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● *Original Contribution*

ROLE OF SHEAR WAVE SONOELASTOGRAPHY IN DIFFERENTIATION BETWEEN FOCAL BREAST LESIONS

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Abstract—Our goal in this study was to evaluate the relevance of shear wave sonoelastography (SWE) in the differential diagnosis of masses in the breast with respect to ultrasound (US). US and SWE were performed (Aixplorer System, SuperSonic Imagine, Aix en Provence, France) in 76 women (aged 24 to 85) with 84 lesions (43 malignant, 41 benign). The study included BI-RADS-US (Breast Imaging Reporting and Data System for Ultrsound) category 3–5 lesions. In elastograms, the following values were calculated: mean elasticity in lesions ($E_{av.l}$) and in fat tissue ($E_{av.f.}$) and maximal ($E_{max.adj.}$) and mean ($E_{av.adj.}$) elasticity in lesions and adjacent tissues. The sensitivity and specificity of the BI-RADS category 4a/4b cutoff value were 97.7% and 90.2%. For an $E_{av.adj.}$ of 68.5 kPa, the cutoff sensitivity was 86.1% and the specificity was 87.8%, and for an $E_{max.adj.}$ of 124.1 kPa, 74.4% and 92.7%, respectively. For BI-RADS-US category 3 lesions, $E_{av.l}$, $E_{max.adj.}$ and $E_{av.adj.}$ were below cutoff levels. On the basis of our findings, $E_{av.adj.}$ had lower sensitivity and specificity compared with US. $E_{max.adj.}$ improved the specificity of breast US with loss of sensitivity. (E-mail: m.sobczak2@gmail.com or kdsobczak@gmail.com)

Key Words: **Breast ultrasound, Shear wave sonoelastography, Young's modulus, Focal breast lesions.**

INTRODUCTION

To diagnose breast diseases, we use radiologic examinations such as ultrasonography (US), mammography and magnetic resonance mammography, as well as radioisotope examinations. Frequently, the first examination in detection of focal lesions in the breast is palpation, on which lesions have different biological and mechanical properties than the surrounding normal tissues of the mammary gland. However, the use of palpation to determine the character of focal breast lesions is not without constraints. palpation detects only superficial lesions and is not recommended by the U.S. Preventive Services Task Force in self-examination (USPSTF 2009).

The fundamental studies conducted in the 1990s, which revealed that glandular tissue and benign lesions undergo greater strain compared with malignant lesions, gave rise to sonoelastography (Krouskop et al. 1998). Its introduction into ultrasound imaging of focal breast lesions allowed for assessment of the strain of lesions.

Currently, two basic techniques are used in sonoelastography of the mammary glands: static elastography, also called strain imaging, and dynamic elastography, also called shear wave elastography (SWE) (Bamber et al. 2013). In strain imaging, the elastograms obtained indicate the relative stiffness (strain) of the tissues examined (semiqualitative method) by means of a color map (Itoh et al. 2006; Wojcinski et al. 2010). With the acquired measurements, the strain ratio (SR) may be calculated. SR expresses the relationship between the strain of the adjacent tissue and the strain of the assessed lesion (semiquantitative method) (Stachs et al. 2013).

Shear wave elastography delivers both quantitative and qualitative information on the elastic properties of assessed tissues in real time. The elastogram presents the stiffness color map and numerical values of the Young's modulus for the assessed tissue, expressed in kPa. Additionally, SWE reports quantitative values for the region of interest on the screen.

In the largest published multicenter trial to date, Berg and co-workers reported that adding the features of SWE examination to the assessment of focal lesions

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in BI-RADS-US classification improves the specificity of the outcomes, leaving sensitivity unaffected (Berg et al. 2012; Cosgrove et al. 2013). Cosgrove et al. (2012) proved that this method is reproducible, especially in calculating the maximal and mean Young's moduli (E). Yoon et al. (2013), however, reported that this method may have limitations resulting from the size of the mammary glands or focal lesions and the depth at which they are located.

In publications concerning the usefulness of sonoelastography in the differential diagnosis of focal breast lesions, the authors pay attention to the usefulness of various indicators that in a quantitative way evaluate tissue stiffness in the lesion and its adjacent tissues (Berg et al. 2012; Evans et al. 2010, 2012).

The objective of our study was to evaluate the different SWE indicators (mean and maximum Young's moduli within the lesion and surrounding tissue) to improve diagnosis of breast masses with respect to ultrasound and histopathologic verification.

PHYSICAL BASICS OF DYNAMIC ELASTOGRAPHY

Ultrasound reveals differences in the acoustic impedance of tissues, which is expressed as a product of density and longitudinal speed (depending on the modulus of elasticity). The elasticity of materials is their ability to return to their original shape after being subjected to external force or distorting stress. Fluids resist changes to their volume, but not to their shape; they only have volumetric elasticity. Solid bodies resist changes to their shape and volume; they have rigidity—shear elasticity and volumetric elasticity. The change in dimensions or shape is called *strain*. It occurs as a result of force, that is, stress, acting on the surface.

In a homogeneous isotropic solid body the stress/strain ratio is constant and is called the modulus of elasticity. Three moduli (N/m^2) are commonly used to describe elasticity: (i) Young's modulus (longitudinal elasticity, E = [stress]/[strain]); (ii) shear modulus, μ; and (iii) bulk modulus, K.

When subjected to stress, material may contract in directions transverse to the direction of stretching or may expand in directions transverse to the direction of compression. This effect is expressed by Poisson's ratio:

$$\gamma = \frac{\text{transverse strain}}{\text{axial strain}} \tag{1}$$

The interdependence between Young's modulus, shear and bulk moduli and Poisson's ratio is given by two linear constitutive equations:

$$\mu = \frac{E}{2(1+\gamma)} \tag{2}$$

$$K = \frac{E}{3(1-2\gamma)} \tag{3}$$

The velocities of mechanical longitudinal wave c_l and transverse (shear) wave c_s in a solid body are equal:

$$c_l = \left(\frac{K}{\rho}\right)^{\frac{1}{2}} \tag{4}$$

$$c_s = \left(\frac{\mu}{\rho}\right)^{\frac{1}{2}} \tag{5}$$

where ρ denotes material density.

Tissue elasticity

The relation between stress and strain of the soft tissue is different in the processes of compression and decompression. When stress rises from 0, strain rapidly increases because fluids are "squeezed" and only then the stress/strain ratio (the Young's modulus) is linear for slight strains (for strains lower than several percent). If stress continues, strain rate decreases faster and faster until rupturing. Wells and Liang (2011) concluded that the practical implication of this is that, to obtain reproducible and useful values of Young's modulus, the tissue needs to be slightly statically preloaded and the measurement needs to be made over a small increment in stress (*i.e.*, in the linear region).

Tissue strain constitutes a certain approximation of tissue stiffness that is palpable for a physician during physical examinations: light tissue strain corresponds to high tissue stiffness and vice versa. Thus, in clinical practice, strain provides important information concerning the condition of the examined tissue.

There are significant differences in studies in the literature concerning large strain values. They may result from the calculating convention—the Lagrangian model (strain calculated with reference to the initial length) and Euler method (strain calculated with reference to the deformed length). The differences in slight strain values are insignificant.

The c_l rate changes from 1450 m/s in fat to approximately 1630 m/s in muscles. Density changes from 916 to 1060 kg/m^3, respectively. When these values are used in the formula for the bulk modulus, K, we obtain strains ranging from 1800 MPa for adipose tissue to approximately 2800 MPa in muscles (Krouskop et al. 1998). The references usually quote the Young's modulus and not the shear modulus. We bear in mind that Poisson's ratio in tissues equals 0.49–0.499 because tissue is nearly