This is a rapidly evolving field. Among mentioned, other promising applications include atheromatous plaque and arterial wall evaluation, venous thrombus evaluation, graft rejection, monitoring of tumor ablation therapy and "slip elastography" for characterizing adherence between two surfaces in contact, minimally invasive surgery, radiotherapy, tissue engineering...
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